An Energy Efficient Cooperative Relay Selection Algorithm for Wireless Sensor Networks

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Abstract

This paper presents an energy efficient algorithm for relay selection in cooperative communication for wireless sensor networks. The algorithm exploits the location information of sensor nodes in order to decide whether to use cooperative communication or direct communication.

Introduction

The main drawback of Wireless Sensor Networks (WSNs) is their limited resources, especially energy. They are operated on batteries and their life span is short. Also, their computational capabilities are limited. In [1], the authors studied different policies to choose the best relay for cooperative communication to reduce energy consumption. Their proposal is an efficient mechanism but requires a great deal of computational capabilities in wireless sensor nodes.

The tradeoff between energy used in transmission and in computation leads to the fact that a simple algorithm is the best solution for energy efficiency in WSNs. The source node can directly transmit to the destination node. Instead, the cooperative communication in which the packets are transmitted through a relay node is used.

Background

The basic idea is that if the energy consumed in two hop transmission is less than that of direct transmission, we can apply cooperative communication.

So, we propose an algorithm to reduce the energy lost in free space propagation. Let E be the energy wasted in free space path loss in direct transmission and E_1 & E_2 be those of two hop transmission. Let L_f stands for free space path loss in direct communication and L_f^1 and L_f^2 stands for those of first and second stages of cooperative communication and d is the distance between the source & destination, d_1 and d_2 for respective stages of cooperative communication and λ stands for the wavelength of the radio wave transmitted.

The target condition for using cooperative communication is:

$$E > E_1 + E_2 \quad (1)$$

In cooperative communication, the relay node retransmits the overheard message. It means that the transmission time for data packet is the same assuming the two data transmission rates are equal. So we can change equation (1) to:

$$L_f > L_f^1 + L_f^2 \quad (2)$$

where, L_f is defined in [2] as:

$$L_f = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (3)$$

Since the participating nodes have same frequencies and consequently same wavelengths, hence we can change equation (2) into:

$$d^2 > d_1^2 + d_2^2 \quad (4)$$

From equation (4), we can clearly conclude that the energy wasted or the free space path loss is directly proportional to the square of the transmission distance. In other words, if we know the location of the WSNs, we can develop an algorithm for relay node selection for reducing the energy.

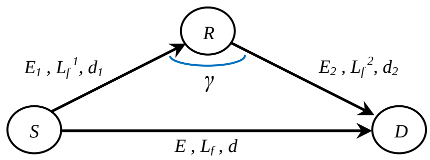

Figure 1. Cooperative Scheme with relay node

Relay Node Selection Algorithm

The potential relay nodes are those which overheard both RTS from the source and CTS from the destination as shown in Figure 2. In Figure 2, the source and destination nodes are placed at their maximum transmission distance. We know that any angle in a semicircle is a right angle and by using Pythagoras theorem, we can prove that nodes which lie on the dotted circle satisfy equation (5).

$$d^2 = d_1^2 + d_2^2 \quad (5)$$

So equation (5) forms the boundary and the nodes that satisfy equation (4) lie within the dotted circle with diameter d.

In [1], the node selection algorithm is based on channel state and current energy level available at each participating nodes. The algorithm does not consider the actual position of the WSNs. In some cases, to process the data sensed from a wireless sensor node at the application layer, we must know its location. We propose to use this known location in communication to enhance energy efficiency. In our proposed scheme, we select the node prioritized by location rather than channel state. Before describing the detailed algorithm, the following assumptions are made.

A1) Every node is location aware.

A2) RTS, CTS messages contains location of nodes

A3) All nodes have the same signal transmission range.

A4) All nodes have the same transmission rate.

A5) WSNs use on demand routing protocol.

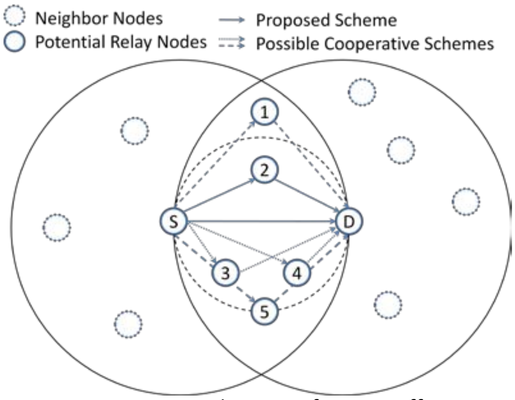

Figure 2. The area of energy efficiency

Table 1: Node Selection Algorithm

1. If buffer is not empty, the source node will send RTS message which includes known location of source.
2. If the medium is free, the destination will calculate *d* and reply with CTS message which includes *d* value and co-op bit. When *d* is greater than minimum threshold, co-op bit is assigned '1' or 'true', default value being '0' or 'false'.
3. The nodes that overheard both RTS & CTS check co-op bit in CTS. If co-op bit is 'true', they calculate d_1, d_2, & γ and check if $d^2 > d_1^2 + d_2^2$. If it is true, then they broadcast their cooperative message with priority "$d_1/d_2 * \cos(180-\gamma)$" for relay contention and the higher priority node contends first.
4. The source, after stage 3, decides direct transmission if there is no available relay OR co-op bit ='false' or '0'. Otherwise, the source transmits through relay which has highest priority.

As shown in Figure 2, for two hop transmission, if the relay is closer to the source or the destination such as node 3 or 4, the received signal of the longer distance transmission will suffer more free space path loss. So, the priority of the potential relay nodes is decided by the ratio d_1:d_2 and cosine value of $(180-\gamma)$. The higher the priority of the node, the closer the ratio is to *1:1* and the larger the value of γ. This priority is used for the contention process in stage 3 of the algorithm in which multiple potential relay nodes may satisfy equation (4). There may be a case where two potential relay nodes have same priority and their cooperative messages collide. Both of them will not win the medium and if there is no other potential relay, the source will transmit directly to the destination.

Numerical Analysis

For the evaluation of the proposed algorithm, we performed numerical analysis with parameters described in Table 2. In Figure 3, we can see that our algorithm reduces free space path loss of up to 1.6 dB. Note here that the energy reduction depends on the location of the relay node which is demonstrated in Figure 4, by fixing the location of source and destination to 10 m and placing the relay at different locations. As displayed in Figure 4, the free space path loss decreases as angle 'γ' between Line of Sight (LOS) of source and relay and that of relay and destination increases As shown in Figure 4, when the relay is located on the LOS between source and destination, that is $d = d_1 + d_2$, the free space path loss reduction is the most.

Table 2: Parameters used in numerical analysis

WSN Standard	IEEE 802.15.4 - 2003
Coding	DSSS
Carrier Frequency	2.4 GHz
Transmission Range	75 m

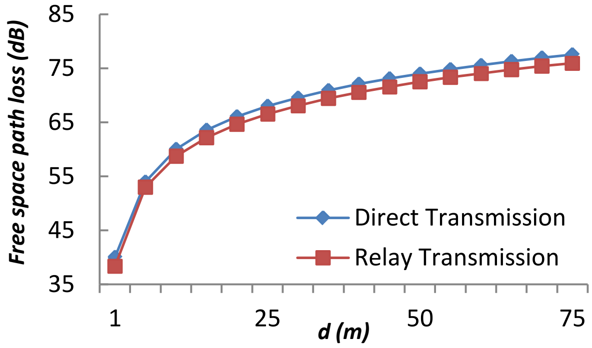

Figure 3. Free space path loss versus distance between source and destination

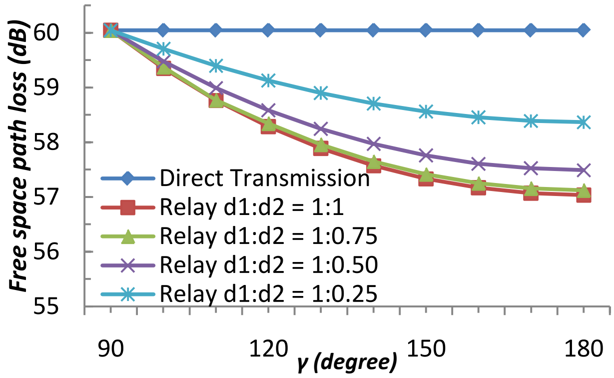

Figure 4. Free space path loss versus γ

Conclusion

In this paper, cooperative communication is applied to reduce the energy wasted in transmission. The proposed algorithm is not perfect as decision making is prioritized by location alone. Our future work is to make a prioritization based on both location and channel state information together.

ACKNOWLEDGEMENT

This research was supported by the MKE, Korea, under the ITRC support program supervised by the NIPA (NIPA-2010-(C1090-1002-0002)). Dr. C. S. Hong is the corresponding author.

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