2012 14th International Conference on Modelling and Simulation

Path Loss Effect on Energy Consumption in a WSN

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***Abstract*—Energy consumption of nodes is a crucial factor that constrains the networks life time for Wireless Sensor Networks (WSNs). WSNs are composed of small sensors equipped with low-power devices, and have limited battery power supply. The main concern in existing architectural and optimisation studies is to prolong the network lifetime. The lifetime of the sensor nodes is affected by different components such as the microprocessor, the sensing module and the wireless transmitter/receiver. The existing works mainly consider these components to decide on best deployment, topology, protocols and so on. Recent studies have also considered the monitoring and evaluation of the path loss caused by environmental factors. Path loss is always considered in isolation from the higher layers such as application and network. It is necessary to combine path loss computations used in physical layer, with information from upper layers such as application layer for a more realistic evaluation. In this paper, a simulation-based study is presented that uses path-loss model and application layer information in order to predict the network lifetime. Physical environment is considered as well. We show that when path-loss is introduced, increasing the transmission power is needed to reduce the amount of packets lost. This presents a tradeoff between the residual energy and the successful transmission rate when more realistic settings are employed for simulation. It is a challenging task to optimise the transmission power of WSNs, in presence of path loss, because although increasing the transmission power reduces the residual energy, it also reduces the number of retransmissions required.**

***Index Terms*—attenuation; path loss; wireless sensor networks; energy consumed; life time**

I. Introduction

Recent advances in wireless communications and electronics have enabled the development of wireless sensor networks (WSNs), which comprise many low cost, low power, and multifunctional sensor nodes to accomplish certain sensing tasks in an intelligent manner. A sensor network is a special type of network which generally consists of a data acquisition system and a data distribution system. The unique characteristics of WSNs in terms of data collection and energy constrains, separate them from other communication networks. In Figure 1 we show the most common techniques for performance evaluation that are analytical modelling, simulation and benchmarking. The existing studies consider benchmarking in form of test beds and measurements for real deployment. The energy constrains of WSNs, limits their processing capabilities and communication. Therefore, using one of these performance evaluation methods, and analysis of deployment and management of such complex systems is a challenging task [1].

Due to inherent complexity and diverse nature of WSNs (dynamic topology, wireless channel characteristics, mobility, density of the nodes etc.), analytical methods may become inappropriate as they require certain simplifications to model and predict the performance of the system. The simplifications may lead to inaccurate results in case of unrealistic assumptions [2],[3]. Experimental studies such as [4],[5],[6],[7] are not always practical for evaluation of systems with different architectures and under various conditions, mainly because of the difficulties in deployment of real systems. Potential difficulties associated may be deploying tens or hundreds of sensor nodes in the physical environment, program the nodes and monitor their behaviour, the high costs involved in obtaining the instrumentation and other aspects such as fault tolerance, and scalability. It is well known that when it comes to benchmarking, the results in many cases cannot be extrapolated to suit the changes in the system or environment. Hence, testing and performance evaluation of WSNs through analytical modelling, real deployment and test beds can become complex, inaccurate, time consuming and/or costly.

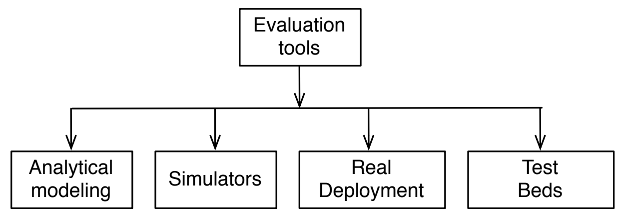

Fig. 1. Performance evaluation methods

Simulation is currently the most widely adopted method for analyzing WSNs. Simulation studies provide quicker evaluation, optimisation and modifications of the proposed algorithms and protocols at design, development and implementation stages. A number of simulation tools are available with different features, models, architectures and characteristics for performance evaluation in WSNs. Packet level simulators offer various optimisation methods for free space scenarios and avoid the effects of path loss [1] that may be caused by different obstacles. The existing studies considering path loss for WSNs on the other hand are quite conservative. The impacts of path losses are not considered, and analysed together with details in upper layers such as network and application.

In this paper, a new approach is considered to combine

[1]Path loss is the attenuation in power density of an electromagnetic wave as it propagates through space.

978-0-7695-4682-7/12 $26.00 © 2012 IEEE
DOI 10.1109/UKSim.2012.87

the path loss related issues with packet level simulation. A case study is presented which uses path-loss as well as network and application layer data in order to predict the network lifetime. Well known path loss computation models are adopted to use with a new tool, which allows the users to deploy sensors in a two dimensional abstraction of the physical environment, and to introduce obstacles. The new tool in turn communicates with well-known Castalia package and OMNET simulation environment. The energy consumption of the nodes considering the impact of path loss for different transmission powers is presented, the tradeoff between traditional performance measures such as packet loss and residual energy is illustrated. The approach presented lends itself as a flexible and efficient tool which provides a more realistic approach for analysing WSNs and evaluating the performance in terms of energy efficiency. The flexibility of abstraction provided for the physical environment, also makes it possible to use various path loss models (even experimental ones).

The rest of the paper is organised as follows: Section II considers various types of simulators. In section III, our approach is presented. Section IV provides the details of home automation application which is chosen as a case study. Section V shows the numerical results obtained. The impact of path loss on energy consumption of the nodes in a WSN is shown as well as the behaviour of nodes for different transmission powers in presence of path losses. In section VI, conclusion and future studies are presented.

II. Related Work

In this section, we consider existing simulators. They can be classified based on their level of complexity in to three main categories: Instruction, algorithm and packet level.

A. Instruction level simulators

Instruction level simulators are often regarded as emulators. They model the CPU execution at the level of instructions. TOSSIM [8], Atemu [9], Avrora [10] are well known emulators. TOSSIM is the most commonly used emulator. However, compared to other emulators, it is not the most precise one. TOSSIM, is a platform specific simulator (a TinyOS mote simulator) which can compile any code written for TinyOS to an executable file. TinyViz, is the basic GUI for TOSSIM which can visualize and interact with the running simulations. TOSSIM is specific for TinyOS applications on Mica motes sensors and do not include power models. Avora, is a java-based emulator used for programs specifically written for AVR microcontrollers produced by Amtel and the Mica2 sensor modes. Atemu provides low-level emulation of the operation of individual sensor nodes. A unique feature of Atemu is its ability to simulate a heterogeneous sensor network. It is scalable and its high fidelity platform is used as a pre-deployment tool for sensor networks.

B. Algorithm level simulators

Shawn [11], AlgoSensim [12], and Sinalgo [13], are well known algorithm level simulators with emphasis on the logic, data structure and presentation of the algorithms. They rely on some form of graphical data structure to demonstrate the communication between the nodes. Shawn is a very powerful tool in simulating large scale networks with an abstract point of view. It supports distributed protocols and generic high level algorithms. AlgoSensim focuses on network specific analysis of algorithms like localization, distributed routing, and flooding. AlgoSensim mainly facilitates the implementation and quality analysis of new algorithms. Sinalgo focuses on the verification of network algorithms and abstracts from the underlying layers. It also offers a message passing view of the network. Sinalgo can be employed for quick prototyping and verification in freely customizable network settings.

C. Packet level simulators

OPNET, Qualnet, NS-2, GloMoSim, are some of the most commonly used packet level simulators. They implement the data link and physical layers in the OSI network layers. Hence, radio models, 802.11b or newer MAC protocols, fading, collisions, noise and wave diffractions are commonly implemented. Network Simulator (NS) is a discrete event simulator written in combination of C++ and OTcl. OTcl is an object oriented scripting language, developed mainly for networking research. It provides extensive support for simulation of TCP, multicast protocols, and routing for wired and wireless networks. With protocol implementations being widely produced and developed, the extensibility of NS-2 has been a major contributor to its success. It has an object-oriented design which allows for easy creation of new protocols. The key features for WSNs include battery models, hybrid simulation support, sensor channels, scenario generation tools and a visualization tool [14]. Scalability, lack of application model and the lack of customization are few limitations of NS-2 along with lacking an application model [3]. OPNET [15] and Qualnet [16] are commercialized network simulator software with powerful standard modules and they provide good simulation environment. OPNET is an excellent choice to simulate Zigbee based networks with the implementation of Zigbee protocol and IEEE 802.15.4 MAC protocol. Qualnet performs well in simulating large scale sensor networks due to its scalability in wireless simulation, but OPNET simulation requires a long time when the number of sensors considered is large.

The above mentioned simulators use rather simple radio/channel models [17]. Also, the simulators are still platform specific and moderately scalable, making them unsuitable for protocol /algorithm design and testing. Furthermore the environmental details and especially the effects of path loss has not been considered in any of the given simulation packages.

III. Our approach

Figure 2 outlines the main components of our approach. This has been implemented in a tool called PlaceLife.

An *environment editor* allows the user to specify the physical environment by using a graphical editor. The environment can include different obstacles and different sensors. An obstacle can have different properties such as the material it is

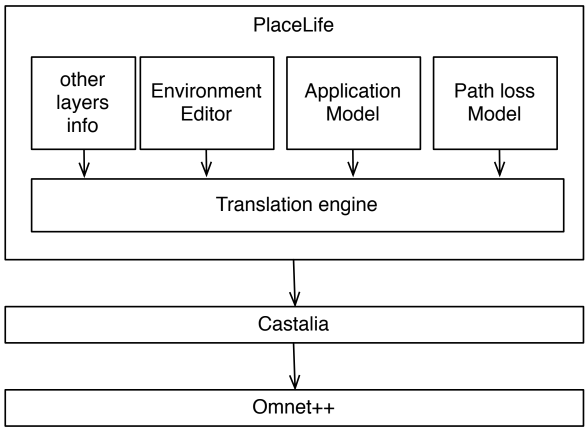

Fig. 2. PlaceLife

made of and its size. The environment editor also allows the specification of the sensor position in the physical environment. Obstacles and sensor position are used to compute the path loss.

An *application model* defines the behaviour of nodes. From this model various performance parameters such as transmission and sensing rates can be derived.

PlaceLife considers information from *other layers* such as network, data and physical layers to have a more realistic approximation for the life time. At network layer different protocols such as AODV [18] and DSR [19] can be specified but also static routing can be defined. This can be easily specified on the environment model. Although various data link layer access methods can be used, the Timeout MAC (T-MAC) has been chosen in this case study. T-MAC is a contention based MAC protocol that use synchronised sleep schedules between the nodes in a WSN to conserve energy [20]. Also T-MAC provides both collision avoidance and reliable transmission.

A. Path loss

Path loss is the attenuation in power density of an electromagnetic wave as it propagates. Path loss is consequence of many effects such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Path loss is also affected by other factors such as propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the frequency of the signal. When the effects of path loss are not considered, the evaluation of underlying structure can become optimistic, since the problems associated, retransmissions and the way this phenomena affects the energy consumption are not taken into account.

In our approach a *path loss model* can be specified by the user. This model is used together with the physical environmental model in order to define the path loss between two nodes. In this paper we consider indoor environment and the dependant path loss model [21]. This is one of the most commonly used path loss models that defines the behaviour of signal strength in an indoor area. The path loss behaviour is dependent on the distance between nodes and the attenuation factor added by the objects. The attenuation can vary based on several factors such as the construction materials (e.g., wood, glass and concrete) and the object size. In the Table I we show some attenuation values in dB introduced by various materials. We provide a detailed discussion in the next Section. The dependant path loss model can be expressed as [21]:

$$L_P = L_0 + 20log(d) + \sum m_{type} w_{type}$$

where, L_P represents the path loss between two nodes, d is the distance between the two nodes, L_0 is the path loss in free space environment, m_{type} refers to the number of objects of the same type and w_{type} is the loss in decibels attributed to that particular object.

B. The translation engine

The *translation engine* takes as an input the environment, application, and path loss models in order to produce simulation scripts. We use Castalia [22] as a simulation tool. Castalia is a WSN simulator used for initial testing of protocols and/or algorithms with a realistic node behaviour, wireless channel and radio models. Since Castalia is highly tunable and can simulate a wide range of platforms, it is used to evaluate different platform characteristics. Castalia features an accurate radio model based on the work of the authors in [23]. It also features physical process model, considering clock drift, sensor energy consumption, CPU energy consumption, sensor bias etc. Unpredictability of the wireless channel, energy spent in transmission/receiving packets, performance degradation experienced by duty cycles, collisions are usually overlooked by simple simulators. However these details are well established in Castalia [17]. All main components that affect the energy consumption of sensor nodes are considered that are the micro-processor, the sensor module, wireless transmitter/receiver and the path loss.

We emphasise that while Castalia provides a good low level simulation platform; it does not provide any means to specify the application behaviour, the environment and the path loss models. The application behaviour is needed to derive application level simulation parameters. The environment and the path loss models allow the calculation of the path loss. In fact while Castalia assumes that the user provides path loss related parameters, our approach automatically derives those values from high level models such as the environment and path loss.

IV. HOME AUTOMATION

Monitoring and automatic control of building environment is a case study considered quite often [24], [25], [26], [27]. Home automation can include the following functionalities: (i) heating, ventilation, and air conditioning (HVAC) systems; (ii) emergency control systems (fire alarms); (iii) centralized control lighting; and (iv) other systems, to provide comfort, energy efficiency and security. In order to validate our approach

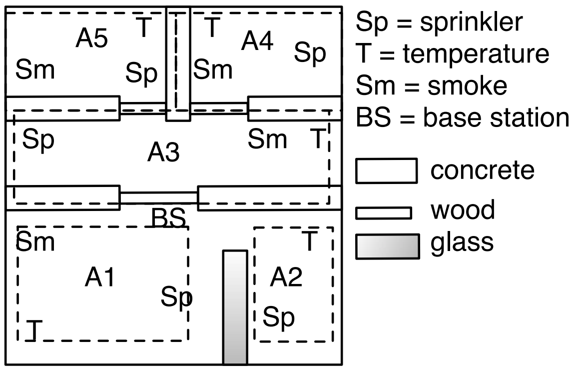

Fig. 3. Home automation

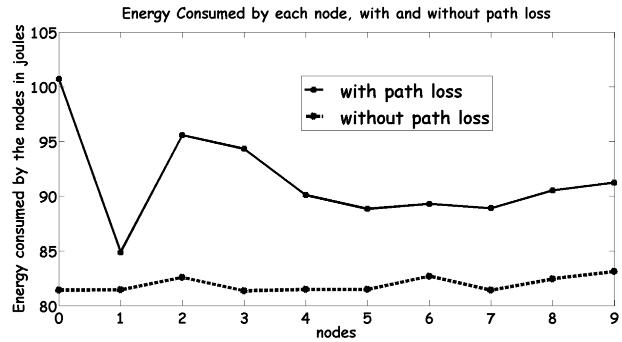

Fig. 4. Energy consumed by each node with and without path loss

we consider the fire alarm system and the automatic heating application. The fire alarm system is composed of different temperature sensors and smoke detectors that are distributed inside the building. There are also sprinkler actuators used to enable the water flow in case of fire. All the temperature sensors monitor the temperature at regular intervals (every 30 seconds). When a temperature sensor reads a value that exceeds a specified threshold; it sends an alert message to the smoke detector. The smoke detector receives the alert and checks for smoke. An alarm is raised when the smoke is detected. In this case the smoke sensor also activates all the sprinklers.

The automatic heating application is composed of different temperature sensors, a base station and various heaters. The temperature sensors send readings every 30 seconds to the base station. This is placed at the center forming a star topology. The base station averages the readings and decides whether or not the central heating system should be on. More specifically the base station works in the following way:

- if the heating is turned on and the average temperature is greater than the minimum threshold, the central heating system turns off.
- if the average temperature is less than the minimum threshold, the central heating system turns on.

We consider the scenario of Figure 3. A flat composed of five rooms (A1-A5). We also consider different obstacles such as wooden doors, walls and glass partition.

V. Numerical results and discussions

In order to show the usefulness and effectiveness of our approach and to analyse various factors affecting the performance in terms of energy consumption of WSNs, the numerical results are presented in this section. The simulation parameters are as follows: CC2420 radio defined by the Texas instruments is used, the output power of the different transmission levels in dBm are varied from 0 to -25dBm. Energy consumption for each transmission level varies. For instance for 0 dBm power consumed for listening (receiving) is 62 mW and for transmission is 57.42 mW. Packet rate is kept at 250 kbps, the radio bandwidth is 20 MHz and the simulation runs for 9000 sec. T-MAC is used as a MAC protocol, and this makes the length of each frame period for all nodes 610 milliseconds, and the duration of listen time out 61 milliseconds.

For our case study, we calculated the path-loss due to the material and explicitly set our path loss map [21], [28]. Refer to Figure 3 and Table I [21] for each type of obstacle and for its contribution to path loss. For the sake of the presentation we use numbers to represent sensors. Node 0 represents the base station. Nodes 1,4,5,7, and 9 monitor temperature in areas A1,A5,A4,A3, and A2 respectively. Nodes 2,3,6, and 8 monitor smoke in the areas A1,A5,A4, and A3 respectively. Table II and Table III show the energy consumed by the nodes for the application scenario considering the path-loss phenomenon and ignoring the path loss respectively. Similarly, Figure 4 shows the difference in energy consumed by each node for two different cases. In case one path loss is ignored, and for the next set of results the path loss is present.

It is evident that the lifetime of the nodes is heavily

TABLE I
Partition dependent losses for 2.4 Ghz

obstacles	attenuation in dB
Concrete wall	12
Wooden door	2.8
Glass wall	2
Cinder wall	4
window	2
Brick	5
Masonry brick	17
metal door	12.4

TABLE II
Energy consumed by the nodes in joules, considering path loss

nodes	0	1	2	3	4	5	6	7	8	9
energy	100.7	84.9	95.6	94.3	90.1	88.8	89.3	88.9	90.5	91.2

TABLE III
Energy consumed by the nodes in joules, ignoring path loss

nodes	0	1	2	3	4	5	6	7	8	9
energy	81.4	81.4	82.6	81.4	81.5	81.5	82.7	81.4	82.4	83.1

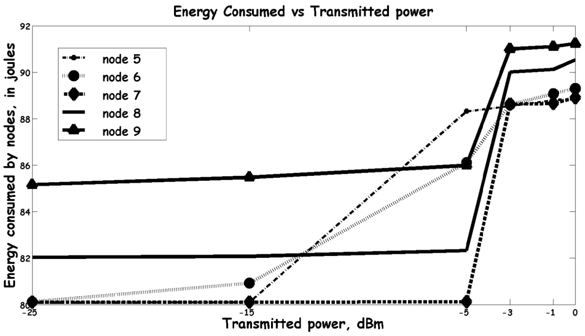

Fig. 5. Energy consumed vs. transmitted power for nodes 5-9

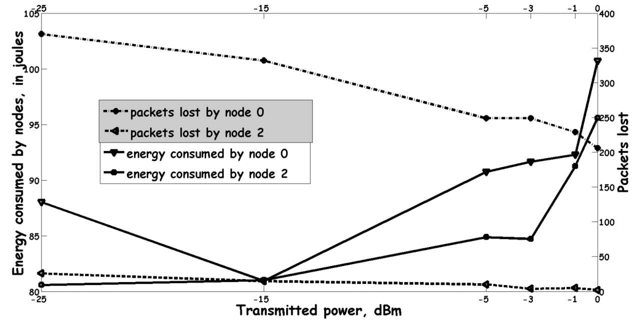

Fig. 6. Energy consumed vs. transmitted power vs. packets lost

dependent on the impact of the path loss, and ignoring the effect of path loss would be an optimistic assumption when energy consumed by each node is considered. This is because, when the effects of path loss are not considered, problems associated, retransmissions and the way this phenomena affects the energy consumption are not taken into account. However these factors affect the life time of the node. Node 3 consumes 13 joules of more energy due to path loss, when compared to no path loss.

Figure 5 shows the life time of the nodes 5 to 9, considering the impact of path loss for different transmission powers. Transmission power is varied from -25 dBm to 0 dBm, the energy consumption of the nodes is increased as we increase the transmission power. For node 7, as the transmission power is increased from -25 dBm to 0dBm, the energy consumed by the node also increases from 80.1 joules to 88.9 joules.

The trade-off between traditional performance measures such as packet loss and residual energy is presented in Figure 6. The dotted lines represent the packets lost and the straight lines represent the energy consumed by each node. As the transmission power is decreased from 0 dBm to -25 dBm, there is a gradual increase in amount of packets lost. For node 0, as the transmission power is decreased from 0 dBm to -25 dBm, the number of packets lost increases to 370, from 206 and the energy consumed increases to 100 joules, from 88 joules. Because of the retransmissions, more energy is consumed by the nodes. But the increase in transmission power does not necessarily mean increase in the life time as there are no retransmissions.

When the tradeoff between the packet loss and the energy consumed is analysed, it can be seen that the optimum transmission power should be between -15 to -5 dBm where the energy consumption is less than 95 joules and packet loss is less than 200 packets.

VI. Conclusion and Future Work

In this paper, a simulation-based study is presented that uses path-loss network and application layer data in order to predict the network lifetime. Physical environment is considered as well. We show that when path-loss is introduced, increasing the transmission power is needed to reduce the amount of packets lost. This presents a tradeoff between the residual energy and the successful transmission rate when more realistic settings are employed for simulation. It is a challenging task to optimise the transmission power of WSNs, in presence of path loss, because although increasing the transmission power reduces the residual energy, it also reduces the number of retransmissions required. This work is by no means complete. The concept is far more complicated than just finding out the network life time. The main focus is to place the nodes in a way to maximise the network life time, which is the major constrain of WSNs. Work is in progress.

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