Service Management in Wireless Sensors Network

Linnyer Beatrys Ruiz [1,2], Thais Regina M. Braga[1], Fabrício A. Silva[1]
José Marcos S. Nogueira[1], Antônio Alfredo F. Loureiro[1]

[1]**Department of Computer Science**
Federal University of Minas Gerais
Belo Horizonte, MG, Brazil

[2] **Department of Informatic**
Pontifical Catholic University of Paraná
Curitiba, PR, Brazil

{**linnyer,thaisrb, fasilva, jmarcos,loureiro**}**@dcc.ufmg.br**

Abstract. *Wireless Sensor Networks (WSNs) are becoming an increasingly technology that will be used in a variety of applications. However, until now, WSNs and their applications have been developed without considering a management solution. In this paper, we have evaluated a management architecture for WSNs, called MANNA, where the service and configuration management are analyzed. We focus on a class of hierarchical and heterogeneous WSNs where sensor nodes collect data and send them to an observer continuously along time. The cost of sending data continuously may lead to a more rapid consumption of the scarce network resources and, thus, shorten its lifetime. However, this is an important kind of WSN and we show that the use of some management services proposed by MANNA did not affect the network behavior and can improve the performance metrics depending on the configuration. At the observer, the management application monitors the Quality of Service. Accuracy, latency, coverage area, and energy consumption are proposed as important parameters in our case study.*

Keywords: wireless sensors network management, MANNA architecture, service management, performance management, configuration management, self-managing.

1 Introduction

A Wireless Sensors Network (WSN) consisting of a large number of sensor nodes deployed over an area and integrated to collaborate through a wireless network, encourage several novel and well existing applications such as environmental monitoring, infrastructure management, public safety, medical, home and office security, transportation, and military [3, 4, 5, 6]. A WSN is composed by very compact and autonomous sensor nodes, each containing one or more sensor devices, computation and communication capabilities, and limited power supply.

Energy is a critical resource in WSNs. Thus, all operations performed in the network should be energy-efficient. Topology may be dynamic because sensor nodes can become out of service temporarily or permanently (nodes can be discarded, lost, and destroyed, or even run out of energy) and new ones can be added to the network. Sensor nodes execute a common application in a cooperative way (i.e., there is clearly a common goal in the overall network), which may not be the case in a traditional network.

A WSN is a tool for distributed sensing of one or more phenomenon, and reporting the sensed data to one or more observers. It is basically composed of two parts: physical network (constitutes of the physical equipments and software) and services. A service is something offered by an user of the network for another user. A WSN provides services for the observer(s) as well as for itself. It produces and transports application data.

Until now, WSNs and their applications has being developed without considering an integrated management solution. In this paper, we propose service management for continuous, hierarchical and heterogeneous WSNs using MANNA – a management architecture (self-managing) for WSNs proposed in [9].

The task of building and deploying management systems, in environments where there will be tens of thousand of network elements with particular features and organization, is very complex. This task becomes worse due to the physical restrictions of the unattended sensor nodes, in particular energy and bandwidth restrictions. The approach used in the MANNA architecture deals with complex management situations by decomposing a problem into smaller sub-problems, in successive refinements steps. This architecture considers three management dimensions: management functional areas, management levels and WSN functionalities. In this paper, we work with the configuration management and performance management in service level, considering WSN functionalities of the configuration and maintenance. In particular we analyze the performance management aspects and evaluate the impact of management services and functions over a WSN.

The management application to be build depends on the kind of application being monitored. In our study, the application that runs in the WSN monitors some parameters that define the air quality such as temperature and carbon monoxide (CO). In this case, the service management must be used in determining how, when and where the application data was produced. The configuration (in terms of the sensor capabilities, number of sensors, density, distribution, self-organization, self-optimizing, and data dissemination) plays a significant role in determining the performance of the network. As such, the performance of the network and provided service are best measured in terms of meeting the accuracy and delay requirements defined by the observer, as well as consumed energy. Additional performance metrics include coverage area, exposure, goodput, cost of the sensors, scalability, and produced data quality.

In performance management there is a trade-off to be considered: the highest the number of managed parameters, the highest the energy consumption and the lowest the network lifetime. On the other hand, if parameter values are not obtained, it may be not possible to manage the network appropriately. The management challenge is to perform this task without adversely consuming network resources.

The rest of this paper is organized as follows. Section 2 briefly discusses the WSNs services. Section 3 describes the MANNA management and discuss how the MANNA architecture can cope with continuous WSNs. It also presents the functional, information, and physical architecture, towards the WSN application defined. Section 4 introduces the management application using the MANNA management services. The simulation model used in our experiments is described in Section 5 and the experimental results in Section 6. Finally, our concluding remarks are presented in Section 7.

2 WSN Service Management

A WSN is used to monitor and eventually control an environment. WSN service management introduces new challenges due to scarce network resources, dynamic topology, large amount of network elements, and associated problems with reliable data delivery.

WSN services are concerned with functionalities (see the upper part of the Figure 1(a)) associated with application objectives. The main services are sensing, processing, and dissemination. A priority for one service can be to minimize energy consumption, and for other service can be to minimize delay or maximize accuracy. We focus on a class of hierarchical and heterogeneous WSNs where sensor nodes collect data and send them to an observer continuously along time. The cost of sending data continuously may lead to a more rapid consumption of the scarce network resources and, thus, shorten its lifetime.

WSNs have inherited the typical problems of wireless networks, including a high percentage of communication data loss and difficulty in controlling energy consumption. Topology changes could affect the available bandwidth. Because of the broadcast characteristic of the radio transmission, the transmission among neighboring nodes could interfere with each other. The available bandwidth varies with the surrounding environment, such as how many neighboring nodes are contending for the transmission channel. Reliable data delivery is still a open issue in the context of WSNs.

Due to the dynamic topology and the constraints, mainly energy, quality of service (QoS) in WSNs is a challenging task. Components involved in QoS support include *QoS models*, *QoS Sensing*, *QoS Processing*, and *QoS Dissemination* which establishes resource reservation signaling, QoS routing (finds a path which satisfies given QoS requirement), and QoS Medium Access Control (MAC) (solves the problem of medium contention, and supports reliable unicast communication) [12]. A QoS model specifies an architecture in which some kind of services could be provided in WSNs. All other QoS components, such as QoS Sensing, QoS Processing, and QoS Dissemination (signaling, QoS routing, and QoS MAC) must cooperate together to achieve this goal.

One of the objectives of the proposed management application is getting and managing the link state information for monitoring QoS. This is very difficult because the quality of a wireless link is apt to change with the circumstances, such as residual energy, nodes distribution, and density (all these change along the network lifetime). We are interested in performance metrics (delay, goodput, energy consumption) and in quality of the produced data considering different configurations of the network (such as clusters number, number of nodes per cluster, density). Configuration characteristics such as coverage area, density, network organization, node deployment (distribution), exposure (time, distance and angle between sensor and phenomenon), latency, and communication range may degrade accuracy of produced data.

We consider the coverage area and accuracy as other metrics relevant in data delivery. S. Meguerdichian [6] defines *coverage area* as a measure of QoS for WSN. In the worst-case coverage, attempts are made to quantify the quality of service by finding areas of lower observability from sensor nodes and detecting breach regions. In the best-case coverage, the management application has to find areas of high observability from sensors and identify the highest accuracy.

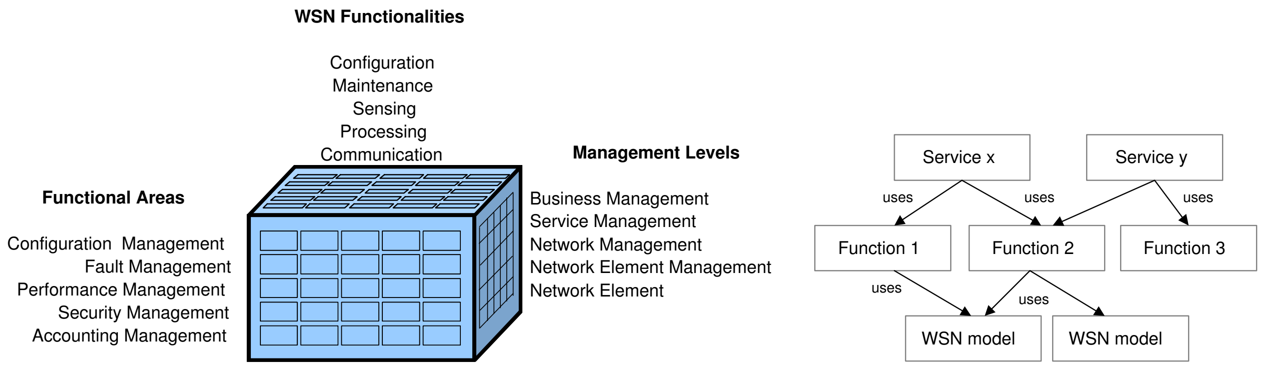
A *denser* network will lead to a more effective sensor network because of the higher accuracy in the network (areas of gather intersection, redundant information) and fault tolerance. On the other hand, this will lead to a large number of collisions and potentially congestion in the network, increasing latency and reducing energy efficiency. Congestion control must not only be based on the capacity of the network, but also on the accuracy level required at the observer. The traffic in a WSN is different from conventional networks. It is a collective communication operation with redundancy. Thus, the management application has the flexibility of meeting the performance demands by controlling the reporting rate of the sensors, controlling the virtual topology of the network (by turning off some sensors), or optimizing the collective reduction communication operation (by data aggregation). In some applications, besides the information about some feature of the phenomenon, it might be necessary to know where (sensor location), when (data–time) and how (sensor calibration and exposure) to manager the WSN performance.

In this work, we design a network with high node density and use the density control management function to turn off redundant nodes. The provision of QoS relies on resource reservation. When the active node goes out of service (due to operational problems), the management application active redundant node, defining a sort of resource reservation scheme. In case of a low density, the network coverage area can be committed affecting the quality of the service. We consider that we are applying resource reservation.

3 MANNA Architecture

The MANNA architecture [9] was proposed to provide a management solution to different WSNs applications. It provides a separation between both sets of functionalities, i.e., application and management, making possible the integration of organizational, administrative, and maintenance activities for this kind of network.

The approach used in the MANNA architecture works with each functional area, each management level, and proposes a new abstraction level of WSN functionalities (configuration, sensing, maintenance, processing, communication) (see Figure 1(a)). As a result, it provides a list of management services and functions independent of the technology adopted. Management services are executed by a set of functions, and they need to succeed to conclude a given service. The conditions for executing a service or function are obtained from the *WSN models*. The WSN models, defined in the MANNA architecture, represent state abstraction of the network and serve as a reference for the management. Figure 1(b) represents a scheme to construct the management, starting at the definition of both management services and functions that use models to achieve their goals. In this work, we use *automatic* services and functions, i.e., executed by



(a) Management Abstractions in MANNA (b) Services, Functions and WSN Models

Figure 1: Approach Used in the MANNA Architecture.

a manager or an agent invoked as a result of information acquired from the WSN models. This is called self-managing. The MANNA architecture also proposes two other types of services: *semi-automatic* and *manual*.

Locations for managers and agents, and functions they can execute are suggested by the *functional architecture*. The MANNA architecture [9] also defines two other architectures: *physical* and *information*.

In the following, we study the service and performance management for a *continuous* WSN and discuss how the MANNA architecture can cope with this kind of network and present the functional, information, and physical architecture, towards the WSN application defined.

Functional Architecture. In the architecture, it is possible to have a diversity of manager and agent locations. The management choice depends on the functional areas involved, the management level considered, and the application running in the WSN, i.e., depends on the network functionalities (Figure 1(a)). In this work, we consider performance and configuration management (functional area) and service management (management level). We have considered a heterogeneous and hierarchical WSN application as a case study. In a hierarchical network, nodes are grouped into clusters. In a heterogeneous network, the cluster-heads have more resources and, thus, are more powerful than the common nodes and are responsible for sending data to a base station (BS). In our implementation, the management agents execute in the cluster-heads and a manager is located externally to the WSN (see Figure 2). The cluster-head performs aggregation of management and application data, which decreases the information flow and energy consumption as well.

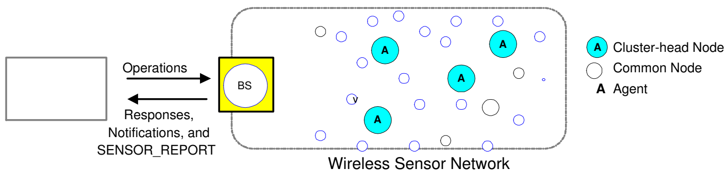


Figure 2: Manager and Agents Location in Management Application.

The main management services executed are *coverage area maintenance*, *network operating parameters configuration*, and *QoS monitoring*. A partial list of the management functions employed in the experiments, in no particular order, is: monitored area definition, node deployment, node self-test, node discovery location, self-organization, density control [10], topology map discovery, aggregation, energy map generation, production map generation, management operation schedule, node operating state control, node administrative state control, and coverage area map generation. The management services, the management functions and management types provided by the MANNA architecture are described in [9].

Information Architecture. In this study, some used object classes are: network, managed element, equipment, observer and phenomenon. We also used some WSN models, such as: network topology (represents the topology map and the reachability of the network), residual energy (represents the remaining energy in a node or in the network), sensing coverage area map (describes the actual sensing coverage map of the sensor elements), communication coverage area map (describes the present communication coverage map from the range of transceivers), cost map (represents the cost of energy necessary for maintaining the desired performance levels), production map (represents which nodes are producing). The information model provided by the MANNA architecture is described in [8].

Physical Architecture. There has been little routing and link protocols for WSNs with available code for simulation and that provide robust dissemination through the use of multi-path data forwarding. Besides, for all them the correct reception of all data messages is not assured [11]. Unlike traditional networks (e.g., IP networks), reliable data delivery is still open search question in the context of WSNs. In this work, we decided to use UDP, IEEE 802.11, and AODV (Ad Hoc On Demand Distance Vector Routing). Between the base station and cluster-heads we use SNMP for the application layer but between common node and cluster-head we use a new lightweight protocol, MNMP (MANNA Network Management Protocol) which we designed.

4 Management Application

In the management architecture, we define how the management entities receive and analyze information and react to it. In our case study, we adopt the external manager which has a global vision of the network and can perform complex tasks that would not be possible inside the network. The performance management in the *service level* involves how, where and when the data were produced. The performance management in the *network level* involves accuracy, goodput and latency. In the *network element level*, the performance is affected by the accuracy of the sensing hardware (transducer), size of memory (the buffering space), battery capacity, capabilities of the embedded processor (determinate the level of optimization that is possible at the sensors without introducing excessive loss of power or intolerable delay), and characteristics of the transceiver (determinate the transmission range of the network and the capacity of the transmission channel).

The proposed management application is divided into two phases: installation and operation. The installation phase occurs as soon as the nodes are deployed in the network. In this phase, each node finds out its position in the area and reports it to the agent located in the cluster-head. The agent aggregates this information and sends a POSITION TRAP of its location to the manager. The common nodes also inform their energy level that the agent aggregates in an ENERGY TRAP, and sent to the manager. The management application builds automatically all needed WSN models based on both local information and data sent by the agents, i.e., the *WSN topology map* and *the WSN energy map*. These two models are used to build the *WSN coverage area map*, which the manager uses to monitor the sensing and communication coverage area, and to calculate the density of the network. The MANNA architecture propose a *coverage area maintenance service* and a *density control function* which can reduce system overall energy consumption, therefore increasing system lifetime, by turning off some redundant nodes in dense networks. This service preserve the sensing coverage with minimum sensing hole and maintain the system reliability. To execute this service management, the manager send a SET operation to change the administrative state value of the node attribute and set a wake up interval. When detecting minimal levels of energy or uncovered areas, the management application activates the backup nodes. The management application also implements a *network operating parameters configuration service*. The manager consults the topology map and adjust the transmission power (communication range) of the cluster-heads. The nearest cluster-heads from the BS will have a reduced range, saving energy.

In some context of WSNs, applications are loss tolerant concerning the data that flows from nodes source to cluster-head, and from cluster-head to base station, called SENSOR–REPORT. On the other hand, management is loss and delay intolerant concerning the data (e.g., POSITION TRAP). For example, the loss of a single message associated with a cluster-head would render imprecise maps. In our experiment, we evaluate the goodput, latency and accuracy of the management and application data, i.e., performance evaluation.

In the operation phase, while the sensor nodes are performing their functions, i.e., collecting and sending temperature and carbon monoxide level data, management activities take place. Among them, energy level monitoring plays a central role. Each node checks its energy level and sends a message to the agent whenever there is a operational state change. This information is transmitted to the manager through a ENERGY TRAP. Any information the agent receives is recorded in its MIB (Management Information Base). The manager can, then, recalculate the energy and topology maps, as well as the coverage area, which characterizes the coverage area maintenance service. When the common node has the critical energy level (less than 10%) it sends a DELETE TRAP which is directly sent to manager (without processing aggregation). The manager receives DELETE TRAP, it tries to activate backup nodes.

The management application uses the production map to manage the quality of service. In a continuous application, when the management application stops receiving SENSOR–REPORTs from a given node, this may be an indication of a problem. Thus, the manager consults the energy map to verify if it has residual energy. If so, the manager detects a production problem and sends a QoS notification to the observer. In this way, the MANNA architecture provides performance monitoring in continuous WSN with associated cost only to TRAPs and some SETs sent because the management takes advantages of the features of the network to obtain management information indirectly.

5 Simulation Approach

In our application, the carbon monoxide level and temperature are the monitoring objects. The nodes sense the phenomenons and disseminate the data continuously along the time. In order to simulate the phenomenons behavior of the environment, random numbers were generated considering a standard deviation of 1, from a temperature interval of 22°C to 32°C and carbon monoxide (CO) level between $30.000\mu g/m^3$ and $50.000\mu g/m^3$. We consider a regular deployment in three distinct kind of network hierarchical organization.

Our aims were to evaluate the impact of the network configuration over the performance and services, and to evaluate the impact of the management application over the WSN latency, goodput and energy consumption. For this, six scenarios were defined and simulated in respect to distinct network configuration and management application:

-scenario1: 16 clusters, 9 common nodes per clusters, 10% redundancy, without management.
-scenario2: 12 clusters, 12 common nodes per clusters, 10% redundancy, without management.
-scenario3: 9 clusters, 16 common nodes per clusters, 10% redundancy, without management.
-scenario4: 16 clusters, 9 common nodes per clusters, 10% redundancy, with management.
-scenario5: 12 clusters, 12 common nodes per clusters, 10% redundancy, with management.
-scenario6: 9 clusters, 16 common nodes per clusters, 10% redundancy, with management.

We have defined a WSN application and some management functions, as mentioned before, and evaluated using the Network Simulator (ns-2) [7], version 2.1b9a. The results presented have a 95% confidence interval. In the scenarios evaluated, we considered the following variables:

Network. It comprises 144 common nodes which are distributed in uniform manner upon the monitored area (115m x 95m) and there is more 10% redundant common nodes. The nodes are organized in clusters. Each cluster will have a cluster-head. Protocols: IEEE.802.11, AODV, SNMP, and MNMP.

Common nodes [1]. Bandwidth: 50kbps, transmission power: 0,036J, reception power: 0.0054J, communication range: 40m, processing power (active: 0.0165J, idle: 0.0048J, sleep: 0,00006J), sensing power (temperature sensor: 0.0006J, carbon monoxide sensor: 0.001J), sensor range: 6m, battery capacity: 0.8J, without mobility.

Cluster-head nodes [1, 2]. Bandwidth: 50kbps, transmission power: 1.176J, reception power: 0.588J, communication range: 140m, processing power (active: 0.0165J, idle: 0.0048J, sleep: 0.00006J), battery capacity: 40J, without mobility.

We are interested in service level performance, conventional network performance metrics, such as throughput, are of secondary interest.

6 Simulation Results

One of the major goals of network management is to promote productivity of the network resources and maintain the quality of the provided service. In this section, we investigate the effect (tradeoff) of the management architecture MANNA on the performance of a WSN. We present the results for the performance metrics accuracy, delay, energy efficient, and goodput. In order to investigate influence of the configuration, we conducted all experiments with three types of hierarchical and heterogeneous WSNs configurations, with and without management.

Accuracy. The accuracy of a measurement at a *network element* is specific to the physical transducer, the nature of the phenomenon, and the exposure. The accuracy at a *network level* depends on the delay in data delivery due to network congestion, the duty cycle of the sensors, or aggregation processing of sample data. The accuracy at a *service level* depends on the metric chosen by the application for establishing the coverage area and amount of energy to be spent in gathering and disseminating data. At the observer, it is likely that multiple samples will be received from the different sensor nodes, producing data quality. For the defined application, depending on network latency and uncover area percentage, the data received by the observer may be of no value and should be discarded.

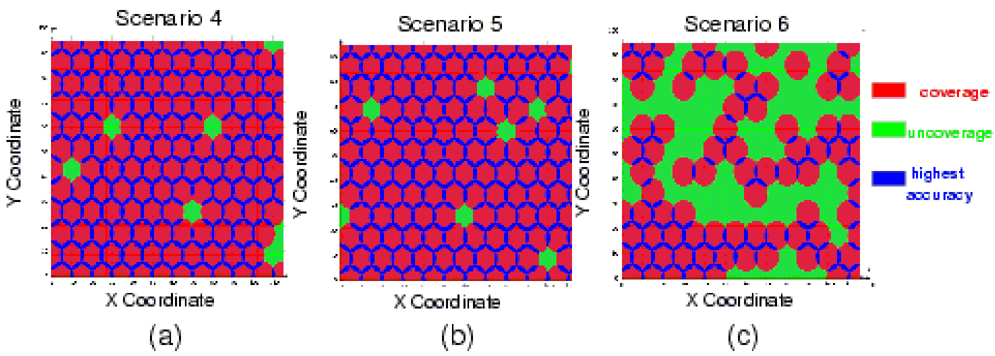


Figure 3: Coverage Area Map at time simulation 31s for the Scenario 4, 5, and 6

It is expect that increasing the number of sensors per clusters results in better accuracy and lifetime. Since there are more sensors in a position to report on the phenomenon, the accuracy of the sensing gets better. The available energy within the network increases and the additional sensor density offer the potential for a better connected network with more efficient paths between the sensor nodes and the observer(s). Nevertheless, increasing the number of sensor nodes per cluster implies in a higher number of nodes disseminating their results per unit time. The problem can be viewed in terms of collision and congestion. For the continuous update reporting model (all sensor report continuously), we study the effect of the number of clusters and number of nodes per cluster. Figures 3 and 4 exhibits the coverage area map (WSN model defined by MANNA) at 31s and 121s of simulation. There are three types of the observability areas: uncoverage, coverage, and coverage intersection (highest accuracy). The uncoverage area in the Figure 3(a) and (b) is significantly smaller than in the Figure 3(c) at 31s. There are more intersection areas in the Figure 3(a). At 121s, the network is not unavailable and the little coverage areas (see Figure 4) are related to the backup nodes that were activated. If there were more available backups nodes, the management application could promote the extension of the network lifetime. This difference can also be observed in the Figure 5 which shows the data delivery for produced data. At 31s of simulation, the scenario 5 has the better delivery rate (91.94%) and the scenario 4 has 90.21% while in the scenario 6, only 66% of the application data is delivered. In time 50s, the scenarios 6 have percentage of data delivery, 92.21% due to late messages that arrived. After 100s of simulation, the major part of the common nodes had already goes out of service permanently due to energy level. There is about 8% of nodes producing, which are the activated backup nodes.

The question is: Why the coverage area and data delivery are different at 31s in the Figures 3(a), (b) and (c)? We

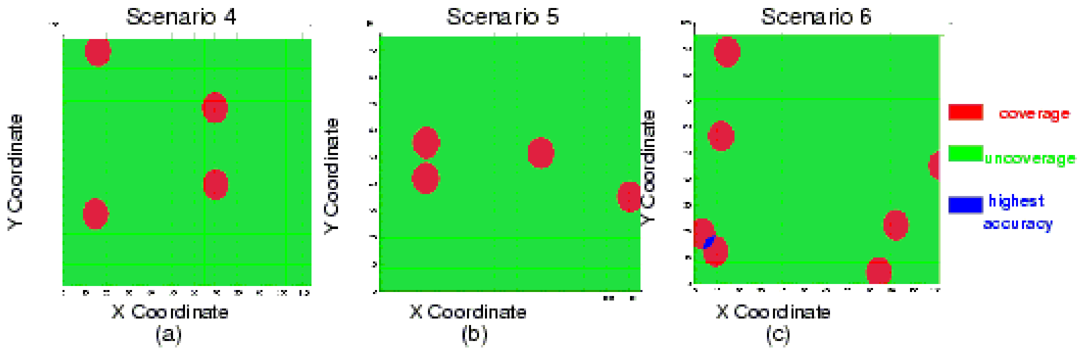
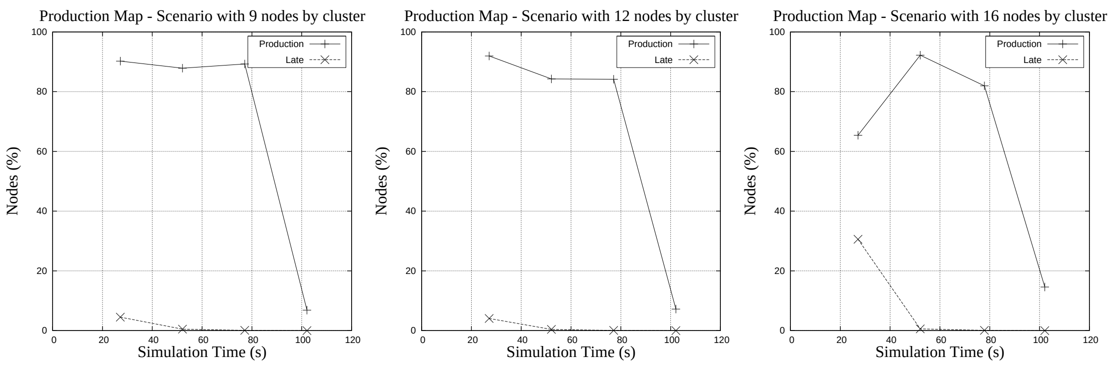


Figure 4: Coverage Area Map at time simulation 121s for the Scenario 4, 5 and 6

can notice that the number of clusters and the cluster size has influence in this metric since the amount of generated messages by the common nodes and protocol stack are the same. Figure 5 also shows the rate of late data packets per simulation time. This rate for scenario 6 is quite greater than the value for scenario 4 and 5, because of the higher number of common nodes per cluster in the former. The delay varies with the number of nodes changing messages, i.e., the transmission among neighboring nodes interferes with each other.



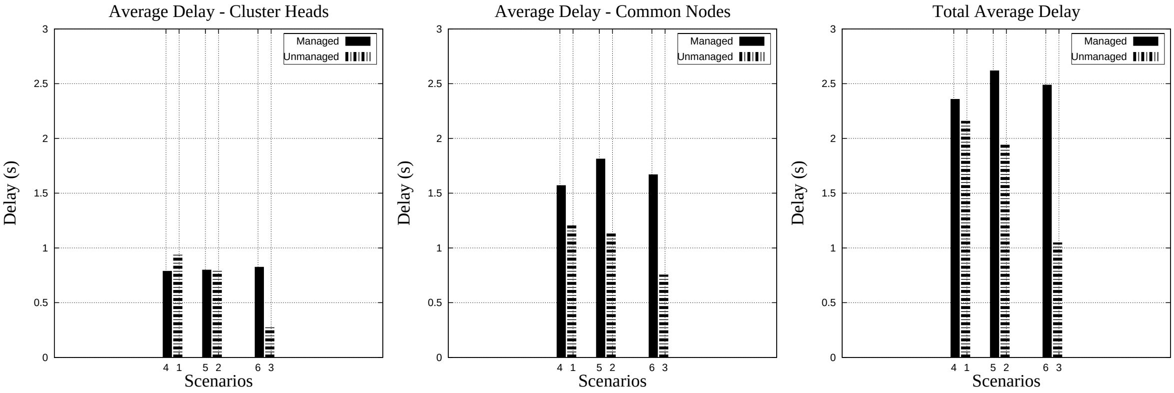
(a) Data Delivery in Scenario 4. (b) Data Delivery in Scenario 5. (c) Data Delivery in Scenario 6.

Figure 5: Delivery rate of Produced Data.

Delay. We observed the effect of increasing the number of sensor nodes per cluster on the data production (delivery) and coverage area. Now, we study the reason why the coverage area map and data delivery is different for scenarios 4, 5 and 6. Observing the Figure 6, two kinds of delay can be considered for the purpose of analysis, which are, the message delay between the agents (cluster-heads) and the manager (see Figure 6(a)), and the communication delay between the agents (cluster-heads) and the common nodes (see Figure 6(b)). In Figure 6(a), the delay of scenario 1 (9 nodes per cluster) is higher because there are more cluster-heads disputing the media. Using management, the performance is better because of the configuration of the transmission power of the cluster-heads, relating it with their distances from the BS. The nearest cluster-head from the BS will have a reduced range, saving energy. In Figure 6(b), the delay acts in a similar way for all the scenarios. The delay with management is higher because of the messages sent by the nodes to inform their positions, in the installation phase and residual energy, along the operating phase (see Section 4). At the end of simulation, the delay is a bit higher too, once the nodes that has a critical level of energy send a DELETE TRAP. The agent does not make an aggregation of this TRAPs. In this case it considers this information as a high priority one and repass it directly to the manager. Without the aggregation service, the number of disseminated messages is quite high, resulting in collision and loss. Due to the configuration characteristics, there are scenarios in which the cluster-heads process a greater number of messages.

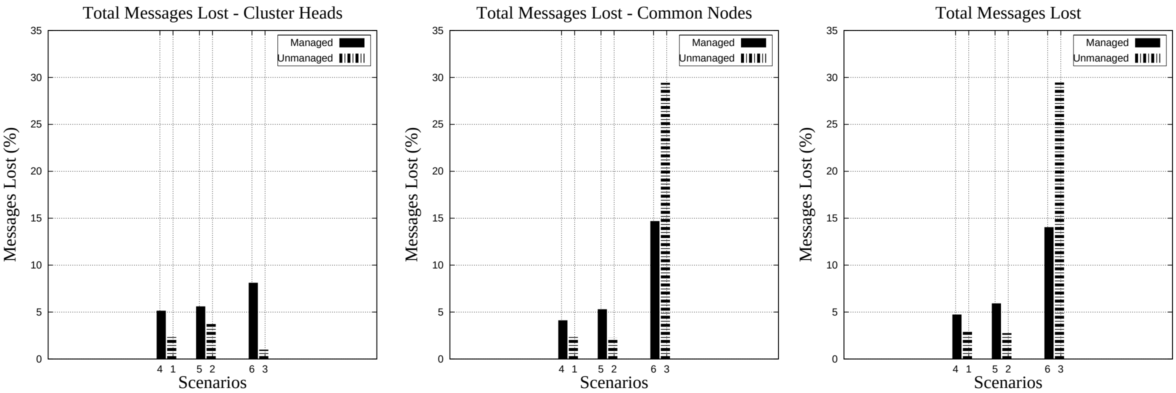
In performance management there is a trade-off to be considered: the highest the number of managed parameters, the highest the management cost (Figure 6(c)). On the other hand, if parameter values are not obtained, it may be not possible to manage the network appropriately.

Goodput. Goodput is the ratio of the total number of packets received by the observer to the total number of packets sent by all the sensors over a period of time. Figure 7(a) shows that the message loss for scenarios 1, 2, and 3 are smaller than the values for scenarios 4, 5, and 6. The difference is 2.7% between scenarios 1 and 4, 1.8% between scenarios 2 and 5. Between scenario 3 and 6, the difference of the lost messages is 7%. In this case, it is possible to notice that with management there is a greater message loss than without it. This difference is due to largest number of produced messages by management application (SETs and TRAPs) and the bidirectional flow (from agents to manager



(a) Delay Agent. (b) Delay Common. (c) Total Delay.

Figure 6: Delay for Hierarchical and Heterogeneous WSNs without and with Management.

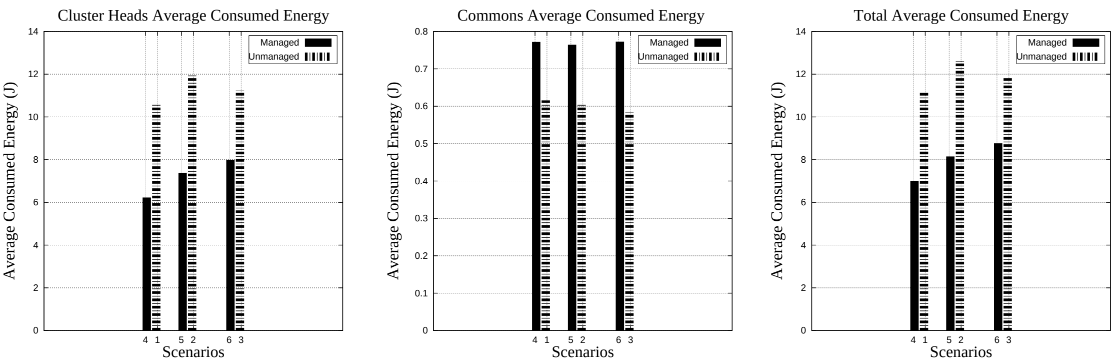


(a) Agent Lost Message. (b) Common Nodes Lost Message. (c) Total Messages Lost

Figure 7: Lost Messages in all Scenarios.

and from manager to agents), which is not the case in the scenarios without management. Besides, in the scenarios with management, there are three entities producing and sending data, manager, agents and common nodes. Figure 7(b) shows the total number of lost messages for the common nodes. The nodes had to transmit more messages with the management, resulting in a bigger number of messages that congested the media, causing messages to be lost. For the scenario 3, the 16 common nodes per cluster without management cause more collisions than scenarios 1, 2, 4, 5, and 6.

In Figure 7(c), it is observed that the scenarios with a bigger number of nodes per cluster, and consequently, smaller number of agent nodes, have a higher total message loss in respect to the number of messages lost inside the clusters. We can notice that management contributes only a small increase in the total lost messages (scenarios 4 and 5) but concerning the scenarios 3 and 6, the management contribute to reduce the total messages loss. We can also notice that the introduction of the management has little impact on this metric.



(a) Cluster-heads (b) Common Nodes (c) Total Consumed Energy

Figure 8: Consumed Energy for Scenario 1, 2, 3, 4, 5, and 6.

Energy-Efficient. Energy is a critical resource in a WSN. In Figure 8(a), we verify that the management provided an energy economy. In Figure 8(b), in terms of common nodes energy consumption, the management consumed more energy. In Figure 8(c), we observe that the management accomplishes with its purposes, contributing to prolong the network life time. Comparing the graphics in Figure 8, we observe that the management of the configurable parameters, promote the network productivity, reducing the energy consumption of the cluster-heads. Considering the common nodes, the energy consumption is distributed in an uniform manner in respect to the application network characteristics. Scenarios 4, 5 and 6 that uses the management, have some nodes, spread along the area, with more residual energy than the others. They are the backup nodes and again, if the application had more nodes like this, the network life time could be extended.

7 Conclusion and Future Work

Environmental monitoring represents an important class of sensors network applications. Many kinds of observers are interested in the sensor data, like public and private companies. Therefore, the WSNs must provide the data of interest in a confidence-inspiring manner.

Management of WSNs is a new research area that only recently started to receive attention from the research community. In this sense, this work presents a contribution to the field, since it proposes the service management using the MANNA architecture which is based on traditional framework of functional areas and management levels. The adoption of this strategy will permit management integration in the future.

In our experiments, we were able to build the models for the WSN topology map, WSN energy map, WSN coverage area map, cost map, and WSN production map. These models are important in different applications specified and designed for WSNs.

Probably the fundamental issues about management of WSN are concerned on how the management application promotes resources productivity and quality of the services. Nevertheless, an important aspect is to verify the impact of the management services over the WSN lifetime, latency, goodput and coverage area. The important point that needs to be stressed is that the introduction of the management services in our experiments did not affect the network behavior considerably. The management reduced the total energy consumption, although it had represented a difference in the number of lost messages and delay in the common nodes. Of course, there is a cost associated to the network management and, at the end, the benefits brought by this solution may outweigh the cost paid.

In agreement with intuition, the results show that increasing the cluster density can result in higher accuracy, but only if the sensing traffic is kept below the network capacity. A WSN specific protocol stack could be used to make the network behavior and consequently the simulation more adequate. Other management services, management functions and management types defined by the MANNA architecture can be implemented.

Acknowledgement

This work is partially supported by Brazilian National Council for Research (CNPq), process n$^o.55.2111/2002-3$.

References

[1] The Commercialization of Microsensor Motes. Available in http://www.sensorsmag.com.

[2] WINS – Wireless integrated network sensors. Available in http://www.janet.ucla.edu/WINS/.

[3] B. R. Badrinath, M. Srivastava, K. Mills, J. Scholtz, and K. Sollins. Special issue on smart spaces and environments. *IEEE Personal Communications*, October 2000.

[4] D. Estrin, R. Govindan, and J. Heidemann. Embedding the Internet. *Communications of the ACM*, 43(5):39–41, May 2000. (Special issue guest editors).

[5] Stephanie Lindsey, Cauligi Raghavendra, and Krishna Sivalingam. Data gathering in sensor networks using the energy delay metric. In *International Workshop on Parallel and Distributed Computing: Issues in Wireless Networks and Mobile Computing*, San Francisco, USA, April 2001.

[6] Seapahn Meguerdichian, Farinaz Koushanfar, Miodrag Potkonjak, and Mani B. Srivastava. Coverage problems in wireless ad-hoc sensor networks. In *IEEE INFOCOM 2001*, pages 1380–1387, 2001.

[7] Network simulator. Available in http://www.isi.edu/nsnam/ns.

[8] Linnyer B. Ruiz, José Marcos S. Nogueira, and Antonio A.F. Loureiro. Functional and information models for the MANNA architecture. *GRES03 - Colloque Francophone sur la Gestion de Reseaux et de Services*, pages 455–470, February 2003.

[9] Linnyer B. Ruiz, José Marcos S. Nogueira, and Antonio A.F. Loureiro. MANNA: A management architecture for wireless sensor networks. *IEEE Communications Magazine*, 41(2):116–125, February 2003.

[10] Marcos A. Vieira, Luiz F. Vieira, Linnyer B. Ruiz, Antonio A. Loureiro, and Antonio O. Fernandes. Scheduling nodes in wireless sensor network: A voronoi approach. *IEEE LCN 2003 – Local Computer Network*, October 2003(to appear).

[11] Chieh-Yih Wan, Andrew Campbell, and Lakshman Krishnamurthy. PSFQ: A reliable transport protocol for wireless sensor networks. *WSNA'02 - ACM International Workshop on Wireless Sensor Networks and Applications*, September 2002.

[12] Kui Wu and Janelle Harms. QoS support in mobile ad hoc networks. *Crossing Boundaries- the GSA Journal of University of Alberta, Vol. 1, No. 1, pp.92- 106*, November 2001.