µSWN Interconnection to External Networks for Healthcare Applications

Agnius Liutkevicius[#], Arunas Vrubliauskas[#], Egidijus Kazanavicius[#], Aggeliki Prayati[*]

[#]Real Time Computing Systems Centre, Kaunas University of Technology, Kaunas, Lithuania

{agnius, aras, ekaza}@ifko.ktu.lt

[*]Industrial Systems Institute, Patras, Greece

prayati@isi.gr

Abstract— **As wireless sensor networks (WSNs) are adopted more and more in every day life applications, their interconnection to external networks and infrastructures become mandatory for increasing the usability and flexibility especially in healthcare application scenarios. This paper presents techniques, mechanisms and devices that provide the WSN under study the ability to connect to external networks in an efficient way transparently to the end user.**

I. Introduction

Most sensor network applications aim at monitoring or detecting phenomena i.e. health monitoring, office building environment control, wild-life habitat monitoring, forest fire detection, etc. By connecting the WSN to an existing network infrastructure such as the global Internet, a local-area network, or a private intranet, remote access to the sensor network can be achieved. The interconnection evaluation is based on criteria like energy efficiency, coverage, scalability, network connectivity, fault tolerance and network performance like end-to-end throughput and packet loss. Interconnection implementation also depends on application scenarios and end-user terminal devices, and as such may vary for mobile users (e.g. PDA) and standard PC users. Interconnection is provided on different architectural levels, namely devices, protocols, operating systems, middleware, the combination of which into one solid interconnection entity is a research challenge.

The gateway-based WSN interconnection to other networks is the most common way not only in healthcare applications, but in other fields as well, because it is most suitable for power-aware wireless sensor networks. The gateway-based approach allows developers to create custom WSN protocol with required characteristics, while multi-gateway architectures ensure high level of scalability, fault-tolerance and energy efficiency.

Several research projects [2]-[9] deal with different interconnection architectures including both single-gateway and multi-gateway. The main purpose of a gateway is to provide WSN network data to external applications and to support WSN network queries, configuration and management from external application side. The gateway is a crucial point in the WSN architecture, allowing to combine the WSN and its users with different end-user devices into one functional entity. A lot of effort is put nowadays to ensure WSN security, availability and operation in real-time, but there are also such important issues as WSN scalability and fault-tolerance.

A thorough study of existing WSN and external networks interconnection techniques [1] showed that the best interconnection solution in terms of energy efficiency, scalability, fault-tolerance and performance is a multi-gateway solution. Several alternative multi-gateway interconnection architectures have been investigated, including architecture using mobile sinks and architecture using multiple mote-gateways selecting the latter as the most suited interconnection solution in the context of health application scenarios.

This paper presents the developed µSWN and its external networks interconnection implementation for three healthcare application scenarios: surveillance, patient tracking and vital-sign monitoring. Our approach connects the WSN with external IP-based networks, eliminating the single point of failure problem in the gateway and notably increasing the WSN scalability and energy efficiency by using multiple mote-gateways and synchronizing vital-sign monitoring events among them.

II. µSWN Healthcare Application Scenarios

The WSN technology could potentially impact a number of healthcare applications, such as: medical treatment, pre- and post-hospital patient monitoring, people rescue, and early disease warning systems. In addition, WSNs can contribute to solving some important social problems, such as caretaking of the chronically ill, elderly people, and people with mental and physical disabilities. This will improve not only their quality of life, but also benefit society as a whole.

After reviewing a large variety of possible WSN application scenarios, three of the most demanding and thus most interesting as far as research is concerned, have been selected: *patient position tracking, sanatorium perimeter surveillance,* and *time-critical vital signs and environmental monitoring* with the prioritization of emergency notifications guaranteeing real-time data communication. These three application scenarios have been chosen as representative of

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the wide variety of existing and future WSN applications at the Versme sanatorium in Birstonas Municipality, Lithuania.

In each scenario, the WSN collects and analyzes data about the sanatorium patients, staff, and surroundings of Versme. The μSWN will provide the sanatorium staff with the precise position of residents and employees as well as patients vital signs to keep track of the health of sanatorium residents. When an incident is detected that needs special attention (e.g. patient experiencing problems with heart), notifications are sent to warn staff and/or patients via PDAs, mobile phones, or their smart bracelets. Staff and patients can then choose their course of action regarding the issue. Data are processed in real time in order for the system to be effective. This is essential so that actions can be taken immediately, in case of emergency. The staff responsible for the issue at hand will receive a warning in his/her PDA or mobile phone and can access to the information provided by the system.

III. μSWN INTERCONNECTION ARCHITECTURE

The gateway-based interconnection approach is better in terms of scalability, power efficiency and allows integrating custom made WSNs to external networks. The cluster-based topology is more power-efficient and scalable than other WSN architectures, providing better coverage and fault-tolerance. To best suit the application scenario requirements for energy efficiency, scalability, fault tolerance and network performance, the multi-gateway approach was chosen with gateways playing the role of cluster heads.

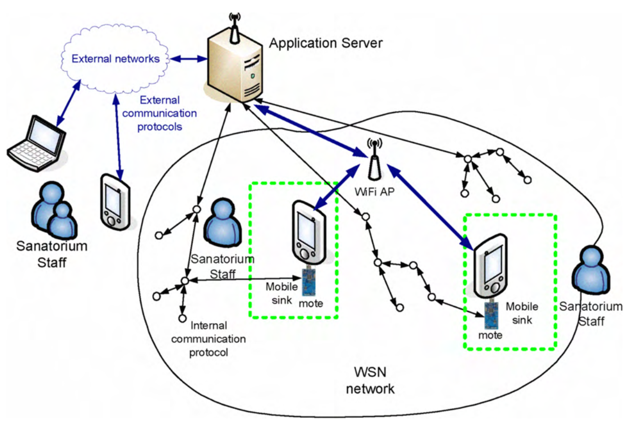

Fig. 1 WSN architecture using mobile sinks

Several alternative architectures were analysed: single-gateway architecture, architecture using mobile sinks (Fig. 1), architecture using mote-gateways (Fig. 2). The main idea of single-gateway architecture is to provide application-specific data from sensor nodes to the Application Server and then to the WSN users PDAs via Wireless LAN (WLAN) network. The main drawbacks of single-gateway architecture are low fault-tolerance due to the single point of failure at the gateway, and low scalability.

A more reliable and scalable solution is the use of multiple PDAs as mobile gateways to collect the data from nearby sensor nodes. Each PDA has a sink mote connected as shown in Fig. 1. However the architecture using mobile sinks has one major limitation related to gateway availability: if at some time there are no PDAs in the WSN, then data will be lost. The architecture using mote-gateways (Fig. 2) has the same advantages as architecture with mobile sinks, but in this case, the gateways are placed statically and have WLAN interface to communicate with the PDAs and the Application Server.

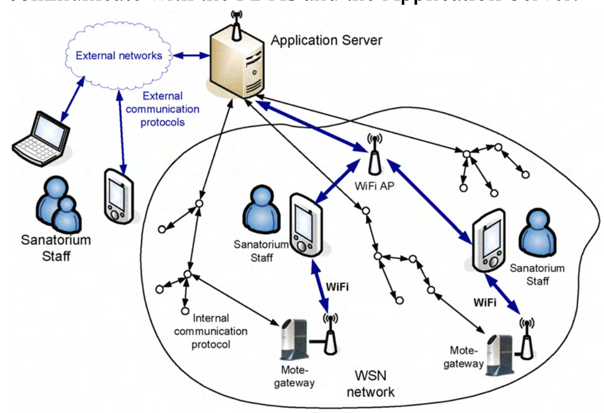

Fig. 2 WSN architecture using mote-gateways

This ensures that sensor network data is always collected at the gateways and forwarded to Application Server and PDAs. Scalability is achieved by placing new mote-gateways and forwarding collected sensor data via the WLAN to external applications. At the same time, if one of the gateway fails, the μSWN network protocol automatically routes the sensor network data to the nearest available gateway.

IV. μSWN GATEWAY ARCHITECTURE

The μSWN network architecture consists of two wireless networks (Fig. 3): the sensors network and the WLAN network. The sensor network communicates to external applications via mote-gateways, which are placed statically using optimal deployment scheme. The μSWN protocol assures that data from the μSWN node is sent to the nearest gateway. Each gateway has Web Services, which allow external applications to access the sensor data and other services provided by the μSWN. The external applications communicate with gateways using the WLAN support network and services accessed using the SOAP protocol. The responsibility of the Application Server is to provide μSWN network configuration services and tools, to store historical healthcare data collected from the sensors, to perform complex computations and data analysis, and to provide web applications to the LAN and Internet users.

μSWN Gateway hardware is a small embedded x86 based (AMD Geode LX800 500MHz CPU) computer that has three types of interfaces: USB-Serial interface, LAN interfaces and WLAN interface and Linux Ubuntu operating system. The μSWN sink mote is connected to the Gateway using USB-Serial interface. To support bidirectional event-based intercommunication between the sink mote and the gateway special software has been developed on both sides. On the Gateway side, multithreaded Gateway middleware is responsible for processing incoming sensor data from the sink mote as well as sending control data to the μSWN network.

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On the µSWN sink side a special Sink Agent is implemented on top of µSWN middleware, which forwards µSWN data via USB-Serial interface to the Gateway as well as forwards data to the µSWN network sent by the Gateway. The Gateway is also responsible for processing raw data received from the µSWN network and for sending it to the Application Server and PDA's via LAN or WLAN by means of web services (SOAP protocol). On the other hand, the Gateway is also responsible for providing various services such as requests and queries, incoming from external PDA or Application server applications. The Gateway Services are implemented as Web Services, which can be accessed from external applications via WLAN or LAN network. Web Services are widespread technology with several advantages such as no use of specific object model, better cross-platform interoperability among systems and ability for integration with legacy systems. For better reliability and scalability, a multi-gateway approach is applied and for increasing reliability synchronisation services between µSWN Gateways are implemented.

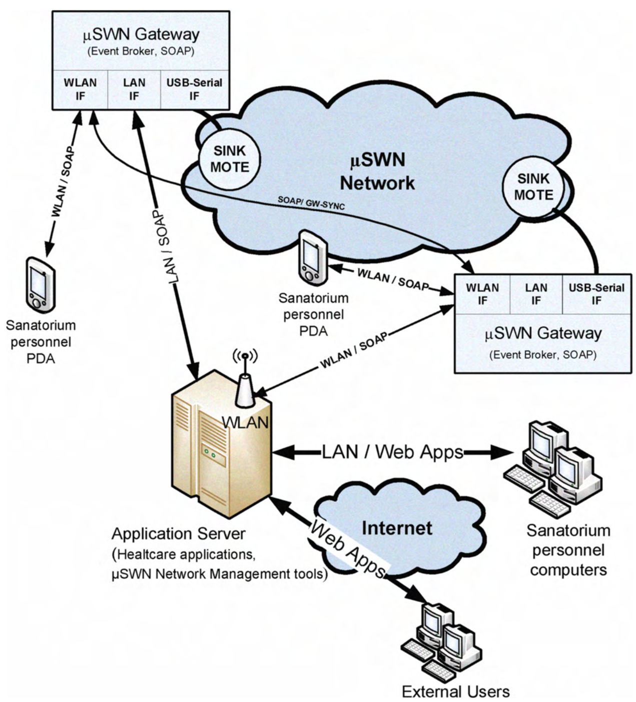

Fig. 3 µSWN network architecture

The µSWN gateway software architecture of Figure 4 consists of two main conceptual parts: **µSWN gateway middleware** and **µSWN gateway Web Services**. µSWN gateway middleware is used for bidirectional communication with µSWN network via sink mote connected to the gateway. The main task of middleware is to manage event subscription and delivery to the end-user applications. The events are produced by the µSWN network and are delivered to the sink. The Sink Agent uses gateway interface to advertise or publish produced events (**GW-Sink** in Fig. 4). The Middleware Sink Agent provided the interface to the gateway Event Broker for subscribing and unsubscribing from events produced in µSWN network (**Sink-GW** in Fig. 4). Different types of external applications are supported including µSWN CAD application and PDA application. External CAD application uses **GW-EA** interface and PDA application uses **GW-PDA** interface to get available events and to subscribe to them. When a specific event arrives to the gateway from the network (sink), the gateway's Event Broker checks if any external applications (CAD, PDA or other) are subscribed to this event. If so, then there are two options. First, if external application uses push mode to get events, then this event is sent by the Event Broker to the application via **EA-GW** or **PDA-GW** interface. This means, that each external CAD application MUST implement **EA-GW** interface and each PDA application MUST implement **PDA-GW** interface in order to get events in real-time push mode. The Event Broker uses **libWSC_PDA** and **libWSC_EA** web clients to communicate with external applications. Second, if the external application uses pull model event delivery, then it itself calls the gateway **GW-EA** or **GW-PDA** interface to check whether an event is already present. In this case, the Event Broker stores events until they are pulled by the subscriber. As multiple gateways may exist in the µSWN system, these synchronize with each other via **GW-GW** interface, which includes synchronization of subscription's and event advertisement's tables of the Event Broker. When a new event is advertised by the µSWN or a new subscription is made, the gateway receiving this advertisement or subscription forwards them to other gateways to maintain the same subscription's and event advertisement's tables.

µSWN gateway Web Services **(USWN_GW_WS_CAD, USWN_GW_WS_PDA** and **USWN_GW_WS_GW)**, are used by external applications and other gateways to list available events, subscribe to and unsubscribe from them, and may also be used for other types of queries. Gateway Web Services use inter-process (**libGW_intercomm** in Fig. 4) communication components for communication with Event Broker. This communication includes resending subscriptions from external applications as well as queries to µSWN.

External PDA application uses real-time event push mechanism for fast personnel response to critical events. PDA software has two main packages: **Mobile Web Server** and **PDA Application**. Mobile Web Server implements **PDA-GW** interface using Web Services (SOAP/WSDL) paradigm to support real-time event pushing to the PDA instead of constantly polling gateway. As soon as a new event arrives to the gateway's Event Broker, the latter sends the event to the corresponding PDA according to the subscription table via **PDA-GW** web service methods.

A PDA Application can be any application, which consumes events received by Mobile Web Server. The PDA application communicates with the gateway using **GW-PDA** web service methods. The internal communication between the gateway local components (**libGW_intercomm** and **EventBroker** in Fig. 4) is based on inter-process communication (IPC) using Sockets API. The same model has been applied for the PDA software subsystems communication. IPC allows a program to handle many user

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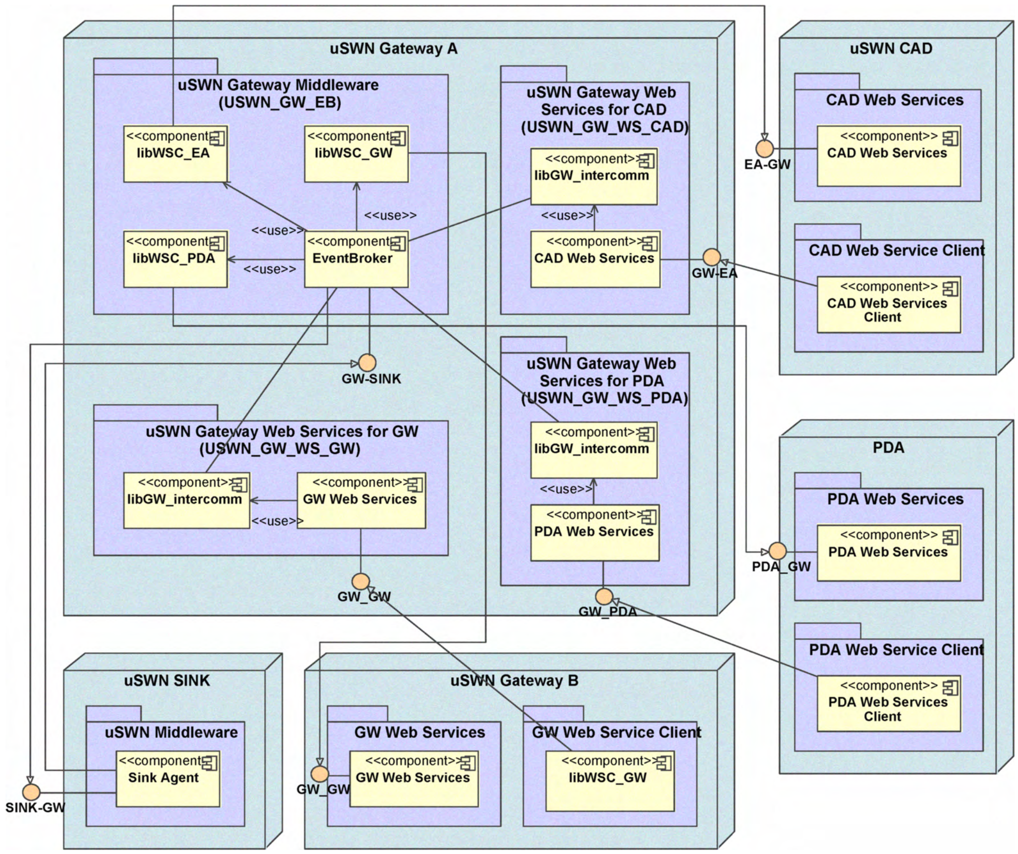

Fig. 4 µSWN gateway architecture

requests at the same time. Since even a single user request may result in multiple processes running in the operating system on the user's behalf, the processes need to communicate with each other and IPC make this possible.

V. CONCLUSIONS

This paper presents a µSWN wireless sensor network interconnection to external networks architecture for healthcare application scenarios: surveillance, vital sign monitoring and tracking. Several alternative topology schemes and architectures are investigated to best suit the application needs. The multi-gateway approach is chosen for better scalability, fault-tolerance and power efficiency. Based on this architecture, the gateway design is presented in detail and the interconnection mechanisms by support of the respective middleware are described.

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