Channel Modeling and Power Control in SENSASim for Wireless Sensor Networks

GEORGE BRAVOS, ATHANASSIOS G. KANATAS
Technology Education and Digital Systems Dpt.
Wireless Communications Laboratory
University Of Piraeus
80 Karaoli & Dimitriou Str., Piraeus 18534
GREECE
{gebravos, kanatas}@unipi.gr

ANTONIS KALIS
Athens Information Technology
19.5 Km Markopoulo Ave., 19002, Athens, GREECE
akal@ait.edu.gr

Abstract: - Wireless Sensor Networks (WSNs) belong to a special network category with several special characteristics and significantly different priorities. Recently an open-source java simulation tool for WSNs has been developed (SENSASim), and an energy model was applied. Based on SENSASim, we incorporated a more realistic channel model with large scale fading characteristics. Furthermore, we proposed and implemented a power control scheme that focuses on energy efficiency. The effect of the channel model modifications along with some evaluation results of the power control technique are described; conclusions are discussed and used as motive for further work.

Key-Words: - Wireless Sensor Networks, Power Control Schemes, SENSASim, Energy Efficiency

1 Introduction

In recent years, the desire for connectivity has caused an exponential growth in wireless communication. The capabilities needed to deliver appropriate services are characterized by an increasing need for data throughput in the network; applications now under development, such as wireless multimedia distribution in the home, indicate that this trend will continue. Wireless Local Area Networks (WLANs) provide an example of this phenomenon. Wireless Personal Area Networks (WPANs), defined as networks employing no fixed infrastructure and having communication links less than 10 meters in length centred on an individual, form another example.

Other potential wireless network applications exist, however. These applications, which have relaxed throughput requirements and are often measured in a few bits per day, include industrial control and monitoring; home automation and consumer electronics; security and military sensing; asset tracking and supply chain management; intelligent agriculture; and health monitoring ([1], [2]). Since most of these low-data-rate applications involve sensing of one form or another, networks supporting them have been called wireless sensor networks (WSNs), or Low-Rate WPANs (LR-WPANs), because they require short-range links without a pre-existing infrastructure. WSN usually consist of hundreds or thousands of small nodes operating on small batteries; thus, in such networks, energy efficiency is of greater concern than data throughput or performance in terms of Quality of Service (QoS).

The special characteristics of WSN result in difficulties when trying to evaluate the performance of such networks using existing simulation tools. SENSASim ([3]), a java-based simulator that focuses on WSNs, has recently been developed. Considering the importance of energy consumption measurements in WSNs, an accurate energy-model ([4]) has already been implemented in SENSASim ([5]) giving the opportunity to gather results about the lifetime of networks and energy efficiency of several protocols. In this paper, we propose an additional extension of the simulator capabilities; first, we implement a log-normally distributed variable with zero mean and user defined standard deviation, in order to achieve a more realistic channel model for the wireless sensor network and second, we introduce a power control scheme for wireless sensor nodes to reduce the energy consumption and increase the lifetime of the network.

The remainder of this paper is organized as follows. In Section 2 a brief description of the existing capabilities of SENSASim is given; the additional implementations are presented in details in Section 3, while in Section 4 the numerical results gathered by the simulations are shown. Finally, Section 5 summarizes and points out challenges for future work.
2 SENSASim

SENSASim is a java-based simulation tool, built for simulating WSN and given great modularity; thus, it is possible for users other than its authors to extend it.

As already stated, WSNs require techniques easy to implement and as energy efficient as possible. Therefore, SENSASim includes simple protocols for every layer. The MAC layer is based on an unslotted pure Aloha protocol, where CSMA (Carrier Sense Multiple Access) and a back-off algorithm may be activated by the user. Moreover, a multicast extension is provided to all protocols, allowing for the network layer to send a packet to more than one node with a single transmission, and inferring additional energy savings. The Network layer implemented in SENSASim provides the user the ability to choose from several different routing algorithms, such as normal flooding, directional flooding, broadcasting etc. Finally, the physical layer not only is based in simple techniques used in the Mica Berkeley motes ([6], [7]) but also introduces the idea of using more than one sectored antennas in a sensor node. It has been shown ([8]) that the use of sectored antennas in wireless sensor networks is in some cases obligatory and in other cases achievable, with minimal additional cost.

Furthermore, SENSASim enables its users to input the values of several parameters considering different layers through its user-friendly Graphic User Interface (GUI), and gather some useful results about the performance of the network from an output file. The additional implementation of the energy model on the other hand ([5]) not only increases the number of parameters controlled by the user, but also creates more detailed outputs, giving thus the capability to measure the energy efficiency of several implemented techniques, to evaluate the effect of different parameters on the energy consumption and to gather consumptions about the lifetime of networks.

Summarizing, SENSASim with the addition of the energy model is an important tool for simulating sensor networks; moreover, the potential for further extensions make it even more useful.

3 Extended Features

The additional implementations in SENSASim proposed in this paper are thoroughly described in this Section. First, the channel model based on the lognormal distribution is presented, followed by the structure of the power control technique.

3.1 Large Scale Fading

Exploiting the modularity of SENSASim, we propose the implementation of a lognormal distribution for the calculation of the received power of each node, so that we simulate the channel as realistically as possible, including the effect of large scale fading.

In the previous version of the simulator, the neighbours of each node were determined considering its range and the distances to all other nodes. The knowledge of the range of each node though should not be able...
to determine whether two nodes are neighbours and thus able to connect or not, as the different channel conditions between different couples of nodes may result in loss of connectivity within their range or ability to connect while being out of it. This is clearly depicted in Fig. 1, where a node with 5 neighbors is shown. Although according to their distances connection should be established with neighbors 1 and 2, the channel conditions and thus the power distribution results in achieving connection with neighbors 2 and 3. Considering the assumption above, we assumed a log-normally distributed variable with zero mean and user defined standard deviation. The received power now at each node depends not only on the transmission power of the source and their distance but also on the random variable, which expresses shadowing. In more details, the link budget equation ([9]) is now formed as in (1), and expresses the transmission power used by each node according to the average range chosen by the user:

\[
P_t = 10n \log \left( \frac{4\pi d}{\lambda} \right) (dB) + \frac{E_b}{N_o \text{ required}} (dB) + 10 \log (R_b) (dB) + N_o (dBW / Hz) + S(dB) - G_t (dBi) - G_r (dBi)
\]

In (1), \( n \) is the Path Loss Factor, \( d \) is the average range of the node and \( \lambda \) the wavelength. \( S \) is the Safety Margin (typical value: \( S=10 \) dB), \( N_o \) is the noise power spectral density (typical value -204 dBW/Hz at noise temperature \( T_o=27 \) °C), \( R_b \) is the bit rate and \( G_t, G_r \) are the antenna gains of the transmitter and the receiver, respectively. The required \( \frac{E_b}{N_o} \) in (1) is evaluated according the modulation scheme, the constellation size and the required BER (Bit Error Rate).

Therefore, the received power at each node may be evaluated by (2):

\[
P_r(d) = P_t - PL(d) + G_t + G_r
\]

\[
PL(d) = PL(d) + \chi
\]

\[
PL(d) = 10n \log \left( \frac{4\pi d}{\lambda} \right)
\]

where \( \chi \) is the zero-mean normally distributed variable in dB with standard deviation \( \sigma_\chi \) also in dB. As far as the simulation is concerned, when a node is trying to connect to a neighbour, it compares their distance to a distance threshold evaluated by (1, 2) using the shadowing conditions and decides whether the connection is possible or not. Practically, the knowledge of neighbours may be achieved by sending a pilot symbol at the beginning of the network’s operation. The channel is assumed to be static; therefore, the distribution of the received power at each node is determined at the beginning of the simulation and assumed fixed until the end. Regarding the simulator’s GUI, this implementation adds one input parameter, that of the standard deviation value.

### 3.2 Power Control Scheme

In the design of a WSN, the techniques and protocols used at almost every layer focus on simple implementation and energy efficiency. Power control is a common technique mainly used to ensure sufficient QoS; in some cases though it may be useful for energy-limited applications. Controlling and dynamically changing the output power of a node according to the channel shadowing and the distance of the receiver may result in significant energy savings.

The power control scheme proposed here and implemented in SENSASim is based on the assumption that each node is able to gather and store information about the distances of its neighbours and the channel shadowing of all possible connections. This knowledge is possible as already stated assuming that each node in the beginning of the network’s operation sends a pilot symbol and receives ACKs from its neighbours; thus, the distances are calculated through the time of the ACK’s arrival while the channel shadowing is evaluated by the power level of the ACKs. In particular, knowing the received power of the acknowledgment symbols, the node may evaluate the path loss and afterwards estimate the minimal required output power when trying to
connect to each of its neighbours based on (3). SENSASim’s user is able to choose via the GUI whether the power control scheme is used or not. 

\[ PL(d) = P_r - P_t(d) \]

\[ P_{r_{\text{min}}} = PL(d) + \frac{E_b}{N_{o \text{ required}}} + 10 \log (R_b) + N_s + S - G_t - G_r \]   \hspace{1cm} (3)

The basic idea of this scheme is depicted in Fig. 2. Indeed such a technique requires that the nodes have enough memory to store that kind of information. In a network with hundreds or even thousands of nodes and high density, it is possible that each node will have decades of neighbours and therefore will need to keep significant amounts of data; this, considering the limited size of such nodes, may not be feasible. We assume though that this power control scheme is theoretically ideal as far as the energy consumption is concerned, considering that each node dissipates the least possible amount of energy for each connection; thus, its implementation in SENSASim may be very useful as a point of reference for evaluation of further implementations.

![Fig. 2: At the beginning, each node sends a pilot symbol. Based on the receiving ACKs, the node determines the output power threshold](image)

4 Results

In this Section, the configuration of the simulations carried out is presented in detail. Moreover, results that depict the effect of the implemented schemes are shown and explained.

4.1 Simulation Setup

The networks simulated for this paper consisted of 30 sensor nodes, which are randomly deployed in an area of 300 m². The nodes are assumed to have 2 directional antennas with forward gain equal to 1 and 120° beamwidth at each lobe. The data transmission speed is set to 100Ksps, but also networks with higher rates (150Ksps) are simulated.

Considering the digital modulation scheme, Binary Frequency Shift Keying (BFSK) is used while the average range of each node is 30m. The channel is assumed to have a path loss factor set to 2.5 or to 2.8 in order to evaluate the effect of the power control scheme to different channel conditions, while the standard deviation of the log-normal distribution may take several values.

Moreover, Carrier Sense Multiple Access (CSMA) mode is enabled with contention window size equal to 5. The routing of the data is based on an already implemented algorithm in SENSASim, which normally floods the information through the network towards the destination (SINK) node. Each time 2 flows of information simultaneously start from two different nodes of the network, and a total number of 1000 flows are carried out.
The simulation setup parameters, as entered in the GUI that SENSASim comes up with, are shown in detail in Table 1.

### 4.2 Numerical Results

The results of the simulations run using the implementations proposed in this paper are examined here. Considering the need for energy efficiency in Wireless Sensor Networks, the effects of the power control scheme as well as of the implementation of the log-normally distributed variable are presented focusing on energy consumption.

<table>
<thead>
<tr>
<th><strong>Topology parameters</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Nodes</td>
<td>30</td>
</tr>
<tr>
<td>Topology</td>
<td>Random</td>
</tr>
<tr>
<td>Area Height</td>
<td>300m</td>
</tr>
<tr>
<td>Area Width</td>
<td>300m</td>
</tr>
<tr>
<td>Density</td>
<td>2.04</td>
</tr>
<tr>
<td>Offered Traffic Load</td>
<td>0.5 pkts / pkt time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Physical Layer Parameters</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Speed</td>
<td>100ksps / 150Ksps</td>
</tr>
<tr>
<td>Path Loss Factor</td>
<td>2.5 / 2.8</td>
</tr>
<tr>
<td>Constellation size</td>
<td>2</td>
</tr>
<tr>
<td>Number of Antennas</td>
<td>2</td>
</tr>
<tr>
<td>Forward Gain</td>
<td>1.0</td>
</tr>
<tr>
<td>Backward Gain</td>
<td>0.01</td>
</tr>
<tr>
<td>Lobe’s Beamwidth</td>
<td>120.0</td>
</tr>
<tr>
<td>Range</td>
<td>30.0 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>MAC Layer Parameters</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>First Back-off mode</td>
<td>NO</td>
</tr>
<tr>
<td>CSMA mode</td>
<td>YES</td>
</tr>
<tr>
<td>Contention Window Size</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>IP – Routing Parameters</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of simultaneous flows</td>
<td>2</td>
</tr>
<tr>
<td>Routing scenario</td>
<td>Normal Flooding</td>
</tr>
</tbody>
</table>

**Table 1 : Simulation Setup**

A first estimation of the gains in terms of energy efficiency due to the implementation of the Power Control Scheme may be excluded from Fig. 3, where the total energy losses (%) are presented. It is obvious that about 10 – 15% of total network energy may be saved using the specific power control technique. Moreover, changing the value of standard deviation (sigma) of the log-normally distributed variable does not have impact on the total energy consumption, as it affects only the range of the channel’s variations.

The consequence of using power control with higher data rates is depicted in Fig. 4. The energy gains (%) are remarkably greater when the symbol rate increases from 100 to 150 Ksps; the difference reaches 90% during the network’s operation.

Some additional useful results may be excluded by Fig. 5, where the number of dying nodes due to lack of energy is shown during network’s operation for 6 different networks. The most rapid increment of dying nodes takes place for worse channel conditions (path loss factor equal to 2.8) and without the usage of power control, while best performance in terms of dying nodes is achieved by the network with 150Ksps symbol rate and power control.

In the case of bad channel conditions, the final number of dead nodes is the same with or without
power control; the use of this scheme though results in the nodes dying more slowly. This has an effect on the lifetimes of the networks, which are presented in Table 2.

![Graph showing total energy losses of networks with/without power control for different values of sigma](image1)

**Fig. 3:** Total Energy Losses of networks with/without Power Control for different values of sigma

![Graph showing energy gains due to power control for different data rates (Ksps)](image2)

**Fig. 4:** Energy gains due to Power Control for different data rates (Ksps)

5 Conclusions – Future Work

This paper deals with the extension of the capabilities of a java-based simulator for wireless sensor networks. SENSASim is one of the very few tools available for simulating WSNs, and its modularity allows users to easily implement several additional techniques.

In more details, we applied a log-normally distributed variable with zero mean and user-defined standard deviation so that a more accurate and reliable modeling of the channel characteristics is achieved. Furthermore, a power control scheme was implemented. Considering the special characteristics of WSN where energy efficiency is of major concern, the proposed scheme focuses on maximum energy savings and thus creates a useful point of reference for prospectively implemented schemes.
Regarding our future work, the incorporation of other power control schemes and evaluation of their performance in terms of energy efficiency has already been planned. Moreover, scenarios of moving nodes are about to be examined, demanding the modeling of a varying channel.

![Graph showing number of dead nodes vs number of flows for different network configurations](image)

**Fig. 5 : Number of Dead Nodes during operation for 6 different network configurations**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N=2.8$, With Power Control</td>
<td>1062.24 sec</td>
</tr>
<tr>
<td>$N=2.8$, Without Power Control</td>
<td>186.57 sec</td>
</tr>
</tbody>
</table>

**Table 2 : Effect of Power Control on Lifetime**

References