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Design and Implementation of Wireless Sensor Network Based on Multilevel Femtocells for Home Monitoring

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Abstract

An intelligent femtocell-based sensor network is proposed for home monitoring of elderly or people with chronic diseases. The femtocell is defined as a small sensor network which is placed into the patient's house and consists of both mobile and fixed sensors disposed on three layers. The first layer contains body sensors attached to the patient that monitor different health parameters, patient location, position and possible falls. The second layer is dedicated for ambient sensors and routing inside the cell. The third layer contains emergency ambient sensors that cover burglary events or toxic gas concentration, distributed by necessities. Cell implementation is based on the IRIS family of motes running the embedded software for resource-constrained devices, TinyOS. In order to reduce energy consumption and radiation level, adaptive rates of acquisition and communication are used. Experimental results within the system architecture are presented for a detailed analysis and validation.

Keywords: wireless sensor network, ambient monitoring, body sensor network, ambient assisted living.

11.1 Introduction

Recent developments in computing and communication systems applied to healthcare technology give us the possibility to implement a wide range of home-monitoring solutions for elderly or people with chronic diseases

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[1]. Thus, people may perform their daily activities while being constantly under the supervision of the medical personnel. The indoor environment is optimized such that the possibility of injury is minimal. Alarm triggers and smart algorithms sent data to the right intervention units in regard to the detected emergency [2].

When living inside closed spaces, small variables may be significant to the entire person's well-being. Therefore, the quality of the air, temperature, humidity or the amount of light inside the house may be important parameters [3]. Reduced costs, size and weight and energy-efficient operation of the monitoring nodes, together with the more versatile wireless communications, make the daily usage of the systems monitoring health parameters more convenient. By wearing them, patients are free to move at their own will inside the monitored perimeter, practically forgetting their presence. The goal is to design the entire system operation for a long period of time without human intervention and at the same time, triggering as few false alarms as possible.

Many studies investigated the feasibility of using several sensors placed on different parts of the body for continuous monitoring [4]. Home care for the elderly and chronic disease persons becomes an economic and social necessity. With a growing population of ageing people and the health care prices rising all over the world, we expect a great demand for home care systems [5, 6]. An Internet-based topology is proposed in [7] for the remote home-monitoring applications that use a broker server, managed by a service provider. The security risks from the home PC are transferred to the broker server and removed, as the broker server is located between the remote-monitoring devices and the patient's house. An early prototype of a mobile health service platform that was based on Body Area Networks is MobiHealth [8]. The most important requirements of the developer for an e-health application are size and power consumption, as considered in [9]. Also, in [10], a thorough comprehensive study of the energy conservation challenges in wireless sensor networks is carried out.

In [11], a wireless body area network providing long-term health monitoring of patients under natural physiological states without constraining their normal activities is presented.

Integrating the body sensors with the existing ambient monitoring network in order to provide a complete view of the monitored parameters is one of the issues discussed in this paper. Providing a localization system and a basic algorithm for event identification is also part of our strategy to fulfill all possible user requests. Caregivers also value information about the quality of air inside the living area. Many false health problems are usually related to the lack of oxygen or high levels of CO or CO_2.

The chapter is organized as follows: Section 2 provides an overall view on the proposed system architecture and detailed insight into the operation requirements for each of the three layers for body, ambient and emergency monitoring. Section 3 introduces the main criteria for efficient data collection and a proposal for an adaptive data rate algorithm for both the body sensor network and the ambient sensor network. This has the aim of reducing the amount of data generated within the networks, considering processing, storage, and energy requirements. Implementation details and experimental results are evaluated in Section 4, where the path is set for long-term deployment and validation of the system. Section 5 concludes the chapter and highlights the main directions for future work.

11.2 Network Architecture and Femtocell Structure

The proposed sensor network architecture is based on hybrid femtocells. A hybrid femtocell contains sensors which are grouped based on their functional requirements, mobility and energy consumption characteristics in three layers: the body sensor network (BSN), the ambient sensor network (ASN) and the emergency sensor network (ESN), as presented in Figure 11.1. Coordination is implemented through a central entity called the femtocell management node (FMN) which aggregates data from the three layers and acts as a interface to the outside world by means of the internet. Communication between different components can be made using wireless technology and radio compatible fiber optic. Table 11.1 lists the high-level characteristics of the two low-power wireless communication standards often used in home-monitoring scenarios: IEEE 802.15.1 and IEEE 802.15.4. This highlights an important design trade-off in the deployment of a wireless sensor network for home monitoring.

Table 11.1 Main characteristics of IEEE 802.15.1 and 802.15.4

IEEE Standard	802.15.1	802.15.4
Frequency	ISM - 2.4GHz	ISM/868/915 MHz
Data rate	1 Mbps	250 kbps
Topology	Star	Mesh
Scalability	Medium	High
Latency	Medium	High
Interference mit.	FHSS/DHSS	CSMA/CA
Trademark	Bluetooth	ZigBee

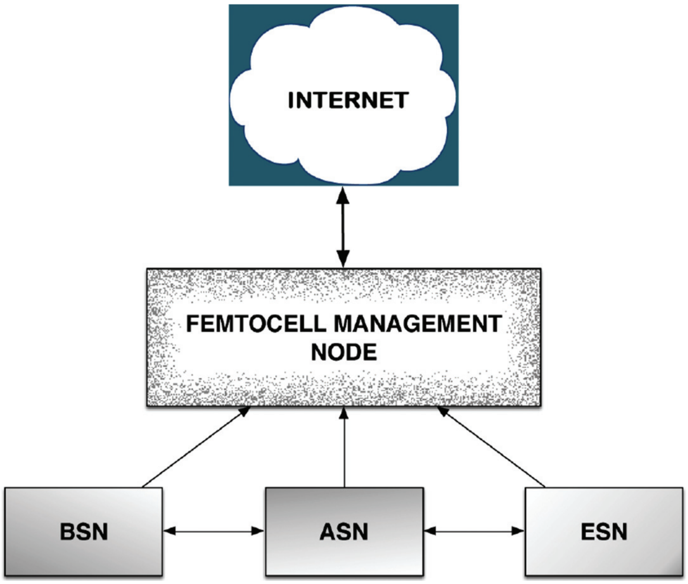


Figure 11.1 Hybrid femtocell configuration.

While IEEE 802.15.4 and ZigBee enable large dense networks with complex mesh topologies, the use of Bluetooth can become an advantage in applications with higher data-rate requirements and low latency.

The layer characteristics and functionalities are further elaborated upon.

11.2.1 Body Sensor Network

The body sensor network functional design includes battery charging nodes along with user-friendly construction and operation. In an idealised case, the size and weight would go unnoticed, immediately or after a short accomodation period, not disturbing the patient or elderly person when wearing them. Nodes communicate using a low-power wireless communication protocol for very short distance data transmission and reception e.g. ZigBee or Bluetooth, depending on the data streaming rate of the application and energy resources on the node. Very low-energy consumption is an essential design criteria as changing the batteries on a daily basis becomes stressful on the long term and ideally the nodes would be embedded into wearable technology. Some on the sensed parameters for the BSN include dual- or tri- axial accelerometers, blood pressure, ECG, blood oxygen saturation, heart rate and body temperature.

The main events that should be detected by the BSN cover fall detection, activity recognition and variations in investigated parameters corresponding to alert and alarm levels.

11.2.2 Ambient Sensor Network

The ambient sensor network is comprised of a series of fixed measurement nodes, placed optimally in the target area/environment as to maximize sensing coverage and network connectivity through a minimum number of nodes. The low-power communication operates on longer communication links than the BSN and has to be robust to main phenomena affecting indoor wireless communication, such as interference, reflections and assymetric links. Though fixed node placement provides more flexibility when choosing the energy source, battery operation and low maintenance, enabled by low-energy consumption is preferred to mains power. For example, in the ASN, the router nodes which are tasked with redirecting much of the network traffic in the multi-hop architecture can be operated from the main power line.

Within the general framework, the ASN can serve as an external system for patient monitoring through a localization function based on link quality and signal strength. The monitored parameters include ambient temperature, humidity, barometric pressure and light. These can be evaluated individually or can serve as input data to a more advanced decision support system which can correlate the evolution of indoor parameters with the BSN data from the patient to infer the conditions for certain diseases. Some nodes of the ASN might include complex sensors like audio and video capture giving a more detailed insight into the patient's behaviour. Their current use is somewhat limited by the additional computing and communication ressources needed to accomodate the sensors into current wireless sensor network architectures as well as by privacy and data-protection concerns.

11.2.3 Emergency Sensor Network

The multi-level femtocell reserves a special role for the emergency sensor network which can be considered as a particular case of ASN tasked with quick detection and reaction to life or property threats through embedded detection mechanisms. The sensing nodes are fixed and their placement is well suited to the specifics of the measurement process. As an example, the house could be fitted with gas sensors in the kitchen next to a stove, carbon dioxide sensors would be placed in the bedroom and passive infrared sensor and pressure sensors would be fitted next to doors and windows. As the operation of the

ESN is considered critical, energy-efficient operation becomes a secondary design criteria. The nodes should have redundant energy sources, both batteries and mains power supply, and redundant communication links. For example, a wireless low latency communication protocol with simple network topology to minimize overhead and packet loss can be used as a main interface with the possibility of switching to a wired interface or using the ASN infrastructure in certain situations.

The main tasks of the ESN are to detect dangerous gas concentrations posing threats of explosion and/or intoxication and to detect intruders into the home such as burglars.

11.2.4 Higher-level Architecture and Functional Overview

One of the features of the hybrid femtocell is that the body sensor always interacts with the closest ambient sensor node, Figure 11.2, in order to send data to the gateway. This function reassures us that the sensors attached to the monitored person are always connected and the energy consumption is optimal because the distance between the person and the closest router is minimal. This feature can also be used as a mean of localization. The person wearing the

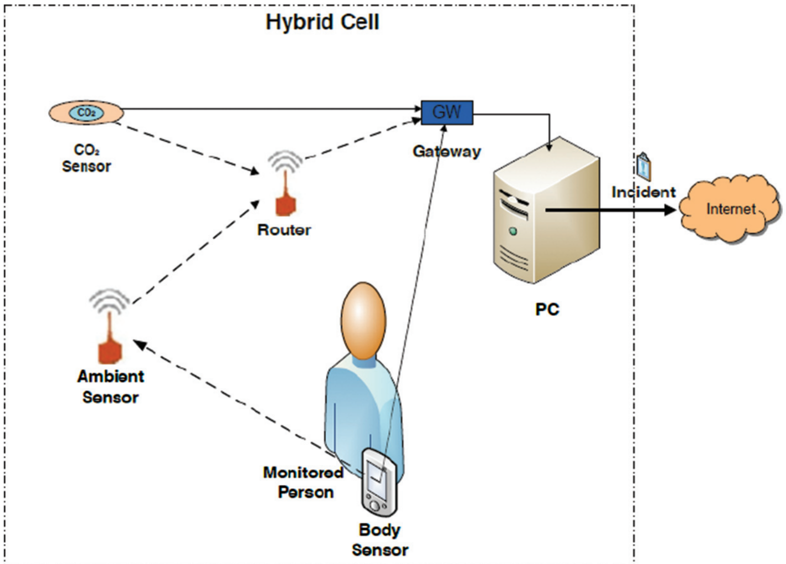


Figure 11.2 Data and information flow within and outside the femtocell.

body sensor will be always connected to the closest router. By using fixed environmental sensors with own ID and previously known positions, we can determine which room is presently used by the inhabitant. In order to have an accurate localization of the patient, an attenuation map of the sensors from each room must be created. Considering that patient is localization in a certain room of the home, by the closest ASN, is not accurate this could happen due to the following scenario: lets suppose that we have an ASN located in the bedroom, situated in the left side of the room. In the right part of the room, we have the door to the living room, and near this door we have the ASN for the living room. If the patient is located in the bedroom, but very close to the door, it will have as closest ASN the one from the living room, but he/she is situated in the bedroom. In order to avoid this localization error, we introduce the attenuation map of the sensors. Every ASN that localizes the BSN on the patient will transmit an attenuation factor. This way, using the attenuation factors from each sensor, we can localize the patient very accurately. In our example, if the bedroom ASN has a 10% factor, and the living room ASN has a 90% factor, using the attenuation map, we localize the patient as being in the bedroom, but very close to the door between the two rooms.

The position of a hybrid femtocell in the large wireless sensor network system is presented in Figure 11.3. Its main purpose is to monitor and interpret data, sending specific alarms when required. The communication between the femtocells and the network is based on internet. The same method is used for

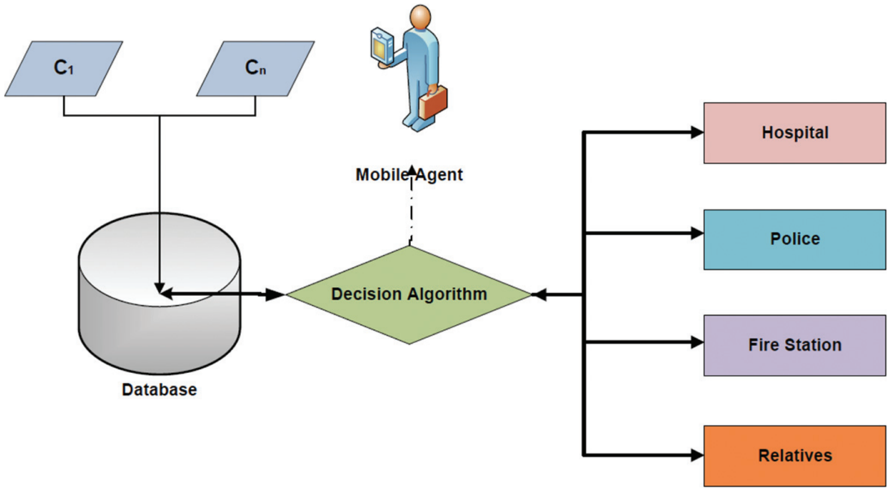


Figure 11.3 System architecture.

the communication between the network administrator and hospital, police, fire station or relatives.

In Figure 11.4, the ambient sensors' spatial placement and reference deployment inside the patients apartment is showcased. This fixed topology is consistent with the routing role of the ambient sensors in regard to the considered mobile body sensors. The goal of the system is to collect relevant data for reporting and processing. Therefore, achieving a very high sensory and communication coverage is among our main objectives.

The entire monitoring system benefits from a series of gas sensor modules strategically placed throughout the monitored space. Thus, the Parallax-embedded gas-sensing module for CO_2 is designed to allow a microcontroller to determine when a preset carbon dioxide gas level has been reached or exceeded. Interfacing with the sensor module is done through a 4-pin SIP header and requires two I/O pins from the host microcontroller. The sensor module is mainly intended to provide a means of comparing carbon dioxide sources and being able to set an alarm limit when the source becomes excessive [4].

A more advanced system for indoor gas monitoring, MICARES, is shown in Figure 11.5. It consists of an expansion module for a typical wireless sensor network platform with the ability to measure CO, CO_2 and O_3 concentrations and perform on board duty-cycling of the sensors for low energy as well as measurement compensation and calibration. Using this kind of platform, data

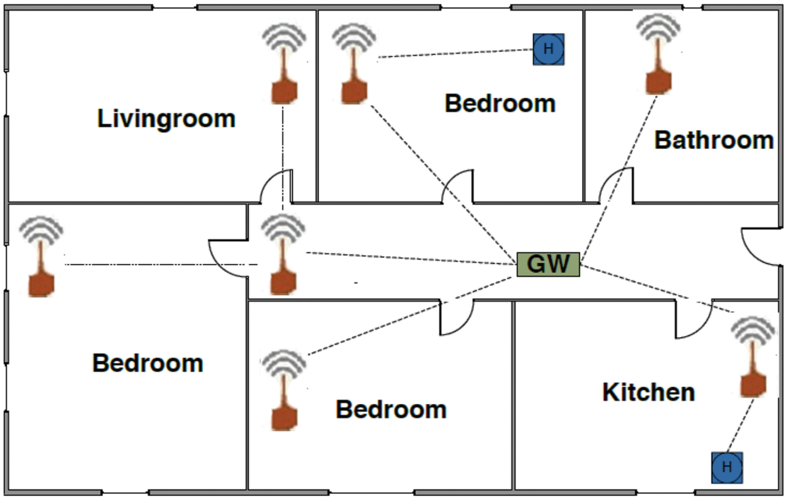


Figure 11.4 Sensor deployment example.

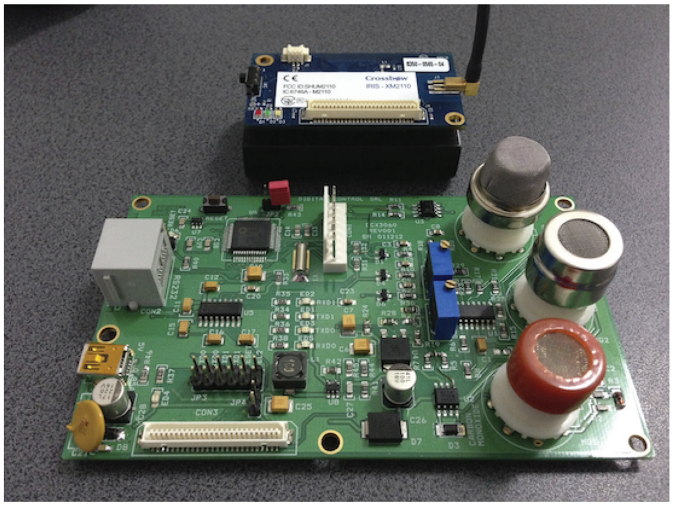


Figure 11.5 Embedded carbon dioxide sensor node module [12].

can be reliably evaluated locally and relayed to the gateway as small packets of timely information. The module can be either powered by mains or draw power from the energy source of the host node. Also, it can operate as a stand-alone device through ModBus serial communication with other information processing systems.

In case an alert is triggered, the information is automatically processed and the alarm is sent to the specific intervention factor (hospital, police, fire department, etc.). These have the option of remotely accesing the fem-tocell mangement node in order to verify that the alarm is valid and act by dispatching an intervention team to solve the issue. Subsequently, all the alarms generated over time are classified and stored in a central database for reporting purposes.

11.3 Data Processing

Data harvesting and processing is performed at the femtocell level, so the whole network is not flooded by useless data from all femtocells. Considering the main goals of conserving node energy, while taking into account the limited storage and processing capabilities of each node, we proposed a strategy to dynamically adapt the sampling rate of the investigated parameters for the BSN and ASN. The ESN is considered crtical home infrastructure and it is not affected by this strategy, with its own specific challenges for reliability, periodic sensor maintenance and calibration.

Adaptive data acquisition is implemented by framing collected data into a safety interval given by [V_{min}, V_{max}]. While the raw values are relatively close to the interval center $V = \frac{1}{2}(V_{max} - V_{min})$ and the recent variation of the time series, given by the derivative, is low over a exponential weighted time horizon, then the data acquisition rate is lowered periodically towards a lower bound. When collected measurements start to vary, data acquisition is increased steeply in order to capture the significant evene, then a stability period is observed and it begins to be lowered again. Though local data storage on the node can be exploited, we prefer to synchornize collection with transmission of the packets through the radio interface in order to conserve data freshness which can prove important in order to effectively react to current events. Energy level must be considered in order to prevent the reception of corrupted data and to avoid unbalanced node battery depletion e.g. in the case of routing nodes in the network. This represents a validation factor of the data and is automatically transmitted together with the parameter value. Energy-aware policies can be implemented at the femotcell level to optimize battery recharge, in the BSN case, and battery replacement, for the ASN.

Evaluation of the parameter derivate takes place for attaining a variable rate of acquisition. The values obtained by calculating the derivate also help us to decide what type of event has happened. This can be done by building a knowledge base during system commissioning and initial operating period which can be used to relate modifications in observed parameter to trained event classes. These can go from trivial associations like high temperature and low oxygen/smoke meaning a fire, to subtle patient state of health detection by changing vital signs and aversion to light. The algorithm described can be summarized as follows:

```
Data: measured values, measurement derivative, energy level
Result: adaptive data rate initialize;
while network is operational do
    collect measurement values;
    check distance from interval center;
    compute time series derivative;
    if high sudden variation then
        increase data rate;
    else
        lower data rate;
    end
end
```

Algorithm 1: Adaptive Data Collection for Home Monitoring

11.4 Experimental Results

In order to bring value to the theoretical system architecture proposed, two experiments have be devised and implemented. They cover the body and ambient sensor layers of the multi-level femtocell for home monitoring. The main operational scenario that was considered involves an elderly patient, living alone at home in an appartment or house with multiple rooms. A caregiver is available on call as well as a permanent connection to the emergency services exists, with the possibility on alerting close relatives in the process. As functional requirements, we target activity monitoring and classification by body-worn accelerometers and ambient measurement of humidity, temperature, pressure and light, along with their correlations.

The first experiment is performed as part of the body sensor network. Therefore, two accelerometers with two axes were placed on the patient, one on the right knee and the other one on his left hip, as shown in Figure 11.6. The sensors are automatically assigned a unique value ID. Therefore, in our

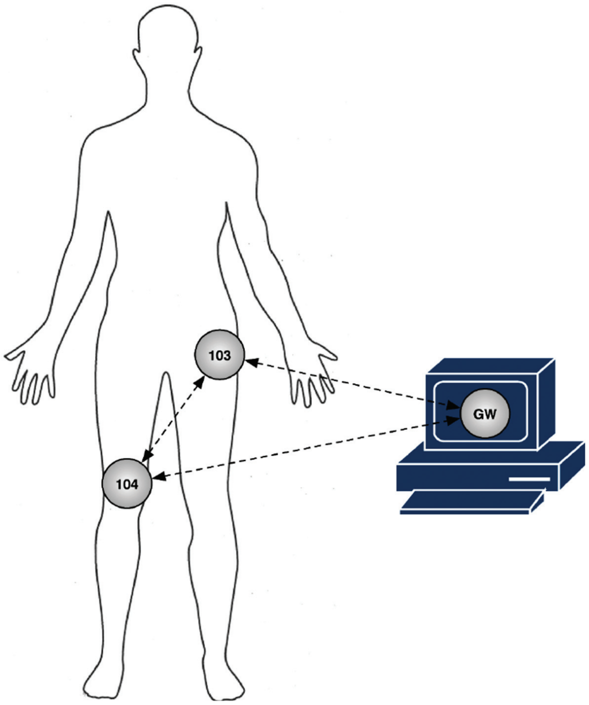


Figure 11.6 Accelerometer node placement on the patient's body.

experiment, the sensor situated on the knee has ID104, and the other one, placed on the left hip, ID103. In order to overcome the hardware limitations, in a tridimensional representation, the representation of the 3 axis using those two accelerometers is the following:

- X axis: front back, X axis of node 104;
- Y axis: left right, X axis of node 103;
- Z axis: bottom up, Y axis of both nodes.

The following activities were executed during the experiment: standing, sitting on a chair, standing again and slow walking from bedroom to living. Data acquisition has been performed using MOTE-VIEW [13]. This is an interface, client layer, between a user and a deployed network of wireless sensors. Besides this main function, the user can change or update the individual node firmware, switch from low-power to high-power mode and set the radio transmit power. Collected data is stored in a local database and can be accessed remotely by authorized third parties.

Multiple experiments have been conducted in order to determine the trust values. Therefore, in the X and Y axis charts presented in Figures 11.7 and 11.8, the readings outside the green lines represent that an event occurred, obtained by thresholding. The following events have been monitored during our experiment in this order: standing, sitting on a chair,

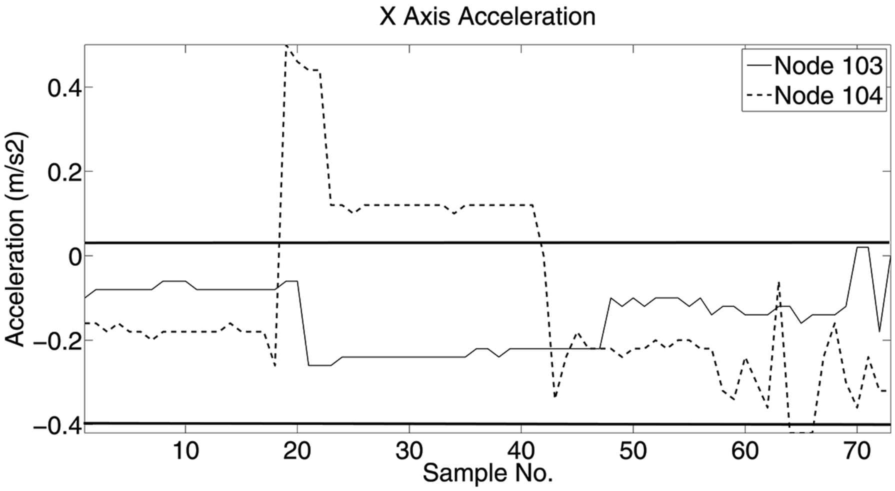


Figure 11.7 X Axis experiment acceleration with thresholding.

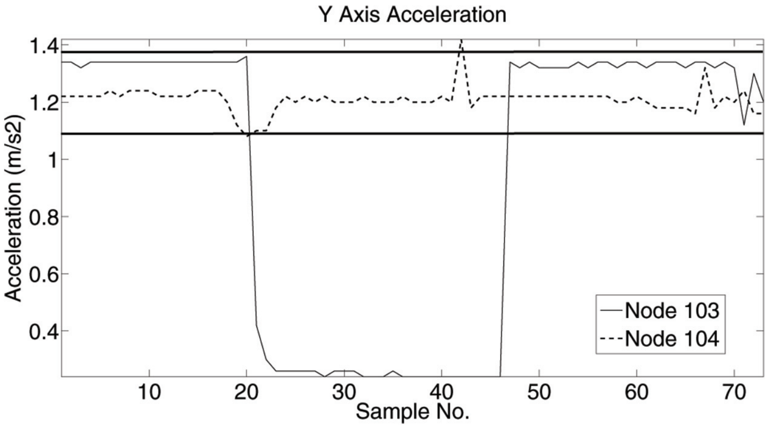


Figure 11.8 Y Axis experiment acceleration with thresholding.

standing again and slow walking from bedroom to living. The used sensors are ADXL202E [14].

These are low-cost, low-power, complete 2-axis accelerometer with a digital output, all on a single monolithic IC. They are an improved version of the ADXL202AQC/JQC. The ADXL202E will measure accelerations with a full-scale range of 2 g. The ADXL202E can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity). The outputs are analog voltage or digital signals whose duty cycles (ratio of pulse width to period) are proportional to acceleration. The duty cycle outputs can be directly measured by a micro- processor counter, without an A/D converter or glue logic. The duty cycle period is adjustable from 0.5 ms to 10 ms via a single resistor (RSET).

The radio base station is made up of an IRIS radio/processor board connected to a MIB520 USB interface board via the 51-pin expansion connector. The interface board uses a FTDI chip and provides two virtual COM ports to the host system. COMx is used for programming the connected mote and COMx+1 is used by middleware applications to read serial data. The used network protocol is called XMesh, owned by Crossbow, based on the standard 802.15.4. The Crossbow sensor networks can run different power strategies, each of these strategies being a trade-off between power, data rates and latency.

XMesh-HP [15] is the best approach for systems that have continuous power, offering the highest message rate, usually proportional to the band rate of the radio. Radios and processors are continually powered, consuming

Table 11.2 XMesh power configuration matrix

Power Mode	MICA2	MICA2DOT	MICAz
XMesh-HP	X	X	X
XMesh-LP	X	X	Async. only
XMesh-ELP	X	X	X

Table 11.3 XMesh performance summary table

Parameter	XMesh-HP	XMesh-LP	XMesh-ELP
Route update interval	36 sec.	360 sec.	36 sec. (HP) / 360 sec. (LP)
Data message rate	10 sec. typ.	180 sec., typ.	N/A
Mesh formation time	2–3 RUI	X	X
Average current usage	20–30 mA	400 uA	50 uA

between 15 and 30 mA depending on the type of the Mote. Route Update Messages and Health Messages are sent at a faster rate which decreases the time it takes to form a mesh or for a new mote to join the mesh.

XMeshLP [15] is used for battery-operated systems that require multi-month or multi-year life. It can run either time-synchronized or asynchronous. The best power efficiency is achieved with time synchronization within 1 msec. The motes wake-up, typically 8 times/second, time synchronized, for a very short interval to see if the radio is detecting any signal over the noise background. If this happens, the radio is kept alive to receive the signal. This action usually results in a base level current of 80 μA. The total average current depends on the number of messages received and transmitted. If data is transmitted every three minutes, the usual power in a 50-node mesh is around 220 μA. XMesh-LP can be configured for even lower power by reducing the wake-up periods and transmitting at lower rates. Also, route update intervals are set at a lower rate to conserve power, resulting in a longer mesh formation time.

XMesh-ELP [15] is only used for leaf nodes that communicate with parent nodes running XMesh-HP. A leaf node is defined as a node that does not participate in the mesh; it never routes messages from child motes to parent motes. The results of the ELP version are very low power because the mote does not need to use the time synchronized wake-up mode to check for radio messages. The mote can sleep for very long times, this way maintaining its neighborhood list to remember which parents it can select. If it does not get a link-level acknowledgement when it transmits to a parent, it will find another parent and so on. This operation can happen very quickly or might take some time if the RF environment or mesh configuration has changed considerably.

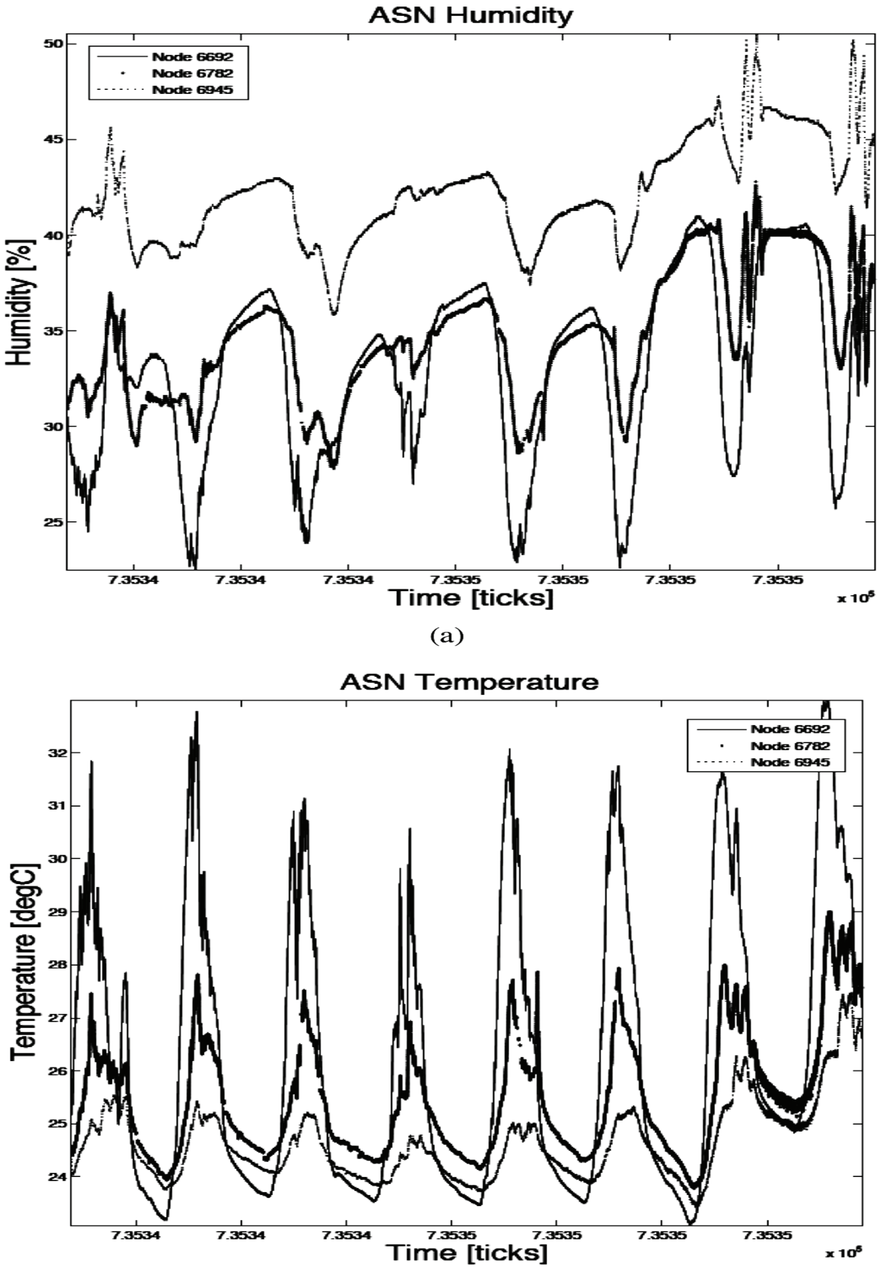
Because of their small size, nodes can be easily concealed into the background, interfering as little as possible with the user's day-to-day routine. We have also the possibility to set the sampling rate at a suitable level in order to achieve low-power consumption and by this a long operating range without human intervention [16].

Our infrastructure also offers routing facilities increasing the reliability of our network by self-configuring into a multihop communication system whenever direct links are not possible. After experimenting with different topologies, we achieved a working test scenario which consisted in a four-level multihop communication network which is more than we expect to be necessary in any of our deployment locations.

Extensive experimental work has been carried out for the ambient sensor layer of the system based on MTS400 IRIS sensor nodes. One of the reasons for choosing this specific board has been that it provided the needed sensors in order to gather a variety of environmental parameters, like temperature, humidity, relative pressure and ambient light. The experimental deployment consists of three measurement nodes organized in a true mesh topology in a testing indoor environment. These aim at modeling a real implementation in the patient's home and were taken over the course of a week-long deployment. In order to assure accounting to uneven sampling from the sensor nodes, we use as reference time MATLAB serial time units which are converted from conventional time stamps entries into the MOTE-VIEW database of the form *dd.mm.yyyy HH:MM:SS*.

In Figure 11.9(a), the evolution of the humidity parameter measured by indoor deployed sensors can be seen. The differences account for node placement in the different rooms and exposure to windows and doors. Subsequent processing can lead to computing average values and to other correlations with ambient and body parameters and an intelligent information system which can associate variations in ambient humidity and temperature to influences on chronic disease. Figure 11.9(b) illustrates temperature variations obtained from the ambient sensor network. These reflect the circadian evolution of the measured parameter and show the importance of correct node placement and data aggregation within the sensor network.

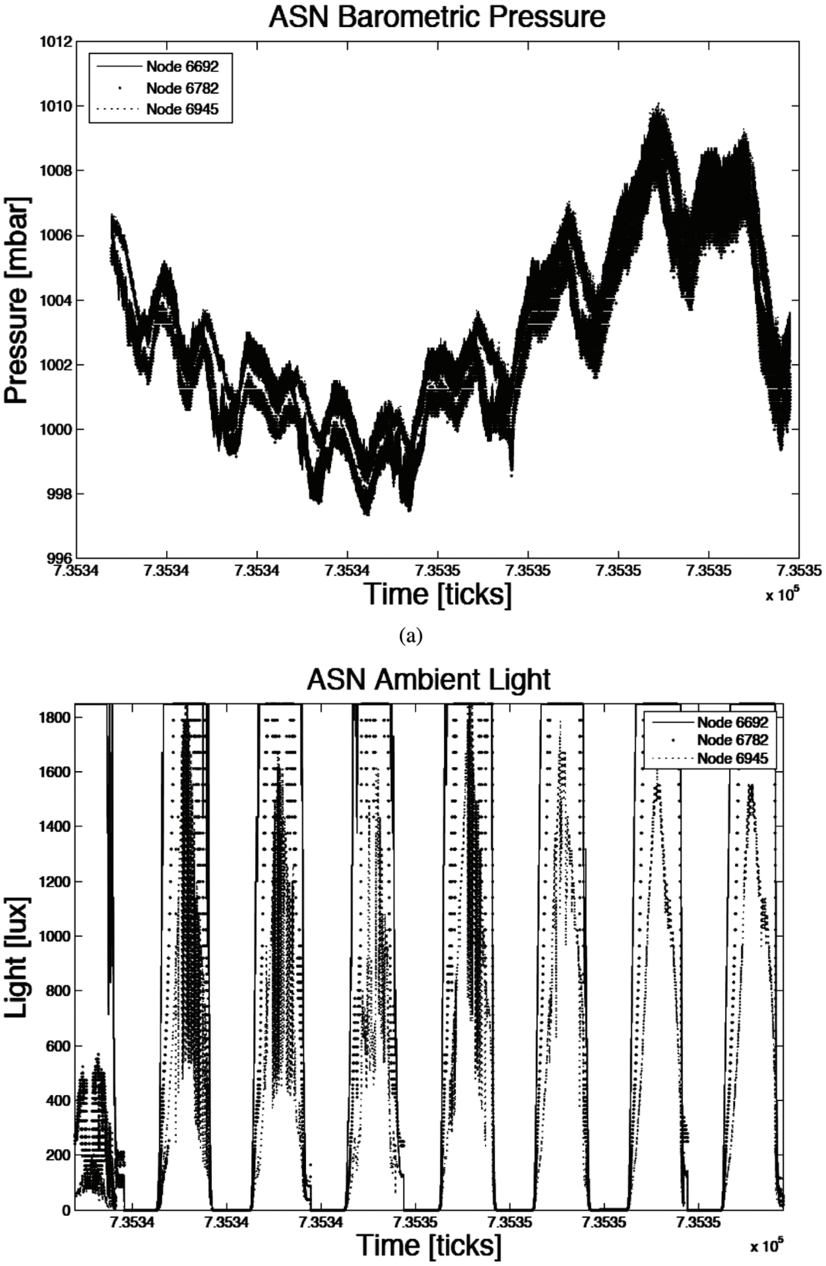
Barometric pressure (Figure 11.10(a)) is also observed by the sensor network over the testing period. This is the parameter that is least influenced by node placement and more by general weather trends. As differences between individual sensor node values of a few percentage points, these can be attributed to sensing element calibration or local temperature compensation. Aggregating data also in this case can lead to higher-quality measurements.



(a)

(b)

Figure 11.9 Measurement data: humidity (a); temperature (b).



(a)

(b)

Figure 11.10 Measurement data: barometric pressure (a); light (b).

Ambiental light values, suitable for feeding data to an intelligent mood lighting system, are shown in Figure 11.10(b). The light sensor saturates in full daylight at around 1850 lux and quickly responds to variations in the measured light. The most important period of the day are dawn and dusk where the information provided can assure a smooth transition from artificial to natural light and reverse.

Data flow coming from the ambient sensor network is processed in multiple steps: at the source node, in the network e.g. through aggregation or sensor fusion, and at the home server or gateway level. Each steps converts raw data to higher-level pieces of information which can be more efficiently operated with and become meaninful through correlation and interactive visualization. Efficient management of this infomation is critical to correct operation of the home-monitoring system. Alerts and alarms have to be reliable and build trust among the end user leading to widespread acceptance whilst assuring a high level of integrity, security and user privacy.

Table 11.4 summarizes the aggregated experimental deployment values for the three nodes over the investigated period. Minimum, maximum, average and the standard deviations of the collected time series for each of the measured ambiental parameters are listed.

Making effective use of the large quantities of data generated by the layers of the femtocell structure, represented by the individual sensor networks, poses a significant challenge. One idea is to apply computational intelligence

Table 11.4 Ambiental Monitoring Summary

Node ID		6692	6782	6945
Humidity [%]	*min*	22.5	27.8	35.8
	max	41	42.8	50.5
	avg	33.39	34.62	42.26
	stdev	4.76	3.22	2.58
Temperature [degC]	*min*	23.08	23.78	23.4
	max	32.98	29.01	27.48
	avg	26.24	25.45	24.66
	stdev	2.7	1.1	0.75
Pressure [mbar]	*min*	997.83	997.34	998.24
	max	1009.6	1009.3	1010.2
	avg	1003.3	1002.2	1003.5
	stdev	2.85	2.7	2.7
Light [lux]	*min*	0	0	0
	max	1847.1	1847.1	1847.1
	avg	952.18	705.87	414.05
	stdev	880.32	801.35	517.96

techniques, either in a centralized manner at the gateway level or in a distributed fashion where computing taks are spread among the nodes according to a dynamic strategy. An example is given for time series prediction on the temperature data collected by the ambient sensor network using neural networks. As a tool, the MATLAB technical computing environment can be used for modeling, testing and validation and embedded code generation at the gateway level.

11.5 Conclusion

The chapter introduced a system architecture composed of a smart hybrid sensor network for indoor monitoring using a multilayer femtocell for ubiquitous intelligent home monitoring. The main components of the system are three low-level wireless sensor networks: body, ambient and emergency, along with a central coordination entity named the femtocell management node. This also acts as gateway towards the internet and the interested stakeholders in an ambient-assisted living scenario. It has been argued that efficient data collection and processing strategies along with robust networking protocols can enable seemless integration into the patient's home and bring added value to home care whilst reducing overall medical and assitance costs. Recent advances in miniaturization of discrete electronic components and systems, along with enhanced computing and communication capabilities of intelligent home device offer a good opportunity in this application area. This can be exploited for both reasearch and development in the field of ambient-assisted living to increase quality of life while dealing with increased medical costs.

The main experimental focus was on the body sensor network layer and the ambient sensor layer and experimental deployment and implementation has been illustrated. First, body-worn wireless accelerometers were used to detect and classify human activity based on time-domain thresholding. Second, extensive results from a medium-term deployment of an ambient sensor network were illustrated and discussed. This had, as a main purpose, the collection of ambient parameters, like temperature, humidity, barometric pressure and ambient light while observing network protocol behaviour. The main conclusion is that wireless sensor network systems and protocols offer a reliable option for deployment in home monitoring, given the specific challenges of indoor environments.

Plans for future development have been established on three main paths. One direction includes extending the system with more measured parameters through additional sensor integration with the wireless nodes. The focus here would be on the body sensor network side where a deep insight into the patient's well-being and health status can be gained. Also, while raw data and machine-learning algorithms can provide high-confidence recommendations and alerts to the caregivers, data visualization in the home and for the patient should not be neglected. This can be done by developing adaptive and intuitive interfaces for the patient or elderly person which enhance acceptance of the system. The quality and accuracy of the expected results has to be increased by integrating state-of-the-art sensing, signal processing and embedded computing hardware along with the implementation of advanced methods for experimental data processing.

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