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Wireless Sensor Networks – a new Promise for Telcos?

MONIRA ABU EL-ATA, RAMUN BERGER, OLIVER LAMPARTER AND JACQUES ROBADEY **What are the current traffic and weather conditions on the way to St. Moritz? How much time do I need to drive there if I leave my home right now? Is it possible to do a safe mountain trip alone with a heart disease? Can I have online safety control of my home even when I am travelling? In the near future, Wireless Sensor Networks will be able to answer all these questions. This technology consists of distributed sensor nodes that communicate via radio through self-organised ad hoc networks.**

Imagine you had arrived at Charles de Gaulle airport on a peaceful Sunday morning, and while waiting to collect your luggage, the whole roof of the terminal building collapses around you. No, this is not a description of a horror scene from a Hollywood movie, this actually happened only a few months ago.

Wireless Sensor Networks (WSN) could have avoided this human and financial disaster. Indeed WSNs allow to continuously monitor and report on the structural health of buildings equipped with appropriate sensors. This situation is just one of countless examples where the use of sensors could save lives (and money) or greatly improve life quality.

A Wireless Sensor Network consists of a large number of wireless sensors spread in an area to observe a certain phenomenon. The sensors need not necessarily be placed at certain fixed positions, but can be randomly distributed and constantly moving. In most cases, WSN sensors transmit their readings to a particular node. This node can act as a gateway to other systems, where data will be processed and stored. At the end of the chain, a customer will be able to retrieve information as shown in figure 1.

In this article, we present the whole WSN architecture including distribution network, storage and service infrastructure. In addition, we discuss the opportunities which WSNs present to Telcos.

Network Architecture

Figure 1 shows the general architecture needed to run WSN applications. It is made of four networks, interface nodes, storage equipment and end devices, and is described in more detail in the section "Demonstrator" below. The WSN (red) is the key part of this architecture and corresponds to the *Collection Network* of figure 1. It consists of distributed Sensor Nodes (red) that combine the ability to sense, compute and communicate. They can measure specific physical parameters such as light, temperature, movement, pressure etc. Each node can perform computations on raw data locally and transmit them to a Gateway (green). A group of nodes in a given area spontaneously forms a communication network under the control of routing and self-organisation algorithms. Usually Sensor Nodes and Repeaters (blue) are deployed in high densities (up to 20 per m^2). Therefore, only a limited transmission range is required, thus allowing low power consumption. For the management of WSNs, the used protocols must be both energy efficient and adaptive. Usually, WSNs are highly redundant; hence the data of one particular node is not important compared to the aggregated data of several nodes. In summary, a WSN must satisfy the following requirements:

- Low power consumption
- Reliability
- Self organisation
- In-network processing
- Security
- Low cost
- Small size

To transfer data collected by the Sensor Nodes to a user, data is first routed to a Gateway. The Gateway is part of the WSN connecting it with the *Transit Network* shown in figure 1. It collects, aggregates and sends the sensor data to the WSN Manager for further processing and management. In the simplest case, Gateway and WSN Manager are directly connected via a serial interface. To cover larger distances, Ethernet, wireless technologies or even satellite links can serve as Transit Networks.

The WSN manager forwards data on a database through the *Distribution Network* that can be based on the Internet, a mobile or fixed network. Before new services can be offered to end users, the data stored in the database must be processed by the application server. It performs filtering, mining, combining and storing of the relevant data. Using different fixed or mobile technologies, a user retrieves the requested information via a number of end-devices such as PCs, PDAs, mobile phones, smart phones etc., through a *Access Network*.

Node Architecture

As shown in figure 2, the wireless nodes consist of the following components:

- *Sensing Unit:* to observe specific parameters.
- *Processing Unit:* to fetch and process the sensor data and implement the networking protocols. Usually a small storage is attached to the processing unit to retain the captured values.
- *Communication Unit:* to communicate through a wire-

less transceiver with other WSN nodes.
– *Power Unit:* to energise the node components.

Standards
The wireless links between individual nodes can use radio or optical signals. Several technologies like Bluetooth, WLAN (IEEE 802.11), UWB (IEEE 802.15.3) or UHF RFID can be used. Most of the existing WSNs operate over radio links in the licence-free ISM (industrial, scientific and medical) bands at 433, 868/915 MHz and 2.45 GHz. Currently almost all networking protocols are proprietary. However, one likely future technology solution for WSNs may be based on ZigBee/IEEE 802.15.4 standards. ZigBee has been designed to support low power consumption. It is therefore best suited to meet the demanding requirements of WSNs and ensures vendor interoperability.

Demonstrator
At Swisscom Innovations, a demonstration platform has been developed using *"Motes"*, which are sensor nodes developed at Berkeley, University of California. One Mote is illustrated in the upper left corner of figure 3. Each node consists of a processing, a communication, a power and several sensor units.

The processing unit runs the TinyOS operating system: free and open source software developed at Berkeley University. It is highly configurable and suitable for small and low power devices. Many universities and laboratories are developing applications based on TinyOS, ranging from animal and vineyard monitoring to robotics and military applications. Software modules for sensor reading, counters, timers or multi hop routing can be written and integrated to perform larger functions. Many useful modules already exist and are available for public use.

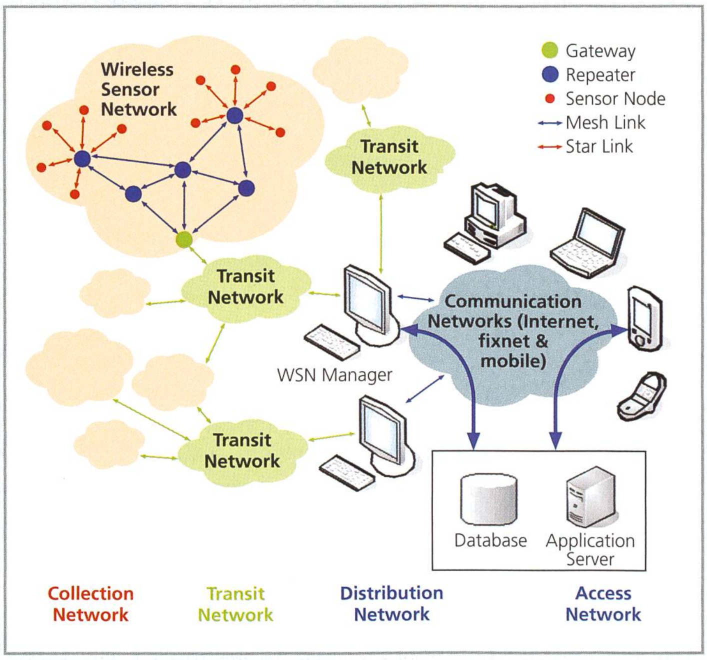

Fig. 1. General architecture necessary for WSN applications.

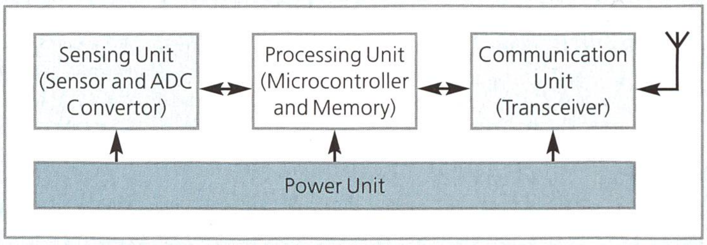

Fig. 2. Components of a sensor node.

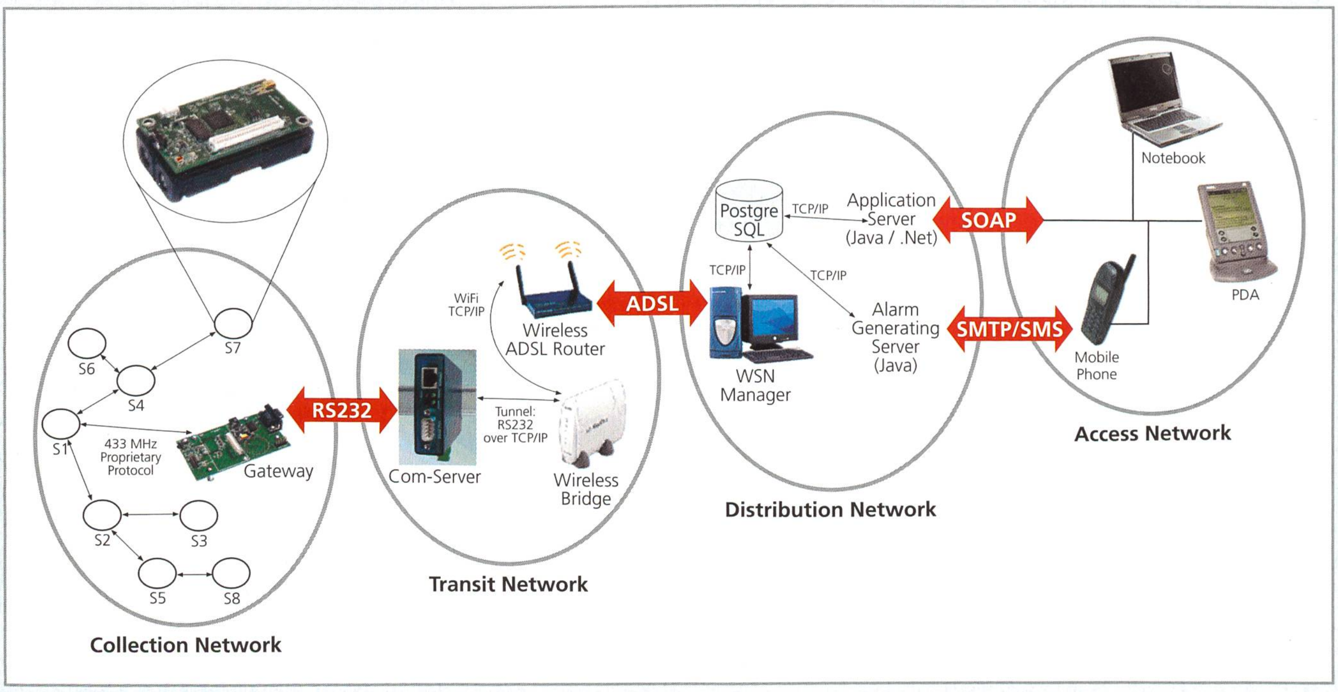

Fig. 3. Architecture of the demo platform.

ZigBee/IEEE 802.15.4

The ZigBee Alliance is an association of companies working together to enable reliable, wireless, cost-effective, low-power monitoring and control products based on an open global standard. Target markets for this technology include industrial control and networking, home automation and control, inventory management, as well as wireless sensor networks.

Figure 4 shows the ZigBee protocol stack and the corresponding responsible standard bodies. ZigBee is based on the physical and MAC layers defined by IEEE 802.15.4. IEEE 802.15.4 is a simple but powerful packet data protocol providing low latency and high reliability. It defines three licence-free frequency bands (868 MHz, 915 MHz and 2.4 GHz) for operation at data rates of 20, 40 and 250 kbit/s. The transmission range is 30 to over 100 meters with a typical output power of 0.5 mW.

The ZigBee Alliance is responsible for the definition of the network topologies, the security management (key exchange) and the application profiles. A ZigBee network consists of at least one network coordinator and up to 255 nodes per network coordinator. The network coordinator sets up a network, manages the network nodes, stores network node information and routes messages between paired nodes. Multiple network coordinators can be linked together to form very large networks with thousands of nodes.

One of the main benefits of ZigBee is its ultra-low power consumption, thus ZigBee devices can run on batteries for months or even years without the need for replacement or recharging. Low cost is another advantage of ZigBee: the ZigBee Alliance is aiming for a price of 5 CHF for initial market offerings, which will decrease when the number of delivered devices increases over time. The IEEE 802.15.4 standard has been ratified in May 2003 and the first ZigBee standards are expected at the end of 2004.

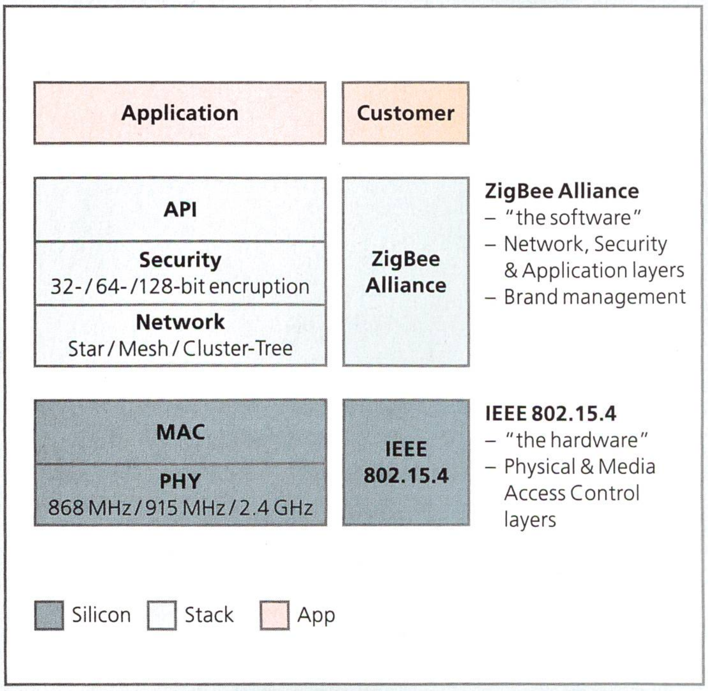

Fig. 4. ZigBee/IEEE 802.15.4 Protocol Stack. *Source: Helicomm*

To communicate, Motes use the 433 MHz ISM band and a proprietary protocol; when available, ZigBee could be used instead. Motes transmit and receive over distances up to 20 meters.

An application was developed to monitor parameters in a home environment, such as temperature, light, movements or noise. The following locations can be monitored with the platform:

- Kitchen: temperature and light Motes for checking appliances and lighting.
- Doors: a Mote measures acceleration and thus indicates the opening of a door.
- Garage: a Mote equipped with a magnetometer determines the presence of a car.
- Children's room: a Mote with a microphone detects baby sounds.

The demonstration platform consists of the four different networks described in figures 1 and 3, and their components:

Collection Network:
The Motes get the data from the monitored locations. They autonomously form a wireless mesh network, using a multi hop routing algorithm. This data is collected at the gateway and forwarded to the Transit Network.

Transit Network:
The Com-Server gets the data from the gateway and forwards it as TCP/IP packets, through a wireless link, to an ADSL router.

Distribution Network:
The WSN Manager is connected to the Internet via ADSL and stores the aggregated sensor readings into a database. The database, running on the same machine as the WSN Manager or located elsewhere, stores the sensor data coming from one or several homes in a central location. An alarm-generating server triggers an alarm if a measured value is above a certain threshold. The alarm is sent via email or SMS to a mobile phone. The application server offers the sensor data as a web service.

Access Network:
When a customer receives an SMS alarm on his mobile phone, he/she can access the application server from any kind of device (e. g. PC, laptop, smart phone, etc.) via the Internet. This way, he/she can check if a hotplate is on or if the baby is crying.

Applications of Wireless Sensor Networks

WSN technology provides a vast potential for exploitation. It has the hallmark of a disruptive technology when the constraints of size, power and cost are resolved. Due to the large number of conceivable combinations of sensing, computing and communication technologies, many widely different applications are possible. A representative small sample of two groups of applications will be briefly discussed here.

The first group deals with environment monitoring and control. A WSN collects data such as temperature, air quality, soil quality, sea bed conditions, earthquake vibration patterns, volcano eruption parameters, ozone layer changes, weather conditions, etc. For example, when WSNs are used to monitor the structural integrity of buildings, sensor nodes can be placed on key construction points to observe force changes, vibrations, levels of chloride in the concrete, etc. These nodes can immediately report signs of dangers for quick enforcement of safety procedures.

The second group deals with object tracking. As an object travels through the domain covered by a WSN, different nodes sense its vicinity and relay the data to another node. Examples include tagged mobile item containers, smart cards, smart banknotes, car-to-car and in-car communications.

Currently, WSNs are extensively deployed in a large number of military applications. However, it is hoped that the near future will bring in an increased number of peaceful and sensible applications that contribute to enhance the quality of life.

Opportunities for Telecom Operators

Telcos have important business advantages in the future WSNs competition. Typically, telcos have global wireless and fixed network resources; extensive networking and data processing know-how; services creation and distribution frameworks; a large customer base; and in-situ communication channels to market, sell and promote new services.

It is therefore possible to envisage new sets of WSN services by utilising the following parts of a telco architecture (figure 1):

- The transit network
- The IT storage & processing infrastructure
- The service distribution network

Companies outside the telecom sector can implement, manage and use WSNs and some will develop services around such capabilities. No doubt, many of the enterprises that will use WSNs extensively will try to run their own services and the required infrastructure. However, they could realise substantial economies by outsourcing their network and storage infrastructure.

The telcos' services framework, assets, experience and skills allow offering large sets of new services both to enterprises and consumers alike. These services can be bundled and charged on per use basis, depending on the nature of the services and the customer requirements. We distinguish two major services areas:

- In the first instance, *companies* might outsource the support of sensor-driven activities to telcos. This could be done in areas such as supply chain management, environment control, physical security monitoring and alert management.
- In the *consumer market,* very different types of services could be offered, such as: home security with a security system connected to customer mobile devices; real-time driving assistant using live traffic and weather information; localisation and control of domestic animals; localisation and control of valuables; medical assistant with sensor control and emergency support for disabled people.

Conclusion and Outlook

WSNs are not yet fulfilling the requirements of low power consumption, small size and low cost. However, important progress has been realised recently in the areas of WSN architecture and protocols for the optimisation of power consumption, routing and processing efficiency. In addition, during the next few years, advances in energy storage, radio communication, microcontrollers and memory are expected to succeed in eliminating many of the limitations. Parallel to these developments, new technologies such as ZigBee are being standardised and hence, low-price, low-power consumption and interoperable products are shortly expected in the market.

As new technologies (RFID, Bluetooth, ZigBee, etc.) become prevalent, growing economies of scale will enable the global integration of sensors networks, leading to a safer and better future. With these networks able to provide access via the Internet, our physical world will be readily available for web services, taking data mining to a new horizon.

The main interest for Telcos in the WSN market comes from their ability to manage global information by using their own telecommunication and storage infrastructure. Telcos, with their infrastructure history and customer experience, are in a good position to define attractive WSNs services.

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