Detection and Recovery for Intermittent Disconnections in Tmote Sky Sensor Networks

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Abstract-*Tmote Sky sensors provide programmable and adjustable output power for transmission. Users can control needed transmission power for each sensor. However, the transmission range for a fixed power changes inconsistently due to the interferences, such as obstacles and other wireless signals. Therefore, the communication between sensors is disconnected sometimes. To solve the problem, this paper demonstrates the implementation of three recovery schemes. As Tmote Sky sensors detect communication disconnection, sensors will increase their transmission power for a certain of time, ask backup nodes for help, or broadcast control messages for cooperation. Practical experimental results reveal the amount of lost packets can be reduced with a little additional energy.*

Keywords: Wireless Sensor Networks, Tmote Sky, Network Disconnections, Energy Consumption.

1. Introduction

Wireless sensor networks are composed of sensor nodes that perform data gathering and/or event monitoring with wireless communication. Recently, sensor networks provide applications such as earthquake report, mudflows and landslides detection, and marine mammals tracking [1, 2]. A wireless sensor module is typically tiny so the size of its battery is limited. Moreover, it is not practical to replace batteries in some conditions, such as in the deep ocean or disaster scene. Therefore, how to reduce energy consumption and increase network lifetime for a wireless sensor network becomes a critical issue [3, 4]. Some researches thus suggested that the sensors do not have to use the maximum transmission power [5, 6]. Instead, the sensors may adjust the needed transmission ranges to their designated one-hop neighbors.

This paper examines the communication performance and energy consumption on *Tmote Sky* sensors [7]. *Tmote Sky* is a wireless module designed by the University of California, Berkeley. *Tmote Sky* is compiled with the TinyOS operating system [8, 9]. *Tmote Sky* features the Chipcon CC2420 radio for wireless communications. The CC2420 has programmable output power [10]. Users can change the transmission power at both compile time and run time. The output power values are ranged from -25dBm to 0dBm [7]. As shown in Table 1 [7], reducing the output power level saves energy consumption for Tmote Sky.

2. Observation: Intermittent Disconnections

Tmote Sky modules were used for constructing a wireless sensor network. During the implementation, however, an interesting result was found. The modules set the lower transmission power for saving energy. When one sensor sent data to another, some packets could not be delivered correctly. By observing the received packets using *Moteiv Trawler* (a display program designed for *Tmote Sky*), we noticed that

Table 1. Current and Power Consumption in Tmote Sky (with Operating Voltage 2.1 V)

Output Power (dBm)	Current Consumption (mA)	Power Consumption (mW)
0	17.4	36.54
-1	16.5	34.65
-3	15.2	31.92
-5	13.9	29.19
-7	12.5	26.25
-10	11.2	23.52
-15	9.9	20.79
-25	8.5	17.85

Figure 1. Tmote Sky deployment.

Table 2. Environment Setup

Experimental parameters	
Output power	-25dBm
Packet transmitted	Every 5 seconds
One round tested time	3600 seconds (1 hour)
Total tested time	5 rounds (5 hours)
Total tested packet	3600 packets

the two sensors could not connect each other intermittently and the disconnection continued for a period of time. To study the communication disconnections in *Tmote Sky*, more experiments were conducted.

The *Tmote Sky* sensors were deployed as Figure 1. In order to observe the received packets, a base station was installed as a *Tmote Sky* sensor plugged with a notebook. Sensor *c* sent packets through path *c*-*b*-*a* to the base station periodically. Sensors *b* and *a* played the role of relays and helped to transmit packets hop-by-hop. The environmental parameters are listed in Table 2.

Figure 2 illustrates the number of lost packets for five rounds (five hours). The lost packets were recorded as continuous if the base station did not receive any packet within ten seconds; the other lost packets were non-continuous. Due to the inconsistent radio signal interface, the results were varied for each round. The continuous lost packets occupied 58.4% of

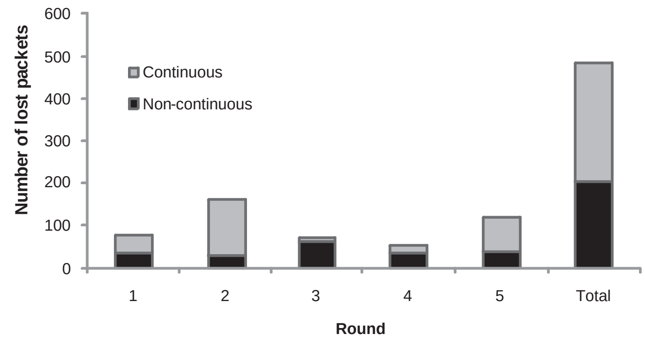


Figure 2. Number of lost packets.

Table 3. Distribution of Lost Packets

Number of continuous loss	Number of times	Number of lost packets
(non-continuous) 1	202	202
2	13	26
3	7	21
5	9	45
10	4	40
16	1	16
30	1	30
105	1	105

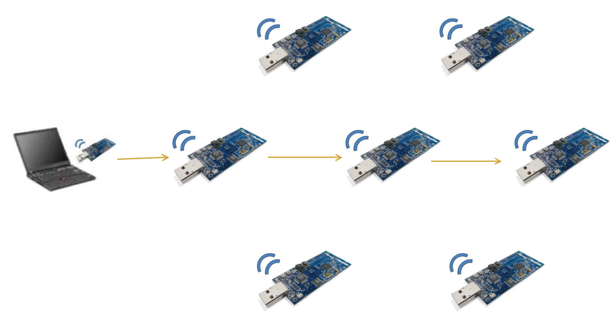


Figure 3. Base station constructed its backbone for communication.

total lost packets. This was called *Intermittent Disconnection*. Table 3 shows the distribution of continuous lost packets for all five rounds.

3. System Model

Since the intermittent disconnections contributed more than half of the lost packets, it is desirable to solve the problem. As *Tmote Sky* sensors are deployed in a field, the base station will construct its backbone for communication. Figure 3 shows the concept of

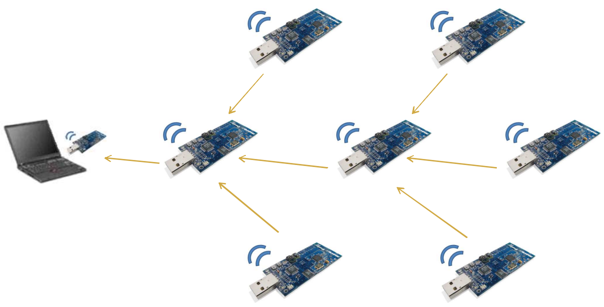


Figure 4. All sensors periodically transmitted sensing data to the base station.

backbone in a *Tmote Sky* sensor network. Some sensor nodes, called backbone nodes, participate in the backbone constructions. Other nodes which do not belong to the backbone are regular nodes. When the backbone is established, all sensors will periodically transmit sensing data through the backbone to the base station. Figure 4 illustrates the route of data transmission.

Constructing a Backbone

The terminal condition of constructing backbone is important. The base station searched one backbone node first. The backbone node continued to find its next sensor to be backbone, and the other of its neighbors became regular nodes. When a backbone node could not find any other sensor to be regular node, the backbone was completed.

Detecting Intermittent Disconnections

Aside from transmitting sensing data received from other sensors, the backbone sensors are also responsible for detecting intermittent disconnections. If a backbone sensor does not receive any packet from its served sensor (either a regular sensor or backbone sensor) continuously, the served sensor will be considered failed. When the failure is detected, one of the following recovery schemes will be started.

4. Solutions

Increasing Transmission Power

Based on our measurements for *Tmote Sky* (see Table 4), the transmission range for a fixed output power

Table 4. Transmission Range for Each Power

Output Power (dBm)	Average Transmission Range (Meter)	Maximum Transmission Range (Meter)	Minimum Transmission Range (Meter)
0	25.10	27.50	22.62
-1	21.82	23.46	19.94
-3	19.34	21.80	16.92
-5	16.04	17.85	14.23
-7	12.14	14.36	10.11
-10	9.37	11.48	7.20
-15	6.38	8.70	5.82
-25	2.20	3.30	1.75

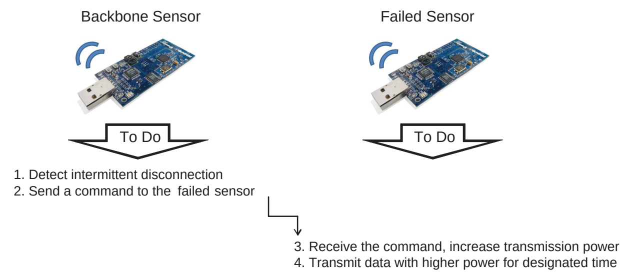


Figure 5. Increasing transmission power.

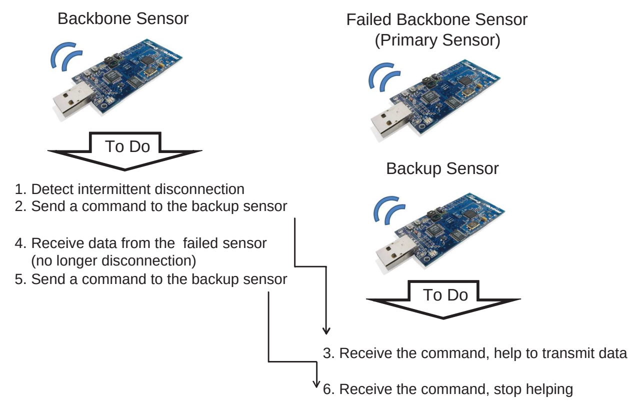


Figure 6. Constructing a primary-backup system.

may vary. For example, when the output power is set to -10dBm, the transmission range is from 7 to 11 meters. It is possible that the transmission range of a sensor is reduced suddenly so the backbone sensor cannot receive any data from the sensor. As the intermittent disconnections are detected, the backbone sensor will try to ask the “failed” sensor to use more output power for transmission. Figure 5 shows the concept of the recovery scheme.

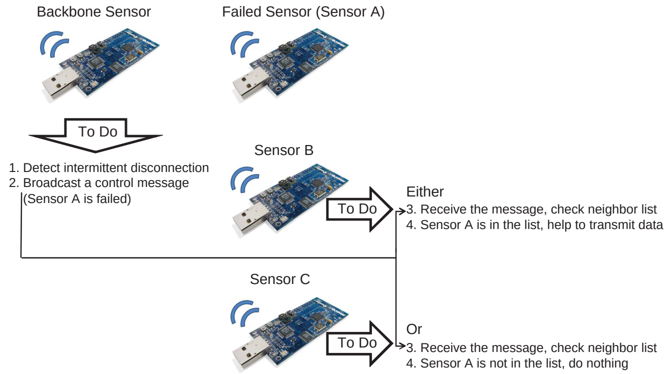


Figure 7. Cooperation.

Constructing a Primary-backup System

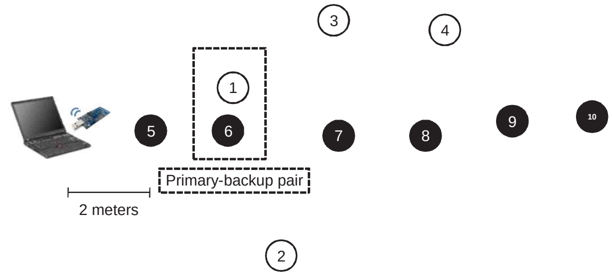
All sensing data are delivered through the backbone so it is critical to protect the backbone nodes from intermittent disconnections. Accordingly, to take advantage of redundant regular sensor nodes was considered. When the *Tmote Sky* sensor network starts, backbone sensors search for regular sensors with small output power to be their backup nodes. These sensors construct primary-backup pairs. As intermittent disconnections occur, the backup node of the "failed" primary sensor will be asked to take over. The backup sensor continues to help transmission during the time when the primary node fails. The procedures of the recovery are displayed in Figure 6.

Cooperation

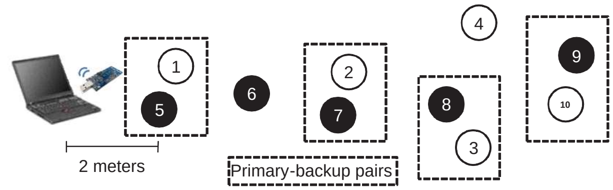
All regular sensors record their one-hop neighbors during the network initialization. When a failed sensor is detected, the backbone sensor will broadcast a message to ask if any sensor can connect to the faulty sensor. Each node receiving the message examines its current valid neighbors. If the node's neighbors include the faulty node, the node will transmit the data for the faulty node. There may be more than one regular sensors that can connect to the faulty node. The backbone sensor assigns one of responded sensors as the cooperator. Figure 7 demonstrates the concept of the cooperation scheme.

5. Experiments

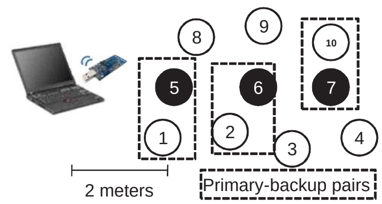
Eleven *Tmote Sky* sensors were used for the experiment. A laptop computer with a sensor acted as a base station and the other ten sensors were deployed in three topologies (see Figure 8). Topology 1 is a sparse deployment where few regular sensors can serve as backup nodes or cooperative nodes. In Topology 2, several primary-backup pairs can be established. In Topology 3, the node density is higher; each sensor has more neighbors. The sensors transmit packets to the base station periodically. Some sensors (in dark color) formed a backbone that helped to transmit packets to the base station hop-by-hop. Four sets of experiments were evaluated, including ORI (without any recovery scheme), ITS (with increasing transmission power), PBS (with primary-backup system), and CO (with cooperation). The parameter settings are listed in Table 5.



(a) Topology 1



(b) Topology 2



(c) Topology 3

Figure 8. Deployment of three topologies.

Table 5. Environment Setup

Experimental parameters	
Topology	3 kinds
Output power	-25dBm or higher
Packet transmitted	Every 5 seconds
Packet size	40 bits
Tested time	5 hours
Tested sensor	10 Tmote Sky sensors
Tested packet	36000 packets

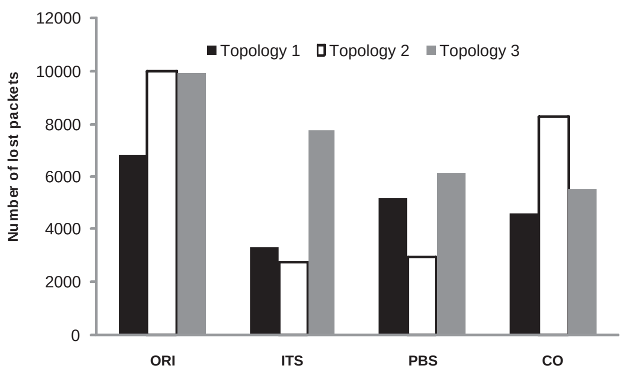


Figure 9. Number of lost packets.

5.1. Transmission Performance

Figure 9 shows the total number of lost packets in four experiments for each topologies. ORI had the largest number of lost packets since it did not have any recovery scheme for the intermittent disconnections. For Topology 1, ITS reduced 51.6% of the lost packets; PBS and CO had about 24.5% and 33.6% reduction, respectively. The result reveals that ITS is a better choice for the less condensed deployment. For Topology 2, PBS achieved about 70.8% reduction of the lost packets. This indicates that constructing primary-backup sensors in the backbone can reduce the effect of intermittent disconnections. For Topology 3, CO had the smaller number of lost packets than ITS and PBS. When each node has more neighbors, CO has the better performance.

5.2. Energy Consumption

Figures 10 and 11 illustrate the average number of transmitted and received packets for each node, respectively. The long I-shaped legends show the maximum and minimum values for all sensors. Energy consumption can be calculated based on the number of

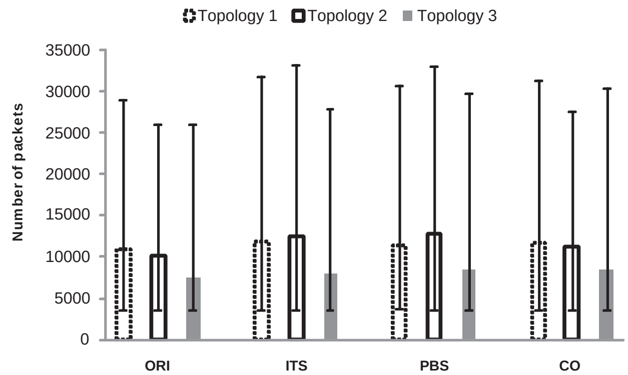


Figure 10. Average number of transmitted packets.

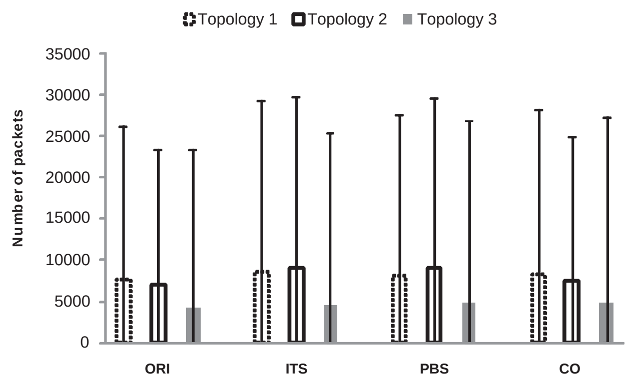


Figure 11. Average number of received packets.

packets sent and received, corresponding power, and required time [11]. Data rate in *Tmote Sky* sensor is 250Kbps. The packet size was set to 40bits so the time for transmission is 0.00016 second. The energy consumption for each node can be computed.

Figure 12 shows the average energy consumption in ten *Tmote Sky* sensors. Compared to ORI, the increased needed power for the three recovery schemes was limited. The recovery schemes spent additional 8.5% energy on average in Topology 1. In Topologies 2 and 3, about extra 22.7% and 12.4% energy were required, respectively. With the little more power consumed, the data transmission was better in the sensor network.

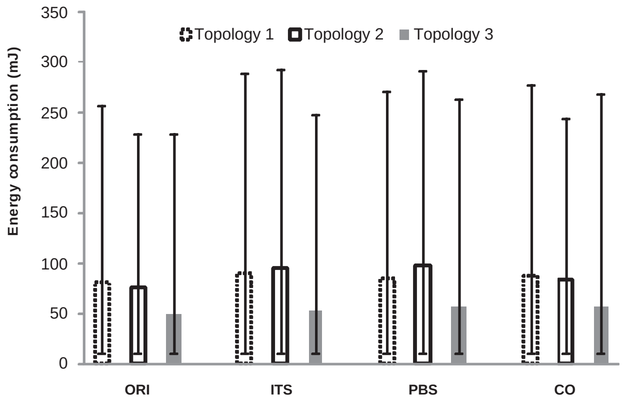


Figure 12. Comparison of average energy consumption.

6. Conclusion

In this paper, the transmission characteristics of *Tmote Sky* sensors were examined. The intermittent disconnection introduced by the inconsistent transmission ranges was also discussed. Three recovery schemes for the disconnection were implemented and evaluated in the *Tmote Sky* wireless network. Experimental results show that the transmission performance can be improved effectively with the limited energy overhead.

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