Energy-Efficient Cooperative Medium Access Control (MAC) Protocol for Wireless Sensor Networks

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Abstract

Recent research activities in cooperative communication focus on achieving energy efficiency and reliability. Relay selection strategy for cooperative communication improves the performance significantly. However, due to imbalance consumption of power, network might die earlier and more than 90% energy remains unused. In this paper, we provide a framework of an energy-efficient medium access control protocol that minimizes these problems and improves energy efficiency.

1. Introduction

Timely delivery of sensory data plays a crucial role in some applications [1] such as tracking the target in battlefield, monitoring critical patient in hospital, controlling temperature in industry etc. In mission-critical applications, high reliability, guaranteed bandwidth, and short delays are highly required to maintain the QoS of wireless network [1].

Current research in cooperative wireless sensor networks mostly focused on protocol that consider only energy efficiency to maximize the lifetime of network [2]. Most of the papers [1], [3], [4] select their relay on the basis of channel state information. In these cases, nodes having good channel condition, might participate frequently and finish their energy earlier and create energy hole [5] . On the other hand, energy of the nodes, having poor channel condition might remain unused. Therefore, the network lifetime ends soon and energy might be left unused up to 90% [6] at the end of life time of network.

Recently, some papers propose residual energy aware cooperative MAC protocol rather than energy consumption aware. In [7], residual energy aware transmission model has been developed to increase the lifetime of the network. Their model selects a relay on the basis of their highest residual energy of a node. Nodes, with higher residual energy might have worse channel condition. Therefore, extra delay might be incurred due to the poor channel condition.

In this paper, we propose a cooperative MAC, where a relay is selected with highest metric value of delay and residual energy of a node. Therefore, it tries to equalize the energy consumption of all nodes as much as possible and improves the lifetime of the network.

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2. Relay Selection

An average weighted metrics (W) of residual energy (E_{res}) and delay (D) is designed to select the relay node. Our formulated average weighted metrics (W) is given by

$$W = w_1 \frac{E_{res}}{E_{ini}} + w_2 \frac{D_{max} - D}{D_{max}} \quad (1)$$

W is the total average weight, w_1 and w_2 are smoothing factors for residual energy and delay respectively. Where $w_1 + w_2 = 1$ and $0 < W \leq 1$. The equation shows that the value of W will be maximum when E_{res} will be maximum. The maximum delay, $D_{max} = T_{sd}^{max} + T_q^{max}$ where T_{sd}^{max} *and* T_q^{max} are the maximum expected transmission time from source to destination via relay and maximum queuing delay of relay respectively. The candidate relay having the highest W, is the best relay

Algorithm 1: Selection of the best relay

Initialization: Initialize $flag = 0$, $W_L = F_c^-(\frac{1}{n})$, $W_H = 1$, $W_{lower} = 0$;
while $W_H - W_L > constant$ **do**
  if $msg = single$ OR $msg = multi$ **then**
    $W_{lower} = W_L$; $W_L = upper(W_L, W_H)$;
    if $msg = single$ **then**
      $flag = 1$;
    end if
  else
    if $msg = empty$ **then**
      if $flag = 1$ **then**
        exit loop
      else
        $W_H = W_L$; $W_L = lower(W_{lower}, W_L)$;
      end if
    end if
  end if
end while
if $flag = 1$ **then**
  $Msg = msg\_coop$
else
  $Msg = msg\_dir$
end if

Here, RTH (Request to Help) message from destination contains lower threshold (W_L) and upper threshold (W_H) of a mini-slot, W_{lower} is initial lower bound of a mini-slot and $F_c^-(\frac{1}{n})$ is inverse CCDF (complementary cumulative distribution function). Interested readers can study the paper [8] to know about mini-slot and how to select the best relay.

3. Protocol Operation

We use Fig.1 to explain the proposed IEEE 802.11 DCF cooperative MAC protocol.

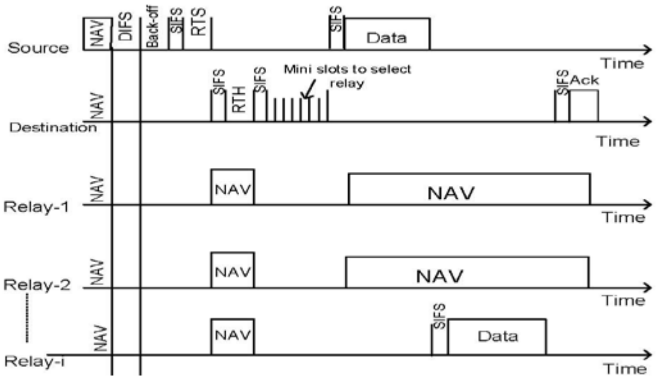

Fig. 1 Proposed MAC protocol

A source node initiates its transmission by sending RTS packet after finishing its DIFS and back-off period. In response, the destination sends RTH message and relay selection process is started after SIFS. Each of the common neighbors hears both RTS and RTH message. The common neighbors compare their own metrics value w_i, if it satisfies $W_L \le w_i \le W_H$ then the node i sends Interested-To-Help (ITH) short message. ITH short message contains its own id and metric value. After each ITH message the candidate nodes receive one feedback message *msg* shown in algorithm 1.

When feedback message is *msg_coop*, it means that the best relay is selected. In this case, source transmits data after SIFS time. The relay decodes this data and forward to destination after another SIFS interval. When feedback message is *msg_dir*, its means that suitable relay is not available and the source node transmits directly to the destination

4. Analysis

Lifetime of a node i with initial energy E_{ini} could be expressed as

$$LT_i = \frac{E_{ini}}{e_i} \qquad (2)$$

here, e_i is the average energy consumed per unit time. Virtual lifetime (LT^{vir}) of a network is $LT^{vir} = (nE_{ini})/e_i$. But in reality, some energy remains as leftover in the network when it becomes nonfunctional. Let, each node i out of m number of nodes has residual energy $E_{res,i}$ as leftover and treated as wasted energy. So average amount of wasted energy of a network could be expressed as,

$$E_w = \sum_{i=1}^{m} E_{res,i} \qquad (3)$$

The average lifetime of a network can be written in terms of wasted energy E_w as

$$LT^{avg} = \frac{nE_{ini} - E_w}{e_i} \qquad (4)$$

In equation (4), n and E_{ini} are constant for a network, thus the network lifetime depends on E_w. In the paper [2], reveals that network lifetime depends on not only the average consumed energy but also the residual energy left after the network lifetime expires. This paper provides optimal value as $minE_w$ and thus network lifetime turned into maximum as $maxLT^{avg}$ and given by,

$$maxLT^{avg} = \frac{nE_{ini} - minE_w}{e_i} \qquad (5)$$

Our protocol depletes to partition the network due balance energy consumption. Therefore, wasted energy is optimal, and thus according to equation (5), improved the lifetime of network.

5. Conclusion

In this paper, we develop a framework to select the best relay. We also provide a cooperative MAC to reduce the leftover energy of network and hence to increase the lifetime of network. Our analysis shows that the network lifetime increases with decreasing leftover energy. Simulation is the major future scope of work for this paper.

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