Mobile multimedia in Wireless Sensor Networks

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Abstract: One of the most referred and promising Wireless Sensor Network (WSN) applications is health monitoring. The small size and portability of nodes have made WSNs the perfect tool to easily monitor a person's health condition. In this type application, as well as in several other critical applications, reliability and mobility are paramount. In this paper we propose a method, based on WSNs and mobile intra-body sensors, to accurately detect the fertile period of women on time and other applications based on intra-vaginal temperature monitoring. In addition, our proposal also includes intra-body micro-cameras to monitor the women's cervix, capable to detect related pathologies. To efficiently support this mobile multimedia application, guaranteeing reliability in a continuous monitoring mode, we make use of a new WSN paradigm based on mobility proxies.

Keywords: Body Sensors, Mobility; Multimedia; Proxies; Wireless Sensor Networks.

Reference

Bibliographical Notes:

1 Introduction

Wireless Sensor Networks (WSN) are on the top of the day. Worldwide researchers from distinct areas have been projecting WSNs to cover an existent gap: the wireless access to real properties, pushing them to the virtual world, and the opposite: actuating from the virtual world in a real environment.

Based on such concept, these two worlds can be merged and countless new applications can be developed and the existing widely improved. However, from theory to practice, WSNs still present a critical drawback: the lack of performance guarantees. Consequently, the use of such technology remains well below its widely vented promises. Hence, we propose in this paper a new architecture to guarantee performance control and therefore reliability, under the most critical conditions and demanding applications. We do understand critical conditions as difficult environments where network nodes are inconstant, mobile and subject to loss of connectivity and intermittent failures. Therefore, mobility is one of the most important issues to control in WSNs. In turn, demanding applications that require specific data, like multimedia, are applied to scenarios where failures are just not allowed.

To better understand our proposal we also present a real scenario, part of an ongoing project, which combines all these requirements.

The remaining of this paper is organized as follows. Section II introduces mobility in WSNs, presenting the background and stressing its impact in critical and multimedia applications. Section III introduces our proposal of proxies to guarantee a performance controlled of nodes, under any situation. Section IV presents an intra-vaginal sensor for collecting temperature and an intra-body sensor for cervix image capture. It also includes the deployment scenario, which combines the most demanding requirements in WSNs. Performance evaluation of the intra-body sensors is presented in Section V and Section VI concludes the paper.

2 Mobility in WSNs

2.1 The Background

There are three different classes of mobility in WSNs: sink mobility, node mobility, and user mobility.

The main objective of mobility of the sink, in Wang *et al*. (2005) and Tong *et al*. (2003), is to avoid the high cost of maintaining long multi-hop paths. The sink supports the movement across the network, increasing the coverage and decreasing the multi-hops to reach each node (Shah *et al*. (2003), Chakrabarti *et al*. (2003), Somasundara *et al*. (2004), Ekici *et al*. (2006), Akkaya *et al*. (2007) and Raja *et al*. 2009)).

The mobility of node, as presented in Dantu *et al*. (2004) and in Euisin *et al*. (2007) is associated with movement, caused by any external property (wind or water), or as a characteristic of the own node. Mobility can be achieved natively or by attaching it to a mobile body. Independently of the mobility type, mobility of nodes can also increase the network coverage, being presented several energy-aware algorithms capable to coverage the area.

Sometimes the phenomenon also presents some type of mobility. Others times the user is mobile (Kim *et al*. (2007)). Although the mobility of users can be considered from different points of view, it is split into two main types. The first type considers the existence of a traditional infrastructure network, so that the mobile user connects to the Sink Node through any external point (like in the Internet). The second type, independently of the application, considers a non-infrastructure network, where Mobile Users can walk freely within the sensors field, allowing the direct communication between nodes and users, without the intervention of the Sink Node.

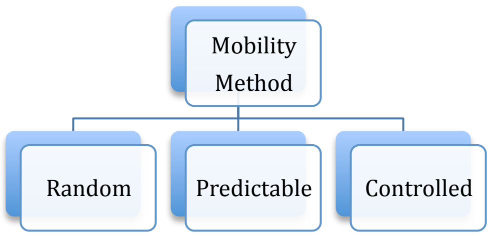
The specific case of node mobility can even be detailed in two sub-groups:

- A sensor node moves within sensor networks, called an intra-sensor-network mobility;
- A sensor node moves across multiple sensor networks, called an inter-sensor-network mobility;

We consider a network as a set of interconnected nodes sharing a common identifier, a network id or a network address prefix. All nodes are able to communicate with each other, considering that all are on-link. Nodes can perform intra-mobility when they are moving but remaining the common identifiers, or inter-mobility when new global identifiers are being acquired along the path.

It is also possible to conclude that in WSNs there are three types of mobile behaviour: random, predictable and controlled. Figure 1 depicts them.

Figure 1 The three types of mobile behaviour in WSNs.



2.2 Multimedia and critical application

So many times pointed as the interface between the virtual and the real world, WSNs still a quite far from the desired when the question is reliability. Heath, Military, Transports, Agriculture or Industries are just examples of crucial areas where WSNs could play an important role. However, when the application is considered critical, traditional solutions have been delaying the implementation of these particular networks.

To accomplish with the majority of requirements mobility of nodes must be supported. Even the most critical application, in general, requires the support of mobility.

Besides that, multimedia might also be desired and crucial to the application, as presented by Akyldiz *et al.* (2007). Hence, to promote the real success of WSNs, it is important to guarantee reliability even under mobility and in the presence of multimedia applications.

In critical application one of the most important requirement is the guarantee of data delivering on time, leading to a scenario of performance controlled. In the presence of mobility, to support such, it is necessary to assure soft and fast handoffs, ensuring no packet losses and controlling the latencies during the movement. Multimedia application, in turn, can survive to controlled packet losses but not to uncontrolled latencies. Therefore, critical and multimedia applications considering mobility of nodes, demand performance controlled to achieve the so desired reliability. In order to support such, the next section presents a new model to control the performance of WSNs in the presence of mobility.

3 The Sensor Mobility Proxy Model

Packet loss and latency are key factors in critical scenarios. In order to support controlled latencies and zero packet losses in the presence of mobility, soft handoff is the solution. Soft handoff means that mobile nodes are capable of communicating with more than one sink node at a time. Thus, if one link is broken, a mote still maintains connectivity through the other one. However, the establishment and maintenance of more than one connection by a single mote can be energetically expensive. Therefore, to solve this problem, our proposal includes a new entity called a Sensor Mobility Proxy (SMP). On the other hand, as one of the aims of the proposal is to be in line with 6lowPAN (Bormann and Mulligan (2004)), all of the proposed mobility mechanisms are based on Mobile IPv6 (Johnson *et al*. (2004)).

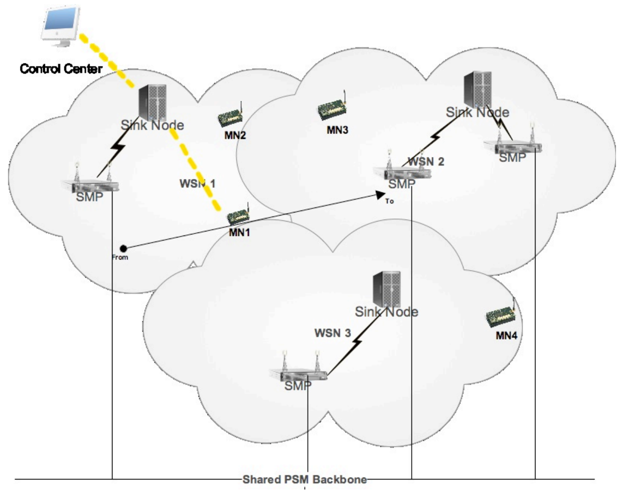
In our proposal, each WSN must be equipped with at least one SMP. A shared SMP backbone connects all existing SMPs located in adjacent WSNs. Each SMP is also connected to the local sink node. SMPs are responsible for a variety of tasks, namely movement detection, best sink node selection, route optimization (RO) and return routeability (RR) presented in Johnson *et al*. (2004). Besides that, SMPs can also be used to support node and service discovery, as well as security mechanisms.

With SMPs, mobility is transparent to sensor nodes. Therefore, they don't spend any energy in executing mobility or handoff procedures. Figure 2 depicts a basic SMP scenario.

In this figure, three distinct WSNs are illustrated, each one with one sink node, at least one SMP and several users to whom sensor nodes (MNs) are attached. The figure also illustrates the shared SMP backbone, as well as the connection between SMPs and sink nodes. The scenario also includes a 'control centre', which is the entity executing the critical application.

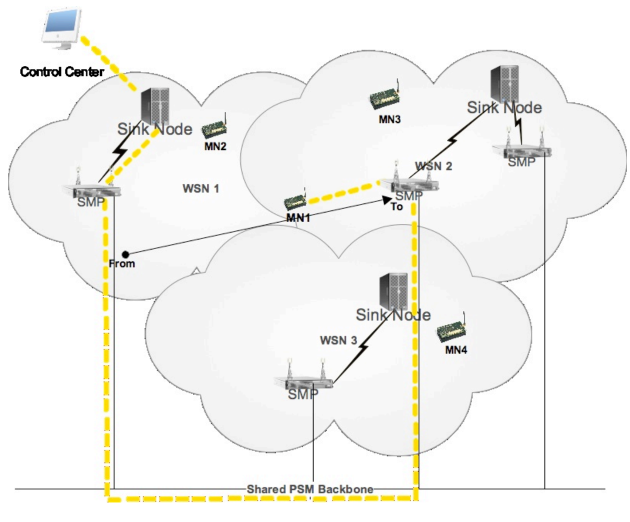
While moving towards WSN2, the link quality between MN1 and its sink node is naturally becoming worse and there will be one point where it will break, as determines Silva *et al*. (2009). The entity whose responsibility is to monitor such situation is the SMP, which, working in promiscuous mode, is able to monitor all activity in its local network. SMPs keep information on all local MNs' link quality, determine when soft handoffs should occur, and execute the necessary procedures through the shared backbone. Figures 3 and 4 depict the process.

Figure 2 PSM based WSN.



During node movement, SMPs agree, via the shared backbone, on which of them is in the best condition to serve the mobile node. Then, MIPv6 handoff procedures are performed between the best SMP and the sink node, simultaneously guaranteeing efficiency and reliability. During handoff, communication is guaranteed through the SMPs and the shared backbone. The handoff process comprises: a) registering the MN in the new sink node binding table, b) reporting the CoA to the home sink node and c) performing the Return Routeability procedure, in order to guarantee an efficient and secure new path between the MN and the Control Center (shown in Figure 4).

Figure 3 Securing communication via the PSM shared backbone.

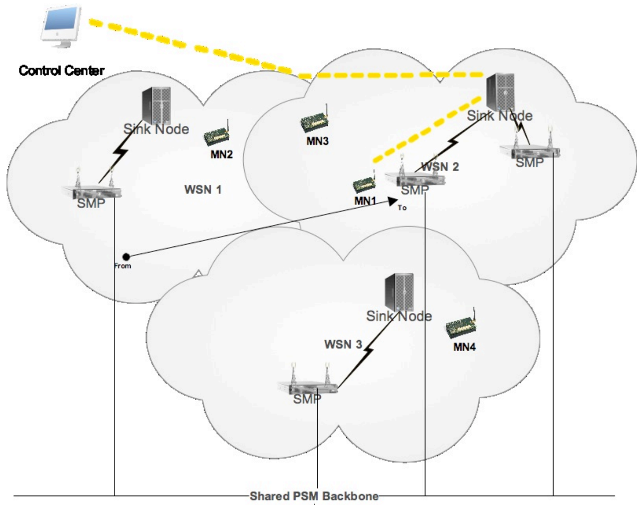


Soft-handoff is in this architecture supported by the switch order of connection. The connection of Figure 3 will only be broken upon the connection of Figure 4 is well established and operating fine.

Thus, with SMPs, mobility is smoothly supported and therefore it is possible to guarantee the control of latencies and packet losses, required by critical and multimedia applications.

The next section presents a real scenario where mobile nodes are applied in a critical application, supporting also multimedia data.

Figure 4 Communicating after performed the RR.



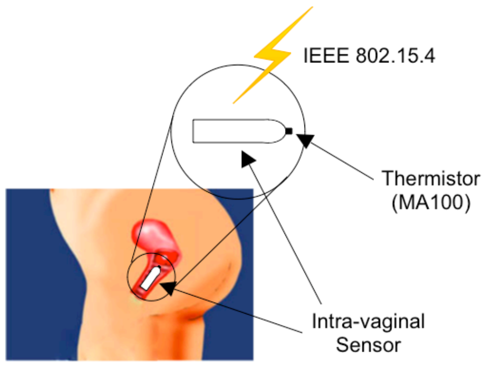
4 Deployment Scenario

4.1 Intra-Body Sensor Description

Body temperature variations in healthy women are highly correlated with women's body stages. For instance, women's core-body temperature increases about 0.5 ºC (centigrade degrees) when their menstrual and fertile periods occur. Medical studies refer that skin temperature changes with environment temperature, as defined in Brengelman (2000) and Compbella(2008). So the acquisition of skin temperature in detection of these symptomatic stages can lead to wrong interpretations. Based on the identification of this problem this section elaborates on an intra-body sensor for acquisition of core-body temperature. The sensor is placed inside the vagina close to the cervix. Then, it can measure the real intra-body women's temperature achieving best results unlike other systems that only measure skin temperature, as the example of DuoFertility (2009).

The intra-body sensor collects temperature measurements in his internal storage memory following a programmed frequency. A micro SD card (up to 2 GBytes) provides the amount of internal storage memory available in the sensor. This sensor provides wireless communications through the standard IEEE 802.15.4 module. It also has an anatomical design in order to be easily placed inside vagina. The women's comfort was also a concern when the sensor was built. A tampon like shape was used for the conception and construction of this new intra-vaginal temperature sensor. This shape became the best solution because it is very anatomic and well known for women. Thus, it causes no surprise to them when they have to use it. The sensor incorporates a rechargeable battery as a power source module. Consumption requirements were carefully evaluated in the choice of all the components that incorporates the intra-body sensor. This sensor integrates an MPS430F1611 microprocessor (Texas Instrument (2009)). It is an ultralow power 16-bit microprocessor developed by Texas Instruments^{TM} (TI). The communication module is guaranteed by the use of a CC2420 single-chip (Textas Instrument/Chipcon (2009)). It is a low-power 2.4 GHz IEEE 802.15.4 compliant RF transceiver available from TI. The core-body temperature is measured using an MA100 NTC (Negative Temperature Coefficient) type thermistor (BD (2009)). This thermistor, from GE Industrial Sensing, was exclusively developed for biomedical applications. To connect this thermistor was used one of the ADC channels available in the MSP430F1611 microprocessor. Previous versions of this intra-body sensor were presented in Neves *et al*. (2009) and Rodrigues *et al*. (2009). Figure 5 shows the operation place of the intra-body sensor for acquisition of intra-vaginal temperature measurements.

Figure 5 Illustration of the working place of the intra-vaginal temperature sensor.



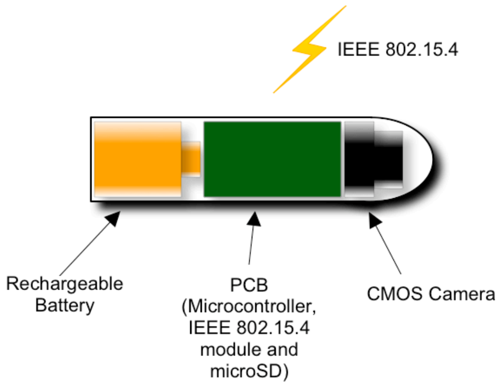
4.2 Multimedia Intra-body Sensor Application

The inclusion of multimedia modules in the intra-body sensor may increase its features in new applications for medical diagnosis. The integration of a micro-camera, as an additional module in the intra-body sensor, to capture images from the women's cervix, helps medical staff in the diagnose of some related pathologies, namely the cervix cancers. Thus, the incorporation of this image capture module, in the intra-body sensor, was considered in order to get visual contact with vagina's inside. Medical team can analyze real-time images, transmitted by the intra-body sensor. The features available in this sensor are the same described for the intra-body sensor for intra-vaginal temperature acquisition. It has also the same shape and dimensions. The same IEEE 802.15.4 standard communication module performs the transmission of the captured images. The configuration of this sensor is presented in Figure 6.

A roll of new medical applications in WSNs is presented every day. Here, a practical implementation of a WSN with mobility in a hospital scenario is described.

Intra-vaginal women's temperature variations are highly refereed in medical and eHealth references, as for instance, in Ngalamou *et al.* (2002) and Beaudoin and Marrocco (2005). As above-mentioned, it changes depending on some women's symptomatic stages. Detection of these variations is critical for women's healthcare. It is more important when it cares to pregnant women. The detection of an abrupt increasing of intra-vaginal temperature, for pregnant women, could prevent preterm labors. Medical studies will also carry out in detection of some behavior patterns that can correlate the variations on this biological parameter with unknown females pathologies.

Figure 6 Design concept of intra-body sensor for image capture.



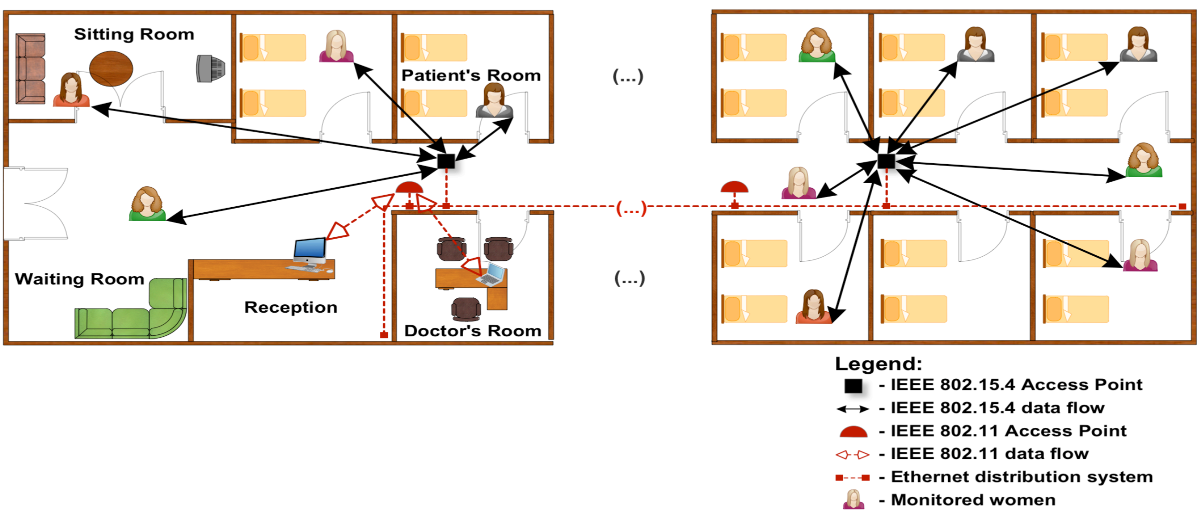
4.3 Scenario Description

This work, carried out in a hospital infirmary, has monitored several hospitalized women. Each woman carries an intra-vaginal sensor placed inside her cervix for temperature collection. The system allows remote access to real-time monitoring of intra-vaginal temperature in each sensor. A WSN was designed for a hospital infirmary to allow the system reaching each one of the sensors. The proposed scenario was based on a typical implementation of a WSN with SMPs. Several IEEE 802.15.4 access points should be placed along the infirmary to cover all its area by an IEEE 802.15.4 wireless network. These access points should aggregate all the intra-vaginal sensors in their range detection and adding SMP functionalities. The system interacts with sensors allowing women moving along the infirmary and always under monitoring in real-time. If women move out the covered area, the intra-vaginal sensors continue collecting data (the intra-body temperature) on their internal storage memory. These data could be easily accessed at any time later by medical staff once women were in the WSN range detection.

The access to the local network of the infirmary (using Ethernet technologies), was made throw a wireless communication. The above-mentioned IEEE 802.15.4 access points are connect to this network that also implements the shared SMP backbone. Furthermore, several IEEE 802.11 access points also offer wireless connection to the local network in all the infirmary area. Medical staff uses an IEEE 802.11 connection to the existing IEEE 802.11 network to access the intra-vaginal temperature sensors.

The same scenario was also used for testing the above presented intra-body sensor for image capture. It is possible to transmit images inside vagina to a given computer using the WSN provided in the infirmary. The scenario implementation is presented in Figure 7.

Figure 7 Experimental scenario in a hospital infirmary.



In this given scenario, it can be identified several IEEE 802.15.4 access points that also act as a bridge between the IEEE 802.15.4 wireless network and the Ethernet local network. Along the infirmary there are several IEEE 802.11 APs that provides Ethernet access in all infirmary area to the medical staff. Medical staff access intra-vaginal sensors, placed inside women's cervix, through an IEEE 802.11 connection using personal computers or laptops available on the infirmary. The IEEE 802.15.4 network was extended to all the infirmary area using several IEEE 802.15.4 access points.

5 Performance Evaluation

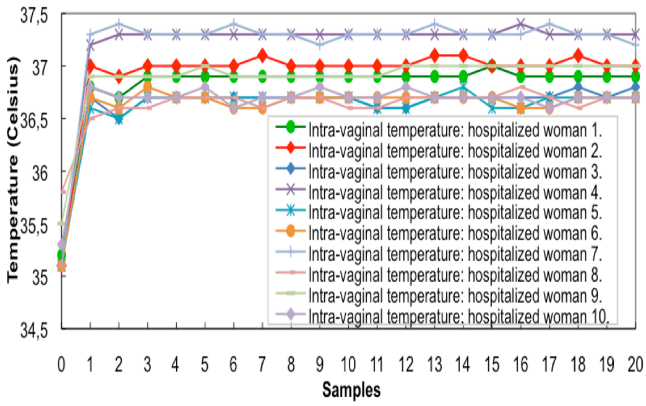
The evaluation, in terms of accuracy, of the intra-body sensor measurements was only possible by the medical confirmation and validation of the captured values. This validation was performed by the use of redundant and certified systems for temperature acquisition. Simultaneously, to the intra-body sensor temperature acquisition, traditional methods were used to confirm the obtained values by this one. A basal digital thermometer was used, as a traditional method, to get intra-vaginal temperature in each woman.

As redundant confirmation a standard digital thermometer was used to get the body temperature under the arm and under the tongue for the same women (at the same time). The collected temperature values were then compared to the ones collected by the intra-body sensor. After that, the correspondent match was confirmed. Thus, the accuracy of the values, obtained by the intra-body sensor, was validated.

Medical team also evaluates the quality of the images captured by the intra-body sensor for intra-vaginal visual contact. The characterization of visual patterns of some vaginal diseases may contribute for the identification of this kind of pathologies with images captured by this intra-body sensor. This proposal is very helpful for the detection and monitoring of cervix diseases, namely, the cancer of the cervix. It was monitored ten women, hospitalized in the infirmary. Each woman was monitored for about ten hours with a sample rate of five minutes between each measure. Periodically it was performed a real-time access to the temperature measurements of each woman in a doctor's laptop. This procedure was performed remotely, as above-described. It uses the WSN access to the respective intra-body sensor (placed inside the selected women's vagina) through an IEEE 802.11 connection. Moreover, a central computer installed in the infirmary, received in real-time (continuous mode) all the values collected by all the intra-body sensors available on the WSN range detection.

The achieved results are presented in Figure 8. It shows the measured temperature of the intra-vaginal sensor, in form of samples. These results were obtained in the above-described scenario from the 10 monitored women.

Figure 8 Intra-vaginal temperature samples in 10 hospitalized women collected with intra-body sensors.



Each curve of the Figure 8 represents a set of the first 20 samples for each monitored women, out of the 120 values collected during the 10 hours of the test. Two main parts can be distinguished in this figure. First goes from sample 0 to sample 1 and it represents the sensor response, i.e., the time that the thermal sensor needs to get the real environmental temperature. The second part can be identified from sample 1 to 20. It corresponds to the real temperature values of the women's intra-vaginal temperatures.

By the analysis of this sample, medical team could confirm that each woman has her own intra-vaginal temperature pattern. It was also possible to confirm that, for these women, their core-body temperature changes between values from 36.3 ºC to 37.3 ºC. The continuous monitoring of this biological parameter, for each woman, helps on definition of her intra-vaginal temperature standard pattern. Thus, can lead to identify possible problematic situations, in a given woman, if this parameter goes out of the previously defined pattern. An elevation on this biological parameter can also indicates that the woman is in her fertile or ovulation period, as previously mentioned. In the figure can be noted that two women had their intra-vaginal temperature over the 37.1 ºC. It was confirmed, near these women, by the medical team, that they were in their fertile period at the time of the performed test. Thus, the use of this intra-body sensor can help women in detection of the occurrence of these periods. This knowledge can help them in both get pregnant or avoid it, once these periods have the greater probability to get pregnant.

6 Conclusions

An efficient and reliable support of mobility and multimedia application are still cornerstones in Wireless Sensors Networks. In this paper we proposed new network architectures capable to support both, providing the required guarantees. Based on proxies capable of doing the critical tasks on behalf of motes, we can guarantee controlled latencies and no packet losses, supporting thus the major requirements of multimedia application while soft and smooth handoffs are performed.

Applied to a specific and critical application, our solution is ideal to be applied in controlled environments such as at home or other indoor spaces. With intra-body thermo sensors and multimedia intra-body micro-cameras we can assure with high level of reliability that women will not only know accurately when they are in the most fertile period, but also when any anomaly or known pathology is detected.

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