Feasibility Study of Direct Communication in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) have been broadly deployed in civil applications as it is economically feasible to deploy large number of sensors over a geographic area. Resource constraint is one of the main drawbacks in WSNs by means of limited power sources and communication ranges. Multiple hops approach is therefore always used in WSNs. However, direct communication is feasible when the two sensor nodes are located within their ranges. Multiple data transmissions and receptions are not required and corresponding energy can be thus saved. This paper investigates the feasibility of direct communications in WSNs. Statistical analysis of the derived measurements demonstrated significant communication ranges for both indoor and outdoor environments.

Keywords: wireless sensor networks; direct communication; single-hop; communication ranges

1. Introduction

Wireless sensor networks (WSNs) enable the distribution of sensors or motes across an area of interest. MEMS (MicroElectroMechanical System) [1] have facilitated smaller and cheaper sensors. One production example being an island [2] that was instrumented to obtain physical data such as temperature and humidity. WSNs consist of resource constrained sensors and base station which are wirelessly connected. Often sensors are powered through batteries. Replacing the batteries may be costly or impractical. Several works have focused on developing energy aware communication protocols [3,4,5]. Furthermore, sensors employ transceivers for data communication which have limited communication ranges. Multiple hops are required to forward data to the base station when direct communication is infeasible.

In this paper feasibility study of direct communication in WSNs is presented. Unlike multi-hop, the sources directly communicate with their base station and energy on data reception and forwarding can be conserved. Communication range of sensor is thus important to make the single-hop communication
possible. Strength is inversely related to the distance and perfect conditions without obstacles and good weather are assumed in the free space propagation model used [6]. Statistical analysis is conducted to discover the feasible indoor and outdoor ranges with the sensors used. A combination of analytical and measurement studies are used to establish the scenarios within which direct communication between a sensor and its base station is possible.

The remaining parts of this paper are organised as follows: Section 2 provides the details of the related works which mainly focus on energy efficient protocols and direct communication or single-hop applications in WSNs. Section 3 describes the determination of the feasible communication ranges of sensor nodes both indoor and outdoor. Measurements and results given by other study are used in the analysis. Finally, conclusion is stated in Section 4.

2. Related Work

Data transmission and reception account for a significant amount of energy in WSNs. A static clustering based heterogeneous routing protocol is proposed in [3]. The sensors are firstly divided into several clusters and the protocol is then employed in each cluster. Lower power can be used for data delivery in the cluster. The heterogeneity of the sensors is also supported. An IEEE 802.15.4 compliant protocol is developed in [4] which minimises energy consumption whilst achieving the required reliability. The approach consists of open and closed loops. In the open loop, the link quality of each node is estimated by using its temperature sensor. The feedback process is then used in the closed loop where three regions based upon the received signal strength threshold are divided and transmission power control mechanism and adaptation are applied accordingly. A consideration of sink mobility is conducted in [5] where the area of interest is virtually divided into several small squares. The sink stops in the middle of each square to receive the data from the awaking nodes whereas the others are in sleep mode.

Single-hop applications have been used in WSNs. An energy balanced protocol for the single-hop is developed [7]. In order to conduct data routing, two phases are introduced. Data packet is routed to suitable cluster which contains the destination node in the first phase. In the second phase, the packet is redistributed within the cluster in a single-hop fashion. The packets will be routed to achieve an equal distribution of workload in terms of communication. A single-hop, and time-synchronised WSNs is assumed in [8]. The remaining power of each sensor is sorted to find the maximum. The sensor which has the highest remaining power will report data in the next transmissions. Reliable data delivery is important in reprogramming the sensors [9]. The single-hop is more suitable for unreliable link and linear or approximately linear topology.

Several habitat and environmental monitoring systems deploy single-hop approach [2,10,11]. In such systems, a duty cycle of approximately 1% is required in [2,10]. Furthermore, the system in [2] is divided into three tiers. Single-hop was used in each communication patch or in the first tier. Environmental monitoring system is observed in [11] where the sensors were located within the ice and collected data such as temperature, strain and pressure.

3. Determination of the Feasible Communication Range of Sensors

The Tmote sensor platform used in this study employs the CC2420 radio which operates at the frequency range of 2.4GHz [12]. According to [6], the radio wave propagation of the 2.4GHz transceiver requires line-of-sight (LOS). The communication range is important in direct communication scenarios as the source transmits directly to the base station. The free space propagation model is widely used to predict the reception signal strength and the strength is inversely related to the distance. Perfect conditions without obstacles and with good weather are assumed in the model. Statistical analysis should be conducted on the measurements to discover feasible indoor and outdoor ranges.
3.1. The free space propagation model

This model is used to predict the received signal strength when an unobstructed line-of-sight path exists between the sender and receiver [13]. The degradation of signal strength varies with the square of the sender-receiver distance ($d^2$). An equation for predicting the expected received signal level (RSL) in dBm is provided by [3] and is shown in (1).

$$RSL = P_t + G_t + G_r - 92.44 - 20 \log f - 20 \log d \quad (1)$$

where $P_t$ is transmission power (dBm), $G_t$ and $G_r$ are transmit and receive antenna gains (dBi), $f$ is frequency (GHz) and $d$ is the distance between the sender and receiver (km).

Fig 1. demonstrates feasible communication ranges of a sensor using the CC2420 transceiver set at various transmission power levels and distances. As the CC2420 does not report the observed Received Signal Strength Indicator (RSSI) below -95dBm, the last distance which provides measurable RSSI is determined as the maximum range. Transmission power levels specified in [14] are used for $P_t$ and they include 0, -1, -3, -5, -7, -10, -15 and -25dBm. Tmote Sky employs an inverted-F and monopole antenna. The $G_t$ and $G_r$ of 3.1dBi are chosen as the corresponding return and they are close to that specified in Tmote Sky datasheet [12]. The frequency is 2.4GHz. The selected eight power settings are the same as those in the data sheets [12,14]. The results demonstrate a significant range for direct communication in WSNs. The feasible ranges based upon -95 dBm are 65, 200, 390, 500, 650, 870, 1,000 and longer than 1,000m for the transmission power settings of -25, -15, -10, -7, -5, -3, -1 and 0 dBm, respectively.

However, there are two main assumptions which, under some circumstances, may make the results impractical in a real production. A clear line-of-sight and good weather are assumed in (1). The theoretical range cannot be achieved in the presence of physical or temporal barriers such as plants and humans. Moreover, weather changes are likely at any time during the operation. Several barriers along with some recommended empirical formula are given in [6]. The calculations of path losses in dB/km (decibel per kilometer) due to precipitation, signal absorption and ground coverage are also provided. The recommended models mainly focus on systems which have communication ranges up to many kilometers and operating frequencies up to hundred or thousand giga-hertz. Sensors have 50m indoor and 125m outdoor ranges. Instead of using the path loss estimation models, experimental measurements should therefore be used to analyze the sufficiency of the prediction model and estimate feasible communication ranges.

3.2. Estimation of communication range

Using results based on the experimental studies on location as a determination of necessary transmission power, provided in our previous study [15] and in [16], models for predicting the
communication ranges by non-linear regression analysis were developed for indoor and outdoor environments.

For an indoor environment, the measurements in [15] are used. In total 10 different distances, 1, 2, 3, 4, 5, 7, 10, 13, 16 and 20m, were used to measure the RSSI at the receiver. The experiment was repeated 50 times for each transmission power setting. The average RSSI was computed and plotted against the distance. Linear, logarithmic and inverse methods of curve estimation were applied to the scatter plots. Fig 2(a) shows the logarithmic curve estimation of the measured RSSI based upon the indoor environment experiment. The logarithmic approach provided the highest R-square value which describes how well a regression line estimates the set of real data. An R-square value of 1 means that the regression line provides a perfect fit. The R-square values of over 0.85 were obtained.

An extensive experiment in an outdoor environment was conducted in [16]. The sources were placed in a free space parking area at varying distances of up to 50m. The heights above ground were respectively set to 2m and 1.10m for the receiver and sender. The average RSSI measurements of 10 distances, 2, 4, 6, 8, 10, 20, 30, 40 and 50m, are used for logarithmic regression analysis. All six power settings, 0, -2.5, -4, -6.5, -10 and -17.5 dBm, are used. The results are shown in Fig 2 (b). The R-square values for an outdoor range analysis are at least 0.80 which mean that the regression lines fit at least 80% of the raw data. Communication range increases if the sensors are deployed outdoors.

Feasible communication ranges at different transmission power settings can be estimated from Fig 2, by using from the fact that TinyOS does not report RSSI when the value is below -95 dBm. An indoor range of up to 96m may be feasible if the maximum power level is used for transmission. A 10m range may be obtained if the sensors transmit at the minimum power. By choosing an appropriate power setting, a direct communication between source and base station is feasible.

The estimations provided in Fig 2 (a) and (b) are based upon the eight and six transmission power settings.
levels, respectively. In TinyOS, the power setting command accepts an integer ranging from 1 to 31. In order to estimate the indoor ranges of all 31 feasible power settings, a regression analysis is conducted and the results are shown in Fig 3.

Linear regression is used as it provides an R-square of over 0.99 implying more than 99% of the data can be fitted by the regression line. The results can be used to estimate the indoor communication ranges at different transmission power settings. In order to achieve a higher communication range, a higher power should be used. On the other hand, an R-square of over 0.98 implying more than 98% of the data can be fitted by the regression line in the case of the outdoor. The results can be used to estimate the outdoor communication ranges at different transmission power settings.

3.3. Feasible indoor and outdoor communication ranges

The previous two sections demonstrate the analysis of communication range of sensor based upon the free space propagation model and the estimation of the indoor and outdoor ranges based upon experimental results. The ranges are obtained by determining the RSSI of -95 dBm which is the minimum value which the receiver’s transceiver interpret the received signal.

However, packet losses are likely to occur if lower transmission is used to produce the RSSI of -95 dBm. One of the key requirements in data delivery in the network is to minimize data losses. According to the RSSI-PRR relationships in [17,18], the RSSI of -85 dBm or higher often produces the PRR of nearly 100%. Similar procedures are applied to the results shown in Figure 1, 2 and 4 to estimate the ranges based upon the -85 dBm. As the chosen power levels in [16] are different from the ones in [14], the estimated outdoor ranges for -95 dBm are based upon the regression line shown in Fig 5. The results are shown in Table 1. The selected eight transmission powers are specified in [14].

Shorter communication ranges are achieved if -85 dBm is required instead of -95 dBm. This is because the reception strength decreases with longer distances. The free space model gives significant ranges as no barriers and good weather are assumed in the model. The indoor and outdoor ranges are obtained from experimental results in [15,16], respectively. The indoor and outdoor ranges specified in [12] are respectively 50m and 125m.

Communication range is important in the single-hop network where the nodes require a clear line-of-sight path. Moreover, nodes must be located within the ranges. The estimated values based upon -85 dBm indicate that direct communication can be applied to wireless sensor networks as the sensor has up to 38m indoor and 143m outdoor ranges whilst the packet losses are minimised.

4. Conclusion

Whilst traditional multi-hop communication paradigm is always used in wireless sensor networks (WSNs), this paper focuses on an alternative approach – direct communication or single-hop. There are several scenarios in the existing WSNs applications where direct communication can apply. For example,

<table>
<thead>
<tr>
<th>Transmission Power (dBm)</th>
<th>Estimated Communication Ranges (m)</th>
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<tbody>
<tr>
<td></td>
<td>Free Space Model Indoor Outdoor</td>
</tr>
<tr>
<td></td>
<td>-95  -85  -95  -85  -95  -85</td>
</tr>
<tr>
<td>-25</td>
<td>3 65  20  10  2.5  15  10</td>
</tr>
<tr>
<td>-15</td>
<td>7 200  70  20  8  70  29</td>
</tr>
<tr>
<td>-10</td>
<td>11 390  120  32  12.5  130  48</td>
</tr>
<tr>
<td>-7</td>
<td>15 500  180  45  18  190  67</td>
</tr>
<tr>
<td>-5</td>
<td>19 650  230  65  24  245  85</td>
</tr>
<tr>
<td>-3</td>
<td>23 870  300  74  29  305  105</td>
</tr>
<tr>
<td>-1</td>
<td>27 1,000 380  80  33  360  124</td>
</tr>
<tr>
<td>0</td>
<td>31 1,000+ 420  96  38  420  143</td>
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sensors directly report their readings to the base station in each cluster. Hence, multiple data deliveries and associated energy can be conserved. This paper focuses on the feasibility of direct communication in WSNs. The free space propagation model may provide impractical results in a real production where two assumptions—a clear line of sight and good weather, do not apply. Previous measurements and results from other works are used in this study to conduct statistical analyses. The Received Signal Strength Indicators (RSSIs) observed at the receivers at different transmission power levels and distances are plotted and the best-fit curve estimation technique is used. Furthermore, estimated communication ranges of all feasible power settings in both indoor and outdoor environments are provided. The RSSI of -85 dBm is used for the estimation as it produces the Packet Reception Rate (PRR) of nearly 100%. The results demonstrate up to 38m indoor and 143m outdoor ranges whilst the packet losses are minimised.

References


