무선 센서 네트워크를 위한 잔여 에너지 인지형 협력 MAC 프로토콜


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요약
최근 신뢰성과 에너지 효율성을 높이기 위한 협력 통신에 대한 연구가 활발하게 진행중이다. 그러나 네트워크 성능 향상을 위해서는 전달자를 선택하는 방법 또한 매우 중요하다. 많은 논문에서 노드 간의 에너지 소비 불균형으로 인해 전력이 쓰고 남을 때 많은 양의 에너지가 사용되지 않고 노드 상에 남아 있는 것을 확인할 수 있다. 본 논문에서는 노드 간의 에너지 소비 균형을 유지하면서 최적의 전달자 노드를 선택하는 프레임워크를 제안한다. 또한 CoopMAC보다 70%이상 에너지 효율적인 REC-MAC 프로토콜을 제안한다. 시뮬레이션 결과를 통해 CoopMAC보다 좀 더 좋고 지연이 더 낮은 것도 확인할 수 있다.

키워드 : 협력 통신, 잔여 에너지, 수명

Abstract
In this paper, we provide a framework to select an optimal relay that keeps the balance of energy consumption among the nodes. We also propose REC-MAC protocol which is more than 70% energy-efficient over CoopMAC. Simulation results also show that end-to-end delay of REC-MAC is better than CoopMAC.

Key words : Cooperative Communication, Residual Energy, Lifetime

1. 서론

Current research in cooperative wireless sensor networks mostly focused on protocol that consider only energy efficiency to maximize the lifetime of network [1,2]. Most of the papers [1,3,4-6] 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 [7]. On the other hand, energy of the nodes, having poor channel condition might remain unused and thus the network lifetime ends soon.

In [8] and [9], residual energy aware transmission model has been developed to increase the lifetime of the network. Both of these models select a relay on the basis of their higher residual energy of a node. Some of the nodes, with higher residual energy might have poor channel condition. Therefore, extra delay might be incurred due to their poor channel condition.

Timely delivery of sensory data plays a crucial role in some applications [10,11]. In these mission-critical applications, short delay are highly required to maintain the QoS [4].

The frequent busy nodes die earlier and create energy hole. Energy holes hamper to acquire critical data if it is found in the target location. Therefore, the network lifetime ends soon and energy might be left unused up to 90% [12] at the end of lifetime of network. Major motivation of taking residual energy into consideration is to make balance the energy consumption among the nodes of the network.

Major contributions of our work are as follows.
- We develop a mechanism to select an optimal...
relay that provides balanced energy consumption
among the nodes of the network.

We propose a cooperative MAC called REC-MAC that enhances to increase the lifetime of
the networks and decreases the end-to-end packet delay.

2. Problem scenario and assumptions

Figure 1 shows the part of a large network where sensor nodes are randomly distributed. In
cooporative communication, some of the relay nodes
might send data frequently and their energy might
be finished quickly. Therefore, the nodes die earlier
that partition the network into multiple parts. A
network dies out when at least one node becomes
non-functional.

In Fig. 1, black colored nodes participate in coo-
operation frequently and reach their residual energy
below threshold level earlier. However, other nodes
contain considerable amount of residual energy. In
this case, we consider that the entire network is
dead although a considerable amount of energy
remains as leftover in the network.

3. Relay Selection

In our protocol, an average weighted metrics ($W_i$)
of residual energy ($E_{res}$) and delay ($d$) is designed
to select a relay. In this protocol, each node $i$, can
compute its own weight ($W_i$). Our formulated
average weighted metrics ($W_i$) is given by

$$W_i = w_1 \frac{E_{res}}{E_{ini}} + w_2 \frac{d_{max} - d}{d_{max}}$$

(1)

where $W_i$ is the total average weight of node $i$, $w_1$ and
and $w_2$ are smoothing factors for residual energy
and delay respectively. Where $w_1 + w_2 = 1$ and $0 <
W_i \leq 1$. The equation (1) shows that the value of
$W_i$ will be maximum when $E_{res}$ will be maximum
i.e. $E_{res} = E_{ini}$ and $d$ will be minimum i.e. $d = 0$
where $0 \leq d \leq d_{max}$. The maximum delay,
$$d_{max} = T_{SD}^{max} + T_q^{max}$$

where $T_{SD}^{max}$ is the maximum expected transmission
time from sender to relay
and relay to receiving node and $T_q^{max}$ is the maxi-
mum queuing delay of a candidate node. A node
can calculate its own residual energy by sub-
tracting the energy spent per unit time from pre-
vious $E_{res}$.

It is assumed that each candidate relay sends
Interested-To-Help (ITH) message at the beginning
of a mini-slot. In response to that a feedback
message FITH (feedback of ITH) is sent by the
receiving node $D$ at the same mini-slot.

Feedback Message: Feedback message is one of
five short messages single, multi, empty, msg_coop,
and msg_dir. When only one candidate node
transmits ITH message in a slot then the feedback
message is called single in our system. If more
than one candidate node transmit ITH message
then the feedback is known as multi. It is also
termed as collision in our work. Feedback message-
empty means no node transmits ITH message in a
slot. Receiver $D$ sends msg_coop then the relay is
finally selected. The feedback message, msg_dir is
the worst scenario: no node is interested to help
for this data burst. In this case, direct transmission
approach is used.

The values of upper ($W_{up}$) and lower ($W_{down}$)
thresholds of the metric are attached in the FITH
message for next mini-slot. The receiving node use
inverse Complementary Cumulative Distribution Fun-
tion (CCDF) to compute the lower threshold and
upper threshold. Initially, the lower threshold is
computed by receiving node using inverse CCDF 
\( W_i = -F_e^{-1}\left(\frac{1}{x}\right) \) and upper threshold is considered as one (1). Here, \( x \) is the number of potential relay nodes. The interested candidate can read the attractive paper [13] to know more about the computational process of thresholds. A node whose metric value satisfies \( W_L \leq W_i \leq W_H \), will transmit to the next mini-slot.

At first, it has been considered several variables \( W_i, W_L, W_H, \) and \( W_{lower} \). RTH message contain lower threshold (\( W_L \)) and upper threshold (\( W_H \)) of metric value. Each of the common neighbors hearing both RTS and RTH message can participate in the relay selection process. The common neighbors compare their own metrics value \( W_i \) with lower threshold (\( W_L \)) and upper threshold (\( W_H \)). If it satisfies \( W_L \leq W_i \leq W_H \) 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 (FITH).

When feedback message is \( \text{msg} \_\text{coop} \), it means that the best relay is selected. In this case, sender node transmits data after SIFS interval. The relay decodes this data and forward to receiving node after another SIFS interval. When feedback message is \( \text{msg} \_\text{dir} \), its means that suitable relay is not available and the sender node transmits directly to the receiving node.

\section{Analysis}

\subsection{Lifetime Analysis}

Lifetime [9] of a node \( i \) with initial energy \( E_{ini} \)
could be expressed as

\[ LT_i = \frac{E_{ini}}{e_i} \]  

(2)

here, \( e_i \) is the average energy consumed per unit time. First we assume that entire network energy is used to transmit, receive, process, idle and listening mode. So virtual lifetime (LT\(^{vir}\)) of a network is,

\[ LT^{vir} = \frac{(nE_{ini})}{e_i} \]

But in reality, some energy remains as leftover in the network when it becomes non-functional. Let, each 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,

\[ E_w = \sum_{i=1}^{m} E_{res,i} \]  

(3)

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

\[ LT^{avg} = \frac{nE_{ini} - E_w}{e_i} \]  

(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. Therefore, to maximize the network lifetime, the protocol should minimize the wasted energy \( E_w \). This paper provides optimal value as \( \min E_w \) and thus the network lifetime turned into maximum as \( \max LT^{avg} \), given by

\[ \max LT^{avg} = \frac{nE_{ini} - \min E_w}{e_i} \]  

(5)

5.2 Delay Analysis

We consider following figure-head to compute single-hop delay in our protocol: transmission time, relay selection overhead, protocol overhead, and queuing delay of a relay. We neglect the propagation delay for its very small value. Since, two links (sender to relay and relay to receiver) are used in cooperation communication so total transmission time from sender to receiver is \( T_{tot} = T_{sd} + T_r + T_q \), where \( T_{sd} \) transmission time from sender to relay and \( T_r \) is transmission time from relay to receiver. But link error has a great impact on the transmission time. If there are \( x \) number of potential relays then there will have \( x+1 \) number of different paths from sender to destination.

In cooperative communication, relay transmits others data besides its own: so, there might have some packets to its buffer to transmit. Therefore, it is more logical to include queuing delay of relay nodes to calculate its local delay. The total delay from sender to receiver is given by

\[ T_{tot} = T_{sd} + T_0 + T_r + T_q \]  

(6)

where, \( T_0 \) is protocol overhead \( T_r \) is relay selection overhead and \( T_q \) queuing delay.

6. Performance Evaluation

We have evaluated the performance of REC-MAC using simulation experiments and compared with CoopMAC [1]. The simulation has been done based on the legacy of 802.11 DCF. In our network setup, we place 2000 number of nodes in a square region of side 2000 meters. Uniform node distribution is used in our network set-up. Initial energy of each node is 20 Joule and the sink is placed at the centre of the network.

The graphs of Fig. 4 depict that the network lifetime of REC-MAC increases more than 70% than CoopMAC. The reason behind this interesting result is, we consider residual energy to select a relay in REC-MAC that implements balanced energy consumption among the nodes. Therefore, less energy remains as leftover when network dies out. On the other hand, CoopMAC don’t consider residual energy, while selecting relay node, and thus the better helpers participate in cooperation frequently and die earlier. As a result, significant amount of energy remains unused in the network.

![Fig. 4 Network lifetime vs. number of deployed nodes](image-url)
The graph of Fig. 5 shows that average end-to-end delay of REC-MAC has significantly improved over CoopMAC. Although, initially end-to-end delay of CoopMAC is lower than REC-MAC but it increases with the node densities. This is because the neighbors might start to transmit data while the transmission of helper is ongoing and thus collision increases in CoopMAC with node densities.

7. Conclusion

In this paper, we develop a mechanism to select an optimal relay to achieve better network lifetime and better end-to-end delay. Using this mechanism REC-MAC protocol is designed which provide balanced energy consumption among the nodes and reduce wasted energy. Thus, it increases the network lifetime significantly. Our simulation results also show that REC-MAC reduces the end-to-end delay.

References


