Enhanced Shortest-Path Technique to Reduce Transmission Power in Wireless Sensor Networks

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Abstract

This paper proposes the transmission power control technique considering the shortest-path to minimize the hop-count without the occurrence of any power control messages. We applied the proposed technique on tree-based network component implemented on Tiny-OS. And we measured the transmission energy with 21 motes. Compared to before, the proposed technique consumes 75% of the transmission energy of the maximum transmission power solution. As a result of considering the shortest-path, the hop-count considering the shortest-path was about 40% less than a normal network.

Keywords: *Sensor Network, Transmission Power Control, Tiny-OS, Shortest-Path, Hop-count*

1. Introduction

Wireless sensor networks refer to the atypical communication networks that wireless sensor nodes are constructed as the structure to be responsible for the communication relay task for each other. At that time, not only the sensor nodes are little durable since they are manufactured to work based upon the insufficient power supply, but also because the network configuration is not always fixed in the situation required mobility, their operations are needed to be disturbed little by such external environment's change.

Therefore, the researches considered the energy efficiency such as LEACH [1], PEDAP [2], SHORT [3] and so on were proposed using such directional characteristics of data transmission. The module consuming most power in a wireless sensor node is the module of radio communication. Therefore, reducing the amount of energy consumption in the radio communication's module could be more efficient method for decreasing the energy consumption of battery than controlling other module.

In order to solve such problem, this paper proposes the transmission power control technique that considers the shortest path not to generate additional control messages to maximize the advertising messages' usage needed for configuring the network in the tree based network. In addition, the proposed method is implemented in Tiny-OS, and the transmission power control technique is applied to measure the amount of energy consumption to compare the amount of energy consumption in the general network.

This paper is organized as follows. Chapter 2 introduces the transmission power control technique considering the shortest path. Chapter 3 evaluates the energy efficiency of proposed transmission power control techniques. Chapter 4 discusses the conclusion and future project.

2. Transmission Power Control Considering the Shortest Path

The transmission power control technique proposed in this paper uses 'Closed Loop' to accurately measure the communication quality for neighboring nodes, and each node independently controls the transmission power continuously [6, 7]. In addition, since it considers the shortest path and controls the transmission power level in order to minimize the number of packets required for transferring messages in the multi-hop communication, it does not generate additional messages. The overall procedure for the transmission power control technique is shown in Figure 1, and the detailed procedure is as follows [4, 5].

① After constructing the tree-based network, the link quality indication (LQI) values between child and parent nodes are measured using the advertising messages.

② The measured values are transferred to other nodes including own advertising message.

③ If it is confirmed that the LQI value in the advertising message received by neighboring nodes is its own value, compare the value with the reference value.

④ If the reference value is higher than the measured value according to the comparison result, the power level is reduced, and if it is lower, the power level is increased.

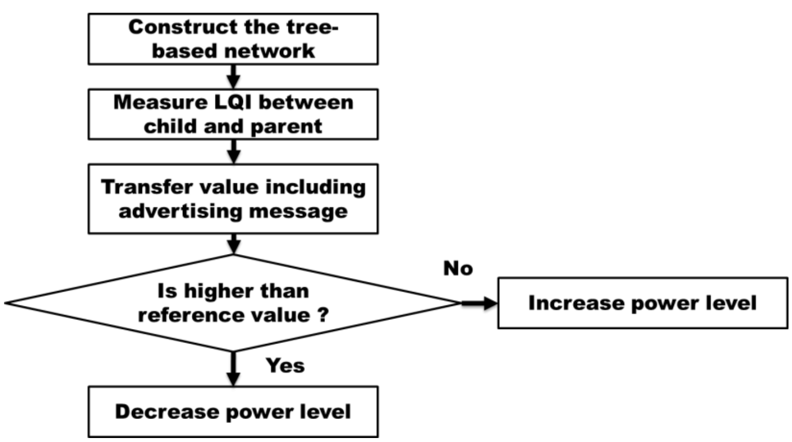


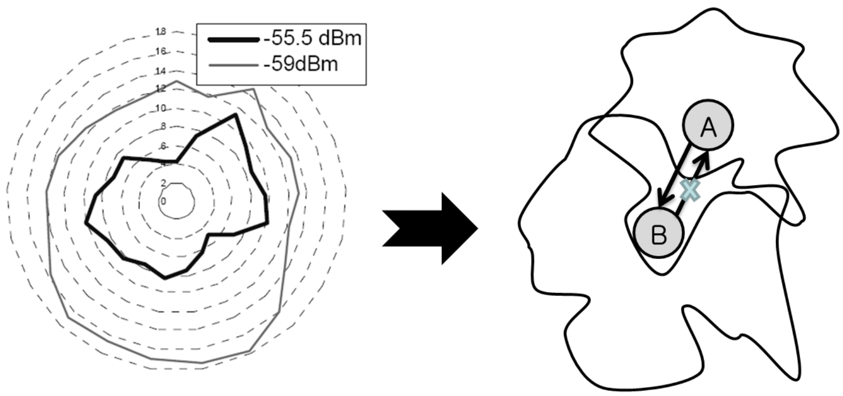
Figure 1. Transmission power control procedure

2.1. Setup the reference value

Plolastre, *et al.*, [4] explained through the experiment that the LQI based on chip error rate (CER) was the better index to predict the PRR than the RSSI in the Telos mote using the CC2420 radio chip.

The transmission power control technique proposed in this paper uses the LQI as the measured value, and uses this measured value to determine the increase and decrease of transmission power level. Although the selection of reference value could be done by various feedbacks after constructing the network, the measurement time for selecting procedure and the additional cost for computation are required. Therefore, the reference value is used to determine in advance prior to constructing the network. The reference value is determined based on the data observed in the experiment.

Shan Lin, *et al.*, [5] experimented the relation between the PRR and the LQI in various environments. The relation between the PRR and the energy conservation is the tradeoff relation becoming different each other according to the reference value. As the transmission power level is increased, the LQI and the PRR are increased. However, the variation of PRR is becoming smaller above certain LQI value. The PRR shows the value more than about 95% when the LQI value is more than 90, and thereafter since the magnitude of variation is small depending on the increase of LQI, the efficiency to raise the PRR value is dropped by increasing the transmission power level. Therefore, the measured value for the transmission power control technique proposed in this paper is based on 90 as LQI value.



(a) (b)

Figure 2. The range of propagation depending on the power strength

2.2. Closed Loop

A radio propagation has irregularity that the range is different depending on the direction [6]. Therefore, between two measurement methods, 'Open Loop' and 'Closed Loop', the 'Closed Loop' method could measure more accurately [7]. An example of a disadvantage for the ‘ Open Loop' is shown in Figure 2.

The (a) in Figure 2 shows the range of propagation depending on the power strength. Although the propagation has approximately similar range depending on the direction for -59dBm of power strength, it is shown that the range of propagation for the directions of about 90° and 270° are smaller than other directions for -55.5dBm.

The (b) shows the situation that node A could transfer messages to node B but node B could not transfer messages to node A due to the propagation's irregularity despite of both nodes use the same transmission power level during the communication procedure between node A and node B.

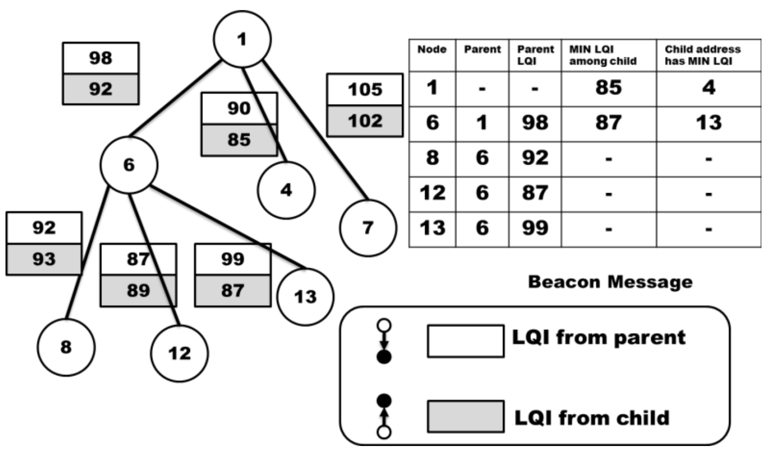
The transmission power control technique proposed in this paper exploits the advertising messages for 'Closed Loop' measurement method. Therefore, there is no additional message to be generated for transferring the measured values. Although each node is storing the parent node's information due to the tree-based network's structure, the measured value of the parent node and the minimum LQI value among the child nodes are included since the number of child nodes is not limited so that all the child nodes' information could not be stored. If the child nodes' information is stored, the table of fixed size is required, and since not only the addresses but also the information such as measured values should be stored, large memory space may be required for concentrated network.

In addition, the table of fixed size is difficult to predict the number of child nodes for determining the size, and if there are more child nodes than the table of fixed size, it should be assigned to other node not to have more child nodes. If it assigns the child to other node, it is occurred the disadvantage that the depth of network is increased. Eventually the number of nodes participating to transfer messages in multi-hop communication is increased to lower the whole network's performance. The procedures that construct the measured value into the advertising message in the tree-based network are as follows.

① Each node measures the LQI values for the parent node and the child nodes.

② The measured value for the parent node, the minimum value among the values for the child nodes, and the address having the minimum value are included in its own advertising message.

By doing so, the parent node could obtain the values measured about itself for each child node, and the child node could decide by itself whether or not its own link quality is bad.



Node	Parent	Parent LQI	MIN LQI among child	Child address has MIN LQI
1	-	-	85	4
6	1	98	87	13
8	6	92	-	-
12	6	87	-	-
13	6	99	-	-

Figure 3. An example for the measured value

Figure 3 shows an example for the measured value that should be included in the advertising message. Node 6 receives the value measured for its own advertising message from all the child nodes, and could know that node 4 has the minimum measured value from the parent node, node 1.

In addition, although node 6 could not know the accurate measured value for itself from the advertising message of the parent node, node 1, it could decide that it is at least more than 85. If the reference value is determined as 90, the power level is increased because node 4's measured value is less than the reference value.

As a result, if node 1's value measured for node 4 is increased to 95, the minimum value is 92 of node 6. Therefore, node 6 knows its own measured value correctly from node 1. Thus, it receives the correct value from the node which has the lowest communication quality, and could control the transmission power level.

2.3. Determining the transmission power level

The transmission power control decreases the range of propagation so that it could increase the average depth of whole network. The increase of depth increases the number of nodes required to transfer messages, and it could consume more energy than the result transmitting as the minimum depth using the maximum transmission power level. It consumes more energy to transfer the message, which could be transferred once using the maximum power, several times using the minimum power.

In order to prevent such a problem, the transmission power is controlled considering the shortest path in the tree-based network. The path establishment after constructing the tree-based network using the maximum power level has the shortest path by the link quality. In order to maintain the path establishment having the shortest path, the power level should be controlled to transfer each node's advertising message to all the both parent and child nodes. In other words, the transmission power level is controlled so that the range of propagation does not include a node to communicate but could include all the parent and child nodes.

The procedure to determine the transmission power level considering the shortest path is as follows.

① The measured values are collected from the advertising messages of the child nodes, and the minimum measured value is calculated.

② The minimum measured value of the child nodes is collected from the advertising message of the parent node.

③ Make a comparison between the minimum measured value received from the child nodes and the minimum measured value for the children received from the parent node.

④ If anyone among the following conditions is satisfied, the power level is increased.

- The value of step ① is below the reference value. The value of step ② is the value for itself and is below the reference value. It is not the disconnected node, but the message for the parent is retransmitted more than 3 times.

⑤ If the following condition is satisfied, the power level is decreased.

- The values of step ① and ② are above the reference value.

The nodes added after constructing the network could also have the shortest path. However, the measured value for the advertising message could be constructed different from the shortest path due to the optimized transmission power level. In order to solve such a problem, the nodes added to the network notify the information that it is the added node to the neighboring nodes by a message. The nodes receiving the corresponding message send an advertising message at the maximum transmission power level for a certain period of time. The added node receives the advertising message sent at the maximum transmission power level, and establishes the parent node considering the depth of the network and the link quality.

The (a) in Figure 4 shows the case that selects the wrong parent due to the optimization of transmission power level. In the figure, node 1 uses the transmission power level required for node 0 and 9 due to the transmission power control technique. Therefore, node 4 could receive only the advertising message of node 9, and establishes node 9 as the parent. However, node 4 should establish node 1 as the parent in order to maintain the shortest path.

The (b) shows the range of propagation appeared when using the maximum transmission power level, as the result, and represents the case that node 4 constructs the shortest path establishing node 1 as the parent. When a node is added, the shortest path could be constructed for a certain period of time as the (b) in Figure 4, and the transmission power is controlled to form the shortest path even if a node is added.

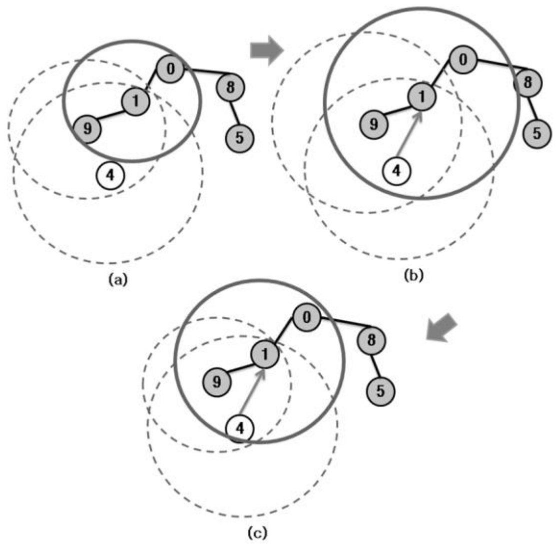


Figure 4. The transmission power control considering shortest-path

3. Implementation the System

For evaluating the performance of the technique proposed in this paper, the experimental environment is implemented on the Tiny-OS which is a public operating system for wireless sensor networks. Figure 5 shows the message structure of Tiny-OS. In experimental environment, the value of *TOSH_DATA_LENGTH* is specified as 28 to be able to communicate each other.

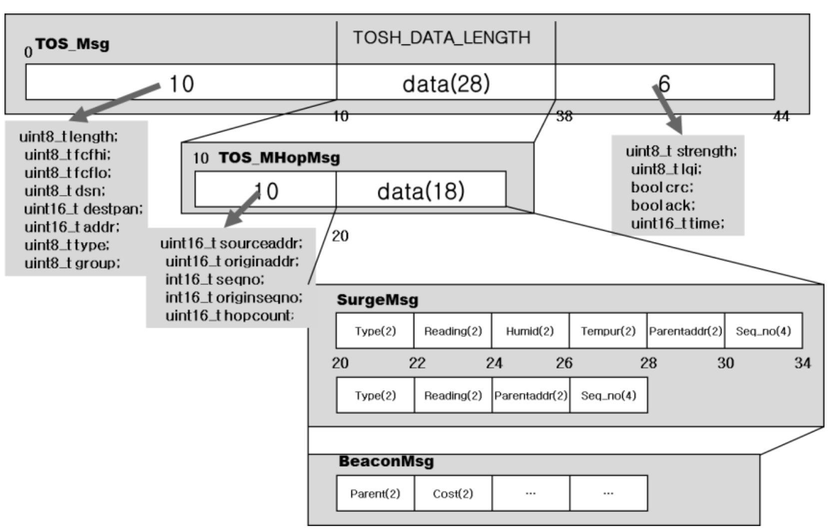


Figure 5. The message structure of Tiny-OS

The RSSI and LQI for all the messages are stored in strength and LQI of *TOS_Msg*, respectively. In Tiny-OS, the tree-based network is implemented in the *LQIMultihopRouter* component. The *LQIMultihopRouter* component establishes the parent by using LQI as a cost.

MultihopEngineM component performs a role that brings the parent's address for establishing the path to send the message to the corresponding address, or participates in multi-hop transferring messages of other node.

MultihopLQI component is responsible for sending and receiving the advertising messages, and performs a role that receives each node's advertising message to measure and established the parent depending on the measured value.

The *MultihopLQI* and *MultihopEngineM* components are modified to apply the technique proposed in this paper. The advertising message basically includes the information such as the address of parent, cost, and number of hops for constructing the tree-based network. Some information is added into the advertising message for the transmission power control technique, and the added information is as Table 1.

Table 1. Information added into the advertising message

Added information	Description
powerLevel	Power level for itself
minLqiChildNode	Child node which LQI is the minimum
parentLqi	LQI of parent node
minLqiChild	The minimum LQI among child nodes
typeAdjustedPower	Level to determine the power strength

3.1. Evaluating the performance of the system

Prior to evaluating the proposed technique, the experimental environments were measured the average amount of current for each transmission power level was measured in the network transferring packets continuously.

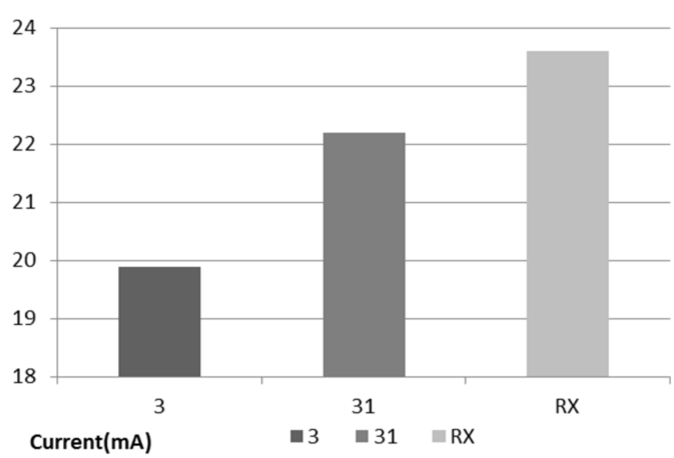


Figure 6. The current consumption in Tiny-OS when sending packets continuously

Figure 6 shows two transmission power levels when sending packets continuously and the average amount of current consumed by whole sensor nodes in receiving mode. Two nodes were used and it was measured with a digital multi-meter.

Figure 7 shows the average amount of current consumed when sending before and after applying the transmission power control technique. The 90 of LQI value was set to the reference value, and the message sending period of the sensor nodes was set to 2 seconds. The average amount of current consumed when sending in the network applied the proposed technique was about 25% less than the previous case.

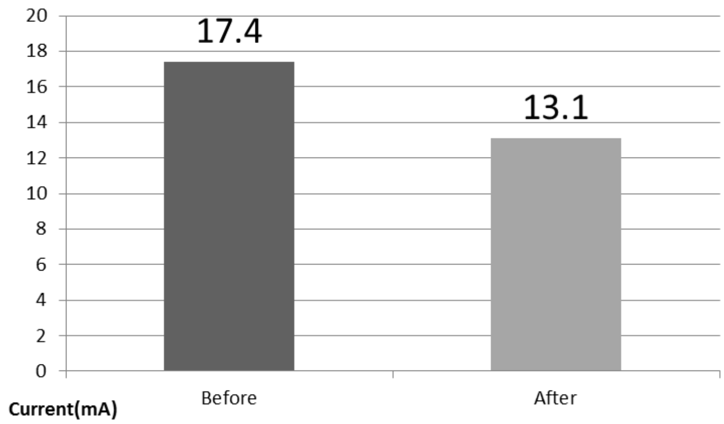


Figure 7. The average amount of current consumed when sending before and after applying the transmission power control technique

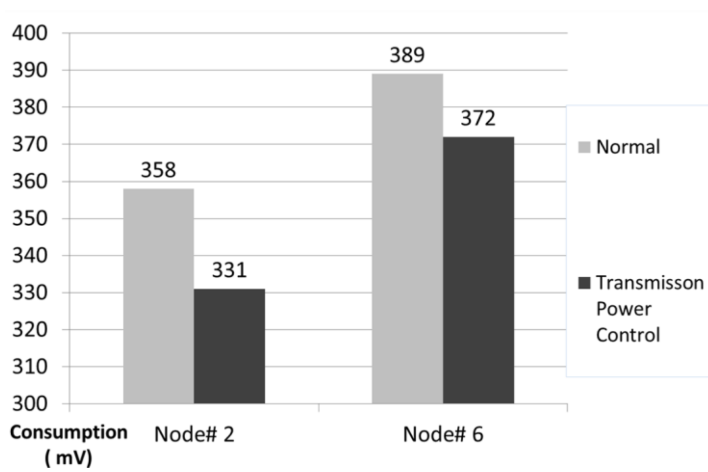


Figure 8. The result that the difference of batteries' residual capacities measured at some node

Figure 8 is the result that the difference of batteries' residual capacities measured at some nodes was compared between the cases before and after applying the transmission power control technique, and node 2 was conserved more battery's consumption than node 6.

The reason is because node 2 was close to the sink node to frequently participate in transferring messages. Usually, as more messages are transferred, more energy is consumed, but since sensor nodes consume more energy when receiving RF signal than when sending it, instead, the node transferring more messages consumes less the battery. In addition, the effect of the transmission power control technique was the largest.

Figure 9 represents the average depth of network for the technique controlling the transmission power not to consider the depth of network and the technique controlling the transmission power to consider the depth of network. The case considering the depth had about 41% less depth than the general case.

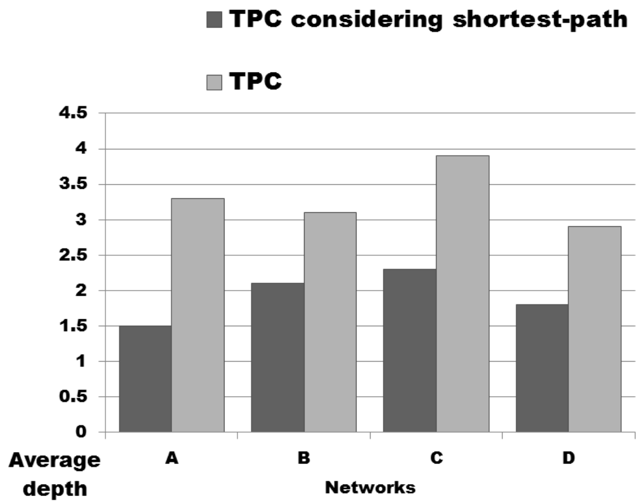


Figure 9. The average depth of network for transmission power control considering shortest-path

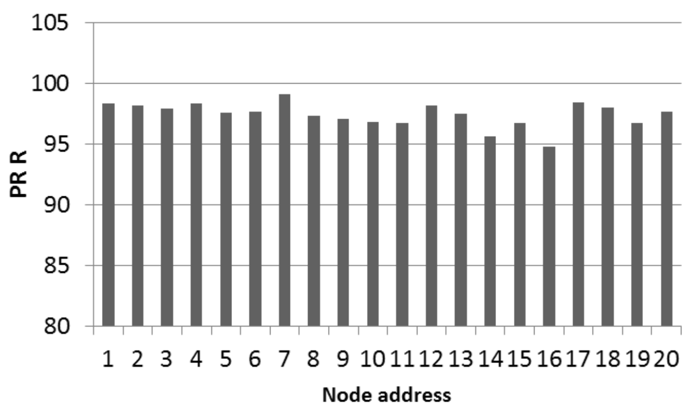


Figure 10. The result measured the PRR of each node

Figure 10 shows the result measured the PRR of each node for about an hour after establishing the packet sending period as 2 seconds and applying the transmission power control technique. As the result of measurement, the average value of the whole network was observed about 96% of PRR.

4. Conclusion

This paper proposed the transmission power control technique considering the shortest path not to generate additional control packets. The network applied the proposed technique reduced the average current during transmission about 25% less than the previous case. And, as a result of considering the shortest-path, the hop-count considering the shortest-path was about 40% less than a normal network. Future research related to this paper is needed to develop the technique to predict the power level in order to prevent the oscillatory phenomenon in the transmission power control technique and to dynamically adjust the initially established reference value for varying environment of networks.

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