Wireless Sensor Networks: The Potential Use of Received Signal Strength in Power Transmission Control for the MICA2

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Abstract

Power transmission plays an important role in prolonging the lifetime of a node. Thus in designing efficient wireless sensor networks protocols it important to take this into account. This paper will help the reader understand the role of both power transmission and received signal strength. Besides that these paper also present results obtained from study which was concerning the relationship distance and power transmission has on received signal strength of a mica2 mote. The paper will gear readers towards the use of power transmission control in new communication protocols for the MICA2.

Keywords: Wireless Sensor Network, Motes.

1 Introduction

Wireless sensor networks (WSN) will be one of the key technologies of the future. These networks are made out of nodes which are used to detect and track a phenomenon in a certain area. Each node is generally made out of a microcontroller, radio transmitter and receiver, and many various kinds of sensors depending on what the node is being used to sense for. The reason WSNs has been gaining a lot of attention from the technological community is because of its ability to be deployed in an ad hoc manner without the need for an external power source. Nodes are usually battery powered however, there is research being done to deploy this nodes using solar power [1].

Which ever way these nodes are deployed or powered, the limited supply of power each node has will always be an issue. The radio transmitters and receivers of the nodes are usually the main consumers of the power supply. Future work needs to be done in designing communication protocols which are energy efficient and intelligent. There is a need to study the radio model on WSNs in terms of received signal strength (RSS), packet reception rate (PRR), transmission power and distance for this new protocols to be designed. The purpose of this paper is to shed better understanding on this so that future WSNs communication protocol designers can take this into account when designing protocols which will be more efficient in their usage of power in terms or radio communication. Through this paper a designer will understand how to minimize transmission power while not having a significant lost in PRR. The paper also will help the reader understand how different settings of power transmission will cause different effects on the WSN’s topology.

Experiments were done using MICA2 motes which are made by Crossbow. These motes used radio transceivers which were running at a frequency of 315MHz. This paper is targeted at MICA2 researchers who are interested in designing protocols which will use RSSI and Packet Reception Rate Readings to adjust the strength of its power transmission. The results of this paper will give MICA2 designers a rough estimate as to what to expect in terms of readings on a MICA2. It will help them understand the constraints that come with radio transmission thus helping them to design better protocols. Results in this paper will also prove useful for researches who are designing range finding protocols.

This paper starts of with a section on related work dealing with current research which has been done concerning radio propagation. This is followed by the section ‘Descriptions of Experiments’ which gives a full account on how the experiments were done and the equipment which were used. This is followed by a section on the results and discussion of the study. Finally we end with a conclusion.

2 Background

MICA2 motes run using TINYOS which is an open source operating system made especially for the use in wireless sensor networks. TINYOS in component based thus providing flexibility to designers. MICA2 motes which run on TINYOS are widely used around the world now, thus the reason why this paper will be applicable to a lot of researchers.
The MICA2 uses a radio transceiver called the CC1000 which is manufactured by ChipCon. The CC1000 uses a built in Received Signal Strength Indicator which outputs an analogue signal which is proportional to the input signal level on the RSSI/IF pin. This output current is converted into a voltage by a resistor which is in turn read by the Analogue to Digital Converter (ADC) channel 0 of the microcontroller.

MICA2 motes are powered by batteries. Battery voltage on the MICA2 decreases as the duration it is deployed increases. A change in battery voltage will cause the reference voltage used by the ADC to change thus causing a variation in results to occur when using the ADC. A study done by [4] indicated that there were variations of up to ±7dBm when the ADC was tested across a voltage of 2.6V-2.9V.

MICA2 comes in a variety of radio frequencies; 433, 868/916, or 310 MHz. The first thing to note is that higher frequencies have higher attenuation. Besides that at higher frequencies they slowly lose their ability to go through obstacles, go around obstacles and to reflect from obstacles. Thus radio frequency will plays a role in RSS.

Distance between the transmitter and the receiver plays an equally important role in RSS. According to [6] the signal loss for the plane earth model is:

\[ L_p(dB) = 40 \log_{10} d - 20 \log_{10} HT - 20 \log_{10} HR \]

\( d = \) distance
\( HT = \) Height of TX antenna
\( HR = \) Height of RX antenna

**Equation 1 Received Signal Strength**

Propagation loss follows the inverse fourth law with distance, which means that the path loss exponent is four. So received power falls by 12dBm when the distance is doubled [7].

3 Related Work

In this section we will taking a look at two separate papers which have relevance to this issue. The first paper [2] concerns a research conducted in a potato field. Many nodes were planted in a potato field and measurements of the Receive Signal Strength (RSS), Packet Reception Rate (PRR) and distance were taken. The paper explores the relationship PRR has with RSS and the relationship of RSS with distance. For this experiment numerous motes were planted in a potato field and RSS was measured in different weather and environment conditions. A result of interest from their experiment is the one concerning the relationship between packet reception rate and RSS. The results show with an RSS of at least -90dBm, a 73% packet reception rate is achievable (Graph included below). It is noted that in all their experiments, a 100% reception rate was never achieved even at the highest RSSI. When the RSSI is below -90dBm, the packet reception rate becomes totally unpredictable. The paper goes on to say that similar results were achieved by [4].

The paper also measured the effect that a flowering crop compared to a crop on its return has on the RSS. The graph below is the result of this study. In the graph July indicates the month where the crop flowered and August is the reduced crop. Ranging measurements are the measurements taken by using only two nodes. The difference between [2] and this paper is that the results of [2] do not take into account the power transmission strength of the MICA2 motes. This paper tries to give a better understanding of the relationship between the three; transmitted signal strength, RSS and PRR.

![Fig. 1 Relationship between PRR and RSS](image1)

![Fig. 2 Signal Strength vs. Distance](image2)
The purpose of writing about this study is so we can compare the results they have obtained with those obtained through experiments we have conducted ourselves.

The second paper [5] studies the effect different transmission power setting has on a network which uses flooding. The paper studies how the link layer, the MAC layer and the application layer are affected by this. Results from the paper show that in terms of the link layer at low transmission power the number of asymmetric links grows faster (compared to high transmission power) as distance grows. The reason for including this paper in this section is to show the reader how different transmission strengths can affect the shape of wireless sensor networks.

In terms of the MAC layer performance were measured using two factors reception latency which is the time taken for the whole network to receive the flood and settling time which is the time taken for each packet. Their results show that at all power settings (very high, medium and low) the reception latency is almost the same. However a closer inspection indicates that at very high transmission power the final 5% of the nodes yet to receive a packet accommodate half the time of reception latency. At low power setting, the packet reception time of all the nodes happen gradually. In terms of settling time, at very high transmission power setting takes a slightly longer time compared to that seen at low transmission power setting. Besides that at high transmission power more backward links are formed then when using low power.

As for the application layer, the effects of different transmission power settings are measured using two fields’ node level and cluster-size. Node level is the number of hops a packet sent from node in a tree has to take to reach the sink. Cluster size is the number of children a parent node has. Results show that at high transmission power there is a high chance that bigger clusters will form. Usually big clusters imply that there will be lower node level.

4 Description of Experiments

For this experiment mica 2 motes were used. The motes radio frequency runs at 315MHz. Two nodes were used in this experiment. One acted as the base station which recorded the received signal strength of all the packets it received from the other node. The transmitting node would send back 100 packets at a fixed transmitting output power every time the experiment was done. In the experiment PRR is the based on the ratio of received packets out of the 100 that were transmitted.

The output power was selected by programming the MICA 2 radio with a fixed decimal number (PA_POW in Table 1). This fixed number than corresponded with a different set of output power and current consumption as shown in Table 1. The frequency at which the radio on the MICA 2 was running at is 433 MHz. In the experiment the numbers ‘PA_POW’ were chosen such that the whole range of transmission power was covered. The ‘PA_POW’ numbers which were used in the experiment are 2, 5, 10, 25, 51, 102, 153, 204 and 255 (numbers in decimal). New batteries were used for the experiment to avoid variation of results that might have occurred because of the change in reference voltage of the ADC.

![Fig. 3 Experiment to study PRR and RSS](image)

### Table 1 Output Power Based on Set Decimal Number

<table>
<thead>
<tr>
<th>Output power [dBm]</th>
<th>PA_POW</th>
<th>Current Consumption [mA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-17</td>
<td>02</td>
<td>7.1</td>
</tr>
<tr>
<td>-9</td>
<td>05</td>
<td>7.9</td>
</tr>
<tr>
<td>-4</td>
<td>10</td>
<td>9.6</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
<td>10.4</td>
</tr>
<tr>
<td>1</td>
<td>51</td>
<td>11.8</td>
</tr>
<tr>
<td>4</td>
<td>102</td>
<td>13.8</td>
</tr>
<tr>
<td>7</td>
<td>153</td>
<td>16.8</td>
</tr>
<tr>
<td>8</td>
<td>204</td>
<td>20.0</td>
</tr>
<tr>
<td>10</td>
<td>255</td>
<td>26.7</td>
</tr>
</tbody>
</table>

5 Results and Discussion

The results covered by this paper are somewhat similar to those covered by [2] with the exception that we have included results concerning those related with the strength of transmission power. By this we hope to point out some things which may prove beneficial to those designing power saving algorithms. The following are the results obtained through the experiment described in the previous section. The
The figure below reveals that as the distance between the two nodes increase the Received Signal Strength (RSS) will drop. This is the inevitable fact that signal attenuates in air over distance.

Looking at figure 4, the drop of RSS when distance was increased by 4m to 8m for transmitters transmitting at power 2 and power 5 is roughly around 12dBm thus satisfying the equation 1 to a certain extend. Please note that for that you will need to refer to table 1 to see the output power in dBm. Results shown in Figure 4 will also prove useful in estimating distances in wireless sensor networks whose nodes use variable transmission strengths. The equation above shows the effect distance has on RSS however it does not include the fact that transmission strength of the sending node has an effect over the RSS of a receiving node at a fix distance. For instance, for the nine different power settings the receiving node at a fix distance of 8

\[
\begin{align*}
\text{Metre} & \quad \text{RSS (dBm)} \\
1 & \quad -90 \\
2 & \quad -85 \\
4 & \quad -80 \\
6 & \quad -75 \\
8 & \quad -70 \\
10 & \quad -65 \\
12 & \quad -60 \\
14 & \quad -55 \\
16 & \quad -50 \\
18 & \quad -45 \\
20 & \quad -40 \\
\end{align*}
\]

Fig. 4 Relationship between RSS and Distance

meters got 9 different RSS readings. This goes to show that the equation above is not able to give a proper model of radio transmission.

\[
\begin{align*}
\text{Packet reception rate} & \quad \text{RSS (dBm)} \\
\text{Power 2} & \quad -90 \\
\text{Power 5} & \quad -85 \\
\text{Power 10} & \quad -80 \\
\text{Power 25} & \quad -75 \\
\text{Power 51} & \quad -70 \\
\text{Power 102} & \quad -65 \\
\text{Power 153} & \quad -60 \\
\text{Power 204} & \quad -55 \\
\text{Power 255} & \quad -50 \\
\end{align*}
\]

Fig. 5 Relationship between PRR and RSS

Besides deploying motes which are able to tune their transmission strength can proof to be very useful when these motes are used in environments where the change in weather can be very extreme. In [2] we see that there is significant effect between the RSS received during the two different periods of when the reception rate of 73%. The results from the experiment done showed that we got good reception rate of around 80% at < -80dBm. A reason that may have caused the slight difference is because we used simple wires as antennas where as they used properly matched antennas.

From paper [5] we can see how protocols such as flooding and the initialization of the network can be affected by various transmission power settings. There is both a benefit to using high and low transmission power setting depending on the density of the nodes and distance between each node.

In future, to make wireless sensor networks more intelligent, nodes should be able to intelligently adjust their transmission power settings. An example of this would be [8] where the nodes using this protocol adjust their transmission power based on the number of neighboring nodes it wants. In this paper we would like to introduce the idea of adjusting the power transmission based on RSS. In both results obtained by [2] and by experiments we conducted. A packet reception rate of 70% and above is achievable with the receiver only getting an RSS of between -80dBm and -90dBm. Assuming that in the application this protocol is being used for can make do with a reception rate of 70% than it would be beneficial to tune the transmission power as such so that it will be sending at a power which will allow the receiver to be receiving it at an RSS of more than -80dBm and not wasting excessive energy transmitting at a high transmission power. Among the benefits of tuning the transmission power is first the node transmitting will eventually need to use less energy to transmit and there will be less transmission collisions.

\[
\begin{align*}
\text{Transmission Power (Pa_Pow)} & \quad \text{RSS (dBm)} \\
1 M & \quad -90 \\
2 M & \quad -85 \\
4 M & \quad -80 \\
6 M & \quad -75 \\
8 M & \quad -70 \\
10 M & \quad -65 \\
20 M & \quad -60 \\
40 M & \quad -55 \\
80 M & \quad -50 \\
160 M & \quad -45 \\
320 M & \quad -40 \\
\end{align*}
\]

Fig. 6 Transmission Power vs. RSS
crop flowered to crop on its return. Future protocols should be designed to be able to make changes according to the different environmental situations in might be facing with the goal of maintaining a good packet reception rate without using excessive transmission strength.

Part of the reason for the experiments were done was to study if there was a clear way the nodes could use to adjust its transmission power accordingly. For instance if a node were to learn that its neighbors are receiving his packets at an RSS of -50dB how much power then should the node drop its transmission power. Based on figure 6, at fix distance of 2 and 6 meters the difference between the highest and lowest power of transmission in terms of RSS is 19dB and 27dB respectively. There is no clear relationship between the RSS and the transmission power because of the different distance. By this we can conclude that the best way the node should decrease its transmission power is through iteration. By iteration it means that the transmitter should slowly adjust its transmission power based on the feedback the receiver sends back, the adjustment stops when the receiver is receiving its ideal RSS.

6 Conclusion

Through this paper we have looked at how distances, power transmission and received signal strength affect each other. The initial transmission power setting, density and distance plays a big role in affecting how flooding and the initialization of the data gathering tree. Future designers should take this into account when designing a protocol or when deploying a wireless sensor network.

The paper also seeks to show that when designing power transmission control protocols based on the use RSS the designer will have to take in factors such as the radio frequency being used, the distance of nodes and battery voltage. Results have shown that with a RSS reading of -80dBm a receiver will be able to get a reception rate of around 80%. Results also seem to point that the use of iteration will have to be used when adjusting transmission power.

With this paper we hope the readers will have a better understanding on using RSS for WSN protocols.

References