Exploring Possibilities for RSS-Adaptive Power Control in MICA2-based Wireless Sensor Networks

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Abstract—Careful control of power transmission levels can play an important role in prolonging the lifetime of a node in a wireless sensor network. Thus in designing efficient wireless sensor networks protocols serious consideration should be given to this factor. This paper investigates the relationship between power transmission levels and received signal strength and packet reception rates, when MICA2 motes are used. The measurement-based approach obtains real-world performance data of MICA2 mote communications as power transmission levels are varied. The results presented here may therefore be of use in the design of power control algorithms in new communication protocols for the MICA2.

Keywords—wireless sensor networks, power control, Mica2

I. 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. 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, although there is research being done on using solar power [1].

Whichever way these nodes are deployed or powered, the limited supply of power of each node will always be an issue. The radio transmitters and receivers of the nodes are usually the main consumers of the power supply. The two biggest current consumers are when the node transmits at maximum power (21.5mA) or when the node does an EEPROM write (18.4mA) [10].

Since transmitting consumes a lot of current, future work needs to be done in designing communication protocols which are more energy efficient and intelligent. There is a need to study radio models for WSNs in terms of the received signal strength (RSS), packet reception rate (PRR), transmission power and distance for these new protocols to be designed. A goal of this paper is to shed better light on this so that future WSNs communication protocol designers can take this into account when designing protocols which will be more power efficient. Towards this aim, we explore how to minimize transmission power while not having a significant loss in PRR.

We also investigate how different settings of power transmission levels will cause different effects on the WSN's topology.

Experiments were done using MICA2 sensor platforms (motes) which are made by Crossbow [13]. The motes used in our studies have radio transceivers which transmit at a frequency of 315MHz. The reason why MICA2 motes were used is because of their popularity in WSN research. Thus, we wanted to obtain results that would be of use to researchers using MICA2. The results in this paper may be useful especially to those who are interested in designing protocols which will use the RSS and the PRR readings to adjust the strength of MICA2 power transmission. The results that will be discussed should give MICA2 designers a rough estimate as to what to expect in terms of the RSS and the PRR on a MICA2. Results in this paper may also prove useful for researchers who are designing range finding protocols.

Section II gives provides some relevant background information. Section III deals with related work. Section IV 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.

II. BACKGROUND

MICA2 motes run using TINYOS which is an open source operating system made especially for use in wireless sensor networks. TINYOS needs only a small “footprint” in RAM, and is component based thus providing flexibility to designers. MICA2 motes running on TINYOS are one of the most widely used research platforms for WSNs around the world [11]. Thus, the measurement-based study (using MICA2 motes) reported in this paper should be of interests to many 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 is read by the Analogue to Digital Converter (ADC) channel 0 of the microcontroller.

MICA2 nodes are powered by batteries. Battery voltage on the MICA2 decreases linearly with the duration it is deployed [12]. The minimum operating voltage is 2.1V. 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. It has been reported [4] that variations of up to ±7dBm were observed when the ADC was tested across a voltage of 2.6V-2.9V. As the voltage decreases the RSS values measured on the receiver also decreases. Besides battery voltage, the deviation of results across the nodes can also occur due to the production process. The same study also shows that when two different MICA2s transmitted to each other at fixed transmission strength, there was a variance in the resulting RSS. The maximum variance was 4.4dBm.

MICA2 comes in a variety of radio frequencies; 433, 868/916, or 315 MHz. The first thing to note is that higher frequencies have higher attenuation. Also at higher frequencies, signals slowly lose their ability to go through obstacles, go around obstacles and to reflect off obstacles. Thus radio frequency also plays a role in the resulting RSS.

Distance between the transmitter and the receiver are also important in the resulting RSS. This is because RSS is the difference between transmission strength and signal loss. The signal loss for the plane earth model [6] is given by (1) when the distance between the transmitter and receiver, d, satisfies (2),

\[
L_p(dB) = 40 \log_{10} d - 20 \log_{10} HT - 20 \log_{10} HR \quad (1)
\]

\[
d >> 20\pi HR HT / 3\lambda \quad (2)
\]

Based on (1) it is straightforward to see, for example, that received power falls by 12dBm when the distance is doubled [7]. Besides distance, environment also plays a big part in influencing the RSS. This is further explained in section III.

PRR is the ratio of successfully received packets over transmitted packets. There are a few factors which contribute to the effectiveness of the PRR. One such factor is the received signal strength. The effect that the RSS has on PRR is explained in the later sections. However, a high RSS alone does not guarantee good PRR. Multipath can cause the receiver to receive a transmission with high signal strength but poor signal quality. Multipath is caused by reflection. Signals which are reflected will reach the receiver later than the direct ones. When the direct and reflected signals combine at the receiver the signal gets distorted thus causing poor signal quality.

Besides being influenced by the RSS, the PRR is also heavily influenced by the type of packet recovery used, the modulation scheme, and the type of encoding scheme used to encode the data bits. The encoding scheme used by the CC1000 is Manchester encoding. This encoding is better than Non-Return Zero (NRZ) encoding because with NRZ, the receiver has difficulty interpreting the transmitted signal when a string of ones or zeros are transmitted [9].

Packet recovery also influences the PRR. Packet recovery can be done using two methods ARQ (Automatic Repeat Request) and FEC (Forward Error Correction). TINYOS does not use FEC but uses a cyclic redundancy check to detect up to 2 bits of error and then packets with errors are dropped. If FEC were used in TINYOS it would improve the PRR.

The kind of radio modulation used can also have an effect on PRR. For example FSK (Frequency-Shift Keying) is more resilient to noise than OOK (On-Off Keying) is. The CC1000 on the MICA2 uses FSK.

III. RELATED WORK

Thelan, Goense and Langendoen [2] conducted a measurement-based study in a potato field. Mica2 motes were planted in a potato field and measurements of the RSS, PRR and distance were taken. The paper explores the relationship the PRR has with the RSS and the relationship of the RSS with distance. For this experiment numerous nodes were planted in a potato field and the RSS was measured in different weather and environment conditions. A result of interest from their experiment is the one concerning the relationship between the packet reception rate and the RSS.

The results show that with an RSS of at least -90dBm, a 73% packet reception rate is achievable (as can be seen in Fig.1). It is noted that in all their experiments, a 100% packet reception rate was never achieved even at the highest RSS. When the RSS is below -90dBm, the packet reception rate becomes totally unpredictable. 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. Fig. 2 shows 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 Reference [2] and this paper is that the results of Reference [2] do not vary the power transmission strength of the MICA2 nodes. Their results also do not show how power transmission strength influences both RSS and PRR. This paper investigates the relationship between the three; transmitted signal strength, RSS and PRR.

Power transmission levels in wireless sensor networks have an impact on not just the radio communication link, but also on other layers of the protocol stack. In other related work, Ganesan, Estrin, Woo and Culler [5] studies the effect of different transmission power settings 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. Thus, the use of different transmission strengths can affect the shape of wireless sensor networks.

In terms of the MAC layer, performance was 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 every node to transmit the 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 first 95% of nodes received the flooded message within half the time of the reception latency (i.e., the time till when the last node received it), and the final 5% of the nodes that had yet to receive the flooded message took the rest of the time. For example, if reception latency was one second, 95% of the motes received the flood after half a second while the final 5% took the final half of the second to receive the flood. At low power settings, the packet reception time of all the nodes is more spread out over the entire duration of the reception latency, unlike the scenario using high transmission power where the final 5% had to wait half the time. In terms of settling time, the packet transmission power the time taken for every node to transmit the packet takes slightly a 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. Backward links are links where the recipient of the flood is closer to the sink than the node that transmitted it.

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.

Thus, adjustments in transmitted power levels can have interesting repercussions on multiple aspects of WSNs. However, in this paper, we focus mainly on the effects on PRR and RSS.

IV. DESCRIPTION OF EXPERIMENTS

For these experiments, 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 RSS 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. The experiment was then repeated, each with different distances (1, 2, 4, 6, 8, 10 meters) between the two nodes. After doing all the distances, the transmitting output power was changed and everything else mentioned repeated. Fig. 3 gives a better understanding how the experiment was done. In the experiment, the PRR is 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 Tab. 1). Each PA POW value corresponded with a unique pair of output power and current consumption as shown in Tab. 1 [14]. 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.

![Figure 3. Experiment to study PRR and RSS](image-url)
those covered by [2] with the exception that we have network protocols are designed for use with MICA2 motes). Use of approximate models (assuming, that the wireless sensor measurements using MICA2 motes could therefore be more needs to satisfy (2). (1) was meant to model Large-Scale Path model isn’t accurate when the distance is small is because (1) doesn’t provide a correct estimate for all distances. This goes to show that (1) doesn’t include the RSS during the two different periods of when the crop extreme. In [2] we see that there is significant effect between strength can also prove to be very useful when these nodes are used in environments where the change in weather can be very important. In 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 the application this protocol is being used for can make do with a 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 whereas they used properly matched antennas. We can see from the figure that the results are in the form of an exponential graph.

From reference [5] we can see how protocols such as flooding and the initialization of the network can be affected by various transmission power settings. It explains the affects of using high/low transmission strength on the network formation. Designers should take this into account when designing a wireless sensor network.

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 neighbouring nodes it wants. In this paper we would like to introduce the idea of adjusting the power transmission based on the 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 the application this protocol is being used for can make do with a reception rate of 70%, then it would be beneficial to tune the transmission power of the transmitter as such so that it will be sending at a power which will allow the receiver to be receiving packets at an RSS of more than -80dBm. This will decrease the use of excessive energy transmitting at a high 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. Designers should note that the accuracy of the RSS value is subjected to the production process and battery voltage. There is a maximum variance of 4.4dBm and 7dBm respectively, so designers should take this into considerations.

Deploying nodes which are able to tune their transmission strength can also prove to be very useful when these nodes 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 during the two different periods of when the crop flowered to crop on its return. Future protocols should be

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<td>1</td>
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<td>4</td>
<td>102</td>
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Fig. 5 shows the relationship between the PRR and the RSS. In [2] it states that with an RSSI of < -90dBm they were able to get a respectable 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 whereas they used properly matched antennas. We can see from the figure that the results are in the form of an exponential graph.

Looking at Fig. 4, the series named ‘model’ is the RSS based on the model. As mentioned earlier RSS is the difference between transmission strength and path loss. In the case for the model we used maximum transmission power (255) which is 10dBm and an antenna height of 0.2m. Table 1 could be consulted to see the output power of the other 8 settings in dBm. When the model is compared with the actual results (Power 255) we see that the model is only able to give a good estimate from 6m onwards. This goes to show that (1) doesn’t provide a correct estimate for all distances. The reason the model isn’t accurate when the distance is small is because (1) needs to satisfy (2). (1) was meant to model Large-Scale Path Loss. For more accurate results, measurements are needed. Our measurements using MICA2 motes could therefore be more useful to wireless sensor network protocol designers than the use of approximate models (assuming, that the wireless sensor network protocols are designed for use with MICA2 motes).

V. 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. Fig. 4 shows how, as the distance between the two nodes increase, the Received Signal Strength (RSS) drops.

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Table I. OUTPUT BASED ON SET DECIMAL NUMBER

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node should decrease its transmission power is through
different distance. By this we can conclude that one method the
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is 19dB and 27dB respectively. There is no clear relationship
highest and lowest power of transmission in terms of the RSS
learn that its neighbours are receiving his packets at an RSS of
transmission power accordingly. For instance if a node were to
would need to be taken.

Part of the reason for these experiments was to study if
there was a clear way nodes could use to adjust their
transmission power accordingly. For instance if a node were to
learn that its neighbours are receiving his packets at an RSS of
-50dB how much power then should the node drop its
transmission power. Based on Fig. 6, at fixed distances of 2 and
6 meters (meter is indicated by 'M') the difference between the
highest and lowest power of transmission in terms of the 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 one method the
node should decrease its transmission power is through
iteration (in other words, there is no simple magic formula that
can be easily applied to change the transmission power to the
optimal level in one step). 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 that gives an
acceptable PRR.

A second method to approach this problem is by fixing the
transmission strength of the route update messages. However,
this method is based on the assumption that nodes have a
bidirectional RSS meaning that if node A transmits to node B
at a particular power and node B transmits to node A at the
same power, then the RSS on both sides will be the same. This
is important because the transmitting node is assuming that the
RSS of the route update message sent by the receiving
neighbor is similar to that which will be obtained by the
neighbor if it was to transmit a packet at the same transmission
strength. By fixing the transmission strength, the RSS becomes
predictable. For instance, if the nodes are fixed to transmit their
route update messages at 255, when a node receives such a
message at a RSS of -55dBm the node then can estimate that its
distance from the node that sent the message would be around
the 8 meter range (based on Fig. 4). Based on Fig. 7 we can see
that at a distance of 8 meters, transmission strength of 5 is able
to obtain a PRR of more than 80%.

VI. CONCLUSION

Nodes in WSNs run on batteries, so power conservation is
very essential. One way to reduce power consumption in the
nodes is to reduce transmitted power levels in communications
between the nodes. However, care needs to be taken in
reducing the transmitted power levels to avoid adverse
consequences such as unacceptable RSS, poor packet reception
rates, higher latencies and so on. Furthermore, the relationship
between transmitted power levels and such performance
indicators, is different from sensor platform to sensor platform.
Therefore, we choose to investigate these relationships for one
of the most popular sensor platforms used by WSN researchers,
namely MICA2 motes.

Through this paper we have looked at how distances, power
transmission and received signal strength are related, when
MICA2 motes are used. The investigations have been
measurement-based using typical MICA2 hardware
configurations. The initial transmission power setting, density
and distance plays a big role in affecting 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 of RSS the
designer will have to take into account factors such as the radio
frequency being used, distances between the nodes and battery
temperature. Results have shown that with a RSS reading of
-80dBm a receiver will be able to get a reception rate of around
80%. Through the results we see that variable transmission
control can be done either through iteration or by fixing the
transmission strength of the route update message. The
iteration can be made adaptive to RSS readings, perhaps
through some form of feedback mechanism while the second

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**Figure 6. Transmission Power vs. RSS**

**Figure 7. PRR vs. Power (dBm)**
method using fixed transmission strength of route update message assumes that the RSS is bidirectional.

REFERENCES


