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RESEARCH INSTITUTE OF INTELLIGENT COMPUTER SYSTEMS

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СОДЕРЖАНИЕ

EDITORIAL

"Wireless Systems"

Guest Editors: Uwe Grossmann, Juergen Sieck, Axel Sikora

This special issue of the International Scientific Journal of Computing includes a selection of invited papers presented partly within the Special Stream Wireless Systems at the Sixth IEEE International Confererence on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS'2011), which was held in Prague, Czech Republic, September 15th-17th, 2011. The Conference was organized by the Research Institute of Intelligent Computer Systems, Ternopil National Economic University, Ternopil, Ukraine and co-organized by the Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic.

The IDAACS Conference series is established as a forum for high quality reports on state-of-the-art theory, technology and applications of intelligent data acquisition and advanced computer systems. These techniques and applications have experienced a rapid expansion in recent years that have resulted in more intelligent, sensitive, and accurate methods of data acquisition and data processing. Subsequently, these advances have been applied to: manufacturing process control and inspection; environmental and medical monitoring and diagnostics; and intelligent information gathering and analyses for the purpose security and safety.

The IDAACS'11 workshop sessions were organized under the following topic areas: Advanced Instrumentation and Data Acquisition Systems; Intelligent Distributed Systems and Remote Control; Virtual Instrumentation Systems; Advanced and High Performance Computing Systems; Cluster and Grid Technologies, Parallel Software Tools and Environments; Embedded Systems; Artificial Intelligence and Neural Networks for Advanced Data Acquisition and Computing Systems; Advanced Mathematical Methods for Data Acquisition and High Performance Computing; Industrial Signal and Image Processing; Data Analysis and Dynamic Modelling; Intelligent Information and Retrieval Systems; Robotics and Autonomous Systems; Information Computing Systems for Education and Commercial Applications; Bio-Informatics and Homeland Security; Safety, Security and Reliability of Software; Wireless Systems – Special Stream.

The Special Stream – Wireless Systems was convened for the third time since 2007. The papers selected for this special issue reflect the variety of research in the area of wireless systems.

The paper *"Virtual WLAN: Extension of Wireless Networking into Virtualized Environments"* of **G. Aljabari** and **E. Eren** considers the task of sharing a wireless network interface. Virtualization can solve this problem. A software platform for hosting multiple virtual wireless networks over a shared physical infrastructure by means of open source virtualization techniques is presented. The hosting platform can extend wireless networking into virtualized environments without compromising the performance, isolation, or wireless LAN security mechanisms.

The paper *"Hybrid Indoor Tracking of Humans in Hazardous Environments"* of **A. Fink** and **H. Beikirch** presents a centroid location estimation technique based on received signal strength (RSS) readings. Sensor fusion of the RSS-based localization with an inertial navigation system (INS) leads to a more precise tracking. The long-term stability of the RSS-based localization and the good short-term accuracy of the INS are combined using a Kalman filter. The experimental results on a motion test track show that a tracking of humans in multipath environments is possible with low infrastructural costs.

Within the paper *"Automated Network Protocol Evaluation – The Potsdam Wireless Testbed"* by **S. Fudickar** and **B. Schnor** the Potsdam Wireless Testbed is presented and discussed. It supports validation and evaluation of Wi-Fi radio stacks and wireless applications in environments with heterogeneous hardware. Scheduled test-runs are executed automatically for a defined duration including compilation and deployment of the protocols and measurement scripts as well as collection of measurement results and log files.

The paper *"Providing household customers with smart meter data on mobile devices"* by **S. Hakobyan, J. Kohlbrecher, J. Pickert** and **U. Grossmann** deals with the suitable visualization of energy data, corresponding costs and tariff information on mobile devices. The household customer is enabled to manage his energy usage consumption in order to hold the optimal load and meet the optimal price. Energy data are acquired by a smart meter and transferred over a Smart energy controller (SEC) to a mobile device to provide the customer with relevant information about his current energy usage. Suitable visualization methods, specific for different tariffs, are identified and presented together with according technologies and methods for communication and data access.

In the paper *"RFID based applications in culture, media and creative industries"* from **S. Bergemann, E. Kuehn, J. Reinhardt** and **J. Sieck** two different approaches to visualise information from culture, media and creative industries by using RFID based tracking and identification are presented. Besides the required RFID backend, the paper also introduces the information system built on top of the backend. The first approach is based on passive RFID whereas the second uses active RFID. In particular, the differences in the processing of system events, delivery of needed information and the implemented infrastructure are discussed and evaluated.

In their paper "*Reducing radio bandwidth load in Nanoloc-based Wireless Networks through selecting appropriate subset of base stations for ranging*" **A. Galov, A. Moschevikin** and **A. Soloviev** discuss the overall performance of radio segment and location accuracy in wireless sensor networks based on nanoLOC standard and using server-centric control depending amongst others on the efficiency of the location engine. The efficiency may be increased by selecting an appropriate subset of base stations for ranging.

The paper *"Gateway architectures for home care applications using wireless sensor networks"* of **A. Sikora, N. Braun, S. Jaeckel** and **D. Jaeckle** deals with Telecare Applications and Ambient Assisted Living. A significant number of challenges within this field exist for real-life applications. Those include the lack of sufficiently standardized and interoperable solutions and thus, the necessity of gateways for integrated solutions, restrictions of the energy budgets, and scalability of solutions with regard to cost and network size. The experience from the inCASA project (Integrated Network for Completely Assisted Senior Citizen's Autonomy) is presented, where architectures for heterogeneous physical and logical communication flow are examined.

Throughout the paper *"Indoor monitoring applications using fixed and mobile wireless sensors"* of **M. Strutu** and **D. Popescu** the idea of a wireless sensor network with applicability in monitoring systems is proposed. The goal of the project is to build a monitoring system capable of data gathering which can benefit from both characteristics of fixed and mobile nodes. In order to implement data acquisition and communication functions, the solution agreed has been to use the MTS400 sensor board. Mobile nodes communicate to a central node individual data and statistical indicators over a period. The proposed energy-aware architecture was tested and validated in an indoor experiment.

The paper *"Nonlinear data coding in wireless sensor networks"* of **V. Yatskiv, S. Jun, N. Yatskiv** and **A. Sachenko** presents a proposed nonlinear method of sensor data coding. The method allows the increase of the useful capacity of the data transmission protocols for Wireless Sensor Networks by 3-5 times using integration of sensor data with different digits capacity and reducing the transmissions number.

This selection of papers represents topics of IDAACS'2011 and results of the area Wireless Systems the editors found worth presenting. We hope the readers find them interesting, useful and even enjoyable, as well.

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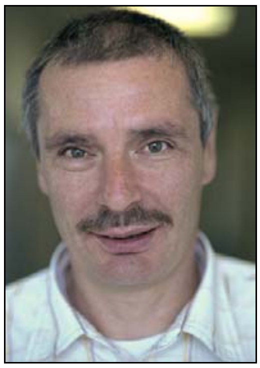

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VIRTUAL WLAN: EXTENSION OF WIRELESS NETWORKING INTO VIRTUALIZED ENVIRONMENTS

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Abstract: *In wired Ethernet networks (IEEE 802.3), a physical network interface can be connected to different network segments or shared among multiple virtual machines. In wireless LAN (IEEE 802.11) sharing a wireless network interface is recognized to be a difficult task. However, virtualization can solve this problem. In this paper we will introduce a software platform for hosting multiple virtual wireless networks over a shared physical infrastructure by means of open source virtualization techniques. We present the design, implementation, and performance testing of this platform. Results have shown that the hosting platform can extend wireless networking into virtualized environments without compromising the performance, isolation, or wireless LAN security mechanisms.*

Keywords: *Virtualization; Wireless LAN; Virtual network; Hypervisor; KVM.*

1. INTRODUCTION

Virtualization technology has been widely adopted in data centers to optimize resource sharing and utilization. This technology has helped to consolidate and standardize hardware and software platforms in data centers, i.e. servers and storage. The main benefit of virtualization technologies is savings in power and infrastructure costs in addition to improving availability, scalability, and security.

In recent years, virtualization has been pushed forward to also virtualize physical network infrastructures. By allowing multiple logical networks to co-exist on a shared physical infrastructure, network virtualization provides flexibility and manageability. Network virtualization often combines hardware and software resources to deploy virtual networks for different architectures. The term virtual network has been used to describe different types of network virtualization such as VLAN (Virtual Local Area Network) and VPN (Virtual Private Network). But recently, network virtualization is moving toward *virtualized environments*.

Virtualization of wireless LANs (WLANs) has become one of the important issues in network virtualization and also for cloud computing by now. It is useful in many scenarios such as hosting multiple wireless service providers on a single shared physical infrastructure, providing wireless services with different authentication mechanisms, and for virtual test bed environments. Hence, there are some research activities in this field [1-4].

There are several approaches to system virtualization and several software implementations, both open source and commercial. However, most of the virtualization approaches are mainly developed for wired Ethernet networks, and are not suitable for virtualizing wireless LAN interface due to the nature of wireless LAN devices. More specifically, the limitations of current virtualization approaches are due the difficulties in emulating wireless LAN management functions [3]. Therefore, existing virtualization approaches require a separate physical wireless LAN device for each virtual machine (VM) to have its own wireless network.

A viable solution to address the above issue is by giving all VMs access to the same wireless network and rely on network virtualization techniques such as VLAN or VPN to provide isolation for VM network traffic. However, this solution will add additional cost and overhead for configuring and maintaining a secured connection to all VMs. As a result, a new approach is needed to enable a single wireless network interface to be shared among several VMs without compromising the performance, isolation, or wireless LAN security mechanisms.

By means of open source virtualization techniques, it is possible to create multiple virtual wireless networks through one physical wireless LAN interface, so that each virtual machine has its own wireless network. Available open source solutions such as KVM, hostapd, and VDE provide the software infrastructure to deploy and implement such an approach on Linux operating system (OS). This paper aims at demonstrating this approach.

2. BACKGROUND

Virtualization approaches enable running multiple OSs and applications concurrently on the same physical machine, eliminating the need for multiple physical machines. Each VM has its own operating system and applications such as the physical machine [5-7]. Thus making the applications unaware of the underlying hardware, yet viewing computing resources as shared resource pools available via virtualization.

The primary benefits offered by virtualization are *resource sharing* and *isolation*. Unlike real environments where physical resources are dedicated to a single machine, virtual environments share physical resources such as CPU, memory, disk space, and I/O devices of the host machine with several VMs. With isolation, applications running on one VM cannot see, access, and use resources on other VMs [5].

Virtualization provides a software abstraction layer on top of hardware. This layer is called *Virtual Machine Monitor* (VMM), also known as a *hypervisor*. The main task of the VMM is to manage the hardware resource allocation for VMs and to provide interfaces for additional administration and monitoring tools [5]. However, the functionality of the VMM varies greatly based on architecture and implementation.

Today, two alternative approaches exist to virtualization on x86 hardware architecture. In the so called *full virtualization* approach, VMs and guest OSs run on top of virtual hardware provided by the VMM. However, the VMM has to provide the VM with an image of an entire system, including virtual BIOS, virtual CPU, virtual memory, and virtual devices to allow the guest OS to run without modification. As a result, the guest OS or application is not aware of the virtual environment. The main advantage of full virtualization approach is that it supports any platform and provides complete isolation of different applications, which helps make this approach highly secure. However, this approach has poor performance in trying to emulate a complete set of hardware in software [5,7].

KVM, which stands for *Kernel-based Virtual Machine*, is a full virtualization solution that takes advantage of *hardware-assist* features such as Intel VT and AMD-V to improve the performance of guest OSs [8]. The first generation of hardware assist features was added to processors in 2006, so that KVM hypervisor supports only newer x86 hardware systems. Using KVM, several fully VMs can be created and operated in Linux environments, since KVM adds VMM capabilities to the Linux kernel. KVM hypervisor consists of two main components: a set of kernel modules providing the core virtualization infrastructure such as CPU and memory management, and a user space program that provides emulation for I/O hardware devices, currently through QEMU [9].

OS assisted virtualization or *paravirtualization* presents each VM with an abstraction of the hardware that is similar but not identical to the underlying physical hardware. This approach requires modifications to the guest OSs that are running in the VMs. As a result, guest OSs are aware that they are executing on a VM, allowing for near-native performance [5].

Xen is an open source virtualization software based on the paravirtualization approach. The Xen hypervisor runs directly on hardware, allowing the host machine to run multiple modified guest OSs concurrently [6]. Modifying the guest OS is not feasible for non-open source platforms such as Microsoft Windows. As a result, such OSs are not supported in a paravirtualization environment. Recently, unmodified guest OSs are also supported by Xen. In this mode, Xen provides a fully abstracted VM with hardware support (Intel VT and AMD-V) referred to as *hardware virtual machine* (HVM) [10].

With the adoption of virtualization in data centers, a new layer of network virtualization is emerging that provides inter- and intra- VM connectivity and has many of the same functions provided by the physical networking hardware. Today, this layer is providing connectivity to tens of VMs for a physical machine [11].

The main network components provided by virtual networking, as shown in Fig. 1, are *virtual Ethernet interfaces*, used by individual VMs, and *virtual switches*, which connect the VMs to each other [12]. VMs can also be configured with one or more virtual Ethernet interface to offer different virtual network appliances for virtual environments such as *virtual routers* (VR) and *virtual firewalls.* VRs are essential components in the virtual networking infrastructure because they operate in much the same way as physical routers, forwarding and routing packets based on standard routing protocols such as RIP and OSPF. Virtual firewalls provide the usual packet filtering and monitoring role provided via a physical network firewall. Thus, virtual networking components manage communication between co-located VMs, and connectivity to physical machines.

Modern OSs provides the ability to create virtual network interfaces that are supported entirely in software. From the OS's point of view, these interfaces behave similar to physical network interfaces. However, the virtual interface does not send the packets into the wire, but makes them available to userspace programs running on the system. Virtual network interfaces are commonly referred to as TAP and TUN interfaces under Linux. TAP interfaces operate with Layer 2 packets, while TUN interfaces can handle Layer 3 packets. VMs use the TAP interface to create a network bridge with the physical network interface [2].

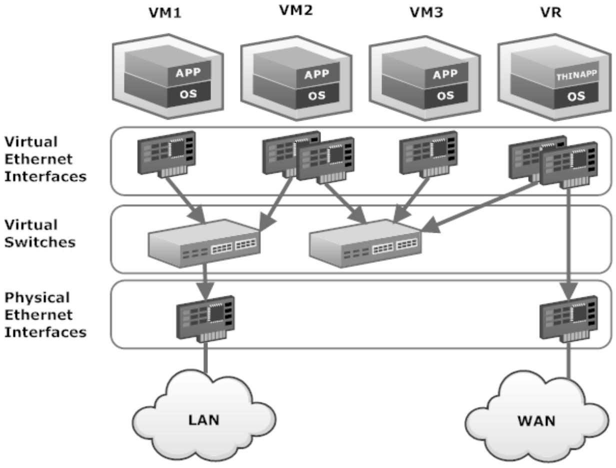

Fig. 1 – Virtual networking components

Most of the virtualization approaches also provide some form of virtual networking. For example, VMware virtualization software has a distributed switch for virtual machine networking [13]. Linux-based virtualization platforms, including Xen and KVM, generally use network bridging or *Virtual Distributed Ethernet* (VDE) switch [14]. A network bridge acts like an Ethernet hub; passing all traffic. While, VDE provides Layer 2 switching, including spanning-tree protocol and VLAN support.

Open vSwitch is an open source software switch that provides connectivity between the VMs and the physical interfaces. It implements standard Layer 2 and Layer 3 switching with advanced features such as traffic monitoring (e.g. NetFlow), port mirroring (e.g. SPAN), basic ACL (Access Control List) and QoS (Quality of Service) policies. The Open vSwitch consists of two components: a fast kernel module and lightweight userspace program. The kernel module implements the forwarding engine, while the userspace program implements forwarding logic and configuration interfaces. Open vSwitch supports multiple Linux-based virtualization software, including Xen and KVM [11,15].

Quagga is an open source routing software that provides implementations of TCP/IP based routing protocols such as OSPF, RIP, and BGP. In addition to traditional IPv4 routing protocols, Quagga also supports IPv6 routing protocols [16]. Vyatta software [17] incorporates open source routing and security projects such as Quagga, IPtables, OpenVPN and many others into a network OS for x86 hardware platforms. Vyatta also can be delivered as VMs, providing routing, firewalling, VPN, and more for virtual and cloud computing environments. Thus, Vyatta network OS complements virtual networking components by delivering the virtual router, virtual firewall, and virtual VPN in the hypervisor.

3. VIRTUALIZATION OF WLAN INTERFACE

A network interface can be shared and hence virtualized using either a *software* or *hardware based approach*, as shown in Fig. 2. In software-based approach, network interface virtualization is completely implemented as software to provide virtual network interfaces (VIF) for multiple VMs [3,18,19]. In this approach, *bridging* functionality is often enabled on the physical network interface to grant all VMs access to the same physical network.

Full virtualization techniques provide virtual network interfaces by emulating legacy Ethernet devices for simplicity. The virtual network interfaces appear to the VM as virtualized hardware devices within the hypervisor. With this technique, no modification is required for the guest OS. However, there is a significant performance overhead due to the context switching between VM and hypervisor. In the paravirtualization technique, the paravirtualized driver is used in the guest OS to achieve high I/O performance. However, this method requires modifying the guest OS and having a special driver to expose some details of the hardware [3].

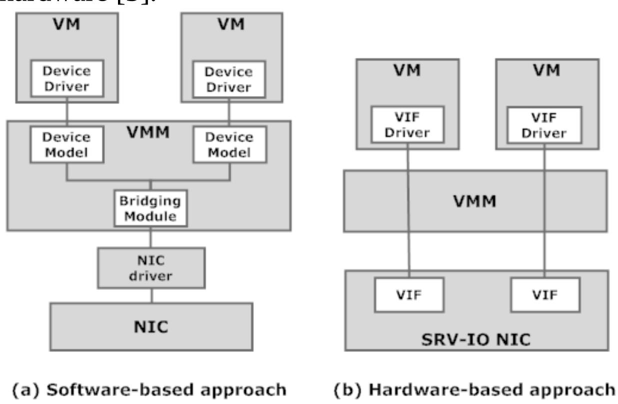

Fig. 2 – Network interface virtualization approaches

The second approach depends on hardware virtualization support to partition a physical network device to multiple virtual network interfaces. Then, each virtual interface can be assigned directly to a specific VM. While this approach reduces the performance overhead of software-based network interface virtualization, it increases the complexity, maintainability and cost of network devices [3,18,19]. An example of hardware-based approach is *Single Root I/O Virtualization* (SR-IOV) where a single PCI device can be divided into multiple Virtual Functions (VFs). Each VF can then be used by a VM, allowing one physical device to be shared among multiple VMs. As a result, close to native I/O performance can be achieved, in addition to fair sharing of the bandwidth [20].

Virtualization of a wireless LAN interface is more complicated than for wired network interface because the capacity of the wireless LAN channel varies with radio signal strength and interference from other wireless LAN devices. This requires including complex management functions into wireless devices to achieve efficient and reliable communication. Examples of such management functions include data rate adaption, power management, and power control. The device driver, which is part of the OS, is also involved in such management functions for control and configuration. In contrast, wired LAN devices are data centric and have very little management functions [3].

A typical WLAN device consists of: RF transceiver, Baseband, and MAC layer. The RF transceiver performs radio signal transmitting and receiving, while the Baseband mainly responsible for digital signal processing. RF transceiver and Baseband are generally referred to as PHY layer. The MAC layer often consists of a hardware controller on the WLAN device and a software driver on the host computer. Most of the wireless LAN functions such as authentication and authorization are performed at MAC layer [3].

In the beginning, the MAC layer was entirely managed by the firmware on the wireless LAN device. This approach is called FullMAC, where full MAC layer functionality is executed by the hardware controller on the wireless device. New implementation of wireless LAN devices is based on SoftMAC approach, where most of the MAC layer functionality is moved to device driver on the host computer, with the firmware providing a set of functional primitives [2]. This approach provides a high degree of software control over the MAC layer functions, while still allowing the PHY layer to define the radio waveform.

MultiNet [21], which was later named VirtualWiFi, proposes a software based approach to virtualize a single wireless interface. Virtualization of wireless LAN interface is implemented with intermediate driver, called MultiNet Protocol Driver, which continuously switches the radio resources across multiple wireless networks. This approach has been adopted in Microsoft Windows 7 to give a user the ability to simultaneously connect to multiple IEEE 802.11 networks with one WiFi card. However, MultiNet approach was not designed to support the VM environment [3].

Recently, a novel virtualization approach on 802.11 MAC layer has emerged in the wireless industry. Multiple virtual wireless LAN interfaces are separated at MAC layer sharing the same PHY layer [3]. As shown in Fig. 3, multiple virtual MAC entities can be active and share a common PHY layer via *Time Division Multiplexing* (TDM) on the same channel. This approach reduces costs, eliminating co-channel interference, and offering smooth roaming as clients move through the WLAN's coverage area. WLAN products that provide support for such an approach include Atheros, Intel, and Marvell.

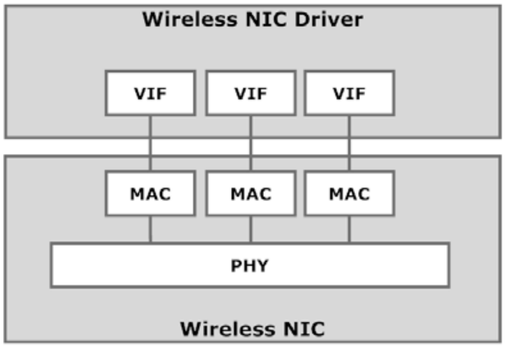

Fig. 3 – Wireless network interface virtualization

In the case that different virtual MACs need to operate on different RF channels, a *time-critical scheduling* is required for multi-channel MAC functions. Implementing such solution will allow the PHY layer to switch between different RF channels and keep virtual MACs in synchronization with the associated networks. Several research efforts have been made in implementing multi-channel virtualization approach for WLAN devices such as Net-X [22] and FreeMAC [23].

Virtualization of the WLAN interface enables several usage scenarios for wireless networking, some of these are:

- **Simultaneous Connectivity:** a wireless device can be connected to multiple wireless networks simultaneously. E.g., One virtual interface operates in STA mode to connect to an AP, while another virtual interface operates in an ad – hoc mode to create a peer-to-peer wireless network.
- **Wireless Relay/Extension:** a wireless client can extend the coverage area of the network by creating a second virtual interface in AP mode, allowing remote clients outside the basic operating range to relay data to the main AP.
- **Soft Handover:** a wireless client can use a second virtual interface to scan all available APs, while the first virtual interface is connected to the

wireless network. After selecting the new AP, a client can authenticate and associate with it without losing the connection with the current AP. In this scenario, we can avoid packet loss and delay times in real-time applications such VoIP and video streaming [2].

- **Multi-Streaming Service:** a mobile device can communicate with multiple APs operating on different channels, as the device has several virtual interfaces. The most stable connection becomes the main connection and others can become sub-connections. By this scenario, we can improve streaming performance such as multi-path streaming without relay server [24].
- **Wireless Mesh Network (WMN):** a multi-hop WMN is built through virtual interfaces created at some mesh nodes. In this case, a mesh node is configured to work in STA mode and acts as AP by creating a second virtual interface in AP mode. Thus, remote clients located outside the coverage range (wireless cell) can get access to the network via clients connected to any AP in the wireless cell [25].
- **Virtualized Environment:** a virtual machine can establish its own wireless LAN connection by creating a virtual interface in STA mode. In this case, multiple wireless connections are supported through one physical wireless LAN network interface.

4. VIRTUAL WLAN APPROACH

With the introduction of IEEE 802.11n and the increase in bandwidth, wireless LAN virtualization is required as an alternative approach for deploying multiple virtual wireless LANs with different authentication methods. Wireless LAN virtualization enables several virtual wireless networks to coexist on a common shared physical device. Multiple virtual interfaces can be created on top of the same radio resources, allowing the same functionality as in multi-radio solution.

All virtual interfaces operate concurrently without considering the physical nature of the wireless medium as well as physical management tasks. Each virtual interface abstracts a single wireless device and has its own wireless network and its own unique MAC address. From the application's perspective, the virtual wireless network behaves like wired Ethernet, but is wireless.

Using wireless LAN virtualization, a virtual interface can be configured to operate as an *access point* (AP) and also as *a station* (STA) device. A virtual AP is bound to a virtual network interface and each virtual AP independently keeps the configuration and service of the wireless network. In this way, several virtual APs can be configured on top of solely one physical wireless LAN device, as shown in Fig. 4.

A virtual AP acts as the master device in a virtual wireless network and operates in much the same way as physical AP, allowing wireless stations to communicate with each other by managing and maintaining a list of associated stations. In general, the virtual AP consists of two parts: *control plane* and *forwarding plane*. The control plane is concerned with the information that defines the functionality of the AP such as the SSID (Service Set Identifier), operation mode, and RF channel. While the forwarding plane defines the part of the AP, that uses a lookup table as a base to forward packets to its destination.

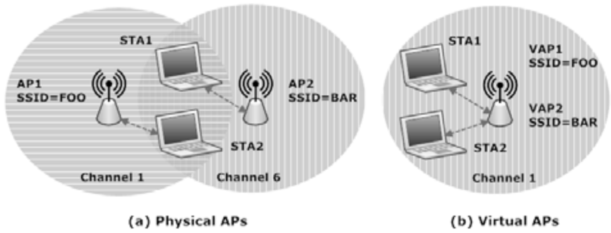

Fig. 4 – Physical and virtual APs

By integrating wireless LAN virtualization techniques into the hypervisor, the wireless LAN interface can be shared among several VMs. To each VM one or more virtual wireless interfaces can be assigned. As shown in Fig. 5, VIFs are configured to operate in one of the wireless operating modes, specifically the AP mode, and then can be assigned to various virtual networking components.

The main goal of this approach is to combine wireless network functionality into a common virtualized environment and to achieve performance levels comparable to the native hardware wireless LAN. A similar approach named virtual WiFi [3] has been taken to provide wireless LAN client functionality inside VMs. However, virtual WiFi approach is intended to support mobile client environments where the VM runs on the client device and has to be aware of the wireless interface to establish its own wireless connection.

The Virtual WLAN approach is suitable for virtualizing wireless LAN infrastructures, where multiple separate wireless LANs can be deployed on a shared physical infrastructures with different security mechanisms such as WPA and IEEE 802.11i. Since each virtual wireless LAN is logically separated, wireless LAN providers may use virtual WLANs to offer multiple services on the same physical infrastructure. Alternatively, virtual WLANs can be shared by multiple providers allowing each provider to offer separate services for their subscribers [1].

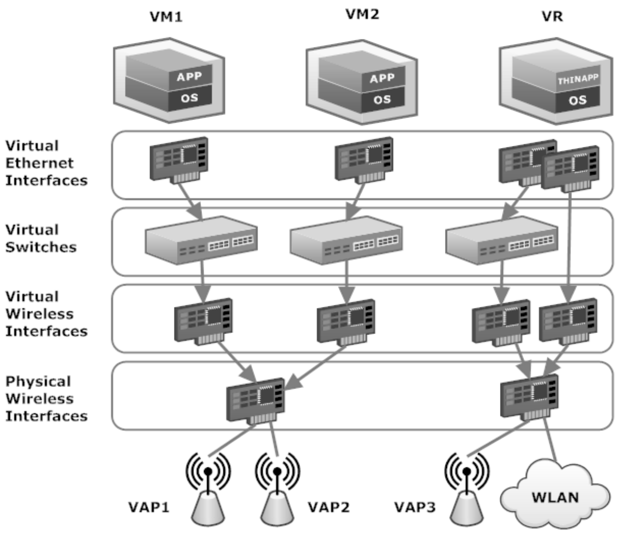

Fig. 5 – Virtual wireless LAN approach

This approach is based on the Atheros WLAN chipset which supports concurrent wireless connections sharing the same PHY layer of the wireless LAN device. This capability in wireless LAN devices is also referred to as multi-SSIDs, where each SSID is equivalent to a VLAN on a wired network. We extend multi-SSIDs capability to operate in the virtualization environments, where each virtual WLAN can have its own addressing, forwarding, routing, and security mechanism.

To emulate a physical AP, it is necessary to provide the emulation at different layers such as layer 2 (MAC), layer 3 (IP), and above. At the MAC layer, the behavior of a physical AP is being emulated by allocating a distinct MAC address and SSID to each virtual AP. At the IP layer, it is emulated by allocating a distinct IP address and potentially a Fully Qualified Domain Name (FQDN) to each virtual AP. In higher layers, the emulation can be carried out by providing each virtual AP with a unique authentication and accounting configuration such as (a shared key, or EAP methods with RADIUS authentication), or SNMP communities.

In our approach, a virtual wireless AP or router is constructed by configuring the VIF to operate in AP mode. This sets the main functionality of the wireless AP such as IEEE 802.11 operation mode and SSID. Once configured, the wireless interface is attached to a virtual switch to enable MAC forwarding similar to a physical AP. Then, the virtual AP interface is connected to a virtual router, in the same way as the virtual Ethernet interface, to enable IP forwarding and routing.

5. IMPLEMENTATION

The multi-SSID capability given by the Atheros chipset allows implementing multiple IEEE 802.11 networks on a single physical wireless card with Linux (Linux kernel version 2.6.33 and higher), since it includes a wireless driver supporting multiple VIF configurations.

The wireless driver for Atheros WLAN devices was initially developed by the madwifi project, and then became part of the Linux kernel. The implementation model of Linux kernel WLAN driver is currently based on SoftMAC wireless devices, where most of the MAC layer functionality is managed by the driver. For the time being, Linux kernel supports all wireless modes with PCI/PCI-Express Atheros WLAN devices only [26].

In order to implement our approach, we used a conventional PC with a wireless LAN card based on the Atheros IEEE 802.11n chipset. It had an Intel Core 2 processor with VT support, Gigabit Ethernet interface and 3 GB RAM. Ubuntu Linux has been chosen to host the virtualization environment for virtual WLAN approach. We used KVM as backend for virtualization and libvirt as frontend for managing VMs. With libvirt, there come two management tools: virt-manager as graphical user interface (GUI) and virtsh as command line interface (CLI).

The virtual wireless interfaces have been created using a CLI configuration utility in Linux named “iw”. Once created, the interfaces have been configured to function as virtual AP or virtual STA interfaces. It is essential for all VIFs to have a unique MAC address, which can be assigned with “ifconfig hw” command or “macchanger” utility.

A virtual AP functionality has been implemented using the hostapd daemon or background service. hostapd is an open source software for controlling wireless LAN authentication and association. It implements IEEE 802.11 AP management and provide support for several security mechanisms such as WPA, IEEE 802.11i, and IEEE 802.1X [27]. The virtual AP interface has been connected to a VDE switch to enable MAC forwarding similar to a physical AP.

For testing our approach, three virtual wireless routers have been hosted on the PC with a shared Internet connection. We created three virtual APs in IEEE 802.11g operation mode, and three virtual routers running Vyatta OS. Each virtual router had two virtual Ethernet interfaces. One of them was connected to the virtual AP interface and the other to the physical Ethernet interface using the Linux interface bridging feature. Each virtual router acted as a DHCP server and DNS forwarder for the virtual wireless LAN and each virtual AP broadcasted different SSIDs to distinguish the wireless networks. NAT functionality was also added to the virtual routers to maintain public IP addresses and to enhance wireless network security. Using these virtual routers, different wireless LAN clients could access the Internet with different wireless LAN security mechanisms.

6. PERFORMANCE AND RESULTS

We have conducted some tests to understand the impact of the virtual software layer on wireless LANs. The objective of the tests was to compare and quantify the performance of both conventional and virtualized wireless networks. Testing WLAN performance primarily included two test metrics: *throughput* and *response time*. These performance metrics were used to evaluate the applicability of our approach for WLAN infrastructure virtualization since the virtual networks had to handle the same kind of traffic as conventional networks.

The throughput of WLAN is defined as the speed with which a user can send and receive data between the client and the AP. Throughput varies across the WLAN's coverage area. For this reason, we placed the test machines at close range to operate on the maximum available channel bandwidth. Theoretically, the maximum TCP rate of 802.11g network is 24.4 Mbps and the maximum UDP rate is 30.5 Mbps. The UDP throughput is higher than TCP throughput because there is less protocol overhead associated with UDP. Therefore, TCP throughput is the most relevant metric in our performance measurements.

To measure the throughput, we used IPerf and JPerf as the graphical interface. IPerf tool was used to measure TCP and UDP throughput in two directions: uplink direction (from the client to the virtual AP) and downlink direction (from the virtual AP to the client). To measure response times or latencies, we used ping. Ping is used to measure the round-trip time between the client and the virtual AP. In our test setup, IPerf was installed on two machines; the machine which hosts the virtual wireless routers functioned as IPerf server and the wireless client machine as IPerf client. IPerf was configured on the wireless client to run tests for 60 seconds in both directions and provided values in Mbps.

We performed the same test in both native and virtual environments. In the native hardware environment, the tests were performed between a remote client and host machine running three virtual APs without virtualization. In the virtual environment, the tests are performed between a remote client and a VM directly attached to the virtual routers. In this case, the wireless traffic passing through the virtual routers.

Fig. 6 depicts the throughput test results where all throughput results have been averaged over three measurements. The average downlink/uplink TCP throughput is 21.8/18.6 Mbps in the native hardware environment and 21.4/18.2 Mbps in a virtual environment. Latency test results show that the average round-trip time in native hardware environment is 1.1 msec and 2.1 msec in the virtual case. This latency overhead comes from the virtualization layer. The results show that our proposed solution achieves performance metrics comparable to the native hardware environment.

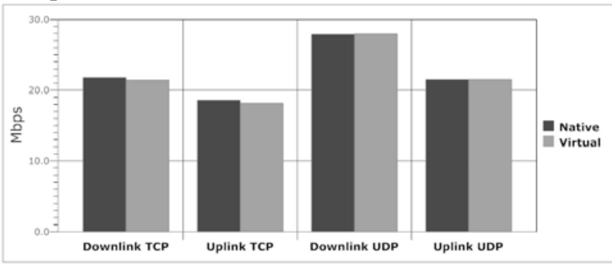

Fig. 6 – Throughput test results

7. CONCLUSION

In this paper, we introduced a virtual networking infrastructure using different virtualization techniques. Also, we proposed a viable approach to realize virtual WLANs by combining wireless LAN virtualization technique with open source virtualization platform.

Our approach adds wireless LAN functionally to virtualization environments. Summarizing some of the benefits, we can conclude that our proposed solution:

- Enables virtualized wireless LAN architectures.
- Builds wired and wireless networks without deploying physical infrastructure.
- Adds the wireless LAN management and control functions to virtualization environments.

For the future, it is planned to investigate performance measurement and optimization with the Xen open source hypervisor. Also, we will design a platform for virtual WLAN approach with different security infrastructures.

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HYBRID INDOOR TRACKING OF HUMANS IN HAZARDOUS ENVIRONMENTS

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Abstract: *The reliable tracking of humans and materials in indoor scenarios is an ongoing research issue. For example, the monitoring of humans in partially hazardous environments – like the surroundings of an underground longwall mining infrastructure – is crucial to save human lives. A centroid location estimation technique based on received signal strength (RSS) readings offers a well known and low-cost tracking solution in such a rough environment where many other systems with optical, magnetical or ultrasound sensors fail. Due to signal fading the RSS values alone cannot ensure a precise tracking. The sensor fusion of the RSS-based localization with an inertial navigation system (INS) leads to a more precise tracking. The long-term stability of the RSS-based localization and the good short-term accuracy of the INS are combined using a Kalman filter. The experimental results on a motion test track show that a tracking of humans in multipath environments is possible with low infrastructural costs.*

Keywords: *Inertial Navigation System, Kalman Filter, Received Signal Strength, Indoor Tracking, Sensor Fusion.*

1. INTRODUCTION

In an environment with partially dangerous areas a rough but high-available localization of humans with a monitoring of their movement patterns is of interest. For example, the detection of maintenance staff in the longwall mining, in particular close to self-advancing hydraulic shields is necessary.

Longwall mining is a highly productive underground coal mining technique where massive shearers cut coal from a wall face, which falls onto a conveyor belt for removal. The hydraulic shields are placed in a long line in order to support the roof of the coalface and maintaining a safe working space along the face for the miners. The automatic motion of the hydraulic shields needs to be stopped when a miner is localized in front of them. The accuracy of the localization system determines the size of the security zone and the amount of shields which are involved. Besides the accuracy also the availability of the localization system plays a significant role for the availability and efficiency of the longwall mining system, since the safety critical system architecture requires an immediate idle state of the system.

The environment of a longwall mining system does not permit a global radio-based positioning (e.g. GPS). A local radio-based system with a multilateration of several distance approximations between an unknown node (blind node, BN) and fixed anchor nodes (reference nodes, RNs) is applicable to find out the position of a miner equipped with a BN.

The received signal strength (RSS) offers a low-cost sensor for ranging-based localization systems. A classification of the ranging-based techniques is shown in Fig. 1. The use of directional sensors like infra-red (IR), ultrasound, optical and magnetic systems is limited to line-of sight (LOS) scenarios. There are several RF-based methods which can be used also in non-line-of sight (NLOS) scenarios. In principle the location estimation can be realized via analyzing signal propagation delays (time of arrival – TOA, time difference of arrival – TDOA), receive directions (Angle of Arrival – AOA) or RSS readings.

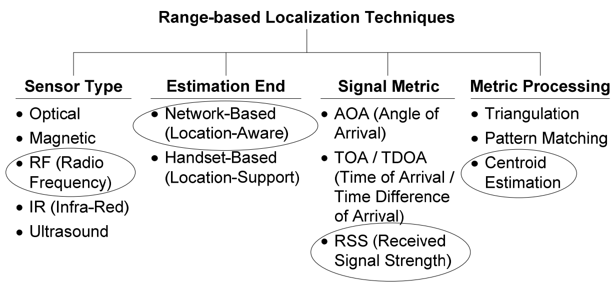

Fig. 1 – Classification of range-based localization techniques. Source: [1]

The methods are more or less affected by the problems of multipath propagation and resulting fading effects. For multipath environments the distances based on RSS measurements are often erroneous, especially for dynamic environments where the position of obstacles (or humans) may change continuously. Thus, for a range-based localization it is difficult to rely only on the raw RSS values. For a correct interpretation of the values according to a path loss model additional measures are required, since the influence of large-scale and small-scale fading effects leads to bad distance estimations. [2],[3]

The small-scale fading due to reflection, diffraction and scattering on obstacles is the main issue. When the transmitter or receiver change their position by small movements in the order of the wavelength (e.g. $\approx 12.5\,cm$ for $2.4\,GHz$) the RSS may vary by three or four orders of magnitude ($30..40\,dBm$). Therefore it is challenging to approximate the distance between transmitter and receiver with the RSS only. A detailed description of fading principles is given in [4], [5] and [6].

With a combining of the information coming from different types of sensors the accuracy of the localization can be improved. Compared to a system relying on a single sensor, the location estimation has a reduced uncertainty and an increased tolerance to single point failures. It is a common used technique to combine the position estimations of an RF-based system with an inertial navigation system (INS) [7], [8], [9]. In comparison to the RSS-based RF positioning system no external references are necessary for the INS.

With the acceleration information of the BN it is possible to calculate the change in velocity and position by successive mathematical integration of the acceleration with respect to time. The rotational motion of the BN according to the environment (reference frame) must also be taken into account so that a three-dimensional INS overall has six degrees of freedom (DOF). The rotations around the acceleration directions may be sensed using gyroscopic sensors. The latest advances in micro-electro-mechanical (MEMS) acceleration and gyroscopic sensors support the design of a low-cost inertial measurement unit (IMU). Sometimes an additional earth magnetic field sensor and a preasure sensor are added to the IMU to support the heading and height calculation in the three-dimensional space.

In this paper we propose the sensor fusion of a proprietary RF localization system and a low-cost INS using a Kalman filter. In section II, the infrastructure components and algorithms of the RF localization system are described together with the challenging multipath fading. In section III, the INS with the system architecture of the low-cost IMU is presented. The procedure of the sensor fusion with a Kalman filter is given in section IV. In section V, we validate the localization system performance by experimental results of a dynamic measurement on a motion test track. In the last section VI, the results are discussed and investigated in terms of an outlook for further system developments.

2. RF LOCALIZATION SYSTEM

The infrastructure components of the RF localization system are shown in Fig. 2. We assume a one-dimensional localization scenario as it is given in an underground longwall mining application [10], although the system is also applicable for a two-dimensional localization (e.g. in a factory building) [11].

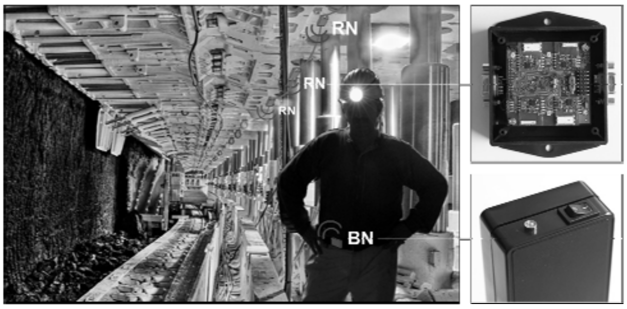

Fig. 2 – RF localization system with infrastructure components in an underground longwall coal mining tracking application (RN – reference node, BN – blind node). Source: Own elaboration

The blind node (BN) which should be located can move in front of a line of reference nodes (RNs) with fixed positions. The RNs are connected to a date concentrator (e.g. industrial PC) via a wired bus interface (e.g. CAN). The localization process can be subdivided into the components data acquisition, data preprocessing and location estimation (cf. Fig. 3). The single processing steps are described briefly in the following.

- In the data acquisition phase the RNs receive packets from the BN and store the corresponding RSS values. Since we use a multimodal diversity platform with four single RF transceivers on the BN and the RNs more than one packet can be received at the RN. The redundant values are transmitted to the data concentrator using the CAN bus.
- In the data preprocessing phase a selection combining (SC) of the redundant RSS values is done. The maximum RSS of each RN is computed and transformed into a weight.
- In the location estimation phase the BN position is calculated with the weighted centroid of the known RN positions. A detailed description of the used selective

adaptive weighted centroid location estimation algorithm can be found in [10].

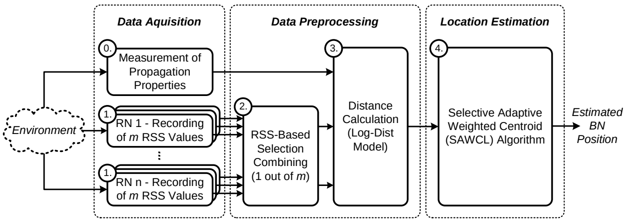

Fig. 3 – Structure of the RSS-based localization system. Source: Own elaboration

When designing an RSS-based indoor location-sensing system it is recommended to concentrate on the proper acquisition of the RSS values since their interpretation has the main influence on the system's accuracy. For an obstructed Indoor environment like the longwall mining application illustrated in Fig. 2 multipath effects have to be taken into account at the propagation of electromagnetic waves. Macroscopic objects with metallic surfaces (e.g. hydraulic shields, shearer, conveyor belt) are characteristic for these environments. Therefore, not only LOS connections but also NLOS connections between transmitter (BN) and receiver (RN) have to be considered. As a consequence of the multipath propagation by reflection, diffraction and scattering effects interferences of different multipath components at the receiver occur. As represented in Fig. 4, the distance-dependent path loss at the propagation of electromagnetic waves between transmitter and receiver is influenced by two different fading components.

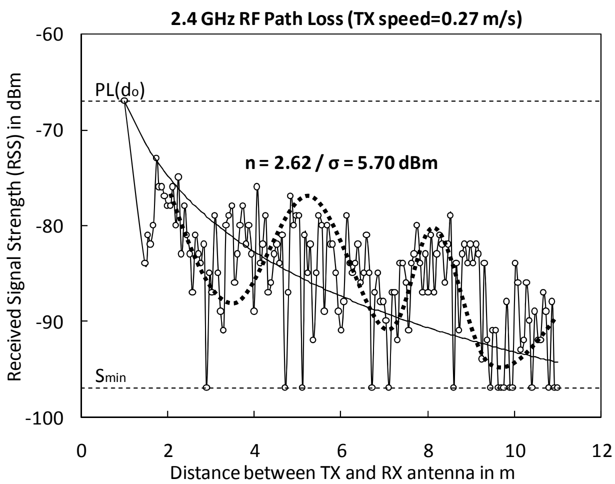

Fig. 4 – 2.4 GHz path loss measurement over a distance of 11 m (TX speed = 0.27 m/s, f = 2440.22 MHz, 250 kHz RF bandwidth, 150 RSS samples, 5 Hz update rate). Source: Own elaboration

Without any disturbances (free space propagation) the distance-depending path loss shows a logarithmic dropping of power with linear increasing distance according to the log-distance path loss model. With (1) the average path loss $\overline{PL}(d)$ (in dBm) over a distance d is given by the average path loss over a reference distance d_0 and the environment-specific propagation coefficient n [4].

$$\overline{PL}(d) = \overline{PL}(d_0) + 10 \cdot n \cdot \log\left(\frac{d}{d_0}\right) \quad (1)$$

For obstructed Indoor environments a log-normally distributed random value X_σ can be added to the above equation to take the large-scale fading due to shadowing through obstacles into account. The small-scale fading due to interferences of different multipath components is the main source of errors for the radio-based localization system. Frequency specific signal dropouts in case of destructive interference effects lead to bad distance approximations and a large location estimation error (LEE). In some cases – when the signal strength at the receiver is below the receiver's sensitivity threshold the signal gets lost and no information for the distance between transmitter and receiver can be calculated. Thus, the small-scale fading influences not only the accuracy of the location estimation but also the availability of the system.

A diversity concept with the use of space and frequency diversity at the same time is used to improve the accuracy of the distance estimation and increase the system's availability.

The RF communication takes place by proprietary radio modules from Amber Wireless. Both the BN and the RN have a multichannel transceiver with four RF modules which are arranged in a rectangle (from the top view, cf. Fig. 5). Two different frequency bands (868 MHz and 2.4 GHz) are used, whereby the diagonal arranged modules use the same frequency band.

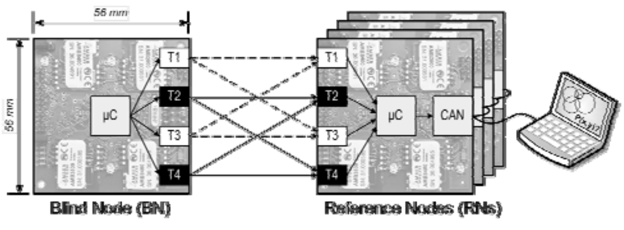

Fig. 5 – Overview of the radio positioning system and diversity concept with eight RF communication channels. Source: Own elaboration

The AMB2500 (T1 and T3) operates at the license-free ISM band at $2.4\,GHz$ ($f_m = 2440.2\,GHz$) and is attached by the CC2500 Low-power RF IC. The AMB8400 (T2 and T4) operates at the license-free ISM band at $868\,MHz$ ($f_m = 868.3\,MHz$) and uses the CC1101 Low-power RF IC. For both ICs the MSK modulation, a data rate of $250\,kbps$ and an output power of $+10\,dBm$ are used. Beside space diversity also frequency diversity is realized with eight uncorrelated communication channels. In the best case eight RSS values are collected for each RN and the best of them is used for the distance approximation after a selection combining (SC). We use two single SC blocks for each frequency and a following SC for their output as it is shown in Fig. 6. After all the maximum RSS value is forwarded to the distance calculation block.

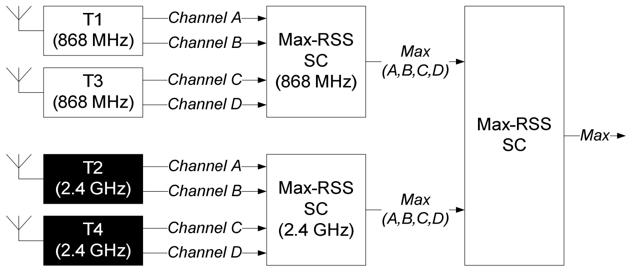

Fig. 6 – Two-stage selection combining (SC) using spatial and frequency diversity channels. Source: Own elaboration

3. INERTIAL NAVIGATION SYSTEM

The fundamentals about inertial navigation are given in [12] and [13]. In principle, an INS consists of the inertial sensor platform (inertial measurement unit – IMU) for the acquisition of the motion and the navigation computer for the calculation of the position of the platform. When the sensors are mounted directly to the the body of the platform it is called a strapdown IMU and a strapdown mechanization can be used to compute the position of the platform in the navigation frame.

The strapdown mechanization of the INS is shown in Fig. 7. It uses a three-dimensional navigation frame with six degrees of freedom. The three translatory motions (a_x, a_y and a_z) and the three rotary motions (w_x, w_y and w_z) are measured in the body frame. For the translatory motions acceleration sensors are used. The rotary motions are measured with angular rate sensors (gyroscopic sensors).

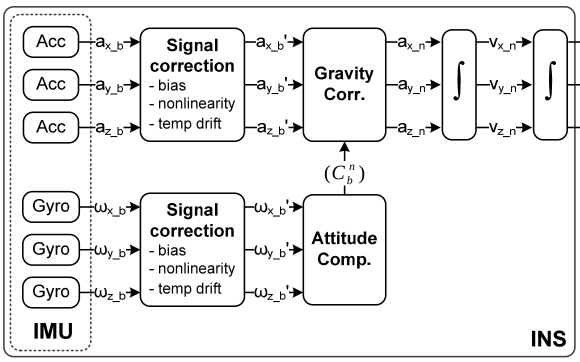

Fig. 7 – Three-dimensional strapdown inertial navigation system. Source: Own elaboration

A temperature compensation is used for the sensors and the values are corrected according to bias and nonlinearity errors. The filtered vector of the angular rates $\vec{w}'$ is used to update the attitude of the sensor platform in the navigation frame. The integrated values are expressed by the Euler angles ϕ, θ and ψ. For small angular rate changes $\Delta\vec{w}'$ the corresponding rotation matrix C_b^n is given with

$$C_b^n = \begin{bmatrix} 1 & -\psi & \sin\theta \\ \psi & 1 & -\phi \\ -\sin\theta & \phi & 1 \end{bmatrix}. \qquad (2)$$

C_b^n is used for the transformation of coordinates from the body to the navigation frame and the gravity correction of the measured accelerations. The corrected acceleration vector in the navigation frame is given with

$$\vec{a}_n = C_b^n \vec{a}_b - \vec{g}. \qquad (3)$$

To get the corresponding velocity vector $\vec{v}_n$ for the movement between the actual measurement at time step t and the last measurement at time step $t-1$ (3) needs to be integrated.

$$\vec{v}_n(t) = \vec{v}_n(t-1) + \int_{t-1}^{t} \vec{a}_n(t)dt \qquad (4)$$

The position vector can be calculated by integrating (4) and is given with

$$\vec{s}_n(t) = \vec{s}_n(t-1) + \int_{t-1}^{t} \vec{v}_n(t)dt. \qquad (5)$$

The Low-cost IMU hardware has six degrees of freedom (DOF) and is shown in Fig. 8. The system architecture has two sockets for the connection of the IMU to the system controller on our multichannel transceiver platform (cf. Fig. 2). We use the features of the IMU platform on both the BN and the RN.

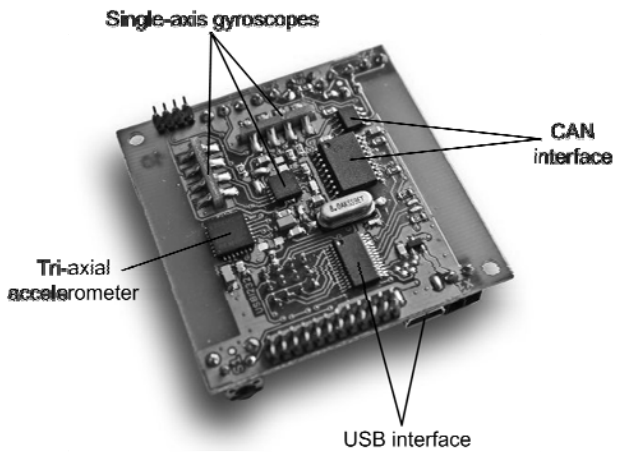

Fig. 8 – Six DOF low-cost IMU hardware platform. Source: Own elaboration

The USB interface is used for the sensor calibration on the BN and the CAN interface for the connection of the RNs to the data concentrator PC as described in section II.

The x-, y- and z-component of the BN's acceleration is measured with a digital LIS3LV triaxial acceleration sensor which operates at a full scale range of $\pm 2g$. The angular rates around the three axis are measured with analog LY530ALH gyroscopic sensors with a measurement range of $\pm 300\ °/sec$. The actualization rates of all sensors are set to $40\ Hz$. The detailed sensor characteristics are summarized in Table I.

Table 1. IMU sensor characteristics

Parameter	LIS3LV Acc	LY530ALH Gyro
Measurement range	$\pm 2g$	$\pm 300\ °/sec$
Resolution	$12\ Bit$	$12\ Bit$
Data rate	$40\ Hz$	$40\ Hz$
Temperature sensitivity	$0.025\ \%/°C$	$0.05\ °/sec/°C$
Nonlinearity	$\pm 2\ \%\ FS$	$\pm 1\ \%\ FS$

The sensors need to be calibrated before they can provide useful results. We use an in-field calibration without the need of external equipment (e.g. three-axis turn-table) as it is proposed in [14].

4. SENSOR FUSION ALGORITHM

In [11] a plausibility filtering of the calculated distances between the BN and the RNs is proposed. In [10] the RSS-based BN position (and not its distances to RNs) is filtered according to an one-dimensional motion vector where the INS position acts as a threshold value. This feedforward architecture is easy to implement and requires only a small amount of additional processing steps. Our new approach uses a feedback architecture for the adaption of the estimated position (cf. Fig. 9).

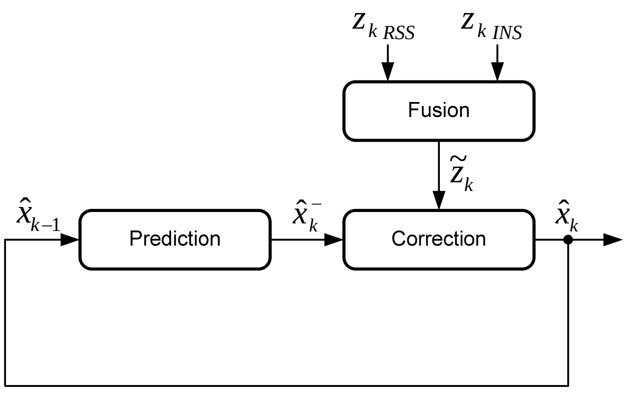

Fig. 9 – Multi-sensor multi-temporal centralized measurement fusion. Source: [15]

The measurements from the RSS-based localization system and the sensor values of the INS are combined with a centralized measurement fusion according to [15]. The resulting observation $\tilde{\mathbf{z}}_\mathbf{k}$ is used for the correction of the a priori state estimate $\hat{x}_k^-$.

The Kalman filter uses a set of mathematical equations that provides an efficient technique to estimate the state of a discrete-time controlled process. The recursive algorithm predicts the actual process state with the last state and the actual measurement for process input. The model for the process and measurement is given as follows:

$$x_k = Ax_{k-1} + w_k, \tag{6}$$

$$z_k = H_k x_k + v_k. \tag{7}$$

The process noise $\mathbf{w_k}$ and the measurement noise $\mathbf{v_k}$ are assumed to be independent (of each other), white, and with normal probability distributions. We take the covariances of a real life path loss measurement for the initial noise estimations. The filter is divided into two parts, the time update (prediction stage) and the measurement update (correction stage). The time update equations for the filter are the following [16]:

$$\hat{\mathbf{x}}_\mathbf{k} = \mathbf{A}\hat{\mathbf{x}}_{\mathbf{k-1}}^-, \tag{8}$$

$$\mathbf{P}_\mathbf{k}^- = \mathbf{A}\mathbf{P}_{\mathbf{k-1}}\mathbf{A}^\mathbf{T} + \mathbf{Q}. \tag{9}$$

The time update equations project forward the current state $\hat{\mathbf{x}}_\mathbf{k}^-$ and the error covariance estimates $\mathbf{P}_{\mathbf{k-1}}$ to obtain an a priori state estimate. **Q** is the process noise covariance matrix. The **n x n** matrix **A** defines the transition from the state at the previous time step $\mathbf{k-1}$ to the state at the current step **k**. The measurement update can be described as follows:

$$\mathbf{K_k} = \mathbf{P}_\mathbf{k}^-\mathbf{H}^\mathbf{T}(\mathbf{H}\mathbf{P}_\mathbf{k}^-\mathbf{H}^\mathbf{T} + \mathbf{R})^{-1}, \tag{10}$$

$$\hat{\mathbf{x}}_\mathbf{k} = \hat{\mathbf{x}}_\mathbf{k}^- + \mathbf{K_k}(\mathbf{z_k} - \mathbf{H}\hat{\mathbf{x}}_\mathbf{k}^-), \tag{11}$$

$$\mathbf{P_k} = (\mathbf{I} - \mathbf{K_k}\mathbf{H})\mathbf{P}_\mathbf{k}^-. \tag{12}$$

The Kalman gain $\mathbf{K_k}$ is used to weight the difference between the a priori state estimate $\hat{\mathbf{x}}_\mathbf{k}^-$ and the current measurement observations $\mathbf{z_k}$. The measurement noise covariance matrix **R** is dependent on the variance of the measurement values. The **n x n** matrix **H** relates the state estimate $\hat{\mathbf{x}}_\mathbf{k}^-$ to the measurement $\mathbf{z_k}$.

5. EXPERIMENTAL RESULTS

The test bed for the localization system is a tracking application on the motion test track shown in Fig. 10. Seven RNs are evenly distributed next to the track. Reflecting walls are installed to force multipath RF propagation for a realistic scenario. During the experiment the BN moves between the end positions A and B and the RSS and INS measurements are collected on the data concentrator.

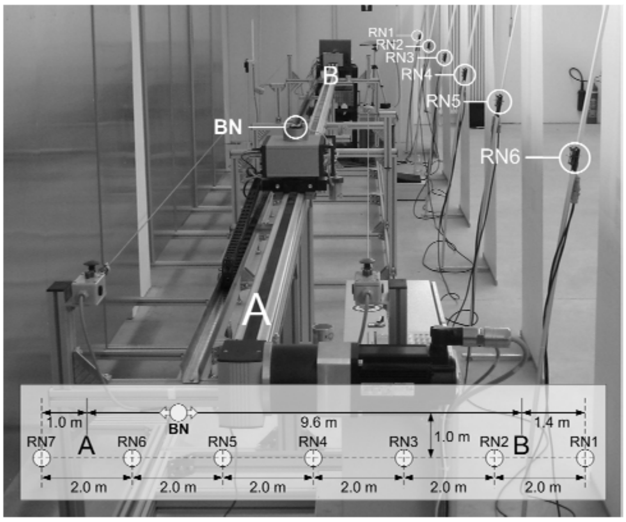

Fig. 10 – RF positioning system on a motion test track in a multipath indoor environment (BN – blind node, RN – reference node). Source: Own elaboration

A Java application (cf. Fig. 11) is running on the PC for the computation and visualization of the BN's position. The central component of the software is the radio map where the infrastructure is visualized. The circles around the RNs represent the RSS-based distance approximations. The recorded RSS values are also saved in a database together with the INS measurements. Therefore an offline calculation of the BN's position is possible and the performance of different measurement noise covariance matrices for the Kalman filter can be compared easily.

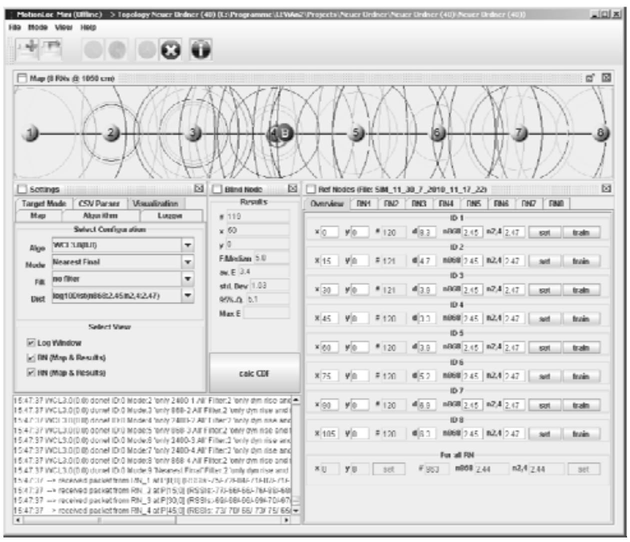

Fig. 11 – Java software platform LEViAn (Location Estimation with Visualization and Analysis) on the data concentrator PC. Source: Own elaboration

We compare the location estimation error (LEE) of four different configurations. The first configuration is the "RSS" reference localization without any additional filtering. The second configuration "RSS+d_filter" uses the distance filter technique from [11]. The third configuration "RSS+INS_filter" uses the motion data from an INS to filter the BN position [10]. The fourth configuration "RSS+INS_fusion" is the proposed sensor fusion of the RSS localization and the INS using a Kalman filter. The cumulative distribution functions (CDFs) of all configurations are shown in Fig. 12.

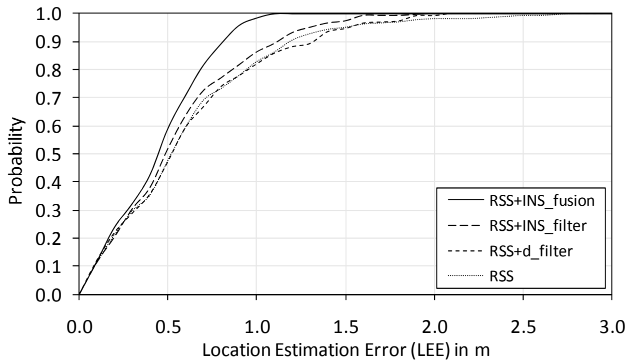

Fig. 12 – Error probability for the location estimation of various filter configurations. Source: Own calculation

A detailed error statistic can be found in Table II. The median error LEEmed is nearly the same for all configurations. Looking at the $\mathbf{99^{th}}$ percentile the influence of the filter and fusion algorithms gets obvious. The maximum error of the RSS localization system without any filter is $\mathbf{2.78\,m}$. With the plausibility filtering of distances the maximum error is reduced by more than $\mathbf{25}$ % to $\mathbf{2.08\,m}$. With the sensor fusion of the RSS localization and the INS the maximum error is reduced by even more than $\mathbf{62}$ % to $\mathbf{1.08\,m}$.

Table 2. Performance comparison of different filter configurations (LEE – location estimation error in m)

	RSS	RSS+ d_filt	RSS+ INS_filter	RSS+ INS_fusion
LEE_{av}	0.52	0.54	0.48	0.46
σ_{LEE}	0.49	0.46	0.39	0.26
$LEE_{99\%}$	2.38	1.89	1.58	1.04
LEE_{max}	2.78	2.08	1.93	1.08

6. CONCLUSION AND FUTURE WORK

Looking at the dimension of the test track with a length of $9.60\,m$, the error range of the RSS localization without filter covers more than the half of the whole track, which indicates a bad system performance. The proposed sensor fusion is useful to reduce the error in a significant way. The combined system has a sufficient precision and enables a localization for many applications, e.g. for the monitoring of maintenance staff in a longwall mining infrastructure. Since the inertial sensor technology based on MEMS techniques evolves rapidly, the accuracy of the combined system can be even more improved with a newer and more precise sensor platform. The purpose of a low-cost localization system should be considered when selecting the appropriate sensors. For the RSS localization system a further development should comprise the replacement of the proprietary RF transceivers by standardized low-power protocols like ZigBee or Bluetooth low energy. For the future we are also consider to test the system in a real scenario of an underground longwall mining application. Therefore, we are currently working on the intrinsic safety of the infrastructure components.

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AUTOMATED NETWORK PROTOCOL EVALUATION – THE POTSDAM WIRELESS TESTBED

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Abstract: *The Potsdam Wireless Testbed supports validation and evaluation of Wi-Fi radio stacks and wireless applications in environments with heterogeneous hardware. In contrast to simulators, wireless testbeds support the network stack validation with specific radio chipsets and radio signal propagations. Furthermore, wireless testbeds unburden programmers from manually updating software on nodes. Scheduled test-runs are executed automatically for a defined duration including compilation and deployment of the protocols and measurement scripts as well as collection of measurement results and log files. The testbed supports heterogeneous processor architectures and radio chipsets via internal cross compilation. The developer can overview the visualized results of its validation and therefore can focus on the code and the results. Next to the support of several device and processor architectures, the Potsdam Wireless Testbed is intended to support additional radio frequency ranges as well as mobile device.*

Keywords: *Test bed, validation, evaluation, wireless, Wi-Fi.*

1. INTRODUCTION

This article introduces the Potsdam wireless testbed utilized for the validation and evaluation of radio network stacks and is an extended version of an article published in the proceedings of the Wireless communications and information conference [1].

A necessity for automated protocol and application validation and evaluation was recognized in the ongoing development of the KopAL [2] support system for elderly. In KopAL users are equipped with mobile devices that assist them by reminding on upcoming appointments, recognizing critical situations (such as falls or losing-tracks) and offering emergency-call functionality.

Since the mobile devices are maintained by their caretakers, long device runtimes and reduced maintenance times are necessary, to be accepted. The development of the necessary energy efficient protocols (e.g. for communication and localization) requires regular validation and evaluations on multiple device types. These devices' characteristics differ regarding radio chips (with radio frequency utilization or functionality variations) and processor architectures.

In case of KopAL, the development covers the routing, logical link control (LLC) or media access control (MAC) layers as well as the radio device drivers and application logic. Therefore the KopAL indicates a tendency towards mobile applications that regularly require cross layer developments and wireless communication stack manipulation to achieve precise in-door localization, wireless sensor node access or higher energy efficiency.

The development of wireless network stacks requires extensive validation and evaluation, in general. Since changes may influence additional layers, an overall validation und evaluation is required especially in case of cross-layer network stack implementations (as found in Sub-1 GHz networks or RFID). As a result, the proper functioning of wireless network stacks can only be ensured by validating the complete communication stack, as recognized by Moss [3].

With heterogeneous hardware even the functional spectrum of device drivers and chips differs as recognized in [4] and therefore radio hardware and drivers' influences have to be taken into account during validation and evaluation, as well.

The proper functioning of wireless network stacks must sufficiently handle inter-node communication and physical phenomena such as noise or reflections to assure sufficient robustness.

As a result, network stacks must be validated with multiple nodes in a representative environment (with realistically placed obstacles and mobility) to assure its proper functioning within the dedicated environments.

Frequent node reprogramming is a time consuming part of the validation and evaluation process. The manual alteration of node software (including node collection, reprogramming and node redistribution) is time consuming and deployed nodes are hard to access. To increase the validation efficiency, alternative approaches have been developed that aim to automate the deployment of software on distributed wireless devices and reduce the manual validation and evaluation effort.

Existing automated validation or evaluation systems can be categorized in network simulators, wireless testbeds and hybrid solutions as discussed in Section Related Work. As shown, the advantage of testbed approaches is that they support the validation of the full network stack including the radio chipsets functionality.

However, since existing testbeds mostly focus on homogeneous equipment, they have limited value for the validation of networks that include devices with heterogeneous hardware capabilities (such as different radio chipsets, processor architectures or memory). Limited solutions support automated node mobility. Since the KopAL system requires the network stacks validation for heterogeneous devices (as summarized in Section 2) and node mobility, the existing solutions do not fit our requirements, as discussed in Section 3 of the KopAL project. A novel testbed system has been developed (as described in Section 5 to 7) and successfully deployed within the Potsdam Wireless test bed. Section 8 gives an overview of future extensions, which are currently under development.

2. HARDWARE

As shown in Figure 1, the Potsdam Wireless Testbed includes a PC with Ethernet and Wi-Fi (IEEE 802.11 b/g) network interfaces acting as a testbed management server and the following Wi-Fi devices:

- The LinkSys WRT54GL Router[1] supports the IEEE 802.11b/g Wi-Fi standard via a Broadcom Wi-Fi chipset and 4 +1 Ethernet interfaces. Next to 4 10/100 GBit Ethernet connectors 16 MB main memory, 4 MB flash drive and a Broadcom BCM5352 MIPS processor with 200 MHz.
- The Nokia N8x0[2] devices are supported as mobile devices. They contain IEEE 802.11b and g Wi-Fi transceivers, next to an USB serial connection, a 400 MHz ARM CPU, 128MB memory.

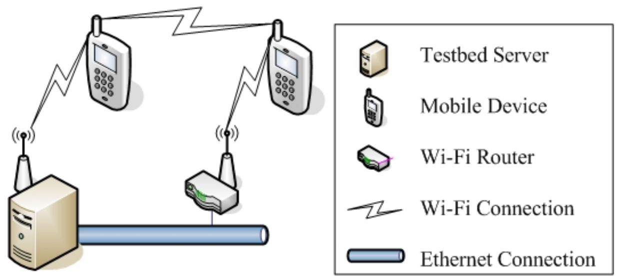

Fig. 1 – Testbed hardware

- The Openmoko Freerunner[3] is an alternate supported mobile device type. It contains as well IEEE 802.11b/g Wi-Fi transceivers, an USB serial connection, a 400 MHz ARM CPU, and 256MB memory.

Therefore the testbed has to support different processor architectures such as x86, ARM 9E and MIPS. As described in Section 3.3, this fact is concealed from the developer, as long as the compilation succeeded. In case of errors, the developer can analyze the logfiles and after alterations restart the compilation.

Depending on the devices network interfaces and mobility characteristics, the devices are connected with the testbed server. While the routers are accessible via an Ethernet connection, the mobile devices connect via Wi-Fi links – either with an in range Wi-Fi access point or directly with the server.

Since the inclusion of additional devices that include Sub-1 GHz radio network interfaces as the Chronoz Watch and the Mica2 sensor nodes is intended the testbed system should be able to handle multiple network standards and additional device classes.

3. REQUIREMENTS

The development of the KopAL System indicated general requirements that must be handled by the Potsdam Wireless testbed. The devices of the KopAL project have heterogeneous characteristics. These heterogeneous characteristics include the available radio interfaces (either the chipset and the frequency ranges and protocols), processor architectures and processing, memory or energy capabilities. In addition the devices mobility differs between the different device classes – while some remain stationary (as the Linksys Wi-Fi routers) others are mobile since carried around by the users. The validation system must handle this device diversity and the resulting necessities, which are further discussed in detail.

[1] http://www.linksysbycisco.com/LATAM/en/products/WRT54GL (14.09.2011)

[2] http://mea.nokia.com/support/product-support/nokia-n800-internet-tablet (14.09.2011)

[3] http://wiki.openmoko.org/wiki/Neo_FreeRunner (14.09.2011)

The intended radio standard diversity (even on a single node) requires the support of multiple network interfaces and the dynamic (de-)activation per node. In addition, the functional implementation provided by radio chips and device drivers differs from each other. As recognized in chips of the Sub-1 GHz frequency band, the implementation of CRC checks is supported by hardware in selected chipsets (such as the CC1100) while others (such as the CC1000) outsource it to the network drivers. In these frequencies even encoding of the Checksum varies (between high-bit and low-bit order). The Wi-Fi chipset variances as found in timestamp precision (of received messages) was recognized by Haustein [4] but complicates the network stack adaptation, next to differences between FullMAC and SoftMAC network cards. Since radio stacks may highly depend on functionalities (such as timestamp precision, RSSI measurements and CRC checks) network stacks must be evaluated on all relevant radio chipsets. The combination of different hardware devices with heterogeneous radio chips is problematic as well (e.g. by differing CRC checksum encoding or signal modulation). To validate robustness for these error types the validation must include all potential radio chipset combinations.

The heterogeneity of the devices (of the KopAL project) is not limited to the included radio chipsets. The devices as well include a various processor architectures (such as x86, ARM and MIPS). The compilation of the network stack for the different architectures should be handled autonomous by the testbed system, to relieve the programmer from preparing several solutions.

In addition, the available main memory of the devices varies. This has to be taken into account, since limiting the storage of measurement and log file on the devices during test runs. To exclude potential message losses, the testbed must handle this challenge as well.

The KopAL system includes localization functionality and supports node mobility. Since the node mobility may influence the link stability and the topology changes, it must be evaluated as well. To assure the comparability of the results, the node mobility must be reproducible.

While some devices exclude an internal energy supply (and are charged via power connectors) mobile devices include batteries and therefore are energy critical. Since the energy efficiency is a critical factor of a network stack – the testbed should support the collection of energy consumption as well.

Additional aspects of heterogeneity include supported programming languages for measurement scripts.

4. RELATED WORK

The manual reprogramming of nodes for the validation of wireless network stacks, can be overcome by several automated validation systems. These systems can be categorized as follows:

- Network simulators emulate virtual devices and simulate the message transmission between them with software. For simulating radio networks, the message transmissions are calculated via radio wave propagation models (such as [5] and [6]). Since the network stack is loaded into the simulator, developers must not reprogram multiple devices. In addition, for network simulation no specific hardware equipment is required. The limited investments and the reduced deployment times make network simulators a good choice for research groups with limited resources. In addition, simulators enable the evaluation of network stacks and protocols on tremendous amount of nodes. Simulators as well give easy debugging functionality and runtime speed-ups (by time accelerated).

However, simulators include several drawbacks that limit their validation usage to primer functional test of the upper layers.

Current radio propagation models approximate the radio propagation for algorithms efficiency, since "propagating each message all over the playground and hence delivering it to each node, slows down the simulation."[6] Therefore, if not excluded, these models [7] approximate phenomena such as interference, reflection or diffraction via ray tracing. In addition, the influence of obstacles (e.g. containing metal or water) on radio waves signal strength is excluded from any propagation algorithms, to the authors' best knowledge.

The recognized differences of radio chipset supported functionalities cannot be covered by simulators, making a validation on the utilized hardware indispensable.

- Testbed systems automate the deployment and validation process of network stacks on multiple devices. Therefore testbeds relieve developers from manual software-deployments, by automatically updating software on nodes. Next to the automatic update mechanism testbeds support the initiation and termination of test runs including the collection of measurement results and log files. Several existing testbeds include node mobility, either via robots [8], [9], or via humans carrying devices [10]. A major drawback of testbed systems is the limited debugging support, which in contrast the detailed simulation debug information is mainly limited to message statistics or log output (as found in MoteLab [11]). While most existing wireless testbed systems support a single radio frequency, the EWANT [12], WHYNET [13] and DES [14] testbeds include wireless network transceivers for multiple frequencies (and combine 2,4GHz Wi-Fi with 868MHz transceivers). However even this system limits a test run to one frequency, while the alternate ones utilization is limited for configuration purposes instead of combined routing purposes. As a result these testbeds do not support the evaluation of hybrid networking solutions, what we aim for.

- Emulators, such as MiNT [15], combine node simulation with package transmissions over physical radio links by utilizing antennas (or attenuators) for message transmissions while the processing is executed on a single computer (similar to the simulator approach). Therefore emulators combine the advantages of both (efficient debugging of the simulation results with realistic radio signal distribution characteristics). However, the proper functioning cannot be validated on different hardware devices via hybrid solutions.

The above mentioned systems include the following restrictions, making their utilization for the KopAL system validation suboptimal. The simulation based testing and debugging seems appropriate for initial debugging, testing and validation – since message flows can be validated (even for large scale networks). However, simulation cannot validate the appropriate functioning on specific hardware and realistic circumstances (e.g. caused by approximate radio propagation models). Therefore an initial simulation based validation of developments must be supplemented by a "physical" test in realistic environments that should cover the intended hardware and physical conditions.

5. TESTBED MANAGER

The testbed manager is the essential component of the testbed. The testbed manager handles creation, deployment, execution and operation of test runs and initiates the collection of measurement results and log files.

Test-runs have a defined duration after which they are stopped.

Created via the Web-Frontend (as described in Section 6) they as well include a routing protocol, a measurement script and a (sub-) set of available nodes.

Once created, test-runs are scheduled in a Fi-Fo queue within the testbed manager for execution. The testbed manager executes uploaded testruns sequentially. When a test-run is executed, the nodes software is updated with the dedicated routing protocols and measurement scripts. In case the nodes have a separate network interface (such as Ethernet) it is used for configuration purposes. Nodes without a separate network interface, connected with the testbed server can continuously lose connection (caused by a faulty routing protocol). To prevent permanent disconnection of any node a management routing protocol is stored on the nodes. In the so called management mode the OLSR protocol [16] is used as "management routing protocol". In case a node permanently lost connectivity to the base station (recognized via heart-beat messages) the management mode is started.

For reprogramming purposes all nodes switch (between test runs) to the management mode as shown in Figure 2. Therefore disconnected nodes automatically switch to the management mode, waiting to rejoin the network after the current test run is finished.

When a test run is finished, the management

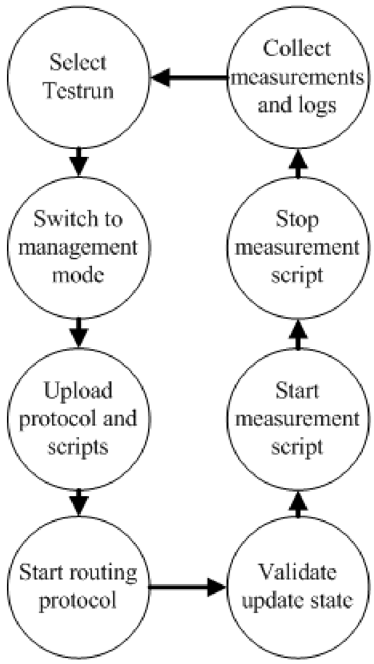

Figure 2: Testbed state transitions

server collects all measurements and log files and generates (visual and textual) summaries of them. Afterwards it requests all nodes to reset its routing protocol to the management mode. Receiving this reset request each node stays connected for 1 minute, to assure sufficient time to forward the reset message to the whole network, before changing into management mode.

After all required nodes have entered the backup mode, the routing protocol and measurement scripts of the new test run are deployed on the devices. The appropriate routing and measurement scripts are transmitted compressed to the nodes and afterwards decompressed and installed on them.

Afterwards the testbed manager initiates a (delayed) start of the uploaded routing protocol on all specified nodes. As a result the nodes leave the managed mode. So does the testbed server.

The installation is validated via a status request message, which is initiated by the testbed manager after the restart. The status response indicates (next to the connection success) the version of the active routing protocol and measurement script.

Unavailable nodes are excluded from the testrun but are logged by the testbed manager for later debugging purposes. The user can interrupt the current testrun manually (at any time) and reschedule an altered version for later execution.

The testbed manager starts the test run by initiating the measurement script. As described in Section 7 measurement scripts collect connection data (such as quality or signal strength measurements) and generate the network traffic. As a result, the message flows during a testrun are regulated by measurement scripts and the routing protocols. Nodes as the Linksys WRT54GL router may regularly face full memory problems. In such case, measurements results can be transmitted (pushed) from the devices, to the testbed server during a test run. To reduce the network load all data is compressed on the devices before transmission. Being aware of potential influences on the measurement results, the measurements (and log files) are preferably stored on the nodes and pulled by the testbed server when the test run is finished. Since the Linksys routers use a wired connection with the testbed server for these transmissions these influences are excluded in our current setup.

On the testbed server the data is decompressed, processed and attached to the test run.

When the specified testrun duration has passed, a stop message is send by the testbed manager to all participating nodes, which finalize the measurement script execution (if not already finished).

All control messages for protocol and measurement script updates, test run management and collection of measurement results and log files are handled by the testbed manager. HTTP is utilized as communication protocol combined with a php processor on each node, to handle incoming requests, for interoperability and portability reasons. Some control tasks (such as the update of routing protocols or packaging of measurement results) utilize additional shell scripts, executed by the PHP scripts.

If available, testbed devices utilize the buildings' Ethernet infrastructure. To minimize the impact of resulting network traffic (which might increase in case of updates) on other computers and the overall network performance, the participating nodes are grouped within a virtual LAN.

Next to the execution and planning of upcoming testruns, the testbed manager handles additional functionality such as the preparation of uploaded routing protocols or measurement scripts.

Uploaded measurement scripts (that require compilation) or routing protocols are immediately prepared for deployment.

Therefore they are automatically compiled for all supported platforms via cross compiler tool chains.

6. USER INTERFACE

All user interactions of the test-bed system are executed via an AJAX Web page. As a result the testbed can be managed location independent.

Users can upload measurement scripts and routing protocols, manage nodes, create configuration and schedule test runs.

In addition the current state of a testrun and the results are summarized. Therefore test run results (including dynamic visualizations and raw data of measurement results as well as log files) are visualized. Automatic generated gnuplots of measurements can be downloaded as well and used for future documentation.

Since the testbed server is developed with Java, the user interface as well was developed in Java including the Spring[4] and Hibernate[5] Frameworks.

7. MEASUREMENT SCRIPTS

Measurement scripts should be executable on all device-types. Since separated from the routing protocols, measurement scripts are applicable in general (as long as the protocol supports the required interfaces) and enable a comparison of routing protocols.

In the Potsdam Wireless Testbed, measurement scripts can be programmed either as shell scripts, or as C programs. Therefore developers can use the full spectrum of the available Linux tools (such as ping or wget through scripting) or may develop specific solutions to precisely fit their requirements. The measurement scripts can be extended by additional precompiled programs (as long as portable to the selected nodes) which then should be packaged with the specific measurement script package.

[4] http://www.springsource.org/ (14.09.2011)
[5] http://www.hibernate.org/ (14.09.2011)

8. FUTURE WORK

The Potsdam wireless testbed currently supports various devices with Wi-Fi transceivers but is currently extended by additional radio spectrums, hardware platforms. The supported hardware platforms are extended by additional devices such as the Mica2[6] sensor nodes and the TI eZ430 Chronos watch[7]. Therefore additional radio spectrums such as Sub-1 GHz are supported as well. To ensure a high portability the inclusion of TinyOS[8] as additional Operating system for these devices is intended.

Furthermore, the testbed will be equipped with robots carrying mobile devices during test runs, including autonomous recharging functionality.

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PROVIDING HOUSEHOLD CUSTOMERS WITH SMART METERING DATA ON MOBILE DEVICES

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Abstract: *One option for reducing carbon dioxide emissions is the future use of renewable instead of fossil resources. A consistent prerequisite is the optimization of household customers' energy consumption behavior. The suitable visualization of energy data, corresponding costs and tariff information on mobile devices is essential to achieve this goal. Energy data are acquired by a smart meter and transferred over wireless networks to a mobile device to provide the customer with relevant information about his current energy usage. The household customer is hence enabled to manage his energy consumption, to hold the optimal load and meet the optimum price. Suitable typs of visualization, specific for different tariffs, are identified and presented together with necessary technologies and methods for communication and data access and delivery.*

Keywords: *smart metering, energy usage, wireless communication, user interfaces, web services, mobile devices.*

1. INTRODUCTION

The reduction of carbon dioxide emission is one of the primary tasks of EU and national policies. To achieve this, energy production has to be changed to use renewable instead of fossil resources. Moreover, the household customer is required to change his attitude using energy by reducing his total annual energy usage and by managing the energy demand to avoid load/demand peaks. Demand peaks cause problems in electricity production and energy distribution within grids. Energy generation plants always need to meet the exact capacity demanded. Generally, the objective is to reach the best conformity of the household's energy consumption profile to the energy provider's supply profile and resp. the energy cost profile. Smart metering technologies enable electricity providers to effectively reflect the change in energy usage. The idea is to use demand response to influence load curve patterns [2], i.e. the change of demand as reaction to price changes [3]. This means introducing new pricing models and new tariffs. Essential for motivating the household customer to change his behaviour of using energy is to provide him with specific information about his current energy load, his usage and the corresponding costs, i.e. tariff information.

The primary target of the work presented in this paper is visualizing smart meter information and therefore giving household customers an opportunity for analyzing their energy usage. Different approaches are discussed for providing necessary and specific information conveniently on mobile devices, e.g. smart phones. Three tariffs, a time variable, a load variable and a tariff depending on total usage together with specific data visualizations and modes of data access are presented. Moreover, the mobile and wireless communication path from the smart meter or from the energy provider's enterprise resource and planning system to the mobile device (smart phone) is discussed. Preliminary results have been presented previously by Kohlbrecher et al. [16].

2. RELATED WORK

Visualizing detailed information on small screens of mobile devices is an important topic. Since mobile devices are used in changing contexts, there is a difference to the same situation with a desktop PC. Nielsen [22] found four main usability hurdles for mobiles devices: small screens, awkward input, download delays and miss-designed sites. Guidelines for designing apps are given by Keck [13] and for designing mobile web sites by the W3C consortium [27]. The guidelines describe how to design an app or a website which can be used and understood easily by the user. An app or website has to be designed along the paradigms of the operating system, for example the back button in iOS is located in the upper left corner as a standard. The corresponding app or website has to follow accordingly.

Leung et al. [18] found age-related differences with the reception of mobile device icons. The W3C consortium [27] offers a mobile OK Checker for validating and optimizing mobile websites.

The decision of using either an app or a website approach depends on the field of application. It is an individual decision and there is no general solution. Advantages and disadvantages are shown by Gather [11].

A software system for visualizing smart meter data on personal computers is developed by Dr. Neuhaus [4]. A similar app for iPhone and iPad was presented by enexoma AG [6].

Kunold et al. [14] developed a smart metering controller (SEC) for wireless transmission and storage of smart metering data within the customer's household. Data analysis and visualization is performed on a notebook.

3. DATA PRIVACY AND SECURITY

Besides the technical solutions of transfering, storing and visualizing energy data data privacy and security is a frequently discussed issue.

Depending on the selected tariff, energy load data items have to be recorded and stored. Data of high granularity, i.e. high resolution in time, storing one load/consumption item per minute for example will be generated. Such precise energy consumption profiles will be generated showing sensitive information concerning the lifestyle of the person or family living in the corresponding household. Thus, data privacy and security will become an important issue. Consequently, as a guideline profiles of high granularity of one household should not leave this household. The energy provider needs profiles of such granularity for forecasting purposes, but these profiles may be of high aggregation, i.e. profiles aggregated over several households of a region. In this context a very important objective is the rational organization of data, which is safe to data misuse [25].

Due to the unbundling of the energy market by the EU the number of the participants in the energy market has risen, for example the German energy law (EnWG 2008) introduces the option of authorizing an independent measuring point operator and/or service provider. There is an increasing number of interfaces between market participants exchanging detailed energy consumption data for billing or forecasting purposes.

Basically four groups of data can be distinguished: consumption profiles, user's data, device data and data which deliver information about the billing system. Besides, the consumption data can be transferred in different granularity for the selected household and various degrees of aggregation. Highly granular energy profiles of a single household need more measures for data protection than profiles of high granularity but aggregated over several households.

Some principles for ensuring data privacy are developed, i.e. transparency, legitimate purpose and proportionality. Within the context of household energy consumption profiles of high granularity and low aggregation a guideline is to keep these profiles should within the household.

Some basic approaches are given by Metke and Ekl [19] and Raabe [26]. Protocols for fraud and leakage detection as well as further statistical processing of meter measurements, without revealing individual meter readings are given by Kursawe, Kohlweiss and Danezis [17].

Household energy consumption profiles of high granularity make it is possible to detect active electrical devices and thus information about the lifesytle as shown by Müller [21] and critically discussed by Fox and Müller [7].

4. SYSTEM ARCHITECTURE AND COMMUNICATION

The main components of the system presented within this paper are: a smart meter, a smart energy controller (data storage) and mobile devices (smartphones). The system presented within this paper is based on the work of Kunold et al. [14]. Data of energy usage are continuously collected by a smart meter and transferred to a smart energy controller (SEC). The SEC serves as a storage device of energy consumption profiles within the household. Typically it can be represented by a WLAN router, for example a Fritz Box [9]. The Fritz Box offers the option to run additional applications, i.e. a data base system for storing energy profiles of high granularity [14]. From the SEC the profiles may be transferred wirelessly to a smartphone of the energy customer.

Data transfer between smart meter and SEC database can be achieved either by wire or wirelessly, e.g. WiFi or ZigBee [14].

The data storage within the SEC is represented by a SQL database, which holds information about energy usage and available tariffs.

Data access by smartphones is achieved by a set of Web Services, thus ensuring the system requirement of platform independency.

The systems functionality is described by two scenarios. Each of the two scenarios represents a specific software and hardware environment. In the first scenario the actual data from a smart meter are stored in local database on a SEC [15]. This scenario provides access to current data of energy usage with high granularity and low aggregation (one household), but cannot provide long term data storage [25].

Within the second scenario packed information with high granularity and medium aggregation from the local data base within the SEC is transferred to the global data storage at the energy provider [25].The global database holds either long term data of low granulatity of one household or long term data of high granularity aggregated over several households.

5. SYSTEM ARCHITECTURE FOR AN INHOUSE SCENARIO

Information (energy profiles) are transmitted wirelessly (Wifi, ZigBee) or by wire to a data storage (database). The database is embedded in a smart energy controller (SEC), which is spatially located close to the smart meter. Additionally, within the SEC an embedded web server is implemented. The SEC has a limited performance and operational memory due to the requirement of a low energy usage. The location of the database within the SEC causes limitations concerning the database implementation regarding volume and performance.

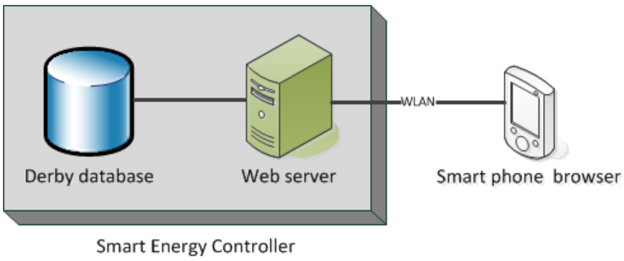

Fig. 1. – System and communication architecture of an inhouse scenario

Figure 1 shows the system's architecture. Limited hardware resources and other restrictive software requirements lead to Java as development software for the embedded system. A Jetty server is used as Java Servlet implementation for web services [5]. Moreover, Jetty provides a database access engine. Both features enable Jetty to be used as web server implementation. An Apache Derby database is installed as data storage [1]. Apache Derby is an open source relational database implemented entirely in Java. The particular advantage of Apache Derby is its small required disc space of about 2.6 MB.

The following diagram (Fig. 2) shows the system architecture and components.

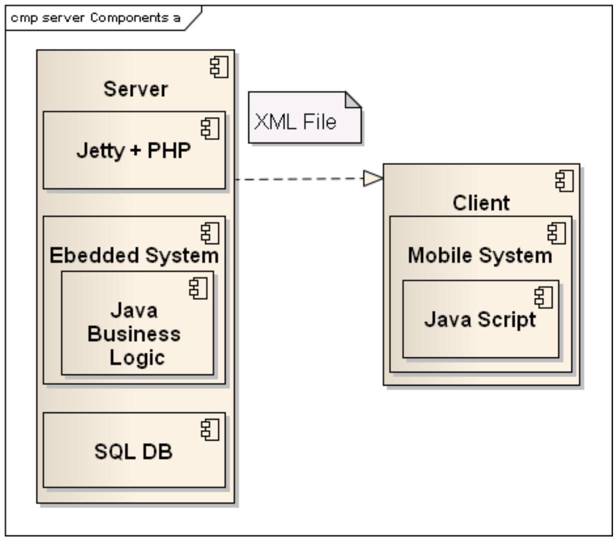

Fig. 2. – System and component diagramm for an inhouse scenario

6. SYSTEM ARCHITECTURE FOR AN INHOUSE/PROVIDER SCENARIO

The inhouse/provider scenario requires two server types. The first type is the server located on the embedded system, which holds high resolution and short life data. The second type is a global server, located at the energy provider. Local data are collected, compressed and stored into the global database. The global data storage is a PostgreSQL database. PostgreSQL is a fast object-relational database management system [23]. Data compression means at least reduction of the time resolution, for example: from one item per second sampling to one item per hour sampling. Fig 3 shows a system overview of the inhouse/provider scenario.

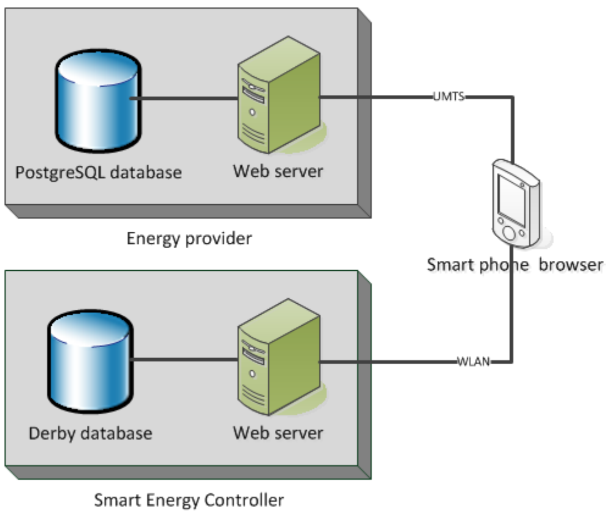

Fig. 3. – System Overview for an inhouse/provider scenario

For flexible access to the provider's database web services located on the provider's server are used. It is possible to run the database and web services on different servers as well. The web services are using the Simple Object Access Protocol (SOAP). This enables other systems, like web server, mobile apps or other applications, to access data independently of database and mobile device platform.

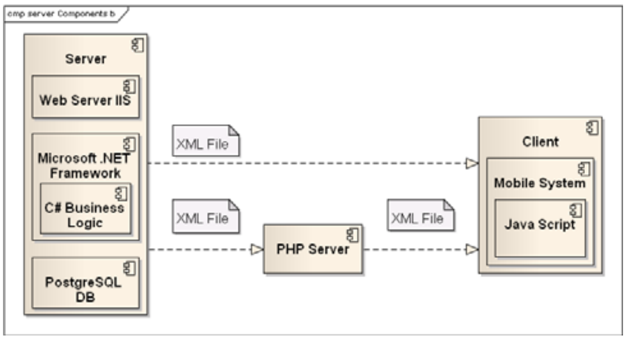

Fig. 4. – Component diagram for an inhouse/provider scenario

7. DATA VISUALIZATION ON SMART PHONES

The mobile device for visualization has to deliver information in a clear, intuitive and easy interpretable format. Nowadays there are numerous mobile devices available for customers [8], [10]. All those devices are based on different platforms and operating systems. That means that the presented system has to be platform independent. Moreover, mobile device have limited hardware resources: small display size, low performance in comparison to desktop computers. The system ergonomic design must take such limitation into account.

In this context the usability and compactness of the displayed information has a significant roll. The information priority is case and tariff sensitive. For different use cases the set of displayed information is varying.

For visualizing data on a mobile device there are two general approaches. The first option is a specially developed application. This application can be installed on a target device – smart phone, e.g. Apple iPhone. The second option is given by a web server, generating a web site which can be called by a browser from a mobile device.

The approach via an application represents a proprietary solution. Then the application adapts to the platform and can make use of all capabilities of the platform. This means an optimization in speed, functionality and design. The disadvantage is the missing flexibility, because the application is dedicated to the platform. In this case a specific application has to be developed.

The main advantage of the website approach is the platform independence. The web server may be called by a browser regardless of the used platform. The disadvantages are the difference in visualization between the platforms, no offline availability and the missing possibility to use the capabilities of the platform. Applications have direct access to the system resources like camera, Global Positioning System (GPS) and other peripheral devices. Some of these systems resources can be used by a website and websites can be stored, too. Therefore it is necessary that the device supports Hypertext Markup Language in Version 5 (HTML5) [27].

The selected option is the website approach. To minimize the disadvantages of the website approach, a framework is used. The jQuery mobile framework is based on the jQuery framework [12], a JavaScript Library. The jQuery mobile framework represents a user interface framework for website approaches independent of mobile device and platform. With this framework, it is easy to give the website approach a flexible app look-alike. With the app look-alike, the user has not to adjust himself from the accustomed use of the platform and the apps on this platform. The capabilities of the platform were unutilized. When the smart phone has access to the data, there is an access to the web server, too. Even the app needs access to the data and couldn't work without. So the missing offline availability of the web site is not a disadvantage in this use case. There are no complex graphical visualizations, which require the whole performance of the smart phone.

8. VISUALIZATION of TARIFF DATA AND ENERGY USAGE

Pueschel et al. [24] analyzed a household customer base of a local energy provider. They performed a segmentation of the household customer base concerning the motivation of household customers to use smartphones and change their habit of energy consumption. They identified several different segments of household customer base. To each of these segments a specific tariff may be associated. Further on, each tariff needs specific information for optimal use which has to be displayed on the smart phone. Consequently, specific information presentation formats for different tariffs have to be developed. These information presentation formats vary depending on the selected tariff.

The acceptance of smart metering systems needs a visualization of data on a smartphone in an intuitive and comprehensible way. Otherwise it would be too complicated for the user to comprehend the data and take decisions.

First, a load-dependent tariff was considered. In this scenario the household customer has an opportunity to watch his actual energy usage in real time mode and also, according to the selected tariff, receive notification messages or graphical presentation about energy usage in relation to tariff threshold. In this case the household customer can make a decision to adjust his usage behavior based on the price ruling. He can reschedule his energy intensive tasks to another time. For this kind of tariff the necessary information for the household customer is the current load.

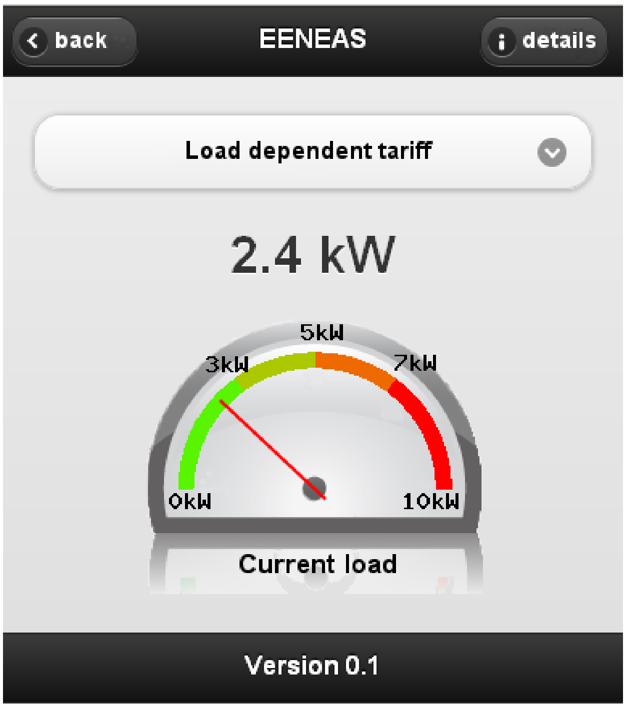

Fig. 5. – Visualizing current energy load for a load dependent tariff on a smartphone

A suitable visualization of the current load changing in time is achieved by a speedometer. The load is represented by the speedometer needle. The minimum of the speedometer is given by the base load, the maximum by the maximum load. The different tiers of a load dependent tariff are assigned by different colours. The size of classification is flexible and depends on the actual tariff (see 0).

Through the assistance of JavaScript the current load and hence the speedometer needle can be refreshed every five seconds without an interaction by the user. An advantage of the speedometer presentation is it's easiness to read.

Secondly, the visualization of a tariff depending on total energy usage is considered. This suits the requirements of data visualization within the in-house/provider scenario. The household customer is enabled to watch his long term energy usage behavior.

The visualization of a tariff depending on total usage can be implemented by a scale like a thermometer (see Figure 6).

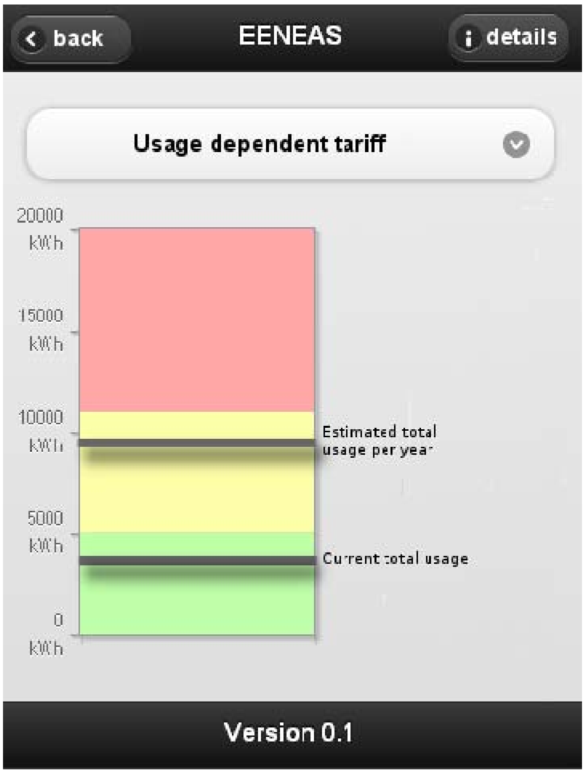

Fig. 6. – Visualizing a tariff depending on total usage of energy

Three different price categories are represented by different colours. The price of the energy unit increases, if the total energy usage exceeds certain threshold values. The current total usage of energy is presented together with an estimation of the total energy usage per year. The user is enabled to adapt his energy usage and prevent exceeding thresholds.

The estimation of total energy usage per is based on historical information of energy usage of the customer or comparable households.

Thirdly, a time dependent tariff is considered (see Figure 7). The visualization is implemented by using a time dependent graph of energy costs. The horizontal axis shows the time period of the last 24 hours to now. The vertical axis shows the costs of energy. The background of the graph presents periods of different energy prices (Euro/kWh) visualized by different colours.

This kind of tariff is essential for motivating household customers to react on demand response signals, i.e. price changes. For optimizing costs with a time-dependent tariff it is important to see the actual costs in comparison to those in other time slots.

For the load dependent tariff it is necessary that the data presented are up to date and presented close to real time, i.e. they are transferred from the SEC on to the smartphone. Otherwise variances in the usage are shown too late and it is not possible for the user to react.

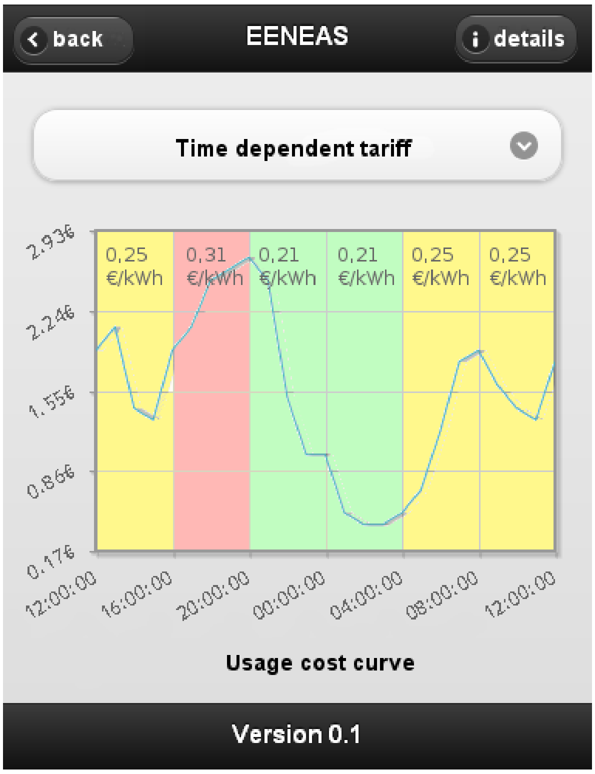

Fig. 7. – Visualizing a time dependent tariff

For the time dependent tariff as well current data are needed. Then current costs can be displayed. Again, this is necessary for the consumer to react.

The tariff depending on total energy usage does not need current data. The current amount of totally used energy may be transferred from the energy provider's database to the customer's smartphone. The expected customer reaction is not a short term reaction, but optionally a long term change in his general habit of energy usage.

Moreover, for assisting the household customer in monitoring his energy usage and for decision support a recommendation tool based on an interactive dialog is developed. The household customer can define certain devices by specific parameters, i.e. mean energy usage. Depending on the actual tariff and user defined parameters the recommendation tool generates optimal strategy for using each device (see Figure 8). In case of load dependent tariff, the system's recommendation avoids excess of the defined maximum load.

In case of time dependent tariff a time period is recommended for the device to use. The user has the opportunity to select the valid time period.

Moreover the user can select any available device to see how the load of the device acts on the total energy load profile. The result is classified in three stages: optimal, satisfied, bad. The corresponding colors are "green", "yellow" and "red".

Fig. 8 – Load Sheduler

9. RESUME

The paper presents several approaches for visualizing energy and corresponding cost and tariff data on mobile devices like smart phones. The data are recorded by a smart meter and presented to a household customer to give him relevant information concerning his energy usage. Thus, the household customer is ubiquitously enabled to take decisions concerning the reduction of his energy usage or the shift of his energy load. Suitable and specific visualizations for different tariffs are presented.

The architecture of the system takes into account data privacy demands by using two different scenarios, an inhouse and a inhouse/provider scenario. The guideline for respecting data privacy concerns is keeping detailed profiles of the customer's energy usage within his household.

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RFID BASED APPLICATIONS IN CULTURE, MEDIA AND CREATIVE INDUSTRIES

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Abstract: *This article presents two different approaches to visualise information from culture, media and creative industries by using RFID based tracking and identification. Besides the required RFID backend, the paper also introduces the information system built on top of the backend. The first approach is based on passive RFID whereas the second uses active RFID. In particular, the differences in the processing of system events, delivery of needed information and the implemented infrastructure will be discussed and evaluated.*

Keywords: *RFID, NFC, multimedia installation, culture and creative industry, fashion.*

1. INTRODUCTION

In the context of a research project for position and context based information systems for museums demonstrating the potentials of RFID, called POSEIDON[14], different applications for the culture, media and creative industries were realised. The key aspects of our work include:

- computer architectures to process RFID data,
- development of a RFID based ticket system,
- position and context based services based on RFID and NFC technology,
- RFID and NFC based point of interest data collection,
- design and implementation of visitor media stations,
- development of personalised web portals and data and security concepts.

This article will introduce two of these applications. They were developed in cooperation with schmidttakahashi – a fashion label in Berlin. The purpose is to visualise additional information, such as washing hints, materials or the price of a specific piece of clothing. A single garment is made from several contributing items of clothing. This principle is based on the project "Reanimation". It describes a completely new and unusual method of creating clothes. The idea is about revival, reanimation and the recycling of used clothes donated by the public for the creation of entirely new and unique pieces by assembling the most interesting and valuable parts of the used clothes into a new outfit. The general concept is illustrated in Fig. 1. In this way the afterlife of the used clothes can be visualised and tracked. Additionally the clothes and materials are considered reasonable and economical as the final products (and also products made from products) would be able to last for hundreds of years. It will save energy and waste less in the long run [1].

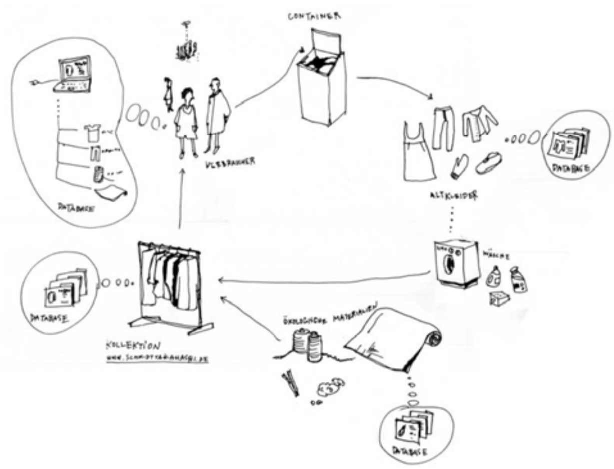

Fig. 1 – The circular flow of the concept called "Reanimation" by the fashion label schmidttakahashi

2. CONCEPTUAL AND TECHNICAL BACKGROUND

All information about the donated clothes and their former owner, the colour, the material of clothing and photographs were stored in a database. Every donated piece is divided into several parts, e.g. the back, front, body, collar or pockets. These parts are treated as the base for the creation of new products being made from different parts of different donations. Hence this design is like a construction plan for further productions.

There is also a unique ID of a RFID transponder that is connected to every product and additionally referenced to the owner. This RFID transponder was designed as a custom chassis, additionally serving as a three-dimensional label and was easily sewn onto the garments that are represented as products in the database. The information about the clothes could now be accessed by reading the ID from the garment and performing a lookup in the database. All information about the parts being used to construct the products can be evaluated.

Based on the available data and the concept "Reanimation" by schmidttakahashi there are two different modes that should be distinguished by the implemented solution. The first one should give the customer the possibility to retrieve information about a single garment they are interested in. The most intuitive design for this case is the development of a hat stand representing the interface to the customer. The second one shall be used in a more dynamic environment such as fashion shows where customers need the appropriate information as soon as models enter the runway. Both modes will be presented consecutively.

RFID and its technology in general is mainly used in production and logistics to optimize and visualize processes around the flow of people and goods. For example, active and passive RFID is used for vehicle identification and traceability, identification of people, animals, and goods, and it is also used as a authentication feature for medics as well as of different other application scenarios. In textile and clothing industries, RFID is being used increasingly in areas like anti-theft protection and surveillance (e.g. [2], [3]) but also to optimize supply and distribution channels [4]. To offer a modern experience and enhanced service, Prada provides plasma screens in the fitting rooms at their Manhattan store in New York City. Depending on the garments a customer took in appropriate fashion shows are triggered visualizing the articles of clothing [5].

These different examples and case studies prove that RFID is already being used for years in fashion industries. Nevertheless, the usage was focused in business processes like distribution and security. Direct interactions for customers and users is a new kind of experience.

3. IMPLEMENTATION OF THE HAT STAND

We used different technologies for the implementation of a stationary installation being able to display information about a single garment. In principle the system consists of a two-tier architecture that is built upon a classic RFID backend system and an information system.

A RFID reader, an external antenna, a computer, which also acts as a host for the information system, form the RFID backend and the RFID transponders being coupled with the clothes of the fashion label schmidttakahashi. The first prototype used a passive RFID system based on 13.56 MHz and the ISO/IEC 15693[1] standard. Passive RFID tags rely entirely on the electromagnetic field being produced by the reader to read their stored value. Therefore the range of passive RFID is usually of the order of centimetres. In our case it is a good compromise between the range of the installation for detecting the clothes and on the other hand the reliability of the detection rate.

As previously mentioned, the computer is also used for the information system. It is connected to the database of schmidttakahashi and provides the runtime environment and web server to guarantee the accessibility of the installation. Querying the database generates the visualisation data. As the system uses a polling mechanism to retrieve the most current information the data is cached to minimise the amount of access to the database. The data being transferred to the website that is displayed on the different client systems uses JSON (RFC 4627[2]), a lightweight yet human readable format. It is used to exchange the data of the clothes.

When a customer attaches a new garment to the hat stand, the transponder moves into range of the installed antenna and so the unique ID is read. By using this ID the RFID backend looks for the JSON dataset. If it cannot be found locally a request to the external database is executed and a JSON file is generated and saved for the following requests.

On the client side there is a standard web browser accessing the information system. It delivers a HTML page that is based on Ajax/JQuery and uses a polling mechanism to submit requests every second. As soon as a new garment is attached to the hat stand, the RFID backend delivers a new JSON file that is analysed by Javascript. Depending on the delivered information the DOM structure of the HTML document is adapted and completed. For example, with the knowledge of the original clothes that were used to create the product a different amount of information and pictures are added to the DOM structure of the HTML document. These include the production number, the name of the clothes, prices or the materials the clothing is made of (see Fig. 3). The

[1] See http://www.iso.org for more details.
[2] See http://www.ietf.org/rfc/rfc4627 for more details.

interaction between the different components of the installation can be seen in figure 2.

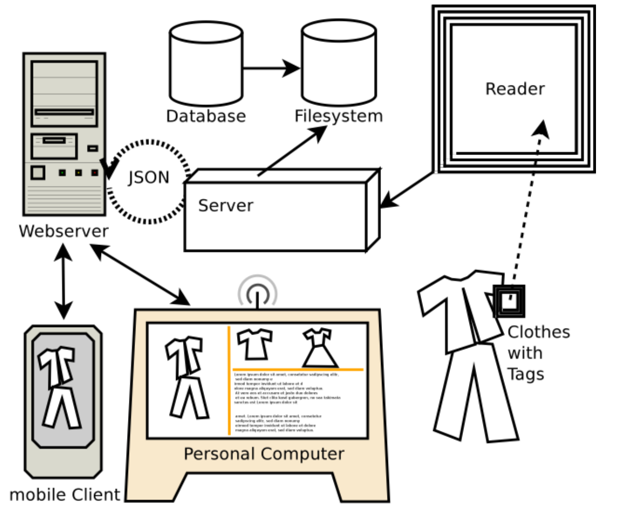

Fig. 2 – Design of the infrastructure of the hat stand

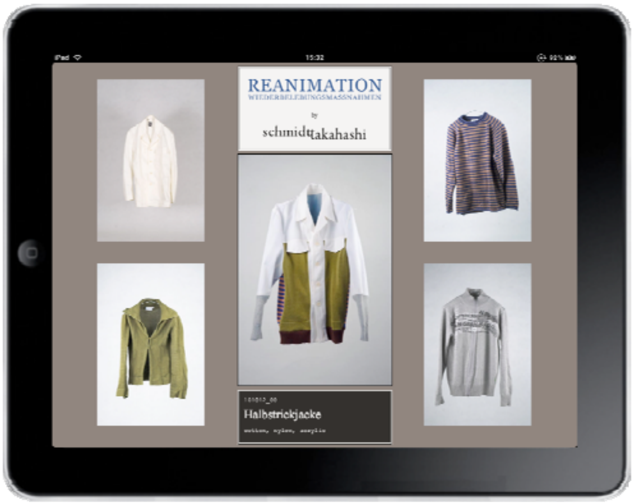

Fig. 3 – Displayed information after a jacket of the collection was attached to the hat stand. The picture in the center is the current product of the selection. On its left and right are the original clothes it was made of. By touching one of the pictures additional information can be accessed

Because of the use of HTML5 and CSS3 to visualise the information of the collection, the portability of the information system is very high. There are a vast number of devices that are able to display the required information: home computer, laptops, netbooks, tablet PCs or smartphones including different mobile operating systems such as iOS, Android or J2ME. In our showcase we attached an Apple iPad that displays the current information.

4. ACTIVE EXPANSION OF THE INSTALLATION

The developed hat stand can be used to present different collections at vernissages or in basic show rooms. By following the principle "Keep it simple and smart" the customer is able to use it without additional assistance. All information is automatically triggered when a single piece of the collection is attached to the hat stand.

In the culture and creative industries there is one more important use where a piece of clothing has to be presented: fashion shows. Typically in a very short space of time, models present different sets of clothes. Interested people have to remember specific pieces or have to take notes on an additional paper to obtain further information afterwards. By introducing a similar technology as the hat stand in the context of fashion shows, this workflow can also be simplified.

A RFID application server as described in [12] converts all messages received from the OpenBeacon RFID system into messages of a self-defined PTN (Proximity Tag Network) Protocol. In figure 4 you can see a package for communicating a contact between two transponders. These packages are central components in the realised solution. Every contact being reported by the RFID application server is analysed by a custom client, a web application that connects to this application server. In principle the RFID application server is implemented to accept an amount of clients being able to register for the different message types (e.g. tracker messages, running contact messages, closed contact messages and position messages) defined by the PTN protocol. Each client obtains all the messages they are registered for by the server.

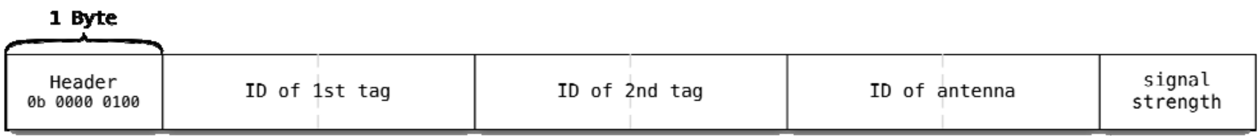

Fig. 4 – Examplary design of a PTNP (short for Proximity Tag Network Protocol) package. This type is used for communicating a contact between two tags being defined in the following four bytes within the package. The concrete type of the package is defined in its header byte. Additionally the ID of the antenna and the received signal strength is appended.

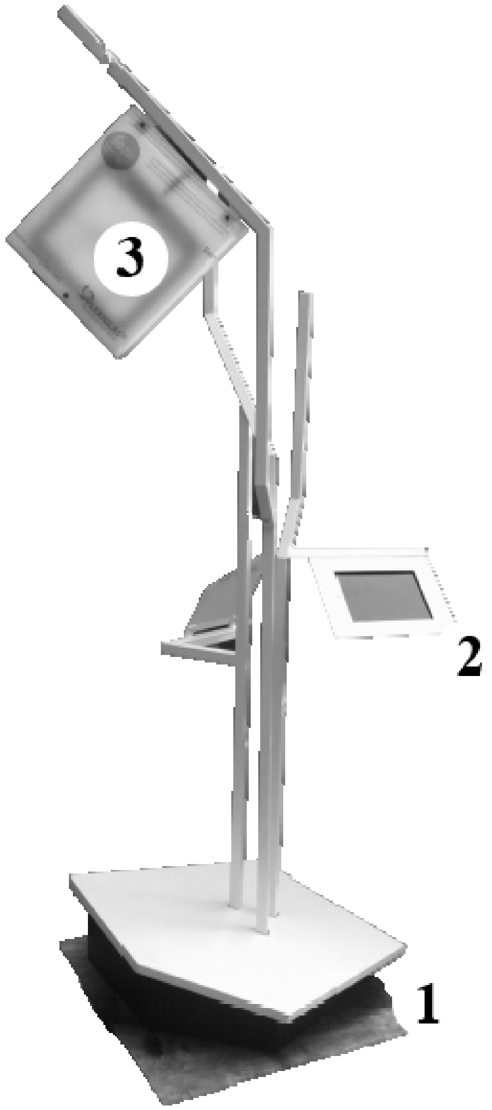

Fig. 5 – Schematic representation of the hat stand. The ground of the installation (1) contains the hardware and cables, e.g. the computer where the software is installed. Additionally there is a small touch display (2) visualizing the information of clothes being attached in front of the RFID antenna (3)

Whereas passive RFID was used in the installation for show rooms, where the range of identification was limited, active RFID has to be used in the very active and dynamic environment of fashion shows. The intent is to display required information to the interested audience of the current set of clothes for a single model as soon as the model enters the runway.

With the help of active RFID, moving objects can be tracked. In contrast to passive RFID, the active solution has its own power supply usually attached in form of a small battery. This power supply is used to periodically broadcast its unique ID. One important problem to solve was how to identify one model at a time and at a specific position without installing a complex RFID infrastructure. The installation should be minimalistic and as invisible as possible: the main focus should be the presented fashion.

5. TECHNICAL IMPLEMENTATION

We decided to use the OpenBeacon [6] technology being actively developed by Bitmanufaktur [11]. OpenBeacon is an open source solution in hardware and software for active RFID. Since 2010 the project offers a new generation of RFID tags, so called proximity tags, broadcasting additional information about the tags in their surrounding. This is realised by setting up the RFID tags in a transceiver mode. The transponders scan their neighborhood by alternating transmitting and reception cycles. They use a specific radio channel to send low-power packets first, then they switch into receive mode and listen on the same channel for packets sent by nearby devices [10]. These responses serve as indicator for proximity evaluations. These special tags can be considered as a kind of RFID reader. As transponders are much smaller and also cheaper than an ordinary RFID reader, the option of using the proximity tags to realise the runway use case was chosen.

Therefore this technology was used to logically register some special tags that had to be installed locally at the entrance of the runway area to detect nearby transponders – the models wearing the different tags. In this way, contacts between the alternative reader and the model tags at this position could be realised by the implemented software.

The final part of the implemented software system consists of two loosely coupled components:

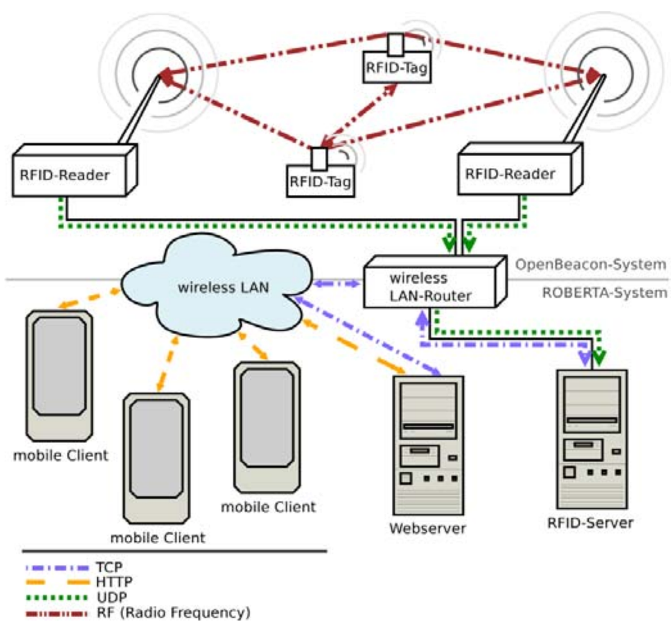

Fig. 6 – Design of the RFID application Server. The web server registers for the different PTNP messages and delivers the contents to the mobile clients

In this case, a web application has been developed to recognise all contacts between a model's transponder and the fixed RFID transponder. This web application also serves as a web server for different client devices like home computers, laptops or mobile devices as described in [13]. In contrast to the first approach that was presented previously, this system uses a long polling mechanism that is a variation of the traditional polling used before. It tries to emulate a real push service by holding the request until relevant data has to be submitted to the client. In this way, requests from the mobile devices to the web server obtain a response just in time when a specific event occurs.

5.1. CONFIGURATION AND INSTALLATION

An important and basic part of the implemented solution is to configure these fixed transponders that virtually represent a gate that all models must pass. This is done with the aid of a XML configuration file as the external database of schmidttakahashi does not have to be changed using this method. All known tags acting as a gate and the tags being linked to sets of fashion must be configured before using the system.

After the configuration process the gates have to be positioned on the gateway and the models have to wear the according transponder. As soon as the model, fully dressed with different clothes of different collections of schmidttakahashi, passes a gate the appropriate PTNP package is triggered and is evaluated by the client. Depending on the fact of the recognised ID belonging to one set of fashion that is presented in the current fashion show, the client sends notifications to all customers that are interested in obtaining information about the garment.

6. CONCLUSION AND FUTURE DEVELOPMENTS

Two different approaches have been developed for the culture, media and creative industries. They have successfully been presented in different events, the Berlin Fashion Week in July 2010 [8] and the show night "Two Worlds – One Future" of Projekt Zukunft [9] in October 2010. Both solutions act as self-contained systems and use different technologies for the technical part and the visualisation of required information. Therefore future developments will concentrate on consolidating both systems and accomplishing a modular system able to support different RFID standards. This will include the integration of positioning and the improvement of tracking moving objects to realise new functionalities, e.g. the illumination of a model on the runway. The development will also deal with the generalisation and optimisation of the current solutions. This will include the establishment of different external interfaces enabling a loose coupling of different systems. For example, the current solution could be extended by integrating the visualisation into a webshop, enabling the customers to buy or track different clothes.

ACKNOWLEDGEMENT

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REDUCING RADIO BANDWIDTH LOAD IN NANOLOC-BASED WIRELESS NETWORKS THROUGH SELECTING APPROPRIATE SUBSET OF BASE STATIONS FOR RANGING

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Abstract: *In wireless sensor networks based on nanoLOCTM standard and using server-centric control, the overall performance of radio segment and location accuracy depends amongst other on the efficiency of the location engine. The efficiency may be increased by selecting an appropriate subset of base stations for ranging. This paper describes the experiments dealing with this problem, and discusses the ways of saving radio bandwidth.*

Keywords: *real time location systems, wireless sensors networks, ranging, accuracy, nanoLOCTM, time-of-flight, round trip time, geometric dilution of precision.*

1. INTRODUCTION[1]

Modern local positioning systems or RTLS (real-time location systems) are based on various wireless technologies: WiFi, ZigBee, nanoLOC^{TM} etc. The main goal of such systems is to determine local position (coordinates) of a wireless mobile device (tag) that may be carried by a human or mounted on a machine, equipment etc. RTLS is a very important instrument to solve the problems of logistics, staff management and security.

The typical RTLS includes a set of base stations (BS) with known geographical coordinates and a set of wireless tags to be located. There are two main approaches for location calculation in wireless sensors networks: based on time-of-flight (ToF) and received signal strength (RSS) [1]. Information acquisition, data processing and implementation of business logics are performed by a server.

As a rule wireless tags have very short periods of radio activity to reduce power consumption and increase the time between recharges. They transmit special blink frame indicating active state. Base stations (anchors) receiving this radio frame re-transmit its copies to a server, which issues commands to base stations to start the ranging procedure.

The performance of a typical local positioning system based on wireless sensors network depends – amongst many other things – on two factors: available traffic load and the number of calculated locations per second. These parameters are mutually dependant and, in addition, depend on the efficiency of location engine of the system.

In an ideal case, it is sufficient to collect only three ranging results to calculate the position of the tag. But in practice in order to achieve stability and reliability in wireless communications, the density of base stations should be higher than the required minimum. So the server should not receive only three copies of an "I am alive" frame, but probably up to 10.

To save bandwidth it is reasonable to minimize the number of base stations which carry out distance measurement to the mobile tag. The main problem concerns the selection of the appropriate base stations from the set.

Many methods help to solve this problem. Geometric dilution of precision (GDOP) is a well known parameter for the analysis of satellites configuration in the GPS [2–4]. Nowadays GDOP is widely used as a criterion for choosing the right geometric configuration of base stations in wireless sensors networks [5–9]. It can be applied, for example, for evaluating positioning accuracy for different positioning algorithms [5] or for improving

[1] The research described in this publication was financed by RTL-Service ltd. and supported by Petrozavodsk State University and the Ministry for economical development of Republic of Karelia (Russian Federation).

performance [6]. In the majority of positioning systems GDOP is the most promising criterion for selecting an appropriate subset of base stations for ranging to increase the positioning accuracy. Nevertheless, the paper shows that this algorithm may be improved by adding a few technical criteria.

Section 2 demonstrates that the problem of selecting an appropriate subset of base stations is very important for accuracy and performance of RTLS. Section 3 describes the basic algorithm of applying GDOP and the possibilities of its improvement. The simplified principle of location calculation in the systems based on ToF approach is described in Section 4. In Section 5 we present the ongoing project of development of TalkLoc™ technology, which implements the proposed algorithm. Section 6 compares the effectiveness of various modifications of GDOP algorithm through experimental results. Conclusions are drawn in Section 7.

2. PROBLEM OF SELECTING AN APPROPRIATE SUBSET OF BS

The impact of satellites disposition on positioning accuracy is well studied for the global positioning systems [10]. The same problem exists in local positioning systems based on wireless sensors network.

Due to the errors caused by non-line-of-sight (NLOS) signal propagation the distance between a mobile unit and a base station measured by ToF method is always above or equals the real distance [11]. That is why circles corresponding to the distances measured from several base stations do not intersect in one point and form a certain location area (see figure 1).

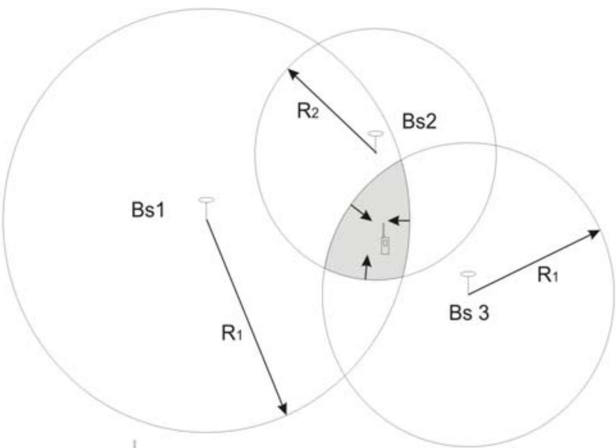

Fig 1 – Typical location area (Bs1, Bs2, Bs3 – base stations)

If there are no errors in measurements except NLOS error a mobile unit is inside this area with 100% probability. With the use of a specific algorithm (it can be MLS, KF or other algorithms [12, 13, 14]) it is possible to clarify the mobile unit position inside the location area.

Geometric configuration of base stations can strongly influence the shape of a location area and thus location accuracy. Let's consider two sets of three base stations (A and B in figure 2) with different positions of BSs as to the mobile unit position. In the first set (A) a mobile unit is homogeneously surrounded by base stations. In the second set (B) base stations are placed on the one side from a mobile unit. Circle radii from base stations BS1, BS2, and BS3 in set (A) are equal to circle radii for corresponding base stations BS1, BS2, and BS3 from the set (B). The distances between the mobile unit and the nearest points of the circles are equal. These distances are characterized by NLOS component. Although NLOS component is the same for the two sets, the location area in case (A) is much smaller than in case (B).

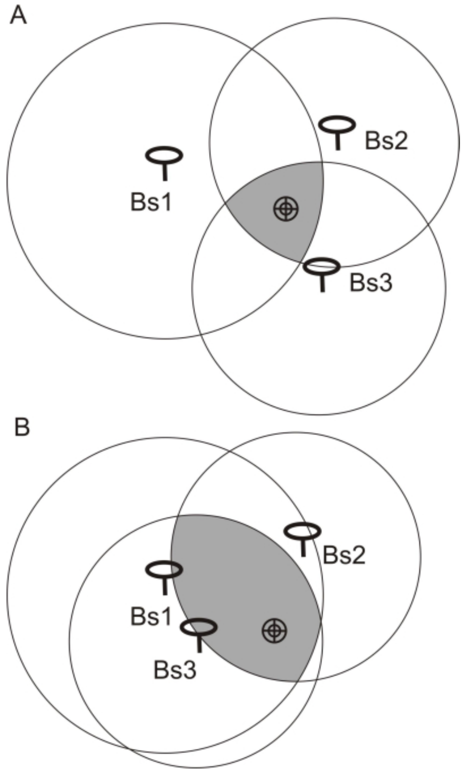

Fig. 2 – The impact of base station placement on the shape of location area

The optimal geometric configuration of BSs is important even in the case when the estimation of the measurements error is known.

Two characteristic pictures (A) and (B) of BSs' geometric configuration with known estimation of measurements error are presented in figure 3.

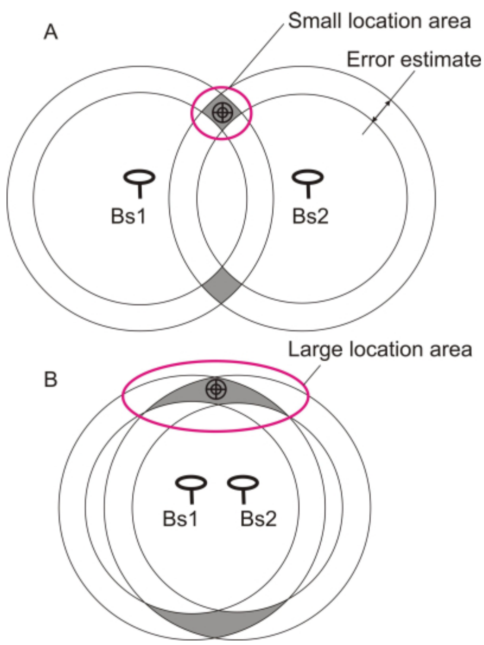

Fig. 3 – The impact of BSs' geometric configuration on the shape of location area (known error estimation)

Rings around the base stations BS1 and BS2 correspond to the most probable distances of a tag (taking into account error estimation). In case (A) the base stations are far apart from a mobile node, giving relatively small areas of possible mobile unit location. In case (B) the errors in measurements are equal to the errors in case (A), but the base stations are closer to each other. As a result the areas of possible mobile unit location in case (B) are larger than the areas in case (A).

3. GEOMETRIC DILUTION OF PRECISION

One of the basic parameters used in GPS for the analysis of satellites disposition is GDOP [2–4, 15]. This parameter can be applied for the analysis of BSs' geometric configuration in the considered wireless sensors network. For the 2D case GDOP is calculated in three steps.

1. First it is necessary to calculate matrix A as

$$A = \begin{bmatrix} \frac{(Xa_1 - x)}{R_1} & \frac{(Ya_1 - y)}{R_1} \\ \frac{(Xa_2 - x)}{R_2} & \frac{(Ya_2 - y)}{R_2} \\ \dots & \dots \\ \frac{(Xa_n - x)}{R_n} & \frac{(Ya_n - y)}{R_n} \end{bmatrix}, \quad (1)$$

where (Xa_1, Ya_1), …, (Xa_n, Ya_n) are the coordinates of the base stations, $(x;y)$ are the coordinates of the mobile unit, R_i is the distance measured between a base station with coordinates (Xa_i, Ya_i) and a mobile unit.

2. Matrix G is calculated as

$$G = (A^T A)^{-1}, \quad (2)$$

G can be written as

$$G = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}. \quad (3)$$

3. GDOP value is calculated as

$$\text{GDOP} = (g_{11}+g_{22})^2 \quad (4)$$

GDOP value can be used as a criterion for the selection of the appropriate subset of base stations to carry out ranging. If it is necessary to choose several base stations from the given set for the distance measurements, the subset with the lowest GDOP should be chosen.

For the use of GDOP in real-time analysis of BSs' optimal geometric configuration it is necessary to know the approximate position of a mobile unit beforehand. There are several ways to estimate the preliminary position of a mobile unit. It depends on the applied positioning algorithm.

In the case of applying Kalman Filter [16] it is possible to use prognosis estimation of a target position. In the case of applying MLS and if the ranging is frequent enough it is possible to use previous position for GDOP calculation. If no prior information is available it is possible to evaluate location by RSS measurements.

4. APPLIED ALGORITHM FOR LOCATION CALCULATION

To analyze the impact of geometric configuration of BSs on location accuracy we used MLS algorithm to calculate locations of a mobile unit. It is rather simple algorithm, but easily demonstrates the proposed solution since ranging was performed by ToF method.

The coordinates $\hat{X}$, $\hat{Y}$ of a wireless tag's position were calculated as

$$\begin{pmatrix} \hat{X} \\ \hat{Y} \end{pmatrix} = (H^T H^{-1}) H^T z \quad (5),$$

where

$$H = \begin{bmatrix} 2Xa_1 - 2Xa_2 & 2Ya_1 - 2Ya_2 \\ 2Xa_1 - 2Xa_3 & 2Ya_1 - 2Ya_3 \\ \dots & \dots \\ 2Xa_1 - 2Xa_n & 2Ya_1 - 2Ya_n \end{bmatrix} \quad (6),$$

and

$$z = \begin{bmatrix} R_2^2 - R_1^2 + Xa_1^2 - Xa_2^2 + Ya_1^2 - Ya_2^2 \\ R_3^2 - R_1^2 + Xa_1^2 - Xa_3^2 + Ya_1^2 - Ya_3^2 \\ \dots \\ R_n^2 - R_1^2 + Xa_1^2 - Xa_n^2 + Ya_1^2 - Ya_n^2 \end{bmatrix}. \quad (7)$$

If information on statistics of measurement errors is available it is possible to use symmetric weight matrix *Q*.

$$Q = \|q_{ij}\|$$

With the use of weight matrix the coordinates of a mobile unit are calculated as

$$\begin{pmatrix} \hat{X} \\ \hat{Y} \end{pmatrix} = (H^T Q H)^{-1} H^T Q z. \quad (8)$$

Matrix *Q* is the inverse of the noise covariance matrix

$$Q = \begin{pmatrix} \sigma_1^{-2} & 0 & 0 & \dots & 0 \\ 0 & \sigma_2^{-2} & & \dots & 0 \\ 0 & 0 & \sigma_3^{-2} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & \sigma_N^{-2} \end{pmatrix}, \quad (9)$$

where σ_k is standard deviation of measurements error for *k-th* base station (measurements are considered to be independent). These deviations were found during preliminary experiments.

The proposed algorithm for location calculation was tested using TalkLoc™ technology.

5. TALKLOC™ TECHNOLOGY

TalkLoc™ is a wireless technology characterized by low power consumption, ranging and voice communication [17]. It is based on nanoLOC™ (IEEE 802.15.4a) radio standard, developed by Nanotron Technologies GmbH. Technical characteristics of nanoLOC™ chips are presented in table 1.

Table 1. NanoLOCTM key features [18]

Modulation technique	Chirp Spread Spectrum
Radio band	2.4-2.48 GHz ISM
Ranging accuracy	2 m indoors / 1 m outdoors
Output power	Up to 20 dBm
Data rates	250 kbps to 1 Mbps
Ranging method	time-of-flight, round trip time

In nanoLOC™ ranging is based on time-of-flight (ToF) method. According to the round trip time (RTT) scheme two radio nodes exchange radio frames and register the times of frames transmission, processing and reception. One of the nodes collects the time data and then performs the calculations of the distance between them. The simplified scheme is presented in figure 4.

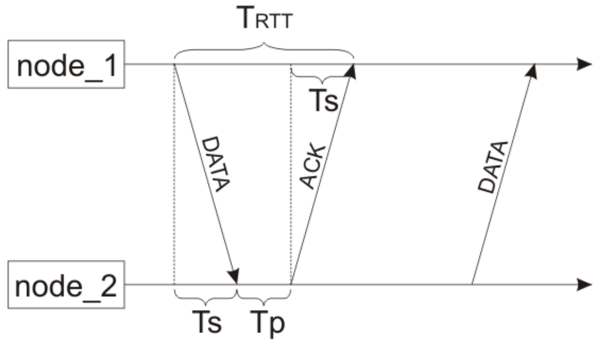

Fig. 4 – Round trip time ranging scheme

To initiate distance measurement node_1 transmits DATA frame. Time Ts corresponds to the signal propagation between node_1 and the node_2. Hardware of node_2 receives this frame and processes it (time Tp) and then sends the acknowledgement frame ACK. In the next DATA frame node_2 sends the value of Tp to node_1. Node_1 registers the moment of reception of ACK frame, measures T_{RTT} time and then calculates the distance D according to the following formula:

$$D = (T_{RTT} - Tp) * c / 2 \quad (11)$$

where *c* – speed of light.

NanoLOCTM chip also provides measurements of received signal strength (RSS) for every frame reception. This information can also be used for position calculation [19–21].

In TalkLocTM systems a radio coverage zone is created by a set of base stations connected to the backbone. For example it may be constructed with the use of optical or copper Fast or Gigabit Ethernet channels. A special dedicated server controls the performance of the wired and wireless subsystems. Besides control functions, it processes and stores the obtained data. In TalkLocTM applications it is used for communications with software clients and phones as well.

As it was mentioned above the larger part of the cycle of the wireless tag corresponds to the power saving mode, tags do not receive radio signals during this period of time. When the specified interval elapses the wireless tag wakes up and broadcasts “I am alive” packet. During a short period of time the device stays in the active state and awaits commands from the server. All the base stations that receive “I am alive” packet re-transmit its copies to the server. These copies are taken into account when the server initiates series of distance measurement commands (commands to base stations to carry out next ranging cycle between them and a mobile tag).

Obviously, location measurement commands can not be sent simultaneously, so the server forms a queue of commands. The next command from the queue is transmitted upon receiving a reply on the previous command. In wireless sensors networks such reply can be lost or not generated at all. In such cases several commands may be not performed and the location measurement cycle for a certain tag will not be finished correctly. It is very important to plan the queue of location measurement commands in the way that obtains the larger number of reliable results. And if timeout occurred the acquired results of ranging would be enough to estimate the location of the wireless tag adequately.

5.1. ADDITIONAL CRITERIA FOR BASE STATION SELECTION

When selecting base stations for a location measurement cycle a few technical considerations should be taken into account as well.

Unless a wireless tag and a base station are located in the range of reliable communication an attempt to perform ranging may fail.

On the other hand, the fact that the server has not received a copy of "I am alive" frame from a certain base station at the instance of initiation of the location measurement cycle does not mean that the base station is not in the reception range of the wireless tag and the ranging is not possible.

For example, this situation may be explained by packets delays. We tested some systems where base stations were interconnected by means of wired and wireless networks introducing essential delays. Delays up to several hundreds of milliseconds occurred in the QLAN segment, delays up to tens of milliseconds occurred in the WiFi segment. Taking into account this fact the algorithm considers the copies of both the last and preceding "I am alive" frame. Thereby, the following values may be proposed as the additional criteria for base station selection:

- the received signal strength;
- the number of failed measurements of location between the base station and the wireless tag (the history of failures should not be very long, because it quickly loses relevance for moving tag);
- the moment when the last copy of "I am alive" frame was obtained through the base station (whether it is the last frame or the preceding frame).

The second and the third criteria are very important for 2.4 GHz radio networks with high probability of interference.

Also an additional criterion of priority (or base station "importance") may be introduced. A base station that unambiguously determines the territory of location (a floor) or is equipped with higher-efficiency antenna may be considered as a higher-priority base station. Any organizational reasons may be considered as priority as well.

6. RESULTS

The experiments to analyze the impact of BSs' geometric configuration on positioning accuracy were conducted in the area of hotel resorts where the real-time location system based on TalkLoc^{TM} technology was installed. The size of the area was 620x270 meters. Solid dots on the scheme in figure 5 correspond to the positions of the base stations.

The territory included many buildings (cottages) especially in zone A. Therefore in this region there were no so many places where base stations and a mobile unit were on the line of sight. Another part of the hotel was the beach area (zone B in figure 5). The line-of-sight conditions were perfect for the major part of the area. The main building (5 floors) corresponded to zone C in figure 5. In order to achieve better accuracy in the case of large percentage of NLOS measurements made indoors the density of base stations was the highest in zone C.

Fig. 5 – Hotel scheme

The experiments were carried out in all zones A, B and C. In all 20 experimental points (marked with crosses with the corresponding numbers) data were collected within 5 minutes. The interval between rangings was 1 second. Only one mobile unit was used to avoid excessive load of base stations.

The experiments were conducted in daytime therefore the intensity of measurement noise caused by moving obstacles at different periods of time was approximately equal.

In all experimental points at least 8 base stations were available for subsequent ranging: all of them transferred "I am alive" copies to the server. So for every point $C_8^4 = 70$ combinations of base stations were available for range measurements. To analyze the impact of BSs' geometric configuration on location accuracy, the mobile unit position was calculated for each combination of 4 base stations from 8 available in each selected point (figure 5). If more than 8 base stations received a packet from the tag, only 8 closest base stations were taken into account.

In every point for a certain subset of the base stations both GDOP value and location of the mobile unit were calculated. These data were used to calculate error cumulative distribution function and determine 90% error border.

For all available subsets GDOP parameter varied from 1.1 up to 11.5. Positioning error (R90%) varied from 2.3 meters for the best subset of the base stations to 13.1 meters for the worst subset.

Calculated GDOP values, quantity of the subsets with the specified GDOP range and corresponding positioning errors intervals are summarized in table 2.

Table 2. GDOP intervals, quantity of the subsets with the specified GDOP range and corresponding positioning errors (R90%).

GDOP value ranges	Quantity of subsets, %	Positioning errors (R90%), m
1-2	47%	2.3 – 4.3
2-3	21%	3.8 – 5.6
3-4	16%	4.7 – 6.1
4-5	9%	5.5 – 7.2
5-6	4%	5.8 – 11.1
> 6	3%	8.1 – 13.1

The example of the subset that gives the best accuracy is shown in figure 6.

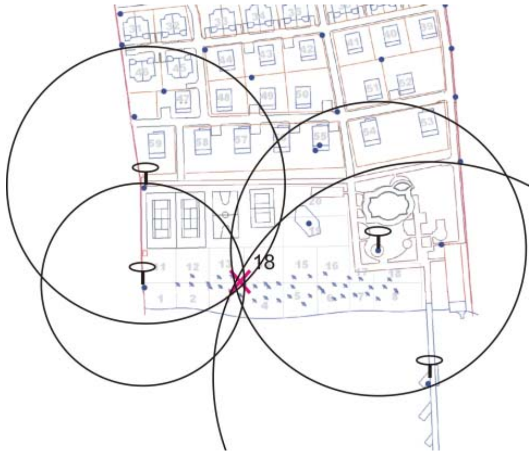

Fig. 6 – The best anchor subset corresponding to the lowest positioning error

As predicted the area with the best accuracy was observed in zone B of the hotel area. This zone is characterized by the absence of obstacles. Therefore the NLOS error is minimal for this zone.

The worst subset for the beach area is shown in figure 7.

As we can see for the worst case (lowest accuracy) all four base stations were grouped to the north-east from the experimental point, while in the case of the best accuracy all base stations homogeneously surrounded the experimental point.

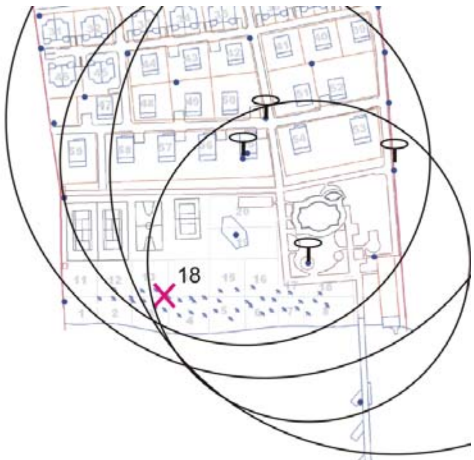

Fig. 7 – Example of the worst anchor subset

Analyzing all the experiments the majority of subsets have GDOP value less than 2 (see table 2). The location accuracy for these configurations is in the range of 2.3 – 4.3 meters. It is not clear what subset should be chosen from this set to perform ranging. To choose the best subset we used signal strength as an additional criterion for base stations selection.

The combined online positioning algorithm with the use of GDOP and signal strength consists of several steps.

1) On the basis of preliminary location estimation examine all possible subsets of the base stations and calculate GDOP values.

2) Divide the available GDOP values into a set of intervals (1-2), (2-3), etc.

3) Select the subsets with the best GDOP range (e.g. (1-2) if such subsets exist).

4) Use the subset with the highest RSS values within the selected GDOP range.

6.1. POSITIONING OF A MOBILE UNIT WITH THE USE OF THE PROPOSED ALGORITHM

The experiments of mobile unit positioning were conducted for three different methods of subsets selection.

The first method corresponds to the selection of a base stations subset based only on RSS values. From the available base stations set the given number of base stations which have the highest RSS values was selected for distance measurements.

The second method corresponds to GDOP criterion: the number of base stations which have the lowest GDOP values was selected for measurements.

And the third method corresponds to the combination of GDOP and RSS criteria. This method was described above.

The results of positioning accuracy for these criteria for a subset of 4 anchors from 8 available are shown in figure 8.

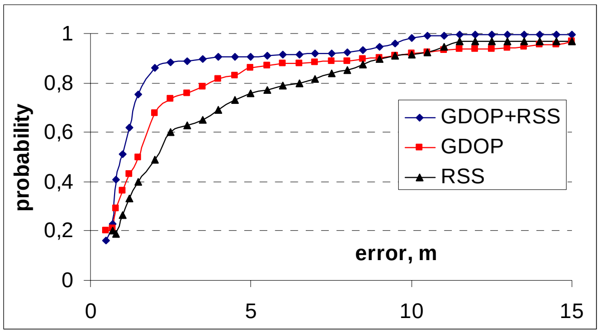

Fig. 8 – Error cumulative distribution function representing position calculation efficiency using subset of 4 BS for different selection criteria

As we can see in figure 8 the best location accuracy was achieved when the combination of two factors GDOP and RSS was used for base stations selection. The GDOP criterion represents better localization performance than RSS. One of the possible reasons is that in the case of GDOP criterion the subset is chosen so that it compensates measurements errors. However additional information that signal strength provides can be used for selection of more adequate measurements. A multipath signal often has less RSS value than a line-of-sight signal. That is why the combination of GDOP and RSS criteria represents the best localization performance.

6.2. VARYING THE NUMBER OF BASE STATIONS

Several tests on varying the number of base stations available for measurements have been performed. The experimental conditions were the same as in previous experiments. The data on location accuracy were collected for all experimental points depicted in figure 5.

Two techniques of base stations selection were used. The first technique uses random selection of several anchors from the given set, and the second is based on combination of GDOP and RSS criteria. The quantity of selected anchors in a subset varied from 4 to 8.

Figure 9 shows the result of the experiment with the use of the first technique. For the random base station selection the location inaccuracy (90% threshold) for the subset of 4 from 8 base stations was more than 15 meters. The best location accuracy was 3.1 meters for 8 base stations. The difference between the best and the worst cases is above 12 meters.

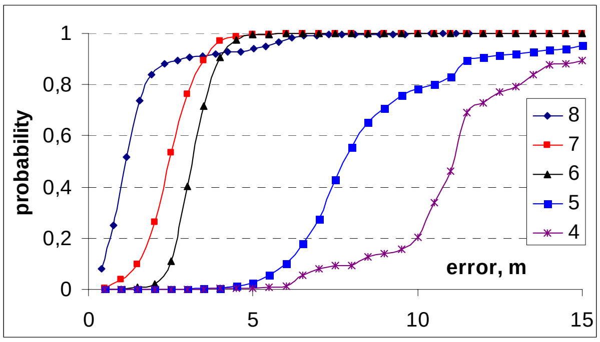

Fig. 9 – Location accuracy for varying number of base stations in subset used for location calculation (random BS selection)

Figure 10 shows the results of the experiments for the proposed base stations selection algorithm (combination of GDOP and RSS criteria).

The difference between location accuracy for 90% threshold for the best and the worst cases is less than 1 meter. The best accuracy was achieved with a subset of 6 base stations. The accuracy in this case was better than 2.6 meters.

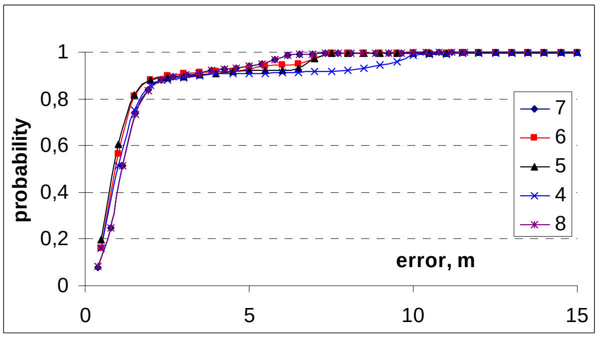

Fig. 10 – Location accuracy for varying number of base stations in subset used for location calculation (GDOP+RSS BS selection)

It should be mentioned that the location accuracy for 6 anchors was better than for all 8 anchors. Possibly the measurements from 2 excessive base stations might introduce additional error due to NLOS signal propagation.

7. CONCLUSION

In this paper the role of the impact of BSs' geometric configuration on location accuracy in local positioning systems was analyzed.

The proposed algorithms may be used both for increasing location accuracy and for radio bandwidth saving.

The proper subset from the set of available base stations seems to be a more important factor for location accuracy than the number of base stations.

The conducted experiments proved that a correct choice of geometric configuration of BSs can increase positioning accuracy in local positioning systems by several times and, thus, save radio bandwidth.

The authors are ready to share raw ranging data with researchers who wish to test their algorithms and to compare their effectiveness.

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GATEWAY ARCHITECTURES FOR HOME CARE APPLICATIONS USING WIRELESS SENSOR NETWORKS

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Abstract: *Home Care Applications and Ambient Assisted Living become increasingly attractive. This is caused as well by market pull, as the number of elderly people grows monotonously in highly-developed countries, as well as by technology push, as technological advances and attractive products pave the way to economically advantageous offerings. However, a significant number of challenges remain for real-life applications. Those include the lack of sufficiently standardized and interoperable solutions and thus, the necessity of gateways for integrated solutions, restrictions of the energy budgets, and scalability of solutions with regard to cost and network size.*

This paper presents the experience from the inCASA project (Integrated Network for Completely Assisted Senior Citizen's Autonomy), where architectures for heterogeneous physical and logical communication flow are examined.

Keywords: *wireless networking, home care, ambient assisted living, Continua, ZigBee, Bluetooth*

1. INTRODUCTION

The number of elderly people across Europe, from now to year 2030, will unbelievably rise, and they are growing more healthy generation-by-generation. Elderly people in good health conditions live longer, but there are a few factors that could radically impact on elderly person's quality of life and reducing his life expectation:

- psycho-emotional instability, related to the patient mental condition;
- the loneliness, related to the user environmental conditions and social life;
- illness, the patient health status.

Many products and solutions are already available in the market [1] and cover both telecare and telehealth applications. Telecare includes social supervision, such as home alarm [3], while telehealth applications have much stronger medical aspects, such as telecardiology [2]. In addition, a broad variety of scientific activities is ongoing in this field. However, it can be observed that most of the current solutions are still isolated devices with no or few interfaces to the outside world. Some newer devices allow networking capabilities, but – by far too often – with the use of proprietary or closed communication protocols.

In order to overcome these shortcomings, the aim of objective 1.3 of the PSP programme of the European Commission is to "significantly improve quality of life and social care for the ageing population" and "substantially prolong the time that elderly people can live independently at home", an enormous number of national and European projects are on their way. The inCASA project (Integrated Network for Completely Assisted Senior Citizen's Autonomy) [4] is one of those and aims at developing a system that will support the aging population and facilitate them to feel well in their own homes. The proposed application will monitor biometric data and track environment parameters of elderly users into their own home.

The remainder of the paper is organized as follows. In ch. 2, possible system architectures and their elements are discussed with its advantages and disadvantages, whereas ch. 3 explains the proposed solution. Then, ch. 4 will give an outlook on the pilot installations, which are currently equipped with the described devices.

2. SYSTEM ARCHITECTURE

2.1. OVERALL NETWORK ARCHITECTURE

For both telecare and telehealth applications, the overall network architecture can be described with four communication levels, as they are shown in

Fig. 1. This classification is very similar to other network topologies with widely distributed sensor and actuator nodes, such as automatic meter reading [6].

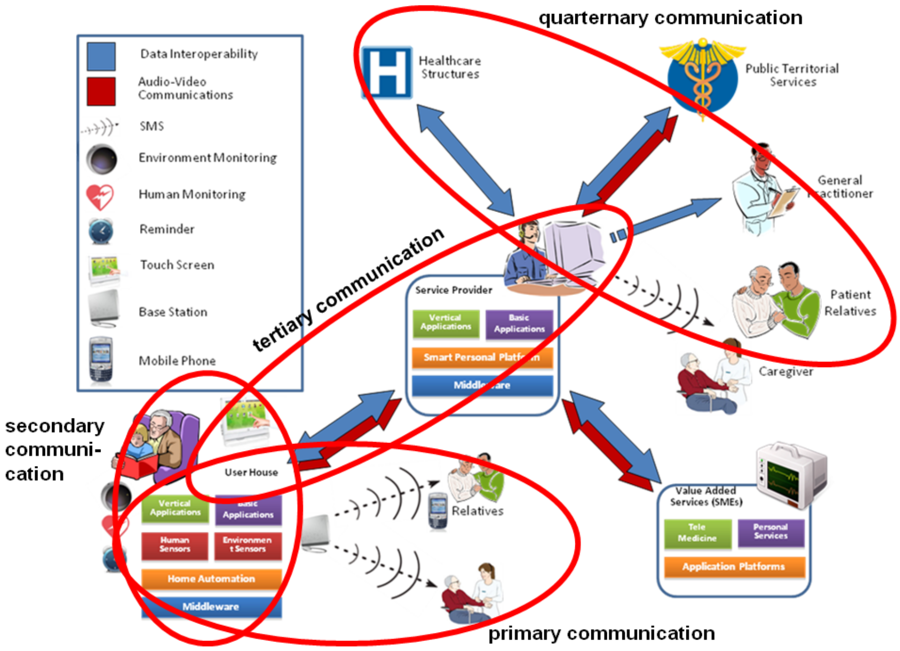

Fig. 1 – Overall Four-Layer Network Architecture

The primary communication covers the path between a local sensor or actuator and a data collector or gateway. Unfortunately, today's world of primary communication is still very heterogeneous with several dozens of technical alternatives [5].

The secondary communication provides the data back to a display at the customer's premises. There are lots of discussions about the best alternative for this secondary communication.

- One alternative is the direct communication from the end-user device to the gateway or middleware.
- The other alternative is the provisioning of the data from the backend system.

It should be mentioned that these two options are often presented as alternatives. However, it is well possible to combine both approaches.

The tertiary communication connects the data collector or gateway to the provider of the functionality (utility). In general, this part of the communication uses public infrastructure. Of course, the Internet protocol is the most widely used network protocol in this field. From data transport point of view, mostly transparent channels over circuit or packet switched networks are used, i.e. ISDN, GPRS, ATM/DSL. In case of legacy telemonitoring systems, the sensors are directly hooked up to the backend system via what is now called tertiary communication.

The quarternary communication connects various backend systems.

In the authors' part of the project, the major focus is on the primary and tertiary communication solutions. Thus, also this paper restricts to it.

2.2. LEGACY NETWORK PROTOCOLS AND DATA MODELS

There is a large variety of different network protocols and data models, which are used for home care applications. Historically, there are two approaches, which impede interoperability: In the worst case, the data models and the network protocols are completely proprietary and not opened to the public. In the better case, they are public, but linked to a certain network protocol. This is the case for protocols like ZigBee, Bluetooth or EnOcean Radio Protocol (ERP), which define their specific application profiles. In these cases, interconnection implies a gateway covering the complete communication stacks from layer 1 through to layer 7.

2.3. CONTINUA AND IEEE11073

Fortunately, this legacy approach is overcome by the application profiles from Continua Alliance [7]. It is specified in IEEE11073 and contains the overall architecture and specific devices. The basic network management is described in the Optimized Exchange Protocol (IEEE 11073-20601), which includes three major elements: The Domain Information Model (DIM), the Service Model (SM), and the Communications Model (CM). In addition, it contains various data transport models, e.g.

IEEE11073-10404 for Pulse Oximeter, IEEE11073-10406 for Pulse / Heart Rate, etc.

IEEE 11073-20601 defines the exchange protocol for information between the agent (sensor) and manager, mostly denominated as Application Hosting Device (AHD). It is designed to be extensible and flexible, and plug and play. To accomplish, it uses object descriptions of the device and data sources. The protocol supports self description of the object model on association.

The major benefit of these profiles is their independence from lower layer protocols, i.e. Continua profile are taken over in Bluetooth Health Device Profile (HDP) [8] and in ZigBee Health Care (ZHC) [9] Profile. It is also applicable over IP and 6lowpan.

However, it also should be mentioned that these profiles are still quite new and thus are not reflected in all related sub-standards. I.e. HDP is not integrated into Bluetooth Ultra Low Energy (ULE) at the time of writing this paper.

2.4. ANTICIPATED SENSOR INTERFACES

In the inCASA project, a broad variety of sensors shall be integrated into the system. These combine health related, home automation, and ambience sensors. I.e. it is anticipated to measure blood pressure, blood oxygen level, body temperature, blood sugar, heart frequency, partial prothrombin time/INR, weight, symptoms scoring, peritoneal dialysis, physiological rehab (back/knee), movement at home, contact (e.g. door/bed/chair), wrist movement (actigraphy), ambient temperature, ambient humidity, water leaks, gas leaks.

3. PROPOSED SOLUTION

3.1. MIDDLEWARE

Despite all the activities for homogenization and standardization, it is clear that not all applications, markets and market players follow these specifications immediately. Therefore, it is obvious that some meta-level is required to integrate all these sensors and data models into one system, although the mid-term future will strive for interoperable solutions, as they are described in [16].

In large scale server system, this integration is supported by a middleware software, which allows multiple processes running on one or more machines to interact. For heterogeneous distributed embedded systems, the same idea has been realized in the Hydra middleware approach (Networked Embedded System Middleware for Heterogeneous Physical Devices in a Distributed Architecture) [10], which is an open source European project. Recently, Hydra was renamed to The LinkSmart middleware is since some time available for download as Open Source from SourceForge and will be maintained by the LinkSmart Foundation [15].

3.2. MULTI-LEVEL NETWORKS

Although the Hydra platform is optimized for resource efficiency, it still comes with a lot of different elements and, consequently, a significant complexity (cf. Fig 2). As a result, in most cases an (embedded) PC-hardware is utilized. Therefore, during the course of the inCASA project, a second level of gateway was introduced, which serves as a low cost, low complexity, and low energy gateway, and is described in section C.

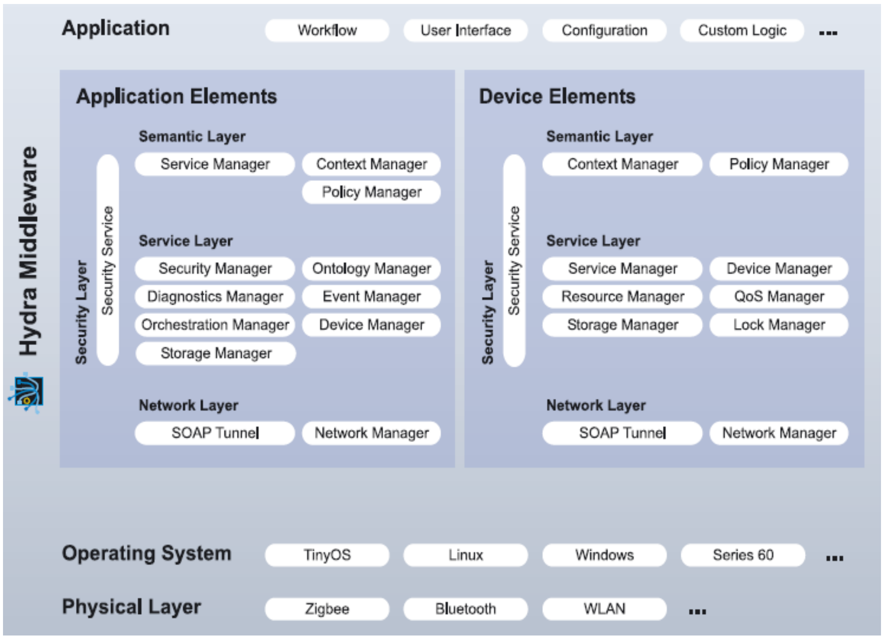

Fig. 2 – Elements of the Hydra Middleware platform [10]

The resulting network architecture is shown in Fig. 3. It is currently under development and will be applied in various pilot installations (cf. ch. 4).

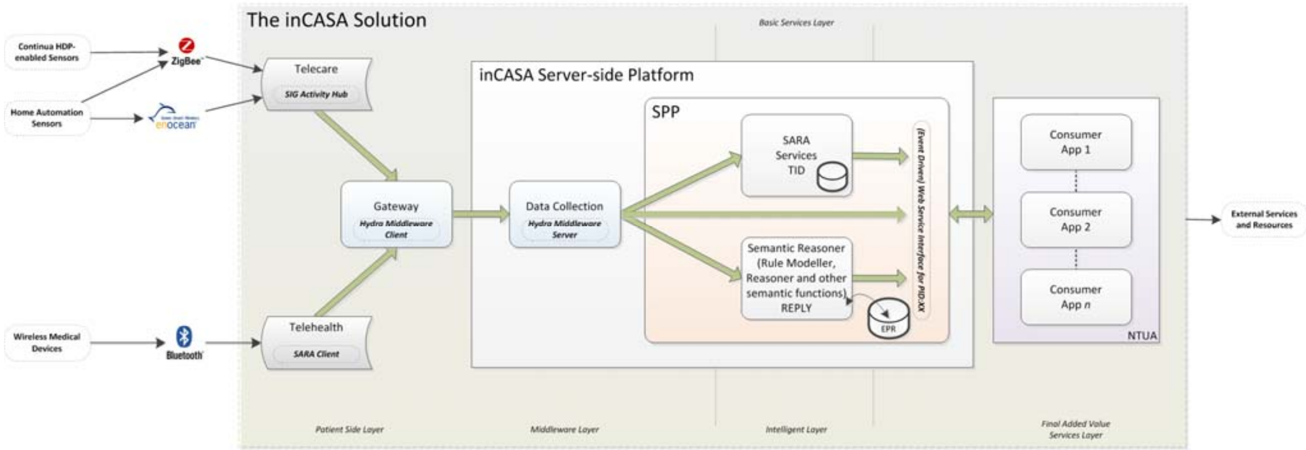

Fig. 3 – Two-level inCASA gateway architecture

3.3. PRODUCT SELECTION

As sensors, low-cost off-the shelf environmental ZigBee sensors are used running standardized application profiles for ZigBee Home Automation [11]. They support the full registration and binding process, as well as security. For the data collector side, Atmel BitCloud is used [12]. The embedded web server and TCP/IP-stack is available from the author's team [14]. The required gateway functionality has been developed within the project.

It was one of the preconditions of the project that the system should work with commercially available off-the-shelf sensors. As the market for monitoring sensors with open and standardized network interfaces is still in its infancy, there is only a restricted list of suppliers. Amongst those, the following have been selected and are currently applied in the project. In order to avoid misunderstanding, it should be mentioned that the selection did not include a fully systematic product scouting, but was based on objectives like availability, pricing, functionality, and support.

In the first phase, two classes of sensors are used:

- ZigBee enabled monitoring sensors from [11] for Temperature and Humidity, Window/Door, Flood Sensor, Inflammable Gas Detector, Wireless CO Detector, Wireless Liquid Petroleum Gas Detector, Activity, and Smoke Detector with Heat Sensor.
- EnOcean enabled sensors for occupancy in beds and chairs from [13]. Major additional feature of these sensors is their energy autonomy, as they run without batteries or external power supply, but make use the energy of the movement.

3.4. Activity Hub

Major part of the author's team is the SIG Activity Hub, which is therefore described in some more detail. It is dubbed as SIG Activity Hub and enables the connectivity between various low-end sensors (e.g. ZigBee protocol and EnOcean radio protocol) and transforms them into XML-IP-format to feed into Hydra platform. It is shown in Fig. 4.

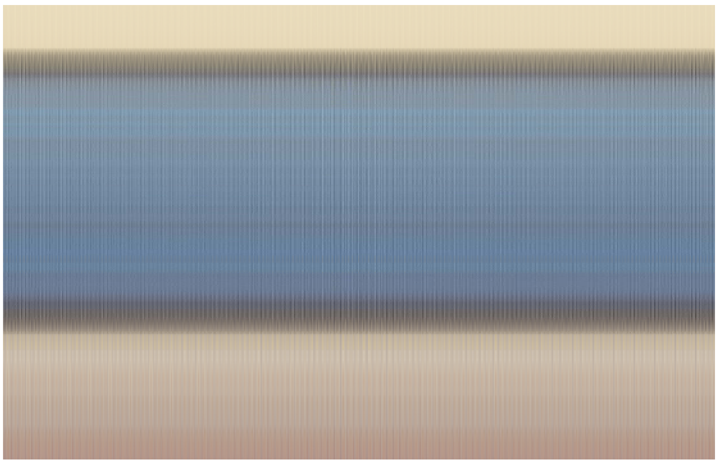

Fig. 4 – SIG activity hub in its housing

It is anticipated in the inCASA architecture to have one SIG activity hub for each apartment. For the physical installation of the SIG activity hub, the following conditions must be met:

- For the easiest deployment mode, the activity hub will be mains powered. Therefore, an access to the electricity network must be available.
- The SIG activity hub must communicate with the wireless sensors in the apartment. This leads to a possibly central positioning in the apartment, so that a direct communication can be supported. In case of the ZigBee enabled networks, this criterion is of lesser importance as ZigBee network layer supports mesh networking. In this case, intermediate other sensor nodes could possibly forward the data to the activity hub. However, using the inCASA basic sensor set, all sensors are run as ZigBee Reduced Function Devices (RFD) only, which do not come with routing capabilities. For this purpose, a mains-powered router, like e.g. a smoke alarm, would be required.
- On the other side, the SIG activity hub shall forward the monitored data to the Hydra middleware platform. For this communication, an IP-based communication channel must be accessible. For the lower network interface layer, the SIG activity hub supports the following options: Ethernet (IEEE802.3), Wireless LAN (IEEE802.11), mobile communication (GPRS), or legacy Public Switched Telephone Network (PSTN) modems. Within the inCASA project, both Ethernet and GPRS based solutions are applied.

The Activity Hub forwards its data to the middleware via HTTP-XML. Transmissions can be both event or time driven. Actual data can also be observed on a website, hosted either locally – with the known limitations in performance – or on a portal server. In addition, the activity comes with an extensive management view (shown in Fig. 5).

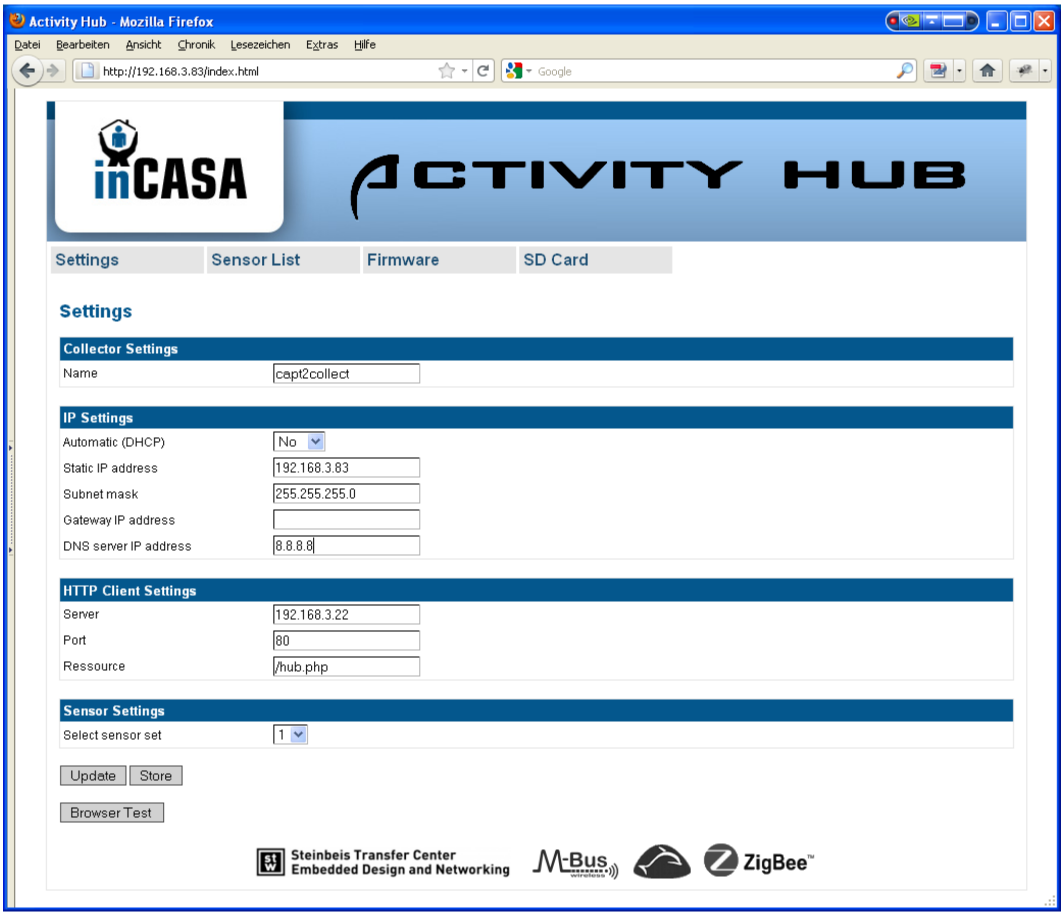

Fig. 5 – Configuration Interface of the SIG Activity hub

4. OUTLOOK

Two of the inCASA pilot installations will include the described elements. It will be used exclusively with the partner Agenzia Territoriale per la casa (ATC) della Provincia di Torino. ATC Torino is the public body with responsibility for social and public housing in the area of Torino and its surroundings. The Pilot will focus on user behavior, providing a useful profile to search and determine behavior that could lead to health problems. Prepilot installations are currently already used for testing purposes.

In addition, it will be used together with other systems in Greece (Konstantopouleio General Hospital of Nea Ionia Agia Olga, KGHNI). Both are described in a little bit more detail in [17].

The further pilot installations of inCASA project are planned in UK (Chorleywood Health Centre), Spain (Fundación Hospital Calahorra), and France (Institut National de la Sante et de la Recherche Medicale, INSERM).

ACKNOWLEDGMENT

The inCASA project is partially funded by the European Commission under the ICT Policy Support Programme.

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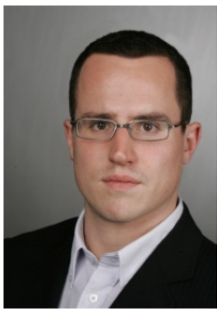

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INDOOR MONITORING APPLICATIONS USING FIXED AND MOBILE WIRELESS SENSORS

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Abstract: *This paper proposes the idea of a wireless sensor network with applicability in monitoring systems. The goal of the project is to build a monitoring system capable of data gathering which can benefit from both characteristics of fixed and mobile nodes. To become flexible, the mobile node has a modular structure with four levels. The flexibility offered by the mobile nodes increases the performance of the entire data acquisition system. These act as autonomous devices that cooperatively monitor physical or environmental conditions. In order to implement the data acquisition and communication functions, the solution we agreed on has been to use the MTS400 sensor board. Mobile nodes communicate to a central node individual data and statistical indicators over a period. The proposed energy-aware architecture was tested and validated in an indoor experiment.*

Keywords: *monitoring system, wireless sensor network, multi-hop mesh network, mobile node, reliability, redundancy, gateway.*

1. INTRODUCTION [1]

A wireless sensor network is typically composed of small, matchbox-sized devices, known as "motes" which support a range of environmental sensing capabilities and can be randomly and densely deployed. Sensor capabilities may include temperature, light, humidity, radiation, the presence of biological organisms, geological features, seismic vibrations and more. Recent development made possible to make these components small, powerful and energy efficient and they can now be manufactured cost-effectively and in large quantities for a wide range of specialized telecommunications applications. Very small in size, the sensor nodes are capable of gathering, processing, and communicating data to other nodes and to the outside world. Based on the information handling capabilities and compact size of the sensor nodes, sensor networks are often referred to as "smart dust" [1].

Benefiting from a large variety of sensors, sensor networks have many fields of applications, including health, agriculture, geology, military, home and emergency management. The limited battery life of a sensor node raises the efficient energy consumption as a key issue in wireless sensor networks [2]. Thus, energy efficiency is a primary requirement in a wireless sensor network and a major design parameter in medium access control protocols for WSN [3].

Wireless sensor networks have attracted a wide interest from industry due to their diversity of applications. Sensor networks are pervasive by nature; the number of nodes in a network is nearly boundless. As a consequence, it is becoming increasing difficult to discuss typical requirements regarding hardware issues and software support. This is particularly problematic in a multidisciplinary research area such as wireless sensor networks, where close collaboration between users, application domain experts, hardware designers, and software developers is needed to implement efficient systems [2]. Therefore, a key to realise this potential is multi-hop mesh networking, which enables scalability and reliability.

One of the most frequently design aims is to minimizing the power consumption in different functional layers of wireless nodes. Many studies have been proposed techniques for energy efficient data processing, communication and storage. As a result, a dynamic balancing between these functions is necessary [4], [5], [6].

The variety of sensing capabilities offered by these devices also provides an opportunity to gain an unprecedented level of information about a target

[1] This work was supported in part by DocInvest Project ID 76813/ POSDRU_Romania (Burse doctorale: investitii in cercetare-inovare-dezvoltare pentru viitor)

area, be it a room, building or outdoor. Wireless sensor networks (WSN) are fundamentally a tool to measure the spatial and temporal characteristics of any phenomena [7].

Because of the presence of people, for particular case of indoor applications, low energy of radiations also is an important requirement. High RF power levels, that imply high energy-consumption, are undesirable for interference with other networks and for health hazards of people due to continuous exposure to radiation antenna radiation levels of the wireless equipment) especially in AAL (homecare monitoring).

Therefore the communication range of BSN is very small (up to 8 m). Now, thanks to the ITC development, intelligent systems are used to support elderly and chronically ill in all aspects of daily life, at home. For example, European program "Ambient Assisted Living Joint Programme" (AAL), in progress, aims to extend the time in which the elderly can live independently in their home by assisting them in carrying out activities of daily living [8]. This means that the environment will be characterized by embedded technology, sensitive, adaptive and responsive to the target people.

In the near future it can be expected that buildings will be equipped with a range of wireless sensors functioning as a part of an overall building management system. It expects such information could be used for a variety of purposes, including guiding occupants to the nearest safe exit in case of emergency [9].

2. MONITORING SYSTEMS

The purpose of deploying a WSN is to collect relevant data for processing and reporting. In this paper are presented the incipient stages of a more complex project we started to develop. Trying to apply a mobile monitoring system to a multi-storey building offers great advantages, but it also raises some questions.

One of the primary advantages of deploying a wireless sensor network is its low deployment cost and freedom from requiring a messy wired communication backbone, which is often infeasible or economically inconvenient [10]. Cattivelli et al [11] study the problem of distributed estimation in order to evaluate some parameter of interest from measurements in an adaptive network. For the global solution they propose a distributed diffusion algorithm based on recursive least-squares (obtain estimates that are close to the global solution).

On the other hand, one of the first questions to be answered is how to deal with obstacles and how to achieve communication over long distances. Energy consumption or, in general, resource management is of critical importance to these networks. Each node will collect raw data from the environment, and communicate with each other to perform a task. Each node has a sensing radius within which it can gather data and a communication radius within which it can communicate with each other. Trying to reach a remote location to gather valuable data can be done using a mobile platform like the one we have (Fig. 1).

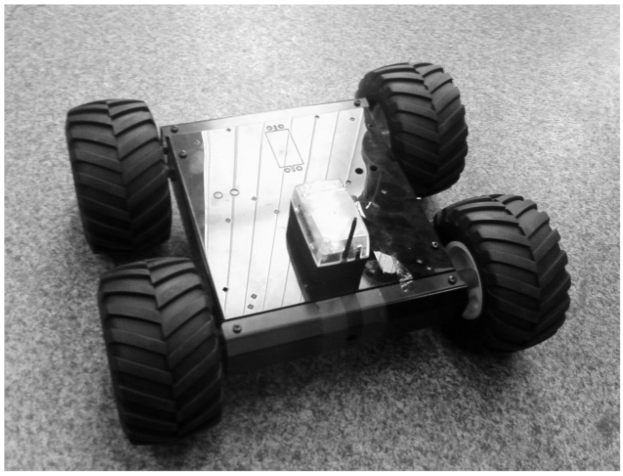

Fig. 1 – Mobile platform equipped with wireless sensor

Using many mobile nodes to achieve a very good coverage of the monitored space can be a good solution but it can become costly in terms of energy consumption and maintenance. One important criterion for being able to deploy an efficient sensor network is to find optimal node placement strategies. Cost driven development resulted in choosing a more versatile topology for our network consisting in both fixed and mobile nodes. This approach of the problem gives us the possibility to easily adapt the network for the requirements of a monitoring system, but also to make it act as an alerting system against a predefined alert situation. An alert situation can be defined as anything from a fire to an earthquake.

The mobile node architecture is a modular one and contains four functional levels: communication, processing & management, data acquisition and power supply & traction (Fig. 2).

Some of the mobile nodes characteristics may prove to be very important for our monitoring solution. The main characteristic is that the topology is not fixed. During functioning, nodes will change position or go offline.

The notion of area coverage can be considered as a measure of quality of service (QoS) in a sensor network, for it means how well each point in the sensing field is covered by the sensing ranges. Our solution presents a practical approach to the coverage problem giving the opportunity for the mobile nodes to demonstrate their great capability in monitoring large areas.

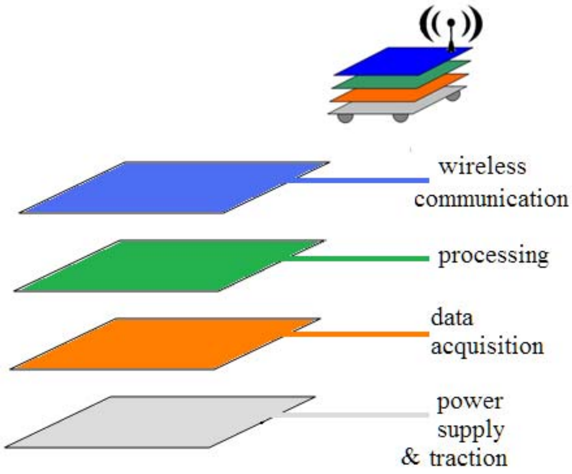

Fig. 2 – Mobile node architecture

Because mobile sensors give us a greater degree of freedom, they can also be quickly deployed and can easily cover a certain area even when human presence may be impossible. Our desired network consists mainly in fixed nodes and also few mobile nodes in order to perform specific tasks. All the nodes will be connected to the gateway and through this to a processing centre which can be accessed using a user interface (Fig. 3).

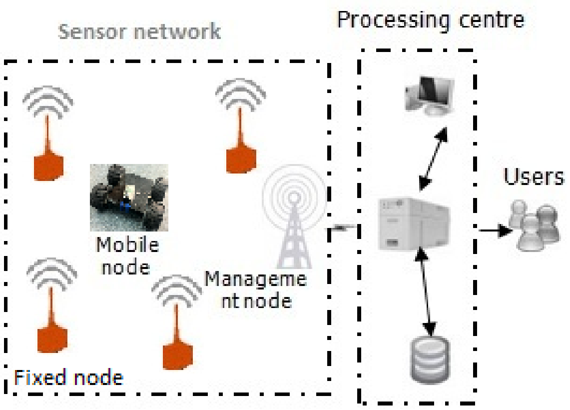

Fig. 3 – Mobile sensor alarm system deployment

The ultimate purpose of implementing a monitoring system is developing a good alerting system capable of early detection of potentially dangerous situations. The end users of the monitoring and alerting system should be the people living and working in the monitored area, in our case, inside the monitored building.

Using a mixture of fixed and mobile nodes induces a great deal of redundancy which makes the entire wireless network more reliable and provides the monitoring system which the means to react in case of emergency. The mobile nodes can also act as an on the scene monitoring system in case a potentially dangerous situation is detected. Having a mobile platform equipped with sensors capable of reaching the place where the problem occurred in case of emergency can be of great help for correctly evaluating the situation and tacking the proper actions against it as soon as possible.

A sensible matter is dealing with false alerts. The alerting system should be capable of dissociating between real alert situations and sensor associated errors. False alarms may result in causing unnecessary panic and bringing resources (such as emergency services) when they are not needed. These kind of situations should be avoided in order to keep a good level of confidence for the implemented alerting solution.

The best way to avoid unwanted triggers is to go through a vast number of test cases and to use a fault detection mechaninsm to validate data obtained from the sensors.

Other constarints for the chosen solution will be the motes size and weighth, the battery life, it should be long enough to perform the tasks without human intervention and also the battery life of the mobile platform.

3. CHOSEN SOLUTION

Our goal is to build a monitoring system which can benefit from both characteristics of fixed and mobile nodes. So, our decision must be made having in mind the fact that the motes should be capable to use both as fixed and mobile nodes without further preparation.

A typical wireless sensor network consists in spatially distributed sensors. These act as autonomous devices that cooperatively monitor physical or environmental conditions. The great advantage of using a wireless network is that you can forget about the messy wired communication which in most cases can be impractical and more costly.

Having in plan to use our sensor network as an environmental monitoring system, the first step in designing our solution has been to choose the needed sensors. In order to achieve a good monitoring level for the environmental conditions indoor or outdoor, we needed to have our nodes equipped for gathering the following parameters: temperature, light, humidity, barometric pressure and also seismic.

To conduct our experiments, we decided to use in the early stages only four motes, three of them as fixed nodes and another one a mobile node on our remotely operated platform [12].

In order to choose the proper technology for our communication infrastructure, a comparison between available wireless communication technologies was made (Fig. 4) [13].

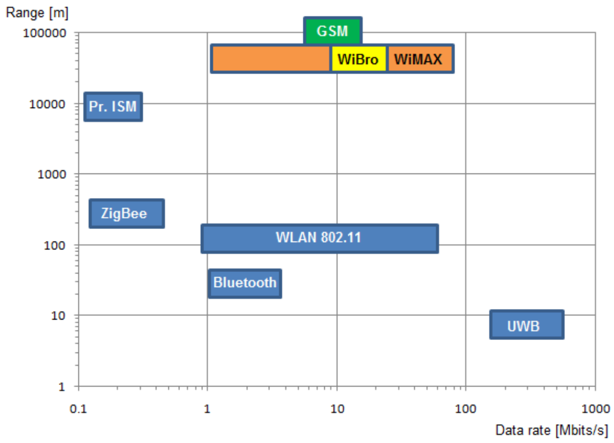

Fig. 4 – Graphical representation of wireless technologies segmentation

Based on requires demanded by the mobile sensor network, this representation can be seen like a guide from which, can be chosen the suitable wireless technology for a communication module.

For technology selection, two important features are represented on the axes, namely distance and data rate, both in logarithmic scale. The area of each technology representation figures the level of energy consumption approach in design of the respective technology.

A small area represents a standard with energy consumption optimization; instead a wide area represents a technology which wasn't designed to be energy efficient.

An example of choice of the proper technology for communication function is presented in [13] where the eliminatory demand was low power consumption. As one can see in Table 1, for low data rate and low range, we remain only with the option for communication infrastructure technology ZigBee, because, practically, it was especially develop for such application as mobile sensor networks.

Table 1. Low power wireless technologies

		Range	
		Low	Wide
Data rate	Low	ZigBee	GSM(GPRS)
	High	UWB	WiBro, GSM(HSDPA)

If the sink is far from the event, the co-operative communication is one of the methods to ensure communication task in energy-aware applications [14], [15].

In order to minimize the total energy consumption a multihop routing is possible. That implies the cooperation of some nodes to communicate data from a node away to the gateway. So, if a mobile node is outside of range of communication or an obstacle is interposed between the node and the gateway, another node can act as a relay to gateway to ensure communication.

The solution we agreed on has been to use the MTS400 sensor board (Fig. 5).

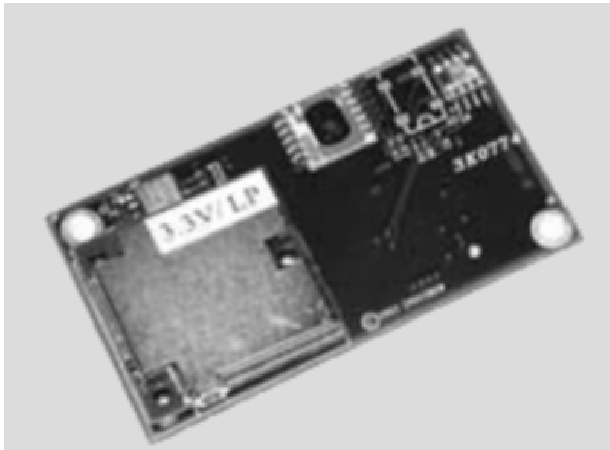

Fig. 5 – MTS400 Sensor Board

The MTS400 environmental sensor board offers five basic environmental sensing parameters and an optional GPS module (only available for MTS420). One of the main characteristics is that they are energy-efficient devices so that they can provide extended battery-life and performance wherever low maintenance field-deployed sensor nodes are required. These versatile sensor boards are intended for a wide variety of applications ranging from a simple wireless weather station to a full mesh network of environmental monitoring nodes. Applicable industries include agricultural monitoring, art preservation, environmental monitoring, sensor location mapping (available for GPS equipped MTS420).

According to the MTS420/400 Datasheet [16], some of the sensor board characteristics are as follows:

Dual-axis accelerometer: acceleration range; resolution: ±2g; 2mg at 60 Hz; sensitivity 167 mV/g, ±17%,

Barometric pressure sensor: pressure range; resolution: 300-1100 mbar; 0.01 mbar; accuracy: ±1.5% at 25˚C

Ambient light sensor: TAOS TSL2550D; spectral response: 400-1000 nm, similar to human eye.

Relative humidity and temperature sensor: Sensirion SHT11; humidity range; resolution: 0-100% RH; 0.03% RH; absolute RH accuracy: ± 3.5% RH; temperature accuracy: ±0.5˚C at 25˚C.

The average operating range for the described sensors is between 2.5 and 3.5 volts [17].

The sensor node (MicaZ), manufactured by Crossbow, has a 7.3 MHz Atmega128L processor, 128Kb of code memory, 4Kb of data memory, and a Chipcon CC2420 radio which supports the 802.15.4/ZigBee WPAN protocol (transmits up to 250 kilobits per second and an outdoor transmission range of approximately 30 m) [17]. The dimensions of the node are 58 mm x 32 mm and have reduced weight, making them ideal for mobile platforms (Fig. 6).

Fig. 6 – Wireless network node equipped with MTS400 sensor

The sink node is connected to a computer using a USB cable and remains permanently connected in order to transmit data to the database. The gateway's role is to aggregate the data from the network, interface the host, LAN, or the Internet, and act as a portal to monitor performance and configurable network parameters [18].

4. EXPERIMENTAL DATA

All the experiments have been made indoor using our faculty building as a test ground for the sensor network. The first stage of the experiment consisted in placing the sensor nodes inside the building, so that they can communicate with each other and to the gateway. Once the fixed nodes have been deployed, we started monitoring the data acquisition using MOTE-VIEW. This is an interface, client layer, between a user and a deployed network of wireless sensors. Once they are turned on, the sensor nodes appear in a list of available nodes on our interface. They can be identified by their unique id.

The first task is to set the update rate for each node. For the first experiment we used a data rate of 10 seconds for all our nodes. Every node will automatically appear in the upper left corner of the MOTE-VIEW interface. Each of them is assigned an ID and a Name for easy identifying within the network. The ID can be also seen on the side of each node (Fig. 6). Once the preparations have been made, real time data from each node are available (Fig. 7).

For the second part of the experiment, we use our mobile platform equipped with one of the nodes to gather data while moving inside the building. The mobile node (Id=6692) has been sending data once every 10 seconds to the gateway directly, or via one of the other nodes.

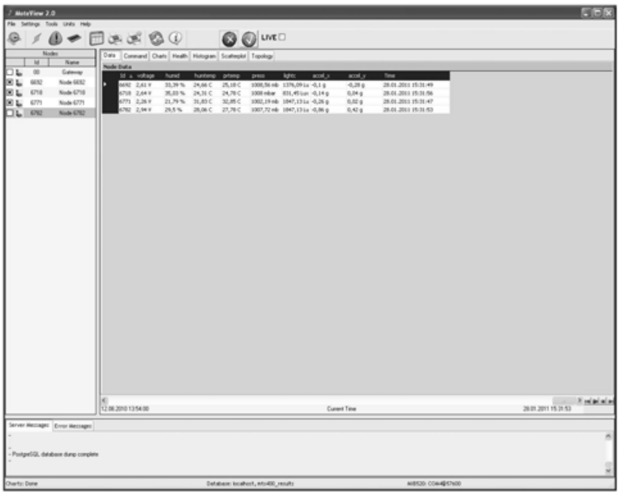

Fig. 7 – Data acquisition using MOTE-VIEW

In Table 2, the following parameters can be tracked over an interval of 5 minutes, 15 seconds: temperature [C], pressure [mbar], humidity [%]. During this period of time, the platform has been programmed to move inside the building.

Some data has been lost because of the poor reception over long distances and thick walls. The advantage of having the possibility to send data to the gateway through another node is underlined by the fact that many data have been gathered this way (as it is shown by the parent column in Table 2).

From the harvested data, we can also automatically generate graphs of a sensor reading against time for one node or a set of nodes. For our experiment, we generated some charts to determine the data change in time for our mobile and fixed nodes. For example, we have generated the temperature evolution graph for the mobile node (Fig.8), and for all the nodes, comparatively (Fig. 9). Similarly, pressure and humidity evolutions are presented in Fig. 10 and Fig. 11, respectively.

As a result, some major temperature changes can be seen over the period of time (14:52:35 – 14:57:50). This is the interval when the mobile platform moved inside the building gathering data. Similar graphs have been generated for the other monitored parameters such as: light, humidity and pressure.

Table 2. Mobile wireless sensor data

Id	Time	Parent	Humidity [%]	Temp [C]	Press [mbar]
6692	14:52:35	0	39,1	25,3	1008,3
6692	14:52:45	0	40,5	25,33	1008,2
6692	14:52:55	0	34,9	25,25	1008,3
6692	14:53:05	0	34,1	25,24	1008,2
6692	14:54:13	6782	27,4	25,03	1008,3
6692	14:55:02	0	25,5	24,49	1008,3
6692	14:55:11	0	26,7	24,48	1008,4
6692	14:55:31	6718	28,2	24,4	1008,3
6692	14:55:41	6718	28,9	24,34	1008,5
6692	14:56:00	0	29,4	24,25	1008,5
6692	14:56:21	0	29,6	24,31	1008,6
6692	14:56:31	0	29,5	24,34	1008,5
6692	14:56:50	0	29,7	24,41	1008,3
6692	14:57:02	6718	29,6	24,4	1008,4
6692	14:57:23	0	29,8	24,44	1008,3
6692	14:57:32	0	29,8	24,47	1008,2
6692	14:57:50	0	29,9	24,48	1008,2

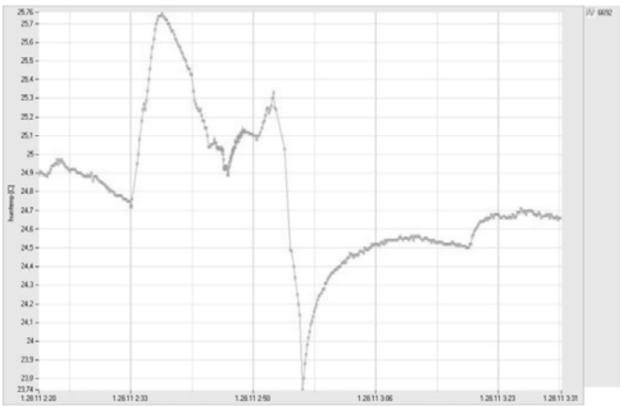

Fig. 8 – Temperature evolution measured by the mobile node

Because the rapid variations of measured values of parameters in the same location, for the evaluation of the real values some statistical indicators for humidity (H), temperature (T) and Pressure (P) are necessary. Thus, average values (μ_H, μ_T, μ_P) and estimations of standard deviations (σ_H, σ_T, σ_P) are also provided by sensor node (Table 3):

$$\mu = \frac{1}{n}\sum_{i=1}^{n} V_i, \qquad \sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(V_i - \mu\right)^2} \quad (1)$$

where V_{i} is an individual value of the measurement and n is the number of these values.

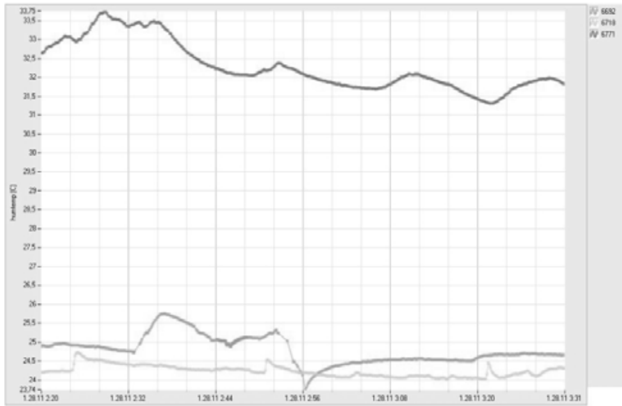

Fig. 9 – Temperature evolution over a period of time measured by 3 sensor nodes (2 fixed nodes and one mobile node)

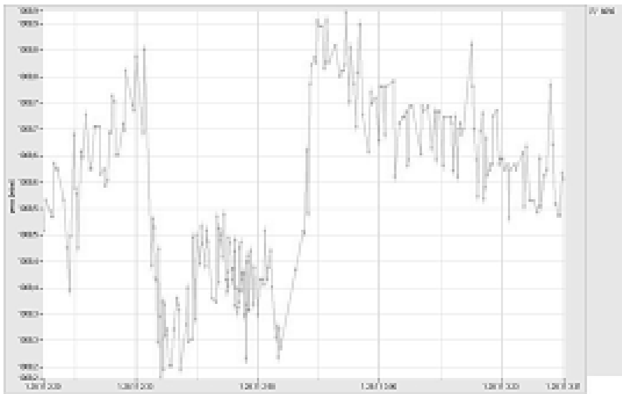

Fig. 10 – Pressure evolution measured by the mobile node

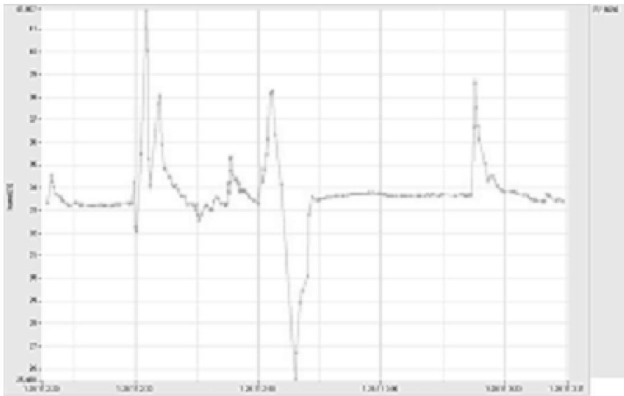

Fig. 11 – Humidity evolution (mobile node)

Table 3. Statistical indicators provided by mobile wireless sensor node

Stat. Indic.	Period	Id	Hum. [%]	Temp. [C]	Press. [mbar]
μ	14:52:35 14:57:50	6692	29,7	24,4	1008,4
σ	14:52:35 14:57:50	6692	4,23	0,46	0,12

The topology of the mote network can be defined placing the nodes in the specific location on the map. This allows the user to visualize temperature or other data gathered by the sensor in an intuitive way using a wide range of colours for the representation of the parameter levels (Fig. 12).

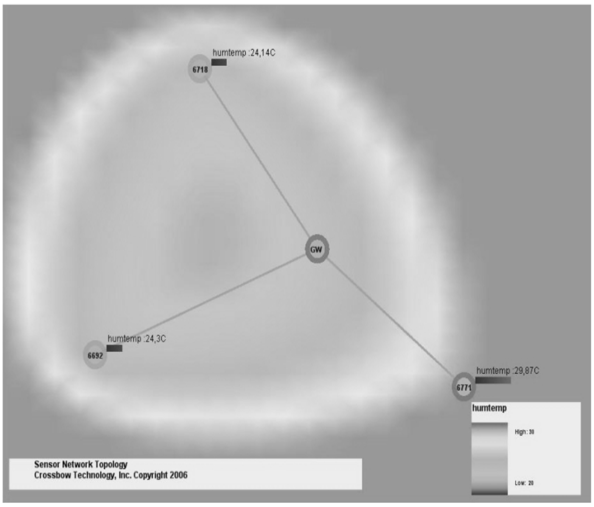

Fig. 12 – Temperature evolution measured by three nodes

In an outdoor implementation, using the GPS capability, the position of the nodes relatively to the gateway would be automatically available.

In Fig. 13 we can see a typical XMesh network diagram. We can see clearly that it has a great deal of redundancy. The real life situation looks more like the one in Fig. 14. So, we have to deal with the bottlenecks and avoiding obstacles in order to reassure that the sensorial coverage and communication coverage are satisfactory.

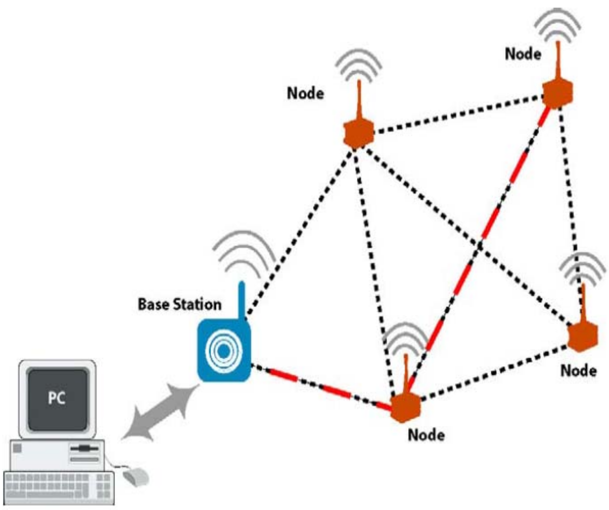

Fig. 13 – XMesh network diagram

The capability of our nodes to communicate to each other helped obtaining satisfactory communication coverage even when obstacles made direct communication to the gateway impossible.

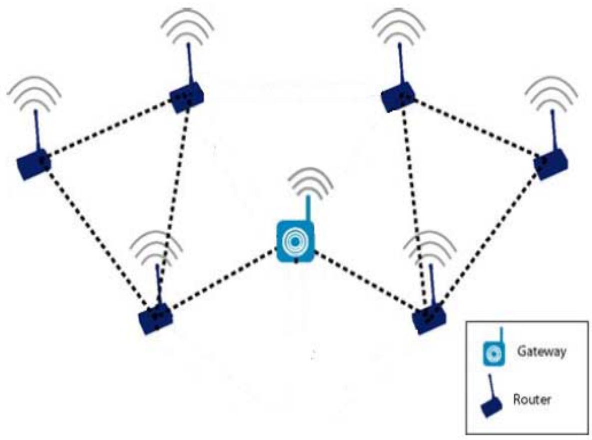

Fig. 14 – Diagram showing an indoor mesh topology with bottlenecks

Confronting our wireless sensor network with a series of test scenarios, the result was a tree shaped topology which could send data over long distances avoiding the obstacles. The mobile node proved to be a great enhancement giving us the possibility to send data over longer distances and replace the node in order to retrieve data from various places inside the building. Another possibility in case a fixed node goes offline is that an operator will place the mobile node in the same position as the fixed malfunctioning node to resume sending data from the same spot inside the building.

Dealing with false alerts is another issue. We can't let our monitoring system feed corrupt data to the alerting system. The false alerts should be avoided in order not to generate panic and distrust in the entire alerting system. The same principle as in case of replacing a malfunctioning node will be used.

In order to validate the alerting data from the fixed node, an operator will move the mobile node near the evaluated node's position. After a short while, the mobile node should start transmitting data similar to the fixed node. In case the alerting data are confirmed, the alerting system will turn the alarm on. In some cases, moving a mobile node near the fixed node's position will only prove that the data is corrupt and the fixed node needs maintenance.

In the third phase of our experiment, we want to test and to find a solution to a real life scenario when one of the retransmitting nodes stops functioning and a part of the network gets cut off from the gateway. A wireless network working inside a building may have many bottlenecks as it can be seen in Fig. 15. These can become a real problem if one of the retransmitting nodes stops working because, even if a part of the network is still operational, data cannot reach the gateway.

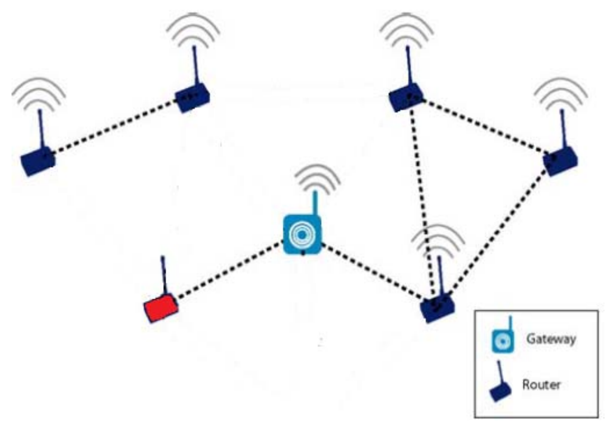

Fig. 15 – Diagram showing an indoor mesh topology with bottlenecks and a faulty node resulting in the loss of an entire branch of the network

In order to limit the risks of losing an entire branch of our network in case of a single malfunctioning node stops acting as an active router, we tried using our mobile node. The solution proved itself helpful (Fig. 16).

The transmission from the lost branch is resumed after placing the mobile node in the vicinity of the malfunctioning fixed node.

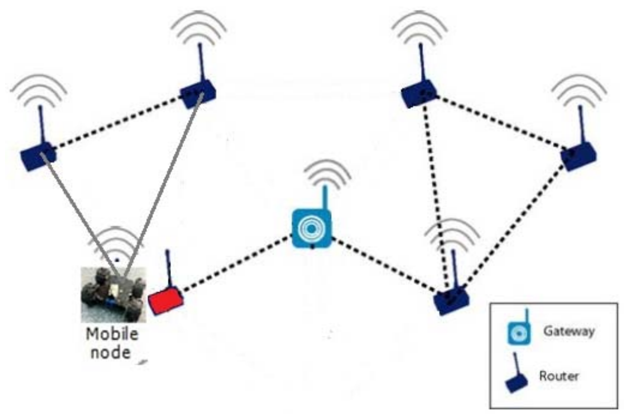

Fig. 16 – After the intervention of the mobile node, the transmission from the lost branch is resumed

So, in order to avoid losing data, we want to use our mobile nodes as retransmitting nodes. In case of a fixed node failure, the mobile node receives a command to automatically position itself so that the data transmission towards gateway may be resumed. The mechanism tolerates failures of random individual nodes in the network.

5. FAULT DETECTION

The goal of fault detection is to identify when a fault has occurred, to pinpoint the type of fault and its location.

The most simple and frequently used method for fault detection is the limit checking of a directly measured variable [19]. In this case, after rigorous testing, we established that the most frequent cause for a node malfunction is power failure. Some power sources can last more than others, so, when one of them runs off or is lower than the optimum working level of the sensors or the antenna, the node starts sending corrupt data and, ultimately, stops working, leaving the rest of the network with no communication link to the gateway. In order to prevent and predict this kind of failures, we implemented a limit checking fault detection system that triggers an alarm each time one of the nodes is dangerously close to the equipment functioning limits (Fig 17). As we said before, the operating range, for the described sensors, is between 2.5 and 3.5 volts.

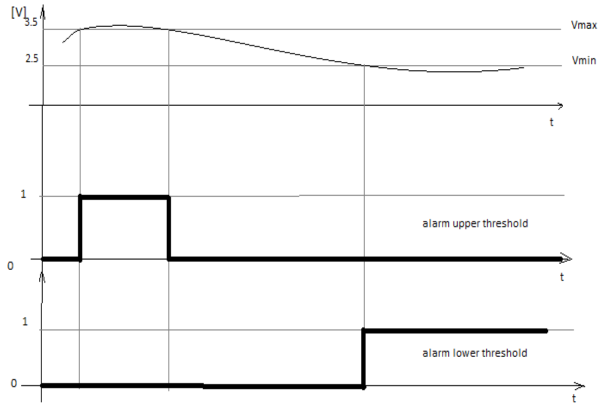

Fig. 17 – Source voltage limit checking.

So, as you can see from the figure above, we have established an upper and a lower threshold in order to have an online fault detection system. One of the data constantly sent by every node is its voltage, so it is relatively easy to predict node malfunction due to power failure related problems.

Another way to deal with the power failure or power fluctuation generated problems is by constantly checking the trend of the measured voltage. If the voltage is climbing or dropping too steeply, it's clear that the node is losing its ability to measure and send data because of exceeding the normal average operating range of the equipment.

6. CONCLUSIONS

Using a mobile wireless sensor network for data acquisition inside a building offers many challenges, but also enjoys many benefits from the wireless capability and the mobility of the nodes. This architecture has a very good potential as an alert and monitoring system for a closely monitored environment building as an art museum or even a hospital, a laboratory or a house for homecare monitoring of people with chronic diseases or elderly. Its features are optimized for monitoring over a long period, autonomously, without maintenance and have a good potential for upgrading.

One major challenge is how to validate the gathered data from one specific node. The mobility of one or many network nodes comes into play, offering the possibility to place another node in the vicinity of the evaluated node and compare the data to validate them.

Our experiments demonstrated that it is possible to use a few mobile nodes in order to achieve greater coverage and redundancy inside a multi-hop network composed mainly by fixed nodes.

One of the challenges we have to overcome is how to move the sensor nodes relatively to each other in order to send data over a long distance, avoiding obstacles and obtaining a good dropped/received data ratio. We also want to improve our network redundancy by teaching the mobile nodes to take the place of the broken nodes in case of failure.

The future project will also benefit from the GPS capability of the more advanced MTS420, giving us the possibility to operate not only indoor, but also in the surroundings of the monitored building. This step will bring more challenges to the project.

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NONLINEAR DATA CODING IN WIRELESS SENSOR NETWORKS

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Abstract: *A proposed nonlinear method of sensors data coding allows to increase the useful capacity of the data transmission protocols for Wireless Sensor Networks in 3 – 5 times by the integration of sensors data with different digits capacity and reducing the transmissions number.*

Keywords: *residue number system; wireless sensor networks; multilevel coding, protocol.*

1. INTRODUCTION

Wireless sensor networks (WSN) with the domain of scientific (theoretical and experimental) research are increasingly moving into the region of the practical use in various areas. WSN can capture information about the condition of physical environment, can perform the simple data processing and transmit them to the remote server. There are such tasks among the practical applications of the Wireless Sensor Networks technologies: water resources monitoring, glacier motion, forest fires, building and manufacture organization, "intelligent" measurements and increasing of the power consumption effectiveness, medicine and public health, sport medicine, patient care and patient monitoring [1].

Wireless Sensor Networks more often use the cluster tree topology in the tasks of monitoring (Fig.1) [1]. In this topology the neighboring nodes are the sources of information and the retransmitters of the data from another nodes simultaneously.

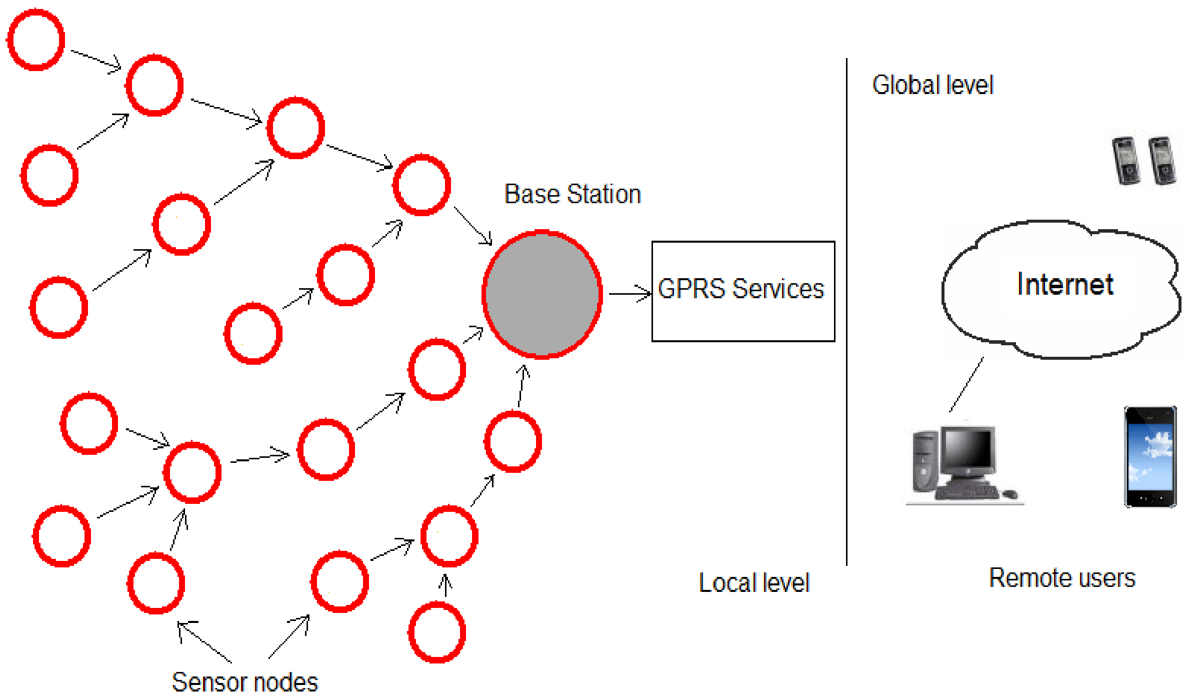


Fig. 1 – The structure of WSN

As a rule the base station transmits data through the wireless communication channel (GSM channel) to the networked remote server.

It is shown in [2] that energy expenses for data transmission in WSN occupy about 70 percent of all expenses. Take into consideration that one bit transmission on radio channel (even ultralow power) is equivalent to the performance of thousand operations by the processor of wireless node [3]. So, the use of the data processing methods in wireless controller is promising. The proposed additional data processing in the nodes is less energy-intensive then redundant data transmission. Taking into account this fact as well as low data transfer rate in WSN (250 Kbit/s) a development of coding methods and effective data transmission protocols oriented on increasing the useful bandwidth of communication channels is the actual issue.

The preliminary analysis has shown that WSN efficiency can be improved due to [4, 5]:

(i) The reduction of service data in network packet;

(ii) The redudancy elimination of measured sensors data.

The different methods are used for the sensors data redundancy decreasing. The mobile-agent-based computing model can decrease the data volume in sensor networks using data redundancy elimination by determined methods [6, 7]. But such approach has a limited application area because of restriction on the network architecture, a distance between sensors and cluster core and etc. To eliminate the data redundancy authors [8] proposed to optimize the traffic using data decorrelation. However such technique can be implemented in data flows for close located nodes only where the same physical quantities are measuring, so it has a limited application.

The service data proportion can be improved in the packet's structure increasing a size of data field. However control and monitoring systems based on WSN technology are characterized by short length of information messages. For example a volume of sensor data in measurements of physical quantities (temperature, pressure, humidity, radiation background and etc) has 8-16 bits. To solve this problem the data from different nodes are integrated in one packet. The simplest method of the packets size increasing is data concatenation. If $\alpha = a_1.....a_n$ and $\beta = b_1.....b_m$ words of alphabet A, then concatenation of word A and word B will be the word γ of the same alphabet A: $\gamma = \alpha\ \beta = a_1....a_n\ b_1....b_m$ [9]. However existing methods of data concatenation work properly for sensor data with a same digit capacity only, its application for data with different digit capacity leads to the essential redundancy increasing.

In this work we are exploring the directions of network protocols improvement by means of increasing network packets size for sensors with different digit capacity.

1. THE EVALUATION OF WSN PROTOCOLS STRUCTURE

Let's explore the protocols of the IEEE 802.15.4 standard and protocol SimpliciTI of the Texas Instruments to determine the volume of control information in the structure of the WSN protocols.

The standard IEEE 802.15.4 and ZigBee protocol stack are developed for the coordination of the equipment of different manufacturers and for the simplification of deploying WSN. ZigBee protocol stack is hierarchical model, which is built on the principle of OSI model that defines a networking framework for implementing protocols in seven layers (Open System Interconnection) [10].

ZigBee protocol stack includes layers of the IEEE 802.15.4 standard, the data-link layer, the network layer, application support sublayer and device profiles. The IEEE 802.15.4 standard defines the specifications of the physical layer (PHY) and sub layer the Media Access Control (MAC) for the low-rate wireless networks.

Physical layer (PHY) provides the data transmission service, performs channel selection and energy and signal management functions. The medium access control (MAC) layer manages access to the physical channel and network. It provides different access mechanisms to the physical channel. MAC layer supports "peer-to peer", "star" and "claster tree" topologies, secure data exchange, and streaming and batch communication. It also defines automatic confirmation of packets reception, provides data transmission in appointed time intervals and uses 128-bit keys to implement its security mechanisms, 16- and 64-bit addressing.

The SimpliciTI protocol, developed by the Texas Instruments is the alternative for the ZigBee protocol stack [11]. The SimpliciTI protocol is destined to the networks with the limited number of nodes and autonomous power supply. This protocol uses physical layer of radio access, elaborated by the Texas Instruments instead of IEEE.802.15.4. The retransmitters and gateways, which are powered by electrical supply network are used for the increasing of distances for networks on the basis of SimpliciTI protocol. The implementation of SimpliciTI protocol requires minimum resources of microcontroller, so the system has low cost in comparison with systems, which used ZigBee protocol. The SimpliciTI protocol supports the transmission of packets with fixed and variable length. The maximum packet size is 255 byte.

The useful network channel capacity means information rate [5]. The next factors have an influence on useful channel capacity: the interference, waiting of the transmission access, the interframe spaces, the service data units (packet header of MAC and physical layer), confirmation and retransmission of the frame. The size of service data units has most important influence on useful channel capacity in WSN.

The frame structures have been designed to keep the complexity to a minimum while at the same time making them sufficiently robust for transmission on a noisy channel. Each successive protocol layer adds to the structure with layer-specific headers and footers. This standard defines four frame structures [10]:

– a beacon frame, used by a coordinator to transmit beacons;

– a data frame, used for all transfers of data;

– an acknowledgment frame, used for confirming successful frame reception;

– a MAC command frame, used for handling all MAC peer entity control transfers.

Each packet transmitted in WSN contains the control information which is required for the safe data delivery and data processing. According to the IEEE 802.15.4, SimpliciTI service data unit consists of preamble sequence, start of frame delimiter, frame length, frame control, sequence number, addressing fields, and checksum (Fig. 2).

Preamble Sequence	Start of Frame Delimiter	Frame Length	Addressing Fields	Data Payload	FCS
32/64	16/32	8	8	255	16

a)

Preamble Sequence	Start of Frame Delimiter	Frame Length	Frame Control	Sequence Number	Addressing Fields	Data Payload	FCS
32	8	8	16	8	32	104	16

b)

Fig. 2 – Schematic view of the data frame and the PHY packet: a) SimpliciTI; b) IEEE 802.15.4

The analysis of the frame structure of WSN protocol (IEEE 802.15.4, SimpliciTI) – conducted by authors of presented paper – confirmed the decreasing of useful bandwidth when user data size is reduces. The percentage of control information in this protocol makes up from 4% to 80 % – and it depends on data field size (Fig. 3).

Let's evaluate useful channel capacity in relation to data area size without regard for the interframe spaces and waiting time of medium access.

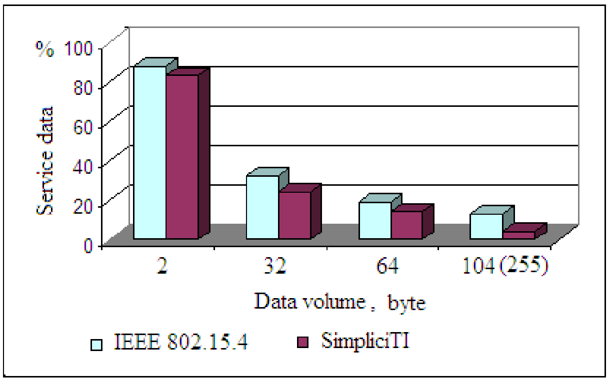


Fig. 3 – Percentage of service data in the packet for IEEE 802.15.4 and SimpliciTI protocols

For this we calculate maximum number of minimum length frames. According to IEEE 802.15.4 standard minimum frame length with preamble sequence is $L_1 = 27$ bytes or 216 bit, so if the transmission rate is equal to 250 Kbit/s it is necessary to 864 microseconds for it's transmission, one bit transmission time is $t = 4$ microseconds. The maximum possible network bandwidth is equal to $m_1 = 1157$ frame/s [5].

According to IEEE 802.15.4 standard maximum frame length with preamble sequence is $L_2 = 127$ bytes or 1016 bit. The time of frame transmission is 4064 microseconds. So, the maximum possible network bandwidth is equal to $m_2 = 246$ frame/s. At the same time it is expedient to calculate useful capacity with the use of maximum length frames and minimum length frames.

For the minimum length frames with user's data size $d_1 = 4$ bytes useful channel capacity is (Fig.4): $C_1 = m_1 \cdot d_1 \cdot t = 37$ Kbit/s, and for the maximum length frames with user's data size $d_1 = 104$ bytes useful channel capacity is: $C_2 = m_2 \cdot d_2 \cdot t = 204{,}7$ Kbit/s.

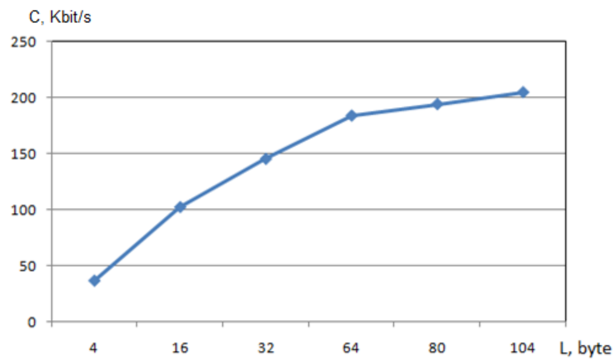


Fig. 4 – Dependence of useful channel capacity on data field size in frame of IEEE 802.15.4 standard protocol

As follows from fig. 4 the useful channel capacity reduced to 5 times if we have minimum data area size in protocol structure.

The transmission of the packets with the maximum length of user's data is more optimal, because the percent of service data relative to user's data considerably less than in packets with the minimum length. Consequently, useful channel capacity approximates to nominal value – 250 Kbit/s (see Fig.3).

3. THE PROPOSED APPROACH

The difference of the proposed method consists in representation of nodes data in residue number system (RNS) (bl. 1) and their transformation in positional number system (bl. 2). In the receiving site (server) inverse transformation of data (bl. 4) in RNS (bl. 5) is occurred (Fig. 5).

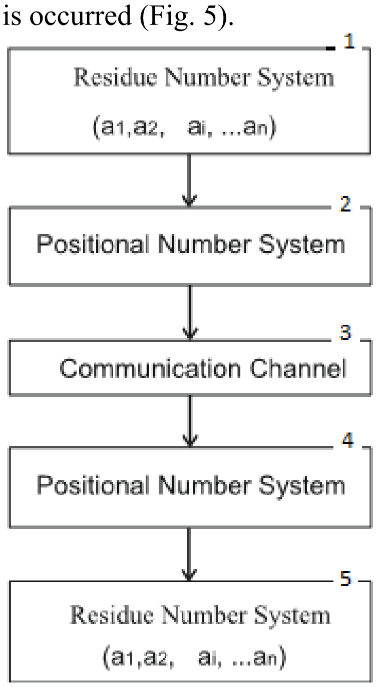


Fig. 5 – Block diagram of proposed coding method

To explain details let's assume that any positive integral number in RNS is represented by the set of smallest positive residues after this number above was divided on the fixed positive integers p_1, p_2, … p_i …, p_n, which are called as modules. Let's designate the smallest positive residue from a division A on p_i as

$$a_i = A - \left[\frac{A}{p_i}\right] \cdot p_i, \quad (1)$$

where $[\bullet]$ is rounding to smaller integer. Then a number A in RNS will be written down as:

$$A = \{\alpha_1, \alpha_2, \ldots \alpha_i, \ldots, \alpha_n\}.$$

The coding concept is based on the following steps. The coprime modules are selected per each level according to a condition

$$p_i > a_{imax}, \quad (2)$$

where a_{imax} is max value of data.

The sensors data are united into packets by the formula [12]:

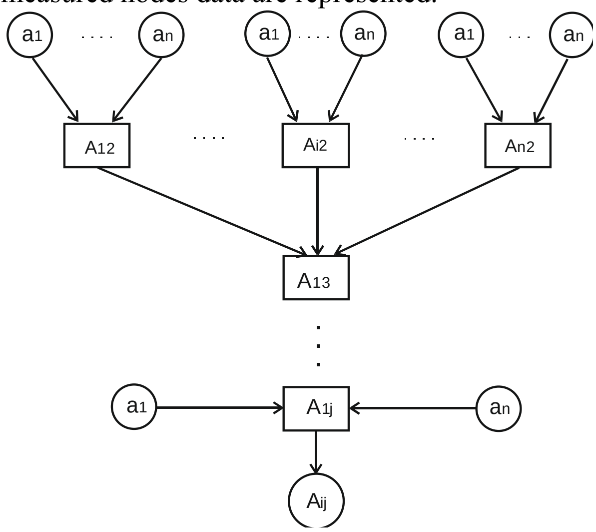
$$A_{ij} = \sum_{i=1}^{n} a_{ij} \cdot B_{ij} (\mathrm{mod} P_{ij}), \quad (3)$$

where a_{ij} – data of sensor, B_{ij} – orthogonal or bases, $P_{ij} = \prod_{i=1}^{n} p_i$, p_i – coprime numbers, n – a number of modules, $i = \overline{1, n}$, j – level number.

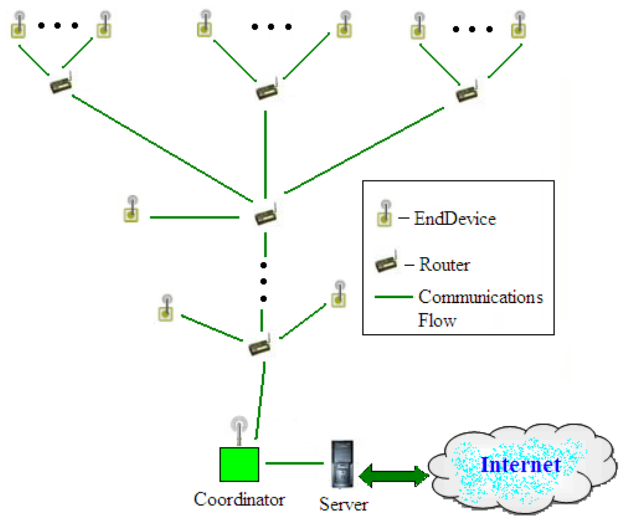
$$B_{ij} = \frac{P_{ij}}{p_i} \cdot \delta_i \equiv 1 (\mathrm{mod}\, p_i), \quad (4)$$

where $0 < \delta_i < p_i$ – a weight of the orthogonal element.

In the blocks A_{12}, A_{i2}, A_{n2}, data $(a_1, \ldots, a_n)$ of upper level nodes associates according to the formula (3) (Fig. 6 a). In the block A_{13} data from the previous level (blocks A_{12}, A_{i2}, A_{n2}) are associated and etc. As a result of multilevel coding we get message in weighted (number) system in which measured nodes data are represented.



a)



b)

Fig.6 – Multilevel coding of sensors data: a) block diagram; b) functional diagram.

Decoding is running via a sequential operation residue of relevant modules:

$$A_{ij-1} = A_{ij} (\bmod P_{ij-1});$$
$$A_{ij-2} = A_{ij-1} (\bmod P_{ij-2}); \quad (5)$$
$$\dots$$
$$A_{i1} = A_{i2} (\bmod P_{i1}).$$

Let's consider the example of the data integration of three nodes A_1, A_2, A_3 (Fig. 7). Let assume that nodes generate the information in the range: $A_1 \in \{0, 6\}$, $A_2 \in \{0, 10\}$, $A_3 \in \{0, 12\}$, according to the condition (2) we choose coprime modulus: $p_1 = 7$, $p_2 = 11$, $p_3 = 13$ and the nodes value $a_1 = 3$, $a_2 = 5$, $a_3 = 9$. According to the formula (4) we calculate base numbers: $B_1 = 715$, $B_2 = 364$, $B_3 = 924$. The result of calculation for the A_{12} by formula (3) is equal to: $a_{12} = 296$. The value a_{12} is transmitted to server by communication channel.

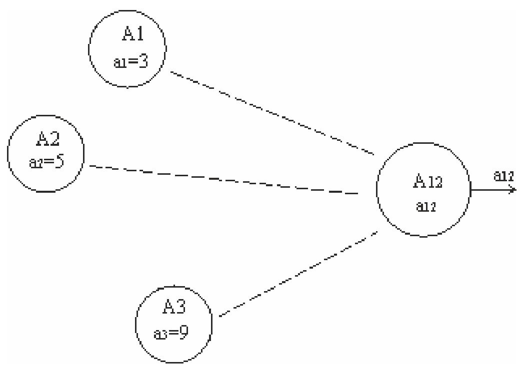


Fig.7 – Data integration on the on basis of RNS

Such approach allows integrate data with different digit capacity and there is no necessity to append node address, because for each node is assigned the unique module of Residue Number System, which performs an address functions.

Note growing the frame size increases the network capacity only in a case of network reliable operation (data not distorted neither lost) (see Fig.4). Otherwise increasing the size of the packet may cause bandwidth decreasing since the network retransmits the lost packets.

4. THE ERROR DETECTION

The wireless networks are characterized by high bit error rate (BER) because of electromagnetic obstacles influence in comparison with cable network. For WSN the typical values of BER are equal to $10^{-4} \div 10^{-6}$ [11].

In the IEEE 802.15.4 standard Cyclic Redundancy Check Codes are used for error detection. The polynome $G_{16}(x) = x^{16} + x^{12} + x^5 + 1$ provides the detection of one-multiple error with probability 100%, another errors number – with probability $P = (1 - 2^{-n})$, where n – is the number of digits of checksum [10].

In WSN after error detection data packet retransmission is executed. That is results to decrease of useful channel capacity and to increase of energy consumption.

We can increase useful channel capacity of wireless network by implementation of error-correcting codes. The use of error-correcting codes reduces the number of packet retransmissions, which were garbled. In the work the algorithms for the error detection and error correction on the basis of RNS correcting code is elaborated. In this algorithm correcting code of RNS with two check basis (see Fig.7).

To investigate the RNS's codes redundancy let's consider a system with bases $p_1, p_2, \dots, p_i, \dots, p_n$ and a range $M = p_1 \cdot p_2 \cdot \dots \cdot p_n$, and call the range M as a working range. Moreover let's introduce a basis p_{n+1}, p_{n+2} which are coprime with any of the accepted basis and let's present numbers in the system with basis $n+1$, $n+2$. It means that we will transfer numbers and make operations at numbers (which are located in a range $[0, M)$) in wider range $[0, P)$ where $P = M \cdot p_{n+1} \cdot p_{n+2}$. Error detection and correction occurs following algorithm (Fig.8). After bases introduction (block 1) and message receiving (block 2) total range $P = \prod_{i=1}^{n+2} p_i$ and operating range $M = \prod_{i=1}^{n} p_i$ are calculated (block 3).

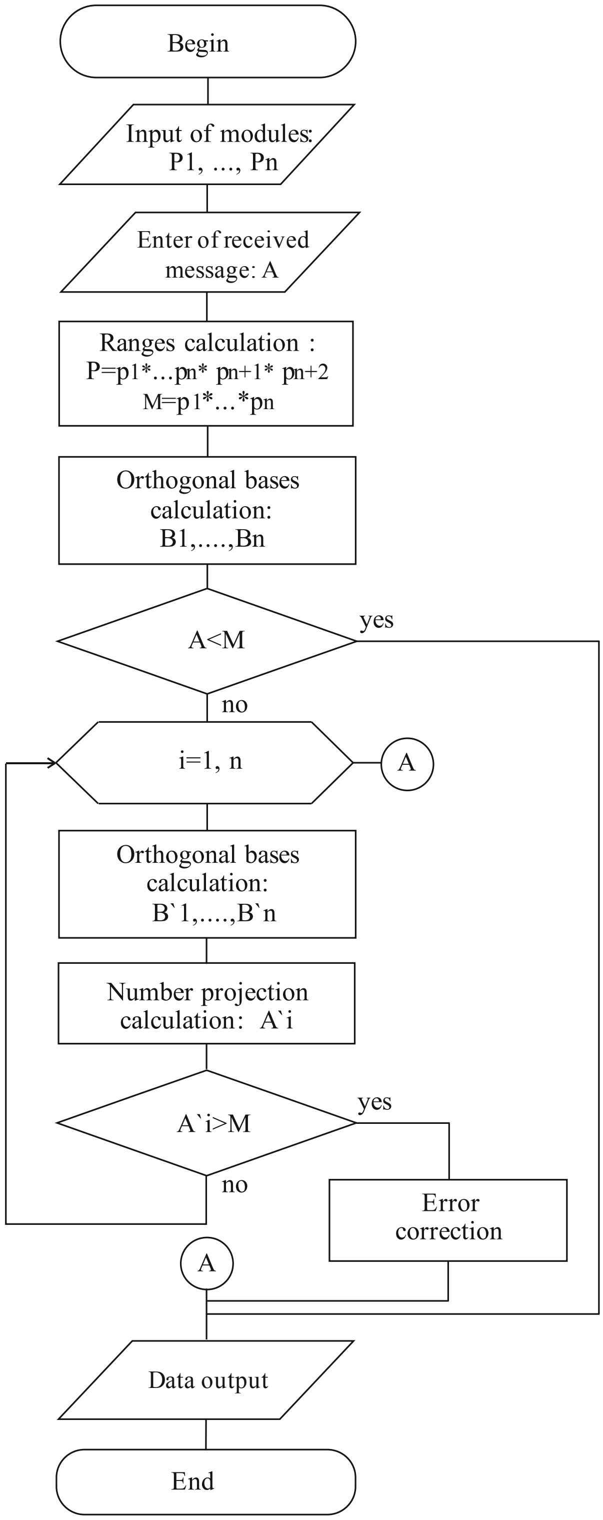


Fig. 8 – Block diagram of the error detection and correction algorithm in RNS

The orthonormal bases are calculated by the formula (4). In the block 5 (see Fig.8) a received message $\boldsymbol{A}$ is compared with the operating range M: if A<M so there is no errors in the received message, and calculations finish by the results output. In another case the serial calculation of the orthonormal bases is performed (block 7) and calculation of the number projection on every basis (block 8). Herewith number projection $\boldsymbol{A_i'}$ is calculated by strikeout of the $\boldsymbol{A}$ $\boldsymbol{a_i}$ digit. If the number projection $\boldsymbol{A'_i}$ is greater than operating range M (block 9), the next basis is verified (blocks 6 – 9), otherwise there is error on this basis, correction of which is performed in block 10 by the formula [12]

$$a_i = \tilde{a}_i + \left[\frac{p_i(1+p_{n+1})}{p_{n+1}} - \frac{\tilde{A}}{B_i}\right],$$

where $\tilde{a}_i$ – is the value of erroneous digit; $\tilde{A}$ – is received number projection.

After error correction (block 10) the results of processing come to the block 11.

Let's consider an example of the use of extended modules system. For the data received from the blocks $A1$, $A2$, $A3$ we extend the range of data representation with the use of modules $p4$, $p5$ in the block A_{12} (Fig.9) to provide opportunity of the error detection and error correction. In this case we obtain

$$a_4 = a_{12}(mod\ p_4);$$

$$a_5 = a_{12}(mod\ p_5).$$

Thereafter, the values $a_1, \ldots, a_5$ integrate according to the formula (3).

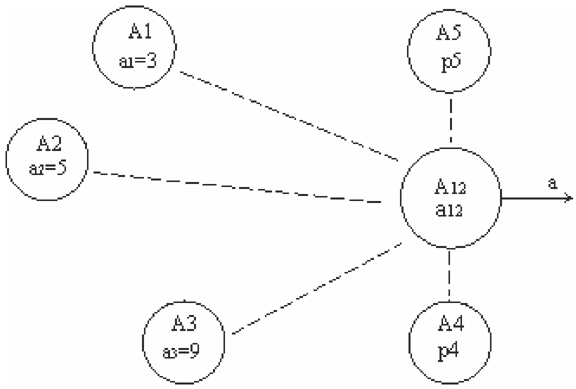


Fig.9 – The integration of data with the correcting moduli

In the receiving side (server) received data are checked for errors and their correction according to algorithm (see Fig.8). For the decoding, decoder must know moduli, which were used in coding process. So, data area of protocol contains data and the numbers of moduli N_M1…N_Mn (Fig.10).

N_M1	N_M2	…	N_Mn	Data

Fig. 10 – The structure of data area of communications protocol

The number of modulo is used for the identification of sensor, which transmits data.

As a result of received data repeated division on coprime moduli RNS we obtain initial data of nodes.

It is known, that numerical system in residual classes gives opportunity of the use of singular noise combating code for correction of errors, which appear in communication channels in time of data transmission and in information system during data processing [11].

RNS codes universality is explained not only by high correcting potential and group error resistance, but adaptive changes of correcting characteristics without change of coding method.

5. THE EXPERIMENTAL RESEARCH

Let's consider the useful channel capacity when we use the RNS error-correcting codes with two check modules. For the maximum length frames (104 – 2=102 bytes, check modules occupy 2 bytes) the useful channel capacity is equal to $C_p = m_2 \cdot (d_2 - 2) = 200{,}7$ Kbit/s.

So, the use of the RNS error-correcting codes with two check modules provides error correction by any module and the useful channel capacity is 200 Kbit/s.

Let's calculate useful channel capacity for different error probability means:

$$C_p = \frac{m \cdot L}{1 + P_b \cdot L},$$

where m – is the number of the frames per second; L – is the length of data area; Pb – is the error probability.

In the Fig. 11 the results of calculation of the useful channel capacity with different bit error probabilities are showed.

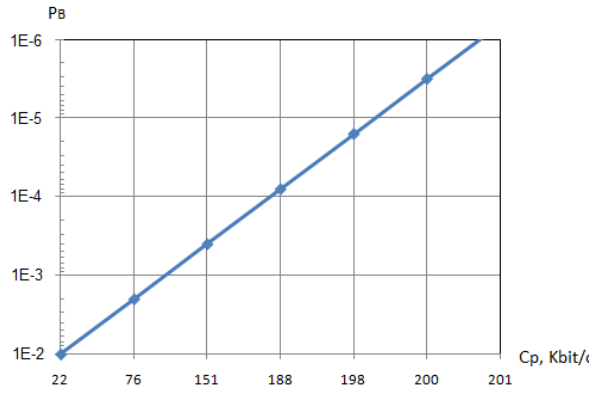


Fig. 11 –Dependence of useful channel capacity on errors probability for the maximum data block size (104 bytes)

Consequently, if the error probability in channel more than 10^{-5} the use of error-correcting codes, particularly RNS error-correcting codes, is expediency (see Fig. 10). If the error probability is 10^{-3} the useful channel capacity reduces in 2 times as shown in Fig. 10.

Thus the proposed approach allows reducing the overhead number as well as increasing the effective capacity of data transmission protocols significantly Moreover we provide the errors detection and correction implementing data coding by RNS transformation.

Taking into account the results above we plan to explore in future the optimal size of data packet for which the network capacity will reach the maximum value at different levels of a noise.

6. CONCLUSIONS

A proposed multilevel nonlinear method of sensors data coding allows to increase the useful capacity of the data transmission protocols for Wireless Sensor Networks in 3 – 5 times by the integration of sensors data with different digits capacity and reducing the transmissions number.

The experimental researches of the useful channel capacity depending on bit error probability with the use of RNS error-correcting codes with two check modules confirmed that the error-correcting codes application is reasonable in a case if the bit error probability exceeds 10^{-5}.

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Ghannam Aljabari, Evren Eren
VIRTUAL WLAN: EXTENSION OF WIRELESS NETWORKING INTO VIRTUALIZED ENVIRONMENTS

In wired Ethernet networks (IEEE 802.3), a physical network interface can be connected to different network segments or shared among multiple virtual machines. In wireless LAN (IEEE 802.11) sharing a wireless network interface is recognized to be a difficult task. However, virtualization can solve this problem. In this paper we will introduce a software platform for hosting multiple virtual wireless networks over a shared physical infrastructure by means of open source virtualization techniques. We present the design, implementation, and performance testing of this platform. Results have shown that the hosting platform can extend wireless networking into virtualized environments without compromising the performance, isolation, or wireless LAN security mechanisms.

Ghannam Aljabari, Evren Eren
ВІРТУАЛЬНІ WLAN: ПОШИРЕННЯ БЕЗПРОВІДНИХ МЕРЕЖ У ВІРТУАЛЬНИХ СЕРЕДОВИЩАХ

У провідних мережах Ethernet стандарту IEEE 802.3 фізичний мережевий інтерфейс може бути під'єднаний до різних сегментів мережі або розподілений між багатьма віртуальними машинами. У безпровідних LAN (IEEE 802.11) розділення мережевого інтерфейсу є складною задачею. Однак, віртуалізація може вирішити цю проблему. У статті представлено програмну платформу для розміщення багатьох віртуальних мереж на фізично розділеній інфраструктурі, використовуючи технології віртуалізації, що розповсюджуються безплатно. В цій статті розглядається проектування, реалізація та тестування даної платформи. За результатами досліджень хостингова платформа може розширити безпровідні мережі у віртуальних середовищах без погіршення експлуатаційних характеристик, автономності або механізмів безпеки локальної обчислювальної мережі.

Ghannam Aljabari, Evren Eren
ВИРТУАЛЬНЫЕ WLAN: РАСПРОСТРАНЕНИЕ БЕСПРОВОДНЫХ СЕТЕЙ В ВИРТУАЛЬНЫХ СРЕДАХ

В проводных сетях Ethernet стандарта IEEE 802.3 физический сетевой интерфейс может быть подключен к различным сегментам сети или распределен между многими виртуальными машинами. В беспроводных LAN (IEEE 802.11) разделение сетевого интерфейса является сложной задачей. Однако, виртуализация может решить эту проблему. В статье представлены программную платформу для размещения многих виртуальных сетей на физически разделенной инфраструктуре, используя технологии виртуализации, распространяемые бесплатно. В этой статье рассматривается проектирование, реализация и тестирование данной платформы. По результатам исследований хостинговая платформа может расширить беспроводные сети в виртуальных средах без ухудшения эксплуатационных характеристик, автономности или механизмов безопасности локальной вычислительной сети.

Andreas Fink, Helmut Beikirch
HYBRID INDOOR TRACKING OF HUMANS IN HAZARDOUS ENVIRONMENTS

The reliable tracking of humans and materials in indoor scenarios is an ongoing research issue. For example, the monitoring of humans in partially hazardous environments – like the surroundings of an underground longwall mining infrastructure – is crucial to save human lives. A centroid location estimation technique based on received signal strength (RSS) readings offers a well known and low-cost tracking solution in such a rough environment where many other systems with optical, magnetical or ultrasound sensors fail. Due to signal fading the RSS values alone cannot ensure a precise tracking. The sensor fusion of the RSS-based localization with an inertial navigation system (INS) leads to a more precise tracking. The long-term stability of the RSS-based localization and the good short-term accuracy of the INS are combined using a Kalman filter. The experimental results on a motion test track show that a tracking of humans in multipath environments is possible with low infrastructural costs.

Andreas Fink, Helmut Beikirch

ГІБРИДНА СИСТЕМА ДЛЯ ВІДСЛІДКОВУВАННЯ ЛЮДЕЙ У НЕБЕЗПЕЧНИХ СЕРЕДОВИЩАХ

Надійне відслідковування людей та предметів всередині приміщень є актуальною задачею. Наприклад, спостереження за людьми у небезпечних середовищах, таких як підземні тунелі для видобутку корисних копалин, є критичним для порятунку людського життя. Технологія приблизної оцінки центру розташування, що базується на таблицях потужності отриманого сигналу (RSS), пропонує добре відоме і недороге рішення для відслідковування у подібних середовищах, де використання систем з оптичними, магнітними та ультразвуковими сенсорами є неможливим. Але значення RSS не можуть забезпечити точного відслідковування, оскільки відбувається послаблення сигналу. Об'єднання даних RSS-базованої локалізації та інерційної навігаційної системи (INS) підвищує точність відслідковування. Поєднання довготривалої стабільності RSS-базованої локалізації та високої короткотермінової точності INS відбувається за допомогою фільтра Кальмана. Результати експериментальних досліджень траєкторій тестових маршрутів підтверджують можливість відслідковування людини в багатошляхових середовищах з низькими інфраструктурними затратами.

Andreas Fink, Helmut Beikirch

ГИБРИДНАЯ СИСТЕМА ДЛЯ ОТСЛЕЖИВАНИЯ ЛЮДЕЙ В ОПАСНЫХ СРЕДАХ

Надежное отслеживание людей и предметов внутри помещений является актуальной задачей. Например, наблюдение за людьми в опасных средах, таких как подземные тоннели для добычи полезных ископаемых, является критическим для спасения человеческой жизни. Технология приблизительной оценки центра расположения, основанный на таблицах мощности полученного сигнала (RSS), предлагает хорошо известное и недорогое решение для отслеживания в подобных средах, где использование систем с оптическими, магнитными и ультразвуковыми сенсорами невозможно. Но значения RSS не могут обеспечить точного отслеживания, поскольку происходит ослабление сигнала. Объединение данных RSS-базированной локализации и инерционной навигационной системы (INS) повышает точность отслеживания. Сочетание долговременной стабильности RSS-базированной локализации и высокой краткосрочной точности INS происходит с помощью фильтра Кальмана. Результаты экспериментальных исследований траекторий тестовых маршрутов подтверждают возможность отслеживания человека в многопутевых средах с низкими инфраструктурными затратами.

Sebastian J.F. Fudickar, Bettina Schnor

AUTOMATED NETWORK PROTOCOL EVALUATION – THE POTSDAM WIRELESS TESTBED

The Potsdam Wireless Testbed supports validation and evaluation of Wi-Fi radio stacks and wireless applications in environments with heterogeneous hardware. In contrast to simulators, wireless testbeds support the network stack validation with specific radio chipsets and radio signal propagations. Furthermore, wireless testbeds unburden programmers from manually updating software on nodes. Scheduled test-runs are executed automatically for a defined duration including compilation and deployment of the protocols and measurement scripts as well as collection of measurement results and log files. The testbed supports heterogeneous processor architectures and radio chipsets via internal cross compilation. The developer can overview the visualized results of its validation and therefore can focus on the code and the results. Next to the support of several device and processor architectures, the Potsdam Wireless Testbed is intended to support additional radio frequency ranges as well as mobile device.

Sebastian J.F. Fudickar, Bettina Schnor

АВТОМАТИЗОВАНА ОЦІНКА МЕРЕЖЕВИХ ПРОТОКОЛІВ – ПОТСДАМСЬКИЙ БЕЗПРОВІДНИЙ ВИПРОБУВАЛЬНИЙ СТЕНД

Потсдамський безпровідний випробувальний стенд проводить перевірку та оцінку Wi-Fi радіо-стеків та безпровідних прикладних програм в середовищах з різноманітним апаратним забезпеченням. На відміну від симуляторів, безпровідні стенди підтримують перевірку мережевих стеків з використанням радіо–чіпів та поширенням радіо-сигналу. Крім того, безпровідні стенди полегшують роботу програмістів, звільняючи їх від необхідності оновлення програмного забезпечення у вузлах вручну. Заплановані тестові завантаження виконуються автоматично для певного періоду часу, який включає компіляцію і введення в дію протоколів та файлів вимірювань, так само як і збір результатів вимірювання та файлів протоколів. Тестовий стенд підтримує різні архітектури процесорів та набори радіо-мікросхем за допомогою зовнішньої крос-компіляції. Розробник може переглянути візуалізовані результати та їхню перевірку, а отже, зосередитись на програмному коді та результатах. Надалі, разом з підтримкою декількох архітектур пристроїв та процесорів, Потсдамський безпровідний випробувальний стенд буде підтримувати діапазони додаткових радіочастот, так само як і мобільні пристрої.

Sebastian J.F. Fudickar, Bettina Schnor
АВТОМАТИЗИРОВАННАЯ ОЦЕНКА СЕТЕВЫХ ПРОТОКОЛОВ – ПОТСДАМСКИЙ БЕСПРОВОДНЫЙ ИСПЫТАТЕЛЬНЫЙ СТЕНД

Потсдамский беспроводный испытательный стенд проводит проверку и оценку Wi-Fi радио-стеков и беспроводных приложений в средах с различным аппаратным обеспечением. В отличии от симуляторов, беспроводные стенды поддерживают проверку сетевых стеков с использованием радио-чипов и распространением радио-сигнала. Кроме того, беспроводные стенды облегчают работу программистов, освобождая их от необходимости обновления программного обеспечения в узлах вручную. Запланированные тестовые загрузки выполняются автоматически для определенного периода времени, который включает компиляцию и введения в действие протоколов и файлов измерений, так же как и сбор результатов измерений и файлов протоколов. Тестовый стенд поддерживает различные архитектуры процессоров и наборы радио-микросхем с помощью внешней кросс-компиляции. Разработчик может просмотреть визуализированные результаты и их проверку, а значит, сосредоточиться на коде и результатах. В дальнейшем, наряду с поддержкой нескольких архитектур устройств и процессоров, Потсдамский беспроводной испытательный стенд будет поддерживать диапазоны дополнительных радиочастот, так же как и мобильные устройства.

Syuzanna Hakobyan, Jan-Philipp Kohlbrecher, Johannes Pickert, Uwe Grossmann
PROVIDING HOUSEHOLD CUSTOMERS WITH SMART METERING DATA ON MOBILE DEVICES

One option for reducing carbon dioxide emissions is the future use of renewable instead of fossil resources. A consistent prerequisite is the optimization of household customers' energy consumption behavior. The suitable visualization of energy data, corresponding costs and tariff information on mobile devices is essential to achieve this goal. Energy data are acquired by a smart meter and transferred over wireless networks to a mobile device to provide the customer with relevant information about his current energy usage. The household customer is hence enabled to manage his energy consumption, to hold the optimal load and meet the optimum price. Suitable typs of visualization, specific for different tariffs, are identified and presented together with necessary technologies and methods for communication and data access and delivery.

Syuzanna Hakobyan, Jan-Philipp Kohlbrecher, Johannes Pickert, Uwe Grossmann
ЗАБЕЗПЕЧЕННЯ ПОБУТОВИХ КОРИСТУВАЧІВ ІНТЕЛЕКТУАЛЬНИМИ ВИМІРЮВАЧАМИ ДАНИХ НА МОБІЛЬНИХ ПРИСТРОЯХ

Одним з варіантів скорочення викидів вуглекислого газу є використання відновлювальних джерел енергії замість корисних копалин. Водночас, інший можливий варіант - це оптимізація споживання енергії побутовими користувачами. Необхідними умовами для досягнення цієї мети є зручна візуалізація енергетичних показників, відповідної вартості та тарифної інформації на мобільному пристрої. Енергетичні показники отримуються інтелектуальним лічильником і передаються через безпровідну мережу на мобільній пристрій, щоб повідомити користувача про поточні витрати електроенергії. Отже, побутовий клієнт отримує можливість керувати споживанням енергії, щоб отримати оптимальне навантаження за прийнятною ціною. У статті визначені та представлені зручні типи візуалізації для різних тарифів, а також необхідні технології та методи зв'язку, доставки та доступу до даних.

Syuzanna Hakobyan, Jan-Philipp Kohlbrecher, Johannes Pickert, Uwe Grossmann
ОБЕСПЕЧЕНИЕ БЫТОВЫХ ПОЛЬЗОВАТЕЛЕЙ ИНТЕЛЛЕКТУАЛЬНЫМИ ИЗМЕРИТЕЛЯМИ ДАННЫХ НА МОБИЛЬНЫХ УСТРОЙСТВАХ

Одним из вариантов сокращения выбросов углекислого газа является использование возобновляемых источников энергии вместо полезных ископаемых. Вместе с тем, другой возможный вариант - это оптимизация потребления энергии бытовыми пользователями. Необходимыми условиями для достижения этой цели является удобная визуализация энергетических показателей, соответствующей стоимости и тарифной информации на мобильном устройстве. Интеллектуальный счетчик получает показатели энергопотребления и передает через беспроводную сеть на мобильное устройство, чтобы уведомить пользователя о текущих расходах электроэнергии. Итак, бытовой клиент получает возможность управлять потреблением энергии, чтобы получить оптимальную нагрузку по приемлемой цене. В статье определены и представлены удобные типы визуализации для различных тарифов, а также необходимые технологии и методы связи, доставки и доступа к данным.

Stephan Bergemann, Eileen Kuehn, Jens Reinhardt, Jürgen Sieck

RFID BASED APPLICATIONS IN CULTURE, MEDIA AND CREATIVE INDUSTRIES

This article presents two different approaches to visualise information from culture, media and creative industries by using RFID based tracking and identification. Besides the required RFID backend, the paper also introduces the information system built on top of the backend. The first approach is based on passive RFID whereas the second uses active RFID. In particular, the differences in the processing of system events, delivery of needed information and the implemented infrastructure will be discussed and evaluated.

Stephan Bergemann, Eileen Kuehn, Jens Reinhardt, Jürgen Sieck

ЗАСТОСУВАННЯ RFID-ТЕХНОЛОГІЙ У КУЛЬТУРНІЙ СФЕРІ, ЗАСОБАХ МАСОВОЇ ІНФОРМАЦІЇ ТА ТВОРЧІЙ ІНДУСТРІЇ

У цій статті розглянуто два різних підходи до візуалізації інформації в культурній сфері, ЗМІ та творчій індустрії з використанням RFID (Radio Frequency IDentification) – відслідковування та ідентифікації. У статті представлені внутрішні інтерфейси RFID, а також інформаційна система на їхній основі. У першому дослідженні використані пасивні RFID, у другому – активні. Зокрема, в статті обговорюються та оцінюються відмінності у обробці системних подій, доставці потрібної інформації та реалізована інфраструктура.

Stephan Bergemann, Eileen Kuehn, Jens Reinhardt, Jürgen Sieck

ПРИМЕНЕНИЕ RFID-ТЕХНОЛОГИЙ В КУЛЬТУРНОЙ СФЕРЕ, СРЕДСТВАХ МАССОВОЙ ИНФОРМАЦИИ И ТВОРЧЕСКОЙ ИНДУСТРИИ

В этой статье рассмотрены два различных подхода к визуализации информации в культурной сфере, СМИ и творческой индустрии с использованием RFID (Radio Frequency IDentification) - отслеживание и идентификации. В статье представлены внутренние интерфейсы RFID, а также информационная система на их основе. В первом исследовании использованы пассивные RFID, во втором - активные. В частности, в статье обсуждаются и оцениваются различия в обработке системных событий, доставке нужной информации и реализована инфраструктура.

Alexander S. Galov, Alex P. Moschevikin, Alexei V. Soloviev

REDUCING RADIO BANDWIDTH LOAD IN NANOLOC-BASED WIRELESS NETWORKS THROUGH SELECTING APPROPRIATE SUBSET OF BASE STATIONS FOR RANGING

In wireless sensor networks based on nanoLOC^{TM} standard and using server-centric control, the overall performance of radio segment and location accuracy depends amongst other on the efficiency of the location engine. The efficiency may be increased by selecting an appropriate subset of base stations for ranging. This paper describes the experiments dealing with this problem, and discusses the ways of saving radio bandwidth.

Олександр Галов, Олексій Мощевікін, Олексій Соловйов

ЗМЕНШЕННЯ НАВАНТАЖЕННЯ НА СМУГУ ПРОПУСКАННЯ РАДІОЧАСТОТ У БЕЗПРОВІДНИХ МЕРЕЖАХ НА ОСНОВІ NANOLOC, ШЛЯХОМ ВИБОРУ ПІДМНОЖИНИ БАЗОВИХ СТАНЦІЙ ДЛЯ РАНЖУВАННЯ

У безпровідних сенсорних мережах, що базуються на стандарті nanoLOC^{TM} і використовують управління з центрального серверу, загальна продуктивність радіо-сегменту та точність місце розташування залежить, серед іншого, від ефективності пошукової підсистеми. Ефективність може бути підвищена за рахунок вибору відповідного набору базових станцій для ранжирування. Ця стаття описує експерименти, пов'язані з даною проблемою та можливі способи економії пропускної здатності.

Александр Галов, Алексей Мощевикин, Алексей Соловьев

УМЕНЬШЕНИЕ НАГРУЗКИ НА ПОЛОСУ ПРОПУСКАНИЯ РАДИОЧАСТОТ В БЕСПРОВОДНЫХ СЕТЯХ НА ОСНОВЕ NANOLOC, ПУТЕМ ВЫБОРА ПОДМНОЖЕСТВА БАЗОВЫХ СТАНЦИЙ ДЛЯ РАНЖИРОВАНИЯ

В беспроводных сенсорных сетях, основанных на стандарте nanoLOC^{TM} и использующих управление с центрального сервера, общая производительность радио-сегмента и точность местоположения зависит, кроме всего, от эффективности поисковой подсистемы. Эффективность может быть повышена за счет выбора соответствующего набора базовых станций для ранжирования. Эта статья описывает эксперименты, связанные с данной проблемой и возможные способы экономии пропускной способности.

Axel Sikora, Nathan Braun, Steffen Jaeckel, Daniel Jaeckle

GATEWAY ARCHITECTURES FOR HOME CARE APPLICATIONS USING WIRELESS SENSOR NETWORKS

Home Care Applications and Ambient Assisted Living become increasingly attractive. This is caused as well by market pull, as the number of elderly people grows monotonously in highly-developed countries, as well as by technology push, as technological advances and attractive products pave the way to economically advantageous offerings. However, a significant number of challenges remain for real-life applications. Those include the lack of sufficiently standardized and interoperable solutions and thus, the necessity of gateways for integrated solutions, restrictions of the energy budgets, and scalability of solutions with regard to cost and network size.

This paper presents the experience from the inCASA project (Integrated Network for Completely Assisted Senior Citizen's Autonomy), where architectures for heterogeneous physical and logical communication flow are examined.

Axel Sikora, Nathan Braun, Steffen Jaeckel, Daniel Jaeckle

АРХІТЕКТУРА МІЖМЕРЕЖЕВОГО ШЛЮЗУ ДЛЯ ПРИКЛАДНИХ СИСТЕМ ДОМАШНЬОГО ДОГЛЯДУ З ВИКОРИСТАННЯМ БЕЗПРОВІДНИХ СЕНСОРНИХ МЕРЕЖ

Прикладні системи домашнього догляду та проживання з доглядом набувають все більшої популярності. Це зумовлено як привабливістю ринку, оскільки кількість літніх людей у розвинутих країнах постійно зростає, так і технологічним поштовхом, тому що технічний прогрес і привабливі рішення сприяють появі економічно вигідних пропозицій. Однак, для реальних застосувань існує велика кількість складних задач. Вони включають недостатню стандартизацію рішень, а також, обмежену можливість взаємодії з іншими мережами, а отже, необхідність міжмережевих шлюзів для інтегрованих рішень, обмеження енергетичного балансу, масштабованість рішень, в залежності від вартості та розмірів мережі.

У цій статті представлені результати проекту inCASA (Інтегрована мережа для автономності літніх громадян, що потребують постійного догляду), зокрема, розглянуті архітектури для гетерогенних фізичних і логічних інформаційних потоків.

Axel Sikora, Nathan Braun, Steffen Jaeckel, Daniel Jaeckle

АРХИТЕКТУРА МЕЖСЕТЕВОГО ШЛЮЗА ДЛЯ ПРИКЛАДНЫХ СИСТЕМ ДОМАШНЕГО УХОДА С ИСПОЛЬЗОВАНИЕМ БЕСПРОВОДНЫХ СЕНСОРНЫХ СЕТЕЙ

Прикладные системы домашнего ухода и проживание с уходом приобретают все большую популярность. Это обусловлено как привлекательностью рынка, поскольку число пожилых людей в развитых странах постоянно растет, так и технологическим толчком, потому что технический прогресс и привлекательные решения способствуют появлению экономически выгодных предложений. Однако для реальных приложений существует множество сложных задач. Они включают недостаточную стандартизацию решений, а также ограниченную возможность взаимодействия с другими сетями, а следовательно, необходимость межсетевых шлюзов для интегрированных решений, ограничения энергетического баланса, масштабируемость решений, в зависимости от стоимости и размеров сети.

В этой статье представлены результаты проекта inCASA (Интегрированная сеть для автономности пожилых граждан, требующих постоянного ухода), в частности, рассмотрены архитектуры для гетерогенных физических и логических информационных потоков.

Mircea Ionel Strutu, Dan Popescu

INDOOR MONITORING APPLICATIONS USING FIXED AND MOBILE WIRELESS SENSORS

This paper proposes the idea of a wireless sensor network with applicability in monitoring systems. The goal of the project is to build a monitoring system capable of data gathering which can benefit from both characteristics of fixed and mobile nodes. To become flexible, the mobile node has a modular structure with four levels. The flexibility offered by the mobile nodes increases the performance of the entire data acquisition system. These act as autonomous devices that cooperatively monitor physical or environmental conditions. In order to implement the data acquisition and communication functions, the solution we agreed on has been to use the MTS400 sensor board. Mobile nodes communicate to a central node individual data and statistical indicators over a period. The proposed energy-aware architecture was tested and validated in an indoor experiment.

Mircea Ionel Strutu, Dan Popescu

МОНІТОРИНГ ПРИМІЩЕНЬ З ВИКОРИСТАННЯМ НЕРУХОМИХ ТА МОБІЛЬНИХ БЕЗПРОВІДНИХ СЕНСОРІВ

У цій статті запропоновано ідею безпровідної сенсорної мережі, яку можна використовувати у системах моніторингу. Мета проекту – створення системи моніторингу, що здатна збирати дані як від нерухомих, так і від мобільних вузлів. Для забезпечення адаптивності мобільний вузол має чотирирівневу модульну структуру. Гнучкість мобільних вузлів збільшує ефективність системи збору даних в цілому. Вони працюють як автономні пристрої, що спільно контролюють фізичні параметри або характеристики середовища. Для реалізації збору даних та комунікаційних функцій використано безпровідний сенсорний вузол MTS400. Мобільні вузли передають до центрального вузла персональні дані та статистичні показники за певний період. Запропонована енерго-ефективна архітектура була протестована та перевірена на достовірність у приміщенні.

Mircea Ionel Strutu, Dan Popescu

МОНИТОРИНГ ПОМЕЩЕНИЙ С ИСПОЛЬЗОВАНИЕМ НЕПОДВИЖНЫХ И МОБИЛЬНЫХ БЕСПРОВОДНЫХ СЕНСОРОВ

В этой статье предложена идея беспроводной сенсорной сети, которую можно использовать в системах мониторинга. Цель проекта - создание системы мониторинга, способной собирать данные как от неподвижных, так и от мобильных узлов. Для обеспечения адаптивности мобильный узел имеет четырехуровневую модульную структуру. Гибкость мобильных узлов увеличивает эффективность системы сбора данных в целом. Они работают как автономные устройства, совместно контролируют физические параметры или характеристики среды. Для реализации сбора данных и коммуникационных функций использован беспроводный сенсорный узел MTS400. Мобильные узлы передают к центральному узлу персональные данные и статистические показатели за определенный период. Предложенная энерго-эффективная архитектура была протестирована и проверена на достоверность в помещении.

Vasyl Yatskiv, Su Jun, Nataliya Yatskiv, Anatoly Sachenko

NONLINEAR DATA CODING IN WIRELESS SENSOR NETWORKS

A proposed nonlinear method of sensors data coding allows to increase the useful capacity of the data transmission protocols for Wireless Sensor Networks in 3 - 5 times by the integration of sensors data with different digits capacity and reducing the transmissions number.

Василь Яцків, Су Дзюнь, Наталія Яцків, Анатолій Саченко

НЕЛІНІЙНЕ КОДУВАННЯ ДАНИХ В БЕЗПРОВІДНИХ СЕНСОРНИХ МЕРЕЖАХ

Запропонований нелінійний метод кодування даних сенсорів дозволяє збільшити корисну пропускну здатність протоколів передачі даних безпровідних сенсорних мереж в 3-5 разів за рахунок об'єднання даних сенсорів з різною розрядністю і скорочення кількості передач.

Василий Яцкив, Су Дзюнь, Наталия Яцкив, Анатолий Саченко

НЕЛИНЕЙНОЕ КОДИРОВАНИЕ ДАННЫХ В БЕСПРОВОДНЫХ СЕНСОРНЫХ СЕТЯХ

Предложенный нелинейный метод кодирования данных сенсоров позволяет увеличить полезную пропускную способность протоколов передачи данных беспроводных сенсорных сетей в 3-5 раз за счет объединения данных сенсоров с различной разрядностью и сокращение количества передач.

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Тематика журналу:

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- Біо-інформатика
- Кластерні та паралельні обчислення, програмні засоби та середовище
- Обчислювальний інтелект
- Комп’ютерне та імітаційне моделювання
- Кібернетична безпека та захист від тероризму
- Обмін даними та організація мереж
- Видобування даних, бази знань та онтології
- Цифрова обробка сигналів
- Розподілені системи та дистанційне управління
- Освіта в комп’ютингу
- Високопродуктивні обчислення та ГРІД
- Обробка зображень та розпізнавання шаблонів
- Інтелектуальні робототехнічні системи
- Інтернет речей
- Стандартизація комп’ютерних систем
- Безпровідні системи

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- анализ последних исследований и публикаций, в которых начаты решения данной проблемы и на которые опирается автор, выделение нерешенных прежде частей общей проблемы, которым посвящается обозначенная статья;
- формулирование целей статьи (постановка задача);
- изложение основного материала исследования с полным обоснованием полученных научных результатов;
- выводы из данного исследования и перспективы дальнейших изысканий в данном направлении.

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(xiv) Издательство осуществляет окончательное форматирование текста в соответствии с требованиями печати.

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Тематика журнала:

- Алгоритмы и структуры данных
- Био-информатика
- Кластерные и параллельные вычисления, программные средства и среды
- Вычислительный интеллект
- Компьютерное и имитационное моделирование
- Кибернетическая безопасность и защита от терроризма
- Обмен данными и организация сетей
- Добыча данных, базы знаний и онтологии
- Цифровая обработка сигналов
- Распределенные системы и дистанционное управление
- Образование в компьютинге
- Высокопроизводительные вычисления и ГРИД
- Обработка изображений и распознавание шаблонов
- Интеллектуальные робототехнические системы
- Интернет вещей
- Стандартизация компьютерных систем
- Беспроводные системы