SIMULATION FRAMEWORK FOR WSN USED IN MONITORING OF ILLEGAL TREE CUTTING

Alexandru NELUS[1], Maximilian NICOLAE[2], Dan POPESCU[3]

This work presents an implementation of a Matlab based Wireless Sensor Network Simulator (WSN) together with its validation on an important use case scenario, namely the designing of efficient algorithms for monitoring of illegal tree cutting. The paper establishes the proper context and methodology, emphasizing the differences of flexibility between well consecrated WSN simulators and the one we propose here. The demanding scenario analyzed constitutes in a proof of approach.

Keywords: wireless sensor networks, simulation framework, synchronization and routing algorithms

1. Introduction

Wireless Sensor Networks contain a large number of nodes with sensing and communicating capabilities. An analytical approach on modeling such types of networks involves a high degree of complexity and more so, tends to be impossible to achieve correctly, the results obtained being over simplified and inconclusive, let alone the aspect of difficulties encountered when setting up the physical scenario.

As a consequence, using a simulation environment where the characteristics and the performance of such systems can be analyzed is essential and is considered to be the main tool when it comes to testing new protocols and applications of Wireless Sensor Networks. The effects are expressed as an explosion of the tools that can be used to simulate these types of systems, but at the same time obtaining the correct results by using these tools is still cataloged as a non-trivial issue.

Before embarking on such an experiment some key aspects must be considered such as the degree in which the proposed simulation environment is appropriate to simulate a certain model and how correct is that certain model itself.

[1] PhD candidate, Institut für Kommunikationsakustik, Fakultät für Elektrotechnik und Informationstechnik, Ruhr-Universität Bochum, Germany, e-mail: alex.nelus@gmail.com
[2] Assist. Prof., Dept. of Automation and Industrial Informatics, University POLITEHNICA of Bucharest, Romania, e-mail: max.nicolae@upb.ro
[3] Prof., Dept. of Automation and Industrial Informatics, University POLITEHNICA of Bucharest, Romania, e-mail: dan_popescu_2002@yahoo.com

On one hand there is real concern regarding the assumptions and methodologies that are used in Wireless Sensor Networks, such as idealistic hardware, non-realistic communications and radio models or protocols, all of these leading to incorrect results. An optimized assumption based model, as close and accurate as possible to the real scenario is the best solution, but at the same time a high level of granularity implies greater computational resources. The necessary balance is the bespoke compromise between the accuracy of the results and desired resolution versus the performance and scalability criteria.

This paper takes into consideration the above mentioned guidelines when analyzing the optimum solution for the simulation of a Wireless Sensor Network, containing tailor made aspects and protocols, and which is designed to detect and prevent illegal tree cutting.

As forests represent a key element in maintaining the planet's ecological balance, the global risks imposed by illegal and abusive tree cutting are more than considerable. At a grander scale, the repercussions of abusive tree cutting have a negative influence on the atmosphere by contributing to global warming and in consequence to flooding, landslides, draught, etc. as shown by Papán et al., [1].

Authorities all around the globe have started taking safety measures to monitor and prevent illegal tree cutting (Al-Turjman et al., [2]) and the need for systems that can monitor the acoustic environment (Harma et al., [3]) is high.

2. Simulation frameworks

This chapter will contain the description of the most popular and relevant Wireless Sensor Networks simulation frameworks, in a perspective that takes into consideration the possibility of analyzing the model of the Wireless Sensor Network for illegal tree detection. All of the considered simulation frameworks are open-source and free.

NS-2. One of the most used network simulators is NS-2, which is a C++ based environment, offering a wide array of protocols, the highest of any available freeware framework (ad-hoc protocols, directed diffusion, SMAC). It is highly reusable and utilizes OTcl as a script and configuration interface. It includes support for NRL and Sensor Sim, the both being NS-2 Wireless Sensor Networks add-ons. It can support up to 1000 wireless nodes, and it is considered an important tool for the network domain, thus optimization will constantly follow. The downside of using NS-2 is the poor graphical support, which mainly consists of displaying the value of certain objects and it is closely followed by the lack of ability to write native code, specific for the most popular node types.

OMNET++. It is as well a C++ written environment, but the learning curve is easier due to the highly efficient graphical interface, which is also useful for debugging and tracing. One of the disadvantages of using OMNET++ is its low number of protocol libraries, but the framework is still under constant development. In addition, some open-source MAC based communication protocols are also due to be implemented. Many of these have been developed by independent groups, lacking a common structure and thus making it more difficult to take advantage of all of the options.

The main trend concerning Wireless Sensor Networks simulation frameworks is to use solutions that emulate the hardware components of the network, thus the simulation allowing for native code use and reacting to that code as the hardware would. Considering that Wireless Sensor Networks scenarios are extremely specific, and under a high number of constraints, these dedicated tools can relay with more precision the output data.

This approach allows for the simulation of real code, simplifying the physical implementation context as a consequence and adds efficiency to debugging and real-time analysis.

The downside is that the user is limited to a sole hardware platform which is usually MICA and a sole operating system which is TinyOS. At the same time, TinyOS and MICA become key factors for Wireless Sensor Networks, being a symbiotic progress.

TOSSIM. This is a discreet events simulator and a TinyOS emulator. For example for every transitioned bit, a new event is generated. TOSSIM simulated TinyOS code execution on MICA motes, allowing for hardware emulation by using hardware interrupts. These alongside the TinyOS code, are compiled using nesC. In this way an executable is obtained that contains TinyOS code and runs on an emulated physical tier. In addition, there are numerous communication services that can allow for data input from external sources. The result is a high fidelity simulator and a TinyOS/MICA emulator.

The goal of TOSSIM is to study the behavior of TinyOS and its applications, without too much emphasis on ways to determine performance parameters for a new algorithm. For example there are no solutions to record the energy consumption, and every node must run the same code. TOSSIM has no real applicability when it comes to testing more complex applications. The maximum number of nodes that can be simulated is close to 1000 and is limited by the level of granularity, the performance being dependent on the network traffic. The channel sampling is simulated bit wise and the use of CSMA is not so efficient in comparison to TDMA.

EmStar/EmSim/EmTOS. EmStar is a Wireless Sensor Networks simulator for special platforms called microservers, which are ad-hoc systems with more hardware performance attributes than a conventional node. This contains a LINUX core, alongside libraries, services, and tools like EmSim and EmCee. The last are a microserver simulator and a low power radio interface emulator. The disadvantages are created by the focus on these specific types of scenarios and the lack of options in regard to other types of Wireless Sensor Networks.

The above described Wireless Sensor Networks simulation frameworks were analyzed in respect to their performance and capabilities to accurately simulate the Wireless Sensor Network for detection of illegal tree cutting concept, and main key points where extracted and reconstructed when developing a bespoke MATLAB Wireless Sensor Network for the earlier mention concept. The model will be described in the following chapters.

3. Related work

Awang & Suhaimi, [4] have developed a forest monitoring system based on Wireless Sensor Networks called RIMBAMON. This system was based on sensor nodes positioned at certain distances that were able to record temperature, light intensity, audio details, acceleration and magnetism indicators. The sensors used were MICA based, and they were installed on trees, near the ground or on the side of the road. They were monitoring illegal logging and forest fires. The acoustic sensors offered comprehensive information regarding the cutting activities, based upon the distinct base frequencies emitted by these devices, for example chainsaws and tractors. The system was tested and simulated to transmit data to a base station. The collected data was displayed as a plot, table or map for immediate response. This system lacked a Web interface.

Harvanova et. al., [5] proposed a Wireless Sensor Networks system based on the ZigBee technology, using real time sound analysis for illegal tree cutting detection. The Wireless Sensor Networks system would periodically acquire samples, process them and send them to a central server. The most commonly used tool for logging is the chainsaw, which produces a distinguishable sound. Every time an audio sample matches the characteristics of the sounds made by logging materials an alarm is triggered, and the authorities are alerted via e-mail or SMS.

Soisoonthorn & Rujipattanapong, [6] have studied the unique chainsaw sound characteristics, in order to help detect illegal logging. Their algorithm was based on limited energy sensors and it combined three techniques that included and adaptive energy threshold, delta frequency detection and energy band for high frequency. Considering that chainsaw energy characteristics are rather constant, a state machine was used to simplify the detection procedure. This method led to a 90.8% detection accuracy level.

Figueiredo et. al., [14] have studied the communication performances of Wireless Sensor Networks for flora and fauna conservation in tropical forest environments. A set of experiments were made to observe how communication is affected by environment parameters like forest density, humidity and extreme temperature variations. It was concluded that the communication range of a Wireless Sensor Networks that is placed in thick forest surroundings can be reduced up to 78% in comparison with an open environment.

The monitoring of illegal tree cutting is a complex and complicated process, and these elements are amplified as resource necessity increases. The concept that this paper proposes is inspired by the above mention work and targets forest areas of medium density from temperate climate zones.

4. Our proposed architecture

In the proposed system, the Wireless Sensor Network motes will be deployed by airplane over the interest forest area. The deployment variables must be adjusted so that the motes land within a valid communication range of each other.

Considering that illegal tree cutting is mainly produced on the outskirts of forest areas, making wood transporting logistics easier, the deployment procedure must consider the correct coverage of the forest's peripheral parts. This means that a greater density of nodes must be deployed in the extremities and cost wise, a smaller density towards the center areas.

The system will employ two types of actions upon detecting a chainsaw sound, both of which have as a main purpose transmitting the message to the responsible authorities. The common step is to spread the message across the network to as many motes as possible. Among these common motes, there will be special motes called sinks which will be responsible for transmitting the message to a nearby base station. The second line of action would imply using dynamically selected sinks that can relay the message in a timely fashion to an overflying drone. The drone can remotely program every node's activity schedule, and select a subgroup of nodes that will serve the purpose. This subgroup can be altered by the drone, within a finite number of flying rounds.

As soon as the drones are deployed, they will start the synchronization procedure, which will be described in the following chapters, after which they will function according to their internal state machine. An air drone will have to patrol the area of interest and to interrogate the nodes until it will obtain the sleep/active cycles, and also to select the subgroup of sink motes. This method will ensure that every time the drone's flies over the Wireless Sensor Network zone, it will be able to communicate with a minimum number of nodes which have high chance of containing sufficient information regarding the state of the entire system.

The following chapters will describe in detail the Wireless Sensor Networks synchronization protocol, communication protocol, energy consumption and efficiency.

5. The synchronization protocol

Cristian [7] has defined the Remote Clock Reading method which handles the message delays between processes. When a process needs time estimation from another process, it sends out a timed request and waits for the other party to respond. After the response has been received, the process computes the time needed to make the round trip, estimates the clock from the peer process and adjusts its own clock accordingly. This method involves many rounds of synchronization as delays are non-deterministic and the quickest response try is considered the best choice, leading to computational overhead

Considering this, the novelty of the system will be the use of the Remote Clock Reading method only on small clusters of nodes, which in turn will act as a reference for a more practical method that will be applied to the entire network, called Offset Delay Estimation. This approach reduces the computational overhead, and when compared to reactive methods such as Reference Broadcast Synchronization, as seen in Sundararaman et al.,[15], has a more comprehensive span, synchronizing the reference sender as well.

The Offset Delay Estimation method needs a reference node to act as an official time setter before it starts to propagate the time across the network. In order to avoid errors that can appear due to a single node's clock anomalies, the reference node will consist of the cluster of nodes which are already synchronized using the Remote Clock Reading Method.

The Offset Delay Estimation method works according to the following:

- A pair of nodes interchange clock information.
- A set of data is constructed using the relationship between the two. The obtained pairs will be of type (F_i, E_i) where:
    - F_i a measure of the offset (θ)
    - E_i the delay between two messages (δ)
- The offset corresponding to the minimum delay is chosen. The offset and the delay are calculated according to: It is assumed that the message *m* needs the time *t* to be transferred, and the message *m'* needs the time *t'* to be transferred.
    - The offset between the clock of X and B is *F*. The time on X is *X(t)* and the time on Y is *Y(t)*:
        - $X(t) = Y(t) + F$ (1)
        - $T_{i-2} = T_{i-3} + t + F$ (2)
        - $T_i = T_{i-1} - F - t'$ (3)
    - $t=t'$, offset F_i is:
        - $F_i=(T_{i-2} - T_{i-3} + T_{i-1} - T_i)/2$ (4)

- The round-trip delay:
  - $E_i = (T_i - T_{i-3}) - (T_{i-1} - T_{i-2})$ (5)
- The most recent pairs will be chosen *(F_i, E_i)*
- The E_i value corresponding to the minimum F_i is chosen to estimate F.

Using the above described scheme will assure that the entire network will be synchronized correctly and without high usage of energy, because the Offset and Delay method, can work for finite number of times.

6. Communication

For the proposed system, three communication protocols were tested, called Flooding, Gossip Sleep based Protocol and a specifically modified approach of Gossip Sleep based Protocol.

Flooding is a method by which every packet is retransmitted to all the nodes in the network. Even if this is considered to be a robust method, it comes with a series of disadvantages. One of them is the implosion effect, meaning that duplicate messages are sent to the same nodes. Another side effect is overlapping, meaning that if two nodes are in the same region, and hear the same sound they will transmit the same alarm message across the network. All of these leading to unnecessary resource consumption.

This method can be seen in Fig.1 where nodes B and C can listen to node A and the other way around. Node D is situated only in the range of B and C. When node A receives a packet, nodes B and D receive it, and send it again. Node A will receive the packet again, and will retransmit it. Eventually the packet is transmitted across the entire network, but the costs are high.

A more energy efficient solution is to follow the Gossip-based Sleep Protocol(GSP) which uses a probability based transmission cycle as shown in Hou et al., [11]. In the first part the radio module is turned on, and in the second part, based on an established probability figure, the radio module can be turned off. This protocol can be observed in Fig.2 where A is the node that is sending the packet. Supposing that node B has its radio on and node C has its radio off, node B will be the one receiving the packet and sending it forward. Thus node C has spent no energy so far. Node D will receive the packet only if the radio module is on. In this case, it will retransmit the packet.

The communication novelty proposed for the Wireless Sensor Network system for the detection of illegal tree cutting consists of a modified version of the GSP algorithm.

Considering that the type of motes used in this system is MICA based, they will be able to offer the use of memory resources. The system will run a normal GSP protocol until it has to handle the transmission of a message that is marked with a modified GSP code; this message can be an alarm message or any other type of user defined message. Once a node has sent this special message it records the timestamp. If the node receives a similar coded message, it will calculate the time interval from the last similar message it has sent and if it is under a user defined time threshold it will ignore the message, thus saving energy on transmission.

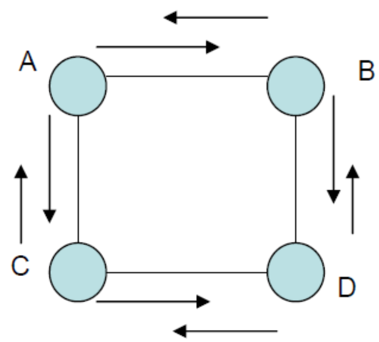


Fig. 1. Flooding algorithm

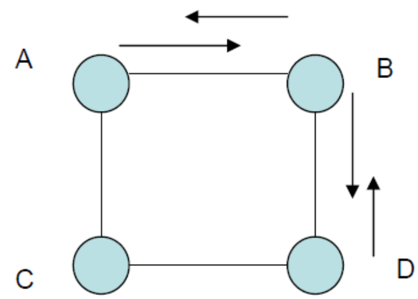


Fig. 2. GSP algorithm

This solution not only saves up energy, but it also helps decongest the network traffic by eliminating inefficient redundancy. All of these are achieved without affecting the transmission of the messages across the entire network as initially intended.

The MATLAB based simulation framework created is designed to allow for the implementation of all of the above listed methods, in order to analyze the effects from the performance and cost perspectives.

7. Experimental setup

The proposed monitoring system uses a set of Crossbow MTS420/400 CC motes, for which a Friis [8] based calculation model is used in order to render an appropriate power based range estimation. The constructed MATLAB simulation framework uses this model for range design on every individual node.

Depending on the height of the nodes a more comprehensive model can be used, a model developed by Texas Instruments[9], which is able to compute a more realistic scenario regarding the communication range. The constructed MATLAB simulation also incorporates this model for communication range prediction.

The calculated data presented above has also been experimentally tested along with the sensing properties of the nodes, in a medium density forest environment as show in the figure 3.

Fig. 3 Communication and sensing experimental measurements

After having the radio communication model it is easy to link a power consumption model, both calculated and measured. Shnayder et.al, [10] have presented a measured performance table for the Crossbow motes.

As a result, the MATLAB simulation framework, which cannot run TinyOS code specific to the nodes, can still properly simulate the behavior of one, in respect to the communication and sensing performances and also to a close to reality energy model.

8. Results

The proposed illegal logging detection model has been used in order to validate the constructed MATLAB Wireless Sensor Network. The model's performance alongside the simulation's performance was analyzed.

The forest area considered is about 100ha in size and the node's deployment procedure is for one scenario, a uniform distributed node matrix, and for the other scenario, a high marginal density node topology. The duration of each experiment was 1h while the chainsaw was used for 10 times. The results are illustrated in Fig. 3.

The protocols used in the simulation where the ones described in the earlier chapters: Flooding, GSP, modified GSP and an extra option of a modified GSP on a node that uses solar power rechargeable batteries.

The simulations were made on a total of 40 nodes, with high peripheral density layout, of which 8 nodes serve as sink nodes that communicate with a drone or base station.

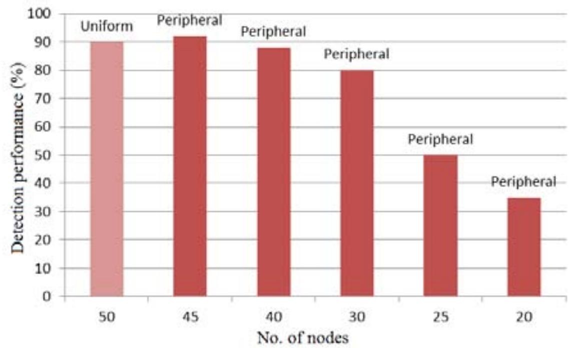


Fig. 4. Model performance results

The simulation's stopping criteria are:

- Total power of the entire system: < 25%
- Total functional nodes: < 25%
- Total functional sink nodes: <25%

The lifespan of the system has been simulated and the results are presented in Table 1. One screen capture of de simulation validating different communication scenarios is shown in figure 5.

Table 1

Model lifespan results

Batteries capacity (mAh)	Solar recharge	No. Chainsaw Appearances Per h	No. Nodes	Layout	Protocol	Hours
3000	No	0.1	40	High peripheral density	Flooding	150
3000	No	0.1	40	High peripheral density	GSP	1700
3000	No	0.1	40	High peripheral density	GSP Modified	2600
5000	Yes	0.1	40	High peripheral density	GSP Modified	5000

Considering that the created MATLAB simulation environment allows for the export of high granularity data to a CSV format, which can be later on analyzed, the performance analysis of the specific model can be easily obtained, as shown in the figures 6 and 7. This type of analysis is vital for large scale sensor network applications as Proakis and Manolakis, [13] have also proven.

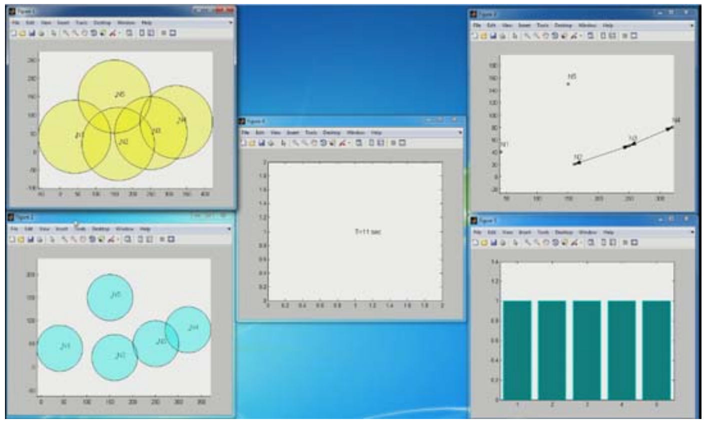
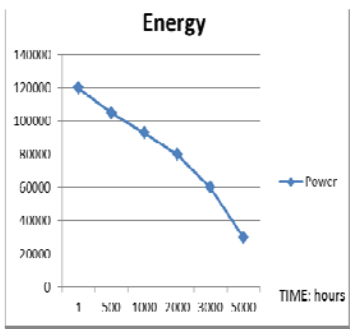


Fig. 5. Screen capture from the simulation



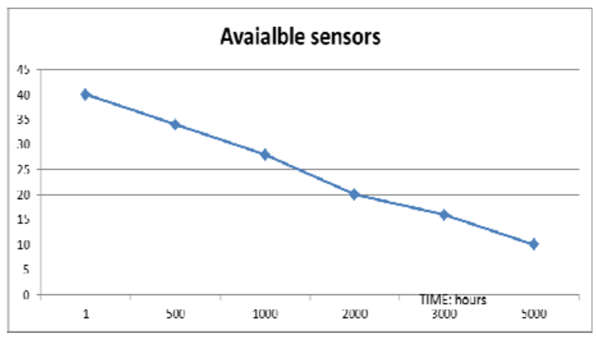


Fig. 6. Total energy over time

Fig. 7. Available nodes over time

9. Conclusions

In this paper a Matlab based simulation framework was presented which can support models of wireless sensor nodes (Akyildiz et al., [12]), designed for monitoring of illegal tree cutting. The framework offers the possibility of configuring the functional profile of nodes in accordance with the physical counterparts (ex: Mica), providing useful information regarding the coverage or performance analysis of various algorithms. The advantages of this framework against its alternatives (that were briefly described in the second paragraph) are the flexibility, power and the familiarity with the language that Matlab environment provides. In order to demonstrate our approach we validated the framework on a real case scenario in which we implemented and compared several algorithms. The results constitutes the proof of the advantages enumerated above.

Acknowledgement

The Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds, through the Financial Agreement POSDRU/159/1.5/S/134398, has funded the work related to simulation framework.

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