무선 센서 네트워크를 위한 잔여 에너지 인지형 협력 MAC 프로토콜

[Residual Energy-Aware Cooperative Medium Access Control (REC-MAC) Protocol for Wireless Sensor Networks]

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요 약 최근 신뢰성과 에너지 효율성을 높이기 위한 협력 통신에 대한 연구가 활발하게 진행중이다. 그러나 네트워크 성능 향상을 위해서는 전달자를 선택하는 방법 또한 매우 중요한 이슈이다. 많은 논문에서 노드 간의 에너지 소비 불균형으로 네트워크가 작동을 멈췄을 때 많은 양에 에너지가 사용되지 않고 노드 상에 남아 있는 것을 확인할 수 있다. 본 논문에서는 노드 간의 에너지 소모 균형을 유지하면서 최적의 전달자 노드를 선택하는 프레임워크를 제안한다. 또한 CoopMAC보다 70%이상 에너지 효율적인 REC-MAC 프로토콜을 제안한다. 시뮬레이션 결과를 통해 CoopMAC보다 종 대 종 지연이 더 낮은 것도 확인할 수 있다.

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-2-end delay of REC-MAC is better than CoopMAC.

Key words : Cooperative Communication, Residual Energy, Lifetime

1. 서 론

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-2-end packet delay.

2. Problem scenario and assumptions

Figure 1 shows the part of a large network where sensor nodes are randomly distributed. In cooperative 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 cooperation 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.

Black nodes have no residual energy

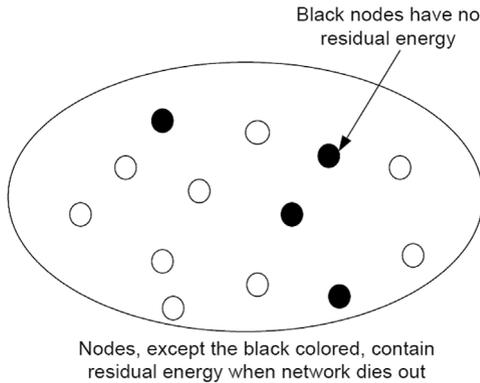Nodes, except the black colored, contain residual energy when network dies out

Fig. 1 Part of a large network

One of the most important assumptions is that the entire network will die when one node becomes non-functional. We consider that each of m number of nodes contain residual energy $E_{res,i}$ among the total number of nodes n, where $n > m$.

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

$$W_i = w_1 \frac{E_{res}}{E_{ini}} + w_2 \frac{d_{max} - d}{d_{max}} \qquad (1)$$

where W_i is the total average weight of node i, $w1$ and $w2$ are smoothing factors for residual energy and delay respectively. Where $w1 + w2 = 1$ 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 maximum queuing delay of a candidate node. A node can calculate its own residual energy by subtracting the energy spent per unit time from previous 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_H) and lower (W_L) thresholds of the metric are attached in the FITH message for next mini-slot. The receiving node use inverse Complementary Cumulative Distribution Function (CCDF) to compute the lower threshold and upper threshold. Initially, the lower threshold is
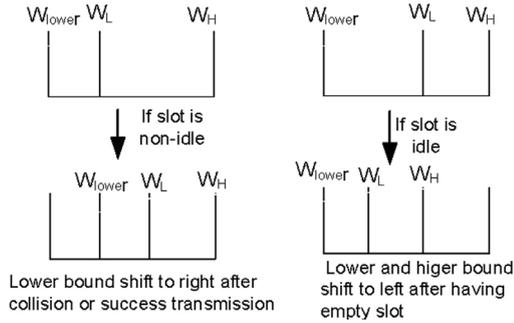
Fig. 2 Upper and lower threshold determination process

computed by receiving node using inverse CCDF ($W_L - F_c^{-1}\left(\dfrac{1}{x}\right)$) 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 a mini-slot. The value W_{lower} is the previous W_L what is shown in Fig. 2.

If there is a collision in a mini-slot then it is evident that there exist more than one candidate nodes within the range W_L and W_H. In this condition, lower threshold is increased and shifted toward upper threshold and a new W_L is calculated using function *upper* (W_L, W_H) and previous W_L is set to W_{lower} shown in Fig. 2. Same strategy is followed if a single node transmits in a mini-slot and the slot is called single-node slot.

We follow a greedy strategy in this protocol. We consider that better potential candidate might be available at higher than upper threshold (W_H). If there is no candidate between W_L and W_H, means empty slot, then the feedback message is *msg = empty*. So, both the values of W_L and W_H are lowered and new values are calculated as $W_H = W_L$ and $W_L = lower$ (W_{lower}, W_L), shown in Fig. 2. When an empty slot is found after a single-node slot it stops searching the relay.

4. Protocol Operation

We use Fig. 3 to explain the proposed REC-MAC with the legacy of IEEE 802.11 DCF.
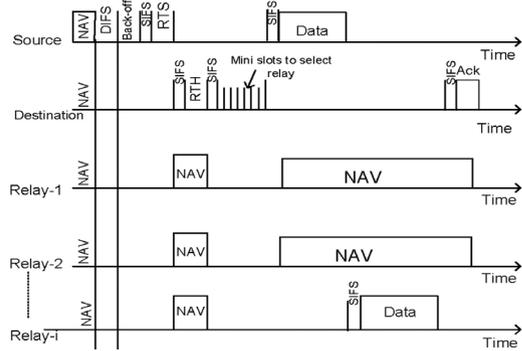

Fig. 3 Proposed REC-MAC protocol

A source node initiates its transmission by sending RTS packet after finishing its DIFS and back-off period. In response, the receiving node sends RTH help request for cooperative communication and relay selection process is started after SIFS interval. RTH message contains slot duration, initial 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 *msg_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 *msg_dir*, its means that suitable relay is not available and the sender node transmits directly to the receiving node.

5. Analysis

5.1 Lifetime Analysis

Lifetime [9] 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. 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, $LT^{vir} = (nE_{ini})/e_i$. 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,

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

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. Therefore, to maximize the network lifetime, the protocol should minimize the wasted energy E_w. This paper provides optimal value as $minE_w$ and thus the network lifetime turned into maximum as $maxLT^{avg}$, given by

$$max LT^{avg} = \frac{nE_{ini} - min E_w}{e_i} \qquad (5)$$

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 $T_{SD} = T_{Sr} + T_{rD}$, where T_{Sr} transmission time from sender to relay and T_{rD} 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

$$T_{tot} = T_{SD} + T_0 + T_r + T_q \qquad (6)$$

where, T_o 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
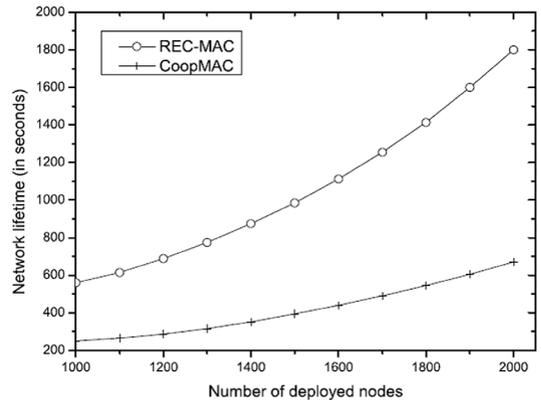

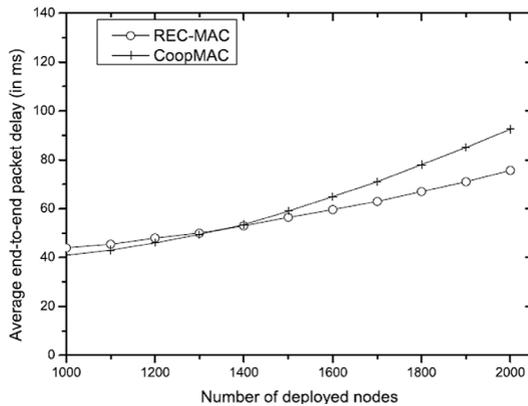Fig. 4 Network lifetime vs. number of deployed nodes

Fig. 5 Average end-to-end Delay vs. number of deployed nodes

when it dies out.

The graph of Fig. 5 shows that average end-2-end delay of REC-MAC has significantly improved over CoopMAC. Although, initially end-2-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-2-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-2-end delay.

References

[1] P. Liu, Z. Tao, S. Narayanan, T. Korakis and S. S. Panwar, "CoopMAC: A Cooperative MAC for Wireless LANs," *Journal on Selected Areas in Communications*, IEEE, vol.25, no.2, pp.340-354, 2007.
[2] Y. Chen and Q. Zhao, "Maximizing the Lifetime of Sensor Network Using Local Information on Channel State and Residual Energy," *Conference on Information Sciences and Systems*, 2005.
[3] C. Zhai, J. Liu, L. Zheng and H. Xu, "Lifetime Maximization via a New Cooperative MAC Protocol in Wireless Sensor Networks," *Global Telecom-*

munications Conference (GLOBECOM), IEEE, pp.1-6, 2009.
[4] X. Liang, I. Balasingham and V.C.M. Leung, "Cooperative Communications with Relay Selection for QoS Provisioning in Wireless Sensor Networks," *Global Telecommunications Conference (GLOBECOM)*, IEEE, pp.1-8, 2009.
[5] H. Adam, W. Elmenreich, C. Bettstetter and S. M. Senouci, "CoRe-MAC: A MAC-Protocol for Cooperative Relaying in Wireless Networks," *Global Telecommunications Conference (GLOBECOM)*, IEEE, pp.1-6, 2009.
[6] H. Shan, W. Zhuang, and Z. Wang, "Distributed Cooperative MAC for Multihop Wireless Networks," *Comm. Mag.*, vol.47, pp.126-133, 2009.
[7] X. Wu, G. Chen and S. K. Das, "On the Energy Hole Problem of Nonuniform Node Distribution in Wireless Sensor Networks," *International Conference on Mobile Adhoc and Sensor Systems (MASS)*, IEEE, pp.180-187, 2006.
[8] E. Liu, Q. Zhang, K.K. Leung, "Residual Energy-Aware Cooperative Transmission (REACT) in Wireless Networks," *Wireless and Optical Communications Conference (WOCC)*, pp.1-6, 2010.
[9] A. Banerjee, C. H. Foh, C. Yeo, and B. S. Lee, "A Network Lifetime Aware Cooperative MAC Scheme for 802.11b Wireless Networks," *Consumer Communications and Networking Conference (CCNC)*, IEEE, pp.1-5, 2010.
[10] O. Gama, P. Carvalho, J. A. Afonso, and P. M. Mendes, "Quality of Service Support in Wireless Sensor Networks for Emergency Healthcare Services," *Annual International Conference of Engineering in Medicine and Biology Society (EMBS)*, IEEE, pp.1296-1299, 2008.
[11] E. Felemban, C. Lee and E. Ekici, "MMSPEED: Multipath multi-SPEED Protocol for QoS Guarantee of Reliability and Timeliness in Wireless Sensor Networks," *IEEE Trans. on Mobile Computing*, pp.738-754, 2006.
[12] J. Lian, K. Naik, and G. B. Agnew, "Data Capacity Improvement of Wireless Sensor Networks Using non-uniform Sensor Distribution," *International Journal of Distributed Sensor Networks*, vol.2, pp.121-145, 2005.
[13] X. Qin and R. Berry, "Opportunistic Splitting Algorithms for Wireless Networks," *INFOCOM*, IEEE, vol.3, pp.1662-1672, 2004.