Use of GPS and 6LowPAN in Mobile Multi-Sink Wireless Sensor Networks - Issues and Feasibility

Ricardo Silva *, Jorge Sá Silva *, Claudio Geyer #3, Valderi Leithardt #4, Fernando Boavida *

* Department of Informatics Engineering
Faculty of Sciences and Technology, University of Coimbra
Polo II, 3030-290 Coimbra, PORTUGAL
1rnsilva@dei.uc.pt, 2sasilva@dei.uc.pt, 5boavida@dei.uc.pt

# Sistemas Largamente Distribuidos, Universidade Federal do Rio Grande do Sul, Instituto de Informatica
Av. Bento Goncalves, 9500-Campus do Vale
Bairro Agronomia - Porto Alegre - RS - BRASIL
3claudio.geyer@gmail.com, 4vrqleithardt@inf.ufrgs.br

Abstract—Wireless Sensor Networks (WSNs) have been the subject of intensive research in the past few years. Several factors have contributed to this, among which the enormous potential for application of WSNs in almost every aspect of day-to-day life is the predominant one. In spite of this, real deployments of WSNs are rare, and virtually all have considerable limitations when node mobility is concerned. Clearly, there is a mismatch between research and reality, and work on deployment, localization, mobility and other hot topics is not producing useful results, which points to the need to give smaller, more practical steps towards real world deployments. This paper is about such a step, by proposing an integration of heterogenous localization techniques, for which single-hop communication, Mobility and 6LowPAN are cornerstones. The paper discusses several issues of the proposal and provides experimental data in support of its feasibility.

I. INTRODUCTION

It is expected that host, device and network mobility will be common in the near future. The same can be said from sensors and wireless sensor networks. Numerous applications of mobility, of WSNs and of their combination can be foreseen and, in fact, are being proposed, developed and studied at the moment.

LowPAN characteristics allow a dynamic network where nodes, considering the application requirements, can play different roles. Nevertheless, energy rationalization to extend the network lifetime has been the researchers main focus. Optimized low power transceivers, CPUs and sensors have been developed [1][2] as well as energy aware routing protocols [3], mobile agents [4] [5] and optimized duty cycle schemes. Natively, Wireless Sensor Networks were not designed to support any mobility. The defined standard for physical and MAC Layer is the IEEE802.15.4, special designed for low power wireless personal networks. Even considering WSNs as a lowPAN, they are a quite different from the first lowPANs. Autonomous devices constitute WSNs and mobility is a desired feature. Several approaches, regarding WSNs, also include mobility. However, mobility is not really supported and existent solutions are not reliable. As to overcome some network constrains (energy, communication range, etc) as caused by the application nature, mobility is now unavoidable.

Mobility of WSNs nodes opens many interesting possibilities. Using mobility it is possible to support optimal location for monitoring, adaptive sampling, network repairing and event detection. Furthermore, mobile sensor networks overcome some of the constraints of static WSNs, leading to improved connectivity and maximization of network lifetime. Mobility of sensor nodes can also be a solution for the bottleneck problem in data gathering in sparse sensor networks. Furthermore, multiple controlled mobile elements can be used to provide load balancing for gathering data in WSNs [6].

Although the recognized potential of using mobility in WSN, apart from the connectivity support, application can suffer from several problems. The most critical case happens with nodes localization. Traditionally, nodes were static and therefore well-known algorithms could easily and at once, locate them. However, regarding mobility, nodes can move, following defined or undefined patterns, which means that tracking and advanced localization mechanisms are now required.

In this paper we propose and study mobility in WSN with localization and tracking in mind. The main objective of this work is at this level to study how feasible is the use of GPS in Mobile WSNs running on 6lowPAN. To support this study we present also a use case related with the GINSENG Project, in which we are involved.

Hence, the root of this procedure will be the use of: 1) multi-sink single-hop operation in order to reduce and/or eliminate routing problems; 2) use of GPS in sensor nodes together with traditional localization algorithms; and 3) use of 6LowPAN, in order to provide increased and enhanced IP connectivity to sensor nodes.

The remainder of this paper is structured as follows. Section 2 presents the rationale for the multi-sink single-hop approach used in the current proposal. Section 3 presents a survey about
mobility in WSNs, stressing the challenges caused by such behavior. Section 4 presents the use case included in the FP7 European Project GINSENG. Section 5 addresses feasibility aspects, by presenting some experimental results concerning the cost of using GPS and 6LowPAN in WSNs. Section 6 presents the conclusions and guidelines for further work.

II. MULTI-SINK SINGLE-HOP APPROACH IN WSNs

Two basic types of topologies can be used in WSNs: Single-sink multi-hop topology, also known as mesh topology, and multi-sink single-hop topology, also known as star topology.

In mesh topologies, all sensor nodes perform not only sensing tasks but also routing tasks, forwarding data towards the sink node through neighboring nodes. This precludes the need for using multiple sink nodes. In addition, several pieces of work, of which [7] is an example, show that multi-hop communication is more energy-efficient when compared to long-range single-hop communication, due to the fact that mesh topologies lead to shorter distances between transmitter and receiver. These factors have led to the fact that almost all research work has concentrated on mesh topologies.

However, the apparent energy optimization of mesh topologies comes with too high a price, which is at the basis of the failure of real world WSN deployment: extreme complexity at various levels. In fact, mesh topologies require aggregation methods, signaling messages, increased memory, broadcast procedures, substantial overhead, complex routing protocols and/or large routing tables. This complexity is more critical in mobile environments. The dynamics of these environments causes changes in the network topology and, therefore, in routing, which leads to additional complexity and overhead.

Naturally, a mesh topology can be transformed into a star topology if several sink nodes are deployed, each covering a relatively small cell comprising several sensor nodes. In this case, energy-efficiency of sensor nodes can still be achieved distances to a sink node can be kept small and, in fact, node nodes can be simpler, as they do not need to forward packets or to perform complex routing tasks. The price to pay is the deployment of more sink nodes, but clearly in many cases it is easier to deploy more sink nodes than to use forbiddingly complex routing protocols.

However challenging and interesting might be the routing problem in mesh-based WSNs, the hard fact is that most (if not all) real applications of WSNs use a star topology. The reason is that with a star topology, the routing complexity disappears, and simple routing solutions can be adopted. Besides that, also the localization algorithms become more simple and efficient when only single-hop is considered. In such case, the possible area where a specific node is located is limited to the range of the Sink Node whereby that node is communicating at a specific moment. Furthermore, the simplest localization algorithm based on triangulation is thus possible to apply and much more efficient. This is, in fact, the rationale for using a multi-sink single-hop approach to support mobility in WSNs, presented in the next section, and therefore to make easier the process of tracking and localization.

III. MOBILITY IN WSNs

Mobility in Wireless Sensor Networks can be classified in three main different fields: Mobility of the Sink, Mobility of the Node and Mobility of the User.

[8] and [9], among others, introduced Sink Nodes mobility, arguing that a sink node serving each node or cluster, closer, would save nodes energy. The objective was to avoid the high cost of maintaining long multi-hop paths. Sinks Mobility might be characterized by three modes, namely: Mobile Base Stations (MBS), Mobile Data Collectors (MDC) or Rendezvous-Based Solutions.

With Mobile Base Stations the same Sink Node is capable to move across the network, increasing the coverage and decreasing the multi-hops to reach each node. [10] recently evaluate sink mobility performance stressing the difference between network topologies and mobility types. Mobility methods are mentioned in several papers and are the follow: random, predictable and controlled. Random mobility means that elements (sink, sensor, user) move randomly in the space. Predictable means that the element moves in a specific path in a specific time. Finally, controlled mobility means that the element movement is controlled in real-time.

Figure 1 schematizes the mobility methods.

![Mobility Methods](image)

Mobile Data Collectors (MDC), in turn, reflects the capacity of the more powerful nodes (Sinks or other) to perform on demand collection, avoiding data travel through several hops. [11] introduced the concept of Data Mules, where mobile sinks move randomly collecting data across the network. [12] presented a predictable solution where the trajectory of the Mobile Data Collector is known but uncontrollable, while [13] introduces a real-time controlled MDC.

Rendezvous-Based solution is a hybrid of both solutions: MBS and MDC [14]. Instead of uncontrolled mobility or on demand data gathering, [15] proposed a careful mobility/positioning of the Sink Node in order to better reach the network. The same author also introduced the capability to dynamically change position, readapting to the network changes.

Mobility of Node, the second type of mobility, is classified in two modes [16]: weak mobility and strong mobility. Weak
mobility is the mobility forced by the death of some network nodes. Due to their own characteristics nodes have limited lifetime, trending to die. Consequently, new nodes must be added to replace dead nodes.

Strong Mobility, in turn, is the type of mobility associated with the movement caused by any external property (wind or water), or caused by an intrinsic characteristic of the own node. Mobility can be achieved natively or by attaching to a mobile body. An example of native mobility of nodes is Robomote [17], a sensor node mechanically adapted with wheels, designed for easy deployment and low cost. Robomote was also equipped with two engines, one IR sensors to detect obstacles and a sun-powered rechargeable battery. Although the recognized potential of Robomote, the majority of the existing applications are based on nodes attached to mobile bodies. In [18] this question is deeply detailed, using real types of parasitism to classify the possible association between motes and mobile bodies.

Independently of the mobility type, [19] and [20] introduced mobility of nodes as a capability to increase the network coverage, being presented several energy-aware algorithms capable to coverage the biggest possible area. Therefore, mobile routes for mobile nodes must be established, assigning the coverage of a specific area to a specific node. Mobility algorithms were developed to achieve the best path to run the network area.

Mobility of users within a sensor network is the last type of mobility approached in the WSN context. Although, the mobility of users can be considered from different points of view, it is split in 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. This second type has been target of several studies. Those studies aimed to achieve an optical solution to guarantee an efficient movement detection and data delivering from the Sink to the Mobile User [21]. Nevertheless, other studies have presented quite different approaches, whose objective is to allow the direct communication between nodes and users, regardless the Sink Node intervention [22]. Therefore, still considering the node within the sensor field, these solutions avoid the routing optimizations problematic and insufficient range from Sinks to Users.

Figure 2 shows the mobility scheme, partitioned by mobile elements and respective types presented before.

Wireless Sensor Networks (lowPANs in general) and mobility have also appeared associated to localization methods. [23], [24] and others, have present solutions based on well known methods, as references, signal strengths or triangulation systems, exploring deployed WSNs to track entities or just to localize nodes and construct a network map. However, these mechanisms induces to some errors, based on which [25] and [26] propose the use of difference estimation, combining difference correction methods with estimation methods. Additionally other techniques have appeared trying to reach the required accuracy, considering its balance with the energy required to achieve it. Localization methods can thus be used to detect or track any mobile sink, node or user. Figure 3 summarizes the different approaches presented above.

As it was possible to realize, there is a huge trend to WSNs be dynamic. Controlled, Random or Predictable mobility of Nodes, Sinks or Users brings a huge challenge not only for communication protocols but also for localization and
therefore deployment and topology control. The existent localization algorithms aren't capable to support the majority of those activities. Advanced methods like measuring distances based on RSSI, Time Difference of Arrival (TDoA), Angle of Arrival (AoA) among others might not be sufficient to guarantee efficiently the right position of a mobile body (sink, node or user).

Besides the problem of localization, the most critical issue is the impact of so many possible movements first in the deployment control and later in the topology control. Considering controlled orpredicted mobility, it is possible to project the deployment and to monitor the network operation during its lifetime. However, in the presence of random mobility, even performing a controlled deployment, is tremendously complex and heavy to control the network topology or even to monitor or track the network devices. Looking again at figure 3, from those 17 different applications for mobility, more than 50% assume random mobility. In front of such scenario, tracking devices using localization methods based on traditional wireless features, might not be efficient and reliable as required. For instance, imagine a sparse network where nodes are constantly moving by open and close spaces, in groups or individually. The existent localization methods designed for WSNs are not sufficient to guarantee the tracking, in such scenario, as reliable or accurate. For that reason, in this paper we study the feasibility of using GPS, in a future attempt to combine this well-known technology with the localization algorithms developed for WSNs.

To better support this issue, the next section presents a real case study, required in the scope of the European Project GINSENG, where localization in random nodes are highly required.

IV. USE CASE

The case study presented in this section is part of a global solution that is growing within the scope of the European project GINSENG. GINSENG aims to provide a performance controlled WSNs, being the main target the GALP oil refinery, located in Sines, Portugal.

Within the scope of the GINSENG Project, mobility is a requirement associated to the employees monitoring scenario. Employees within the refinery area are constantly under dangerous situations, when in or even out of the considered hazardous areas. Therefore, it is extremely important to monitor the state of such people, guaranteeing not only their health condition, but also guaranteeing that if any uncommon situation is detected the system triggers immediately an alarm and the employee can be assisted as fast as possible.

To support such application, it is necessary that employees are equipped with specific sensors to monitor their vital signals. Moreover, it is necessary to guarantee that all sensor nodes are always connected independently of their localization. Hence, a solid infrastructure network supporting mobility is crucial. To do so, accomplishing with section II of this paper, multi-sink nodes must be deployed guaranteeing total coverage of the required area. Employees, independently of their activity and type of movement must be always on-line with the system, and therefore localizable.

Figure 4 shows a basic scheme of the scenario. As figurative, the background of the image is the Petrol refinery of Galp in Portugal, where this scenario will be applied. As we can see there are several employees sparse through the refinery and under different physical conditions. Although using Multi Sink-nodes, their connectivity is different from place to place.

To assist the employees as fast as possible it is extremely important to know where they are located. To support such, localization algorithms are required. However, as mentioned before, this is a case where employees move randomly and through very different scenarios (close or open spaces). Thus, our objective is to find an efficient solution to track and localize employees independently of their situation. The Multi-Sink environment presented in section II and shown in figure 4, is a valid help to restrict the possible area where a specific node can be. Nevertheless, the Sinks’ range is unknown and therefore, such limited area can be bigger than the desired, and therefore the rescue take more time.

To solve that question we are thus considering a cross-technology system, using indoor based localization algorithms when possible and GPS in outside scenarios. However, the use of GPS in WSNs, regarding energy consumption, is unknown and therefore we don’t know how feasible it is. For this reason we evaluated, over real platforms, the battery behavior of a Wireless Sensor Node when working with GPS. The next section presents our evaluation and the obtained results.

V. FEASIBILITY ASPECTS

In the previous section, a specific and real use case where random mobility in WSNs is present was shown. It is important, nevertheless, to assess the impact of the design paradigm at the base of the proposed solution: multi-sink single-hop topology, use of GPS and use of 6LowPAN.
In respect to the former aspect, it is clear that multiple sink nodes lead to smaller distances between sink and sensor nodes, thus creating the potential for less energy consumption. More important than this is the fact that they create an environment where all sensor nodes are one hop away from a sink node, which simplifies the localization process. This topology is, in fact, the one that, in practical terms, is used in real world deployments of WSNs.

Regarding the other two aspects GPS and 6LowPAN the following subsections address their use and feasibility in WSNs, from an energy consumption perspective.

A. GPS in WSNs

Up to some years ago, the energy requirements of GPS systems were not compatible with their use in WSNs. However, current technology makes the integration of GPS in sensor nodes possible.

Although use of GPS in WSNs is not new, little or no evaluation of its impact on energy consumption has been made. With this in mind, we performed some experiments with the aim of assessing the energy requirements of using a commercial GPS solution in sensor nodes.

We used Crossbow equipment: Micaz and mib520 modules. For the GPS support we used MTS420/400CC. We began the experiments by comparing the energy required by a sensor that was periodically monitoring its battery level with and without the GPS system.

The MTS420CC board is composed of several digital sensors which allow the measurement of temperature, humidity, pressure and light. It also includes an analog accelerometer and a GPS receiver provided by uBlox, the LEA-4A. MTS420CC is the newer version of this board family. The older versions, like MTS420CA/CB, also provide the same features. However, in the GPS case, they use a different receiver the LeadTek GPS9546.

The Crossbow platforms only support TinyOS version 1. Neither of these boards have an official driver for TinyOS version 2. In general, there is no guarantee of its functionality over TinyOS-2.x. However, for versions CA/CB, i.e., using the GPS receiver from Leadtek, there was a contribution provided by Rincon Research Corporation, which can be adapted.

After having studied and analyzed all implementation code for versions CA/CB, we started the adaptation task. Hence, as the next step, we studied both datasheets, in order to adapt the Rincon code to the MTS420CC board. This was a very low-level task and required the adaptation of connection settings, including adaptation of the baud rate to 9600 bps instead of the 4800bps of Leadtek and Nmea. After that, the driver for MTS420CC, adapted from the Rincon driver for versions CA/CB, was installed and worked successfully. The GPS receiver could then read the position and send an Nmea packet toward the base station.

The objective of this study was to turn on the GPS receiver and to test its impact on the battery consumption of the mote. To evaluate such parameter, one mote was programmed to read the battery level and the GPS values, and send them toward the base station at each 5 seconds. All battery values were measured in mV, according to the sensor datasheet.

Figure 5 presents the voltage level drop in the tested mote during one hour. The voltage level dropped from 2852.68mV to 2820.55mV, which means a total drop of approximately 32.13 mV. After that, the same mote, with the same AA batteries, was programmed to measure only the battery level at each 5 seconds. Figure 6 shows the result. The motes voltage level dropped from 2820.55 mV to 2795.37 mV, that is, a total drop of 25.18mV in one hour. When comparing this value with the 32.13mV of the previous experiment, it can easily be seen that the impact of GPS on the battery consumption is very modest, representing an additional 8 mV voltage drop.

B. GPS with 6LowPAN in WSNs

Recently the IETF launched the 6LowPAN working group [27] with the aim of studying the transmission of IPv6 packets over low capability devices in wireless personal area networks, where WSNs are included, using the IEEE 802.15.4 standard. This group proposes a thin sub-layer that compresses the IPv6 header to a maximum of 2 bytes.

Although the impact of 6LowPAN is expected to be low, the fact is that the integration of IP in WSNs has already motivated heated discussions and debates. If, on the one hand,
WSNs are energy limited and the TCP/IP stack is too complex, on the other hand the use of a thin version of IP can have several advantages. The integration of IP and sensors can be the basis for transparent communication between nodes and for providing Internet connectivity, thus eliminating the need for translation gateways. This integration will be more needed in mobile environments. With the aim of determining the impact of using 6LowPAN, with and without GPS, several experiments were carried out. The conditions used in these tests were similar to the ones described in the previous subsection. One mote, using AA batteries, was programmed, firstly to report the battery value and the GPS data, and secondly to report only the battery value. In both tests the mote performed its tasks periodically, every 5 seconds, during one hour. The driver developed for MTS420CC was also applied to 6lowPAN.

Figure 7 presents the results for the 6LowPAN with GPS case, while the results for 6LowPAN without GPS are depicted in Figure 8. Figure 9 summarizes the overall obtained results.

![MTS420CC + MicaZ + 6lowPAN with GPS](image1)

**Fig. 7.** MTS420CC + MicaZ + 6lowPAN with GPS

![MTS420CC + MicaZ + 6lowPAN without GPS](image2)

**Fig. 8.** MTS420CC + MicaZ + 6LowPAN without GPS

Using the MTS420CC with 6lowPAN and GPS causes a voltage drop of 2878.79 - 2795.25 = 83.54mV per hour. It is a significant value, but when compared to the voltage drop of 2789.20 - 2734.39 = 54.81mV of Figure 8, where the mote just reported its battery value, we can conclude that GPS did not provoke a considerable voltage drop.

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**VI. CONCLUSION**

WSN deployment is far behind what it should be expected. The main cause of this is the complexity of theoretical models coming out from current research, namely in what concerns communication, localization and mobility.

In this paper, mobility for WSNs was studied considering its impact on localization methods. Based on a real and actual use case, we demonstrated how much problematic can be this question. Trying to solve the problem we approached a model built on simple and feasible paradigms and approaches, in order to ease implementation and deployment, and to bridge the gap between theory and practice. These are the use of multiple sink nodes in order to achieve single-hop communication, the extension of localization mechanisms using GPS and, last but not least, use of 6LowPAN for enhanced connectivity.

The contributions of the paper are the approached model itself, the obtained experimental results that confirm the feasibility of the proposal, notably in what concerns the use of 6LowPAN and GPS.

Further work will address the evaluation of the approach in scenarios and applications as real as possible. In addition, further evaluation and optimization of 6LowPAN functionality will be carried out, as this is considered crucial for the future of wireless sensor networks. Further study and optimization of GPS in WSNs is being planned, as well as the integration in the presented use case. Finally, development of additional
WSN applications for outdoor and indoor environments capable of taking advantage of the integration of GPS with conventional localization algorithm, will also be addressed.

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