

An Energy-Balanced Cooperative MAC Protocol in MANETs

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Abstract. In order to improve the network performance of Mobile Ad Hoc Networks (MANETs), an Energy-balanced Cooperative Media Access Control (EC-MAC) protocol in MANETs was proposed in this paper. It adopted the best partnership selection algorithm to select the cooperative node with better channel condition, higher transmission rate and more balanced energy consumption. Simulation results showed that EC-MAC outperforms Cooperative MAC (CoopMAC) and IEEE 802.11 Distributed Coordination Function (DCF) in terms of the packet delivery ratio, network throughput and network lifetime under two distinct channel noise levels, especially under the bad channel condition.

Keywords: Mobile Ad hoc Network (MANET), cooperative, Media Access Control (MAC)

1. Introduction

Cooperative communication [1] which takes full advantage of the broadcast nature of the wireless channel and creates spatial diversity is becoming a promising technology for wireless networks. Research verified that cooperation communication can achieve great improvement in the network capacity, delay, robustness, energy consumption and significant reduction in interference as well. The early exploration of the cooperative communication was for the physical layer cooperation [2][3], and now it has been developed to the Media Access Control (MAC) layer [4][5] and the network layer [6][7]. Some researchers also focused on the cross-layer cooperation design [8][9], coupling the functionality of multiple layers, in order to improve the network performance.

In this paper, we proposed a new cooperative MAC protocol, Energy-balanced Cooperative MAC (EC-MAC), in Mobile Ad Hoc Networks (MANETs). In EC-MAC, the sender takes three factors into consideration, the wireless channel condition, transmission rate and energy fairness factor, and then selects a single cooperative node among all the neighbors according to the best partnership selection algorithm. The rest of paper is organized as follows: Related work on cooperative MAC is summarized in Section 2. Section 3 presents the best partnership selection algorithm. Section 4 describes the EC-MAC protocol in details. Simulation results and performance comparison of three protocols are given in Section 5. Finally, Section 6 concludes the paper.

2. Related Work

Two similar MAC protocols, relay-enabled DCF (rDCF) [4] and Cooperative MAC (CoopMAC) [5], are both proposed by taking the advantage of the multirate capability of IEEE 802.11. Each node maintains a cooperative table, where the required information of the candidate cooperative nodes is stored. CoopMAC and rDCF both send packets in a high rate two-hop manner instead of low rate one-hop manner, and thus improve the network performance. The Cooperative MAC protocol (CO-MAC) [10] was designed to provide better performance due to the receiver diversity gain than rDCF and the implementation complexity is as low as that of rDCF. The Network Coding enabled Cooperative MAC protocol (NC-MAC) [11] attempted to

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combine the cooperative communications with the network coding approach. Simulation results showed that this protocol provides greater network throughput by the network coding gain than rDCF. The Opportunistic Cooperative MAC protocol (OC-MAC) [8] was proposed based on the cross-layer information utilization. Opportunistic cooperative [12] strategy was also exploited to use relay only when it can improve the performance of network system. Moreover, the relay node selection considers the channel fading factor. The work [13] also proposed a cooperative MAC protocol based on the opportunistic relaying, where the node with the best channel quality among all the neighbors is selected as the cooperative node. This protocol can significantly improve the network performance when the quality of the direct transmission path is poor.

3. Best Partnership Selection Algorithm

Unreliable wireless fading channels and limited energy of mobile terminals restrict the whole network performance. In order to avoid these problems caused by the nature of MANETs and improve QoS of the network, a best partnership selection algorithm is presented in this section.

Each node maintains a cooperative table, shown in Table 1. Through the exchanges of the control frames, each node records the MAC addresses of its neighbor H_i and the destination D_i , the latest time T_i when receiving the packets from the neighbor, transmission rate R_{shi} between the neighbor and itself, transmission rate R_{hid} between the neighbor and the destination, residual energy E_{ri} of the neighbor, and average channel condition C_i of the path from the source to the destination through the neighbor. The cooperative table is periodically updated and records the latest instantaneous information of all its neighbors.

Table 1 Format of the cooperative table

MAC Address of H_1	MAC Address of D_1	T_1	R_{sh1}	R_{hd1}	E_{r1}	C_1
.....
MAC Address of H_n	MAC Address of D_n	T_n	R_{shn}	R_{hdn}	E_{rn}	C_n

Once the source needs to send packets to the destination, it will first check whether there is a neighbor node satisfying the requirement in the cooperative table. The requirement is shown in formula 1, where C_d is the channel condition of the path directly from the source to the destination.

$$C_i \geq C_d \quad (1)$$

If there is one node, it will be selected as the cooperative node. If there is more than one node satisfying the requirements, the source node adopts the best partnership selection algorithm. Otherwise, the source will send packets directly to the destination according to the traditional IEEE 802.11 DCF. The average channel condition (C) is calculated in formula 2, and the channel condition between any two nodes is estimated on the Signal-to-Noise Ratio (SNR) of the received signal. C is the harmonic mean, and reflects the average channel quality from the source to the destination in the two-hop manner. The larger the C , the better the channel quality is.

$$C = 2/(1/C_{sh} + 1/C_{hd}) \quad (2)$$

Then the source calculates the transmission time through cooperation (T_{coop}) and the energy fairness factor (η), as shown in formula 3 and 4.

$$T_{coop} = 1/R_{sh} + 1/R_{hd} \quad (3)$$

$$\eta = E_i/E_r = (P_r/R_{sh} + P_t/R_{hd})/E_r \quad (4)$$

Since the values of T_{coop} , C and η are obtained, a neighbor with shorter transmission time, better channel condition and higher energy utilization should be selected as the cooperative node. Therefore, we introduce Q , a selection criteria to be used by the source for the cooperative node selection.

$$Q = T_{coop}\eta/C \quad (6)$$

Obviously, the neighbor with the smallest Q is selected as the cooperative node. The introduction of the energy fairness factor can effectively avoid the situation that some neighbor is frequently selected as the cooperative node which results in the early death and network partition. Although the selection method considering the energy fairness factor does not ensure to minimize the total energy consumption, it can maximize the minimum value of the residual energy and keep the energy levels of all the nodes in the network in a balanced state. Therefore, the introduction of the energy fairness factor η can prolong the network lifetime by extending the node survival time.

4. EC-MAC Protocol

Besides three control frames (RTS, CTS and ACK) supported in IEEE 802.11MAC, three new frames are introduced in EC-MAC. They are Cooperative Request-to-Send (CRTS) frame, Helper-to-Send (HTS) frame, and Cooperative Clear-to-Send (CCTS) frame. The handshake process of EC-MAC is described as follows.

1) Before the transmission of a data packet, if the source finds a cooperative node, it senses the channel to see if it is idle for a DCF Interframe Space (DIFS) time. When the source has completed the required backoff procedure, a CRTS frame (including the MAC address of the cooperative node) will be sent, and this frame also reserves the channel for Network Allocation Vector (NAV) duration. If the source cannot find a cooperative node, it sends RTS frame directly to the destination.

2) When the neighboring node receives CRTS, it checks whether it is the cooperative node. If it is and is able to participate in the cooperative communication, it sends the HTS frame after a Short Interframe Space (SIFS) time and also reserves the channel for NAV duration.

3) When the destination receives CRTS and then receives HTS after a SIFS time, it sends CCTS, indicating the cooperation communication is ready. If the destination receives CRTS, but does not receive HTS in $HTS_timeout$ duration, it sends CTS, indicating the direct communication is ready. Meanwhile, the destination reserves the channel for NAV duration.

4) If the source receives HTS and CCTS in $CCTS_timeout$ duration, it sends data packets to the cooperative nodes. If the source receives CTS from the destination, it sends data packets directly to the destination. If the source receives neither CCTS nor CTS, the channel contention fails and the source resumes the backoff procedure.

5) The destination indicates its successful reception of the data packet by sending ACK directly back to the source.

6) If the source receives ACK, the data transmission is successful and the source stays idle. If the source does not receive ACK in $ACK_timeout$ duration, the data transmission fails and the source resumes the backoff procedure and contends the channel again.

5. Performance Evaluation

In order to evaluate the performance of EC-MAC, we simulate IEEE 802.11 DCF, CoopMAC [14] and EC-MAC by using Network Simulator 2 (NS2) [15] network simulator. Nodes are uniformly distributed in an area of 600m×800m and able to move randomly with the speed of 0-5 m/sec. For different requirements of the performance analysis, the number of nodes varies from 5 to 40. The transmission power is fixed to 1.65W and the receiving power is fixed to 1.4W. The initial energy of all nodes is set to 60J. Multirate capability of IEEE 802.11b is employed and four different rates, 1Mbps, 2Mbps, 5.5Mbps, and 11Mbps are supported. In order to simulate a more realistic reception model, we adopt the modified signal reception model in [16], which takes BER into consideration when determining the success or failure of a received signal. The environment noise level of -78dBm to -90dBm is modeled as a Gaussian random variable with the standard deviation of 1 dB. Each simulation runs for 600 seconds. Three performance metrics, packet delivery ratio, network throughput and the network lifetime are evaluated.

Figure 1 shows the packet delivery ratio of three protocols with different environment noise levels from -90dBm to -78dBm. The number of node is 40 in this scenario. We can observe that the performance of three protocols all degrade sharply as the noise level increases. Since EC-MAC considers the channel condition in

the cooperation communication and data packets can be transmitted on the links with higher quality, EC-MAC consistently outperforms the other two.

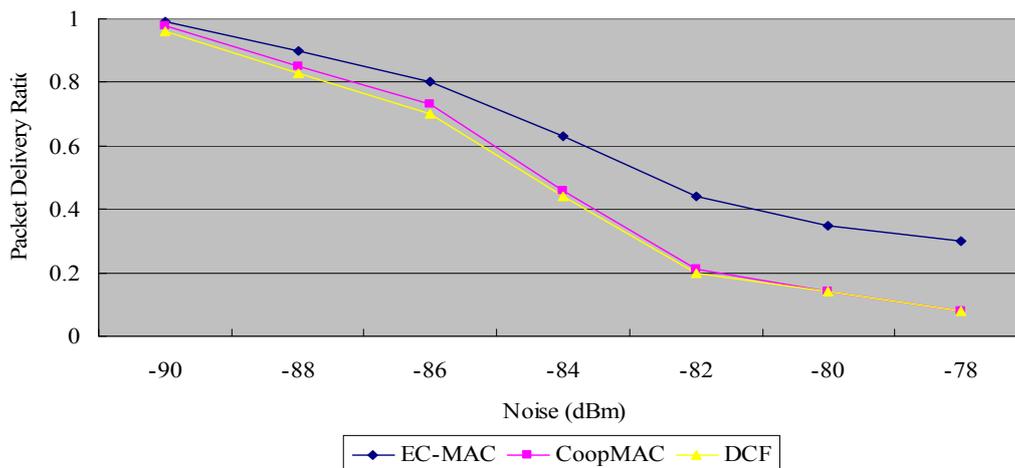


Fig. 1: Packet delivery ratio as the noise level increases

Figure 2 shows the network throughput of three protocols as the number of nodes increases with two environment noise levels of -90dBm and -86dBm. Network throughput of three protocols all decreases as the noise level and the number of nodes increase. EC-MAC performs best since it takes channel condition into consideration. CoopMAC performs better than DCF due to the benefits of cooperation. As the number of nodes increases, there are more candidate nodes to be selected as the cooperative nodes, and thus the network throughput is improved.

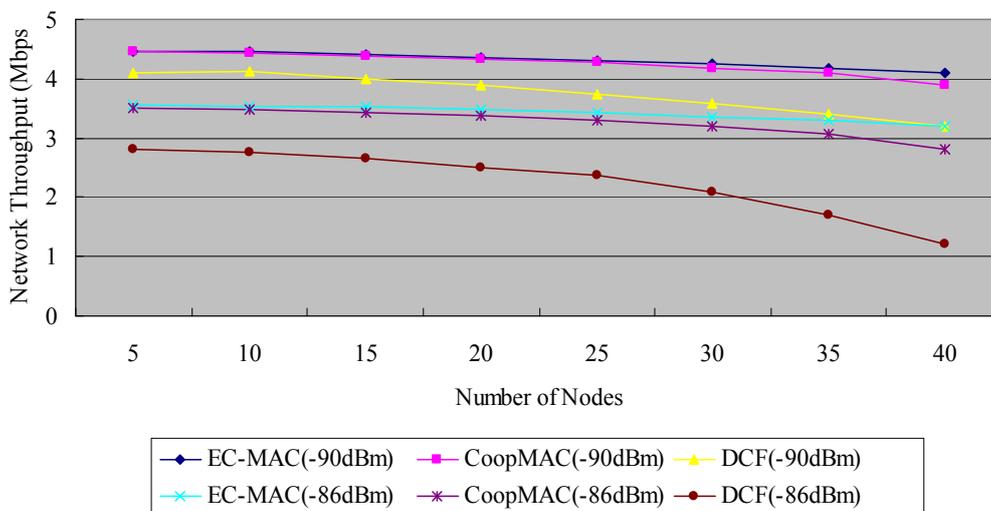


Fig. 2: Network throughput as the number of nodes increases

Figure 3 shows the network lifetime of three protocols as the number of nodes increases with the environment noise levels of -90dBm. In this scenario, the initial energy of nodes is randomly set in [5J, 60J]. We can observe that the network lifetime of three protocols all increases as the number of nodes increases. EC-MAC has the longest lifetime, while CoopMAC and DCF both performs worse. Simulation results verify that the energy fairness factor in the best partnership selection algorithm can balance the energy consumption of nodes and prolong the network lifetime.

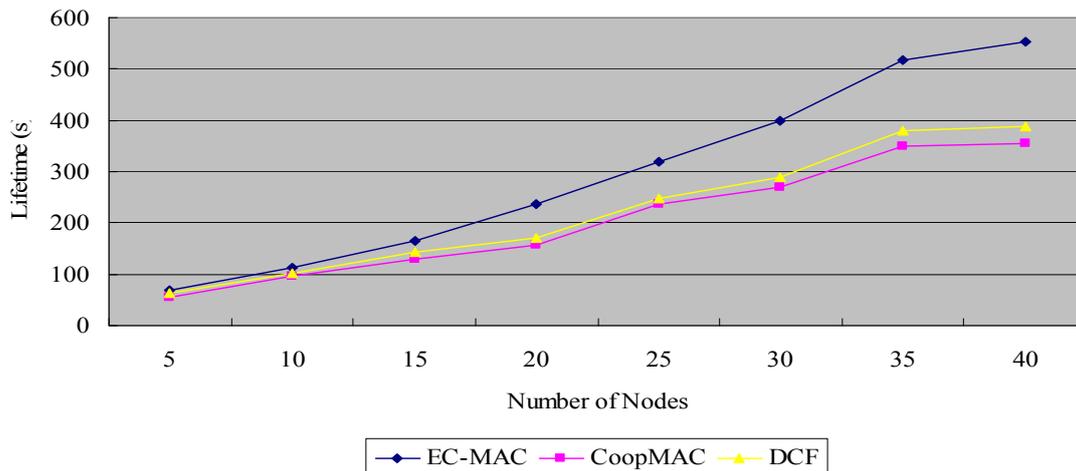


Fig. 3: Network lifetime as the number of nodes increases

6. Conclusion

Traditional cooperative MAC protocols are proposed to increase the data transmission rate and thus improve the network throughput. However, they do not consider the QoS caused by the unreliable wireless environment and limited energy resources. In order to solve these problems, we proposed an energy-balanced cooperative MAC protocol, EC-MAC, in MANETs. Through the best partnership selection algorithm, the cooperative node with better channel condition, higher transmission rate and energy fairness factor is selected to participate in the cooperation communication. Simulation results verify that EC-MAC can improve the packet delivery ratio, network throughput and the network lifetime more than CoopMAC and IEEE 802.11 DCF in different communication environments.

7. References

- [1] A. Sendonaris, E. Erkip and B. Aa zhang, User cooperation diversity-part I: System description, IEEE Transactions on Communications, vol. 51, no. 11, Nov. 2003, pp. 1927-1938.
- [2] J. N. Laneman and G. W. Wornell, Distributed space-time coded protocols for exploiting cooperative diversity in wireless networks, IEEE Transactions on Information Theory, vol. 49, no. 10, Oct. 2003, pp. 2415-2525.
- [3] J. N. Laneman, D. N. C. Tse, and G.W. Wornell, Cooperative diversity in wireless networks: Efficient protocols and outage behavior, IEEE Transactions on Information Theory, vol. 51, no. 12, Dec. 2004, pp. 3062-3080.
- [4] H. Zhu and G. Cao, rDCF: A relay-enabled medium access control protocol for wireless ad hoc networks, Proc. of IEEE INFOCOM, vol. 1, Miami, USA, 2005, pp. 12-22.
- [5] P. Liu, Z. Tao, and S. Panwar, A cooperative MAC protocol for wireless local area networks, Proc. of IEEE ICC, vol. 5, Seoul, Korea, 2005, pp. 2962-2968.
- [6] R. Ahlswede, N. Cai, S. R. Li, and R. W. Yeung, Network Information Flow, IEEE Transactions on Information Theory, 2003, pp. 371-381.
- [7] A. S. Ibrahim, Z. Han, and K. J. R. Liu, Distributed energy-efficient cooperative routing in wireless networks, IEEE Transactions on Communications, vol. 7, no. 10, Oct. 2008, pp. 3930-3941.
- [8] A. Azgin, Y. Altunbasak, and G. AlRegib, Cooperative MAC and Routing Protocols for Wireless Ad Hoc Networks, Proc. of IEEE GLOBECOM, 2005, pp. 2854-2859.
- [9] Y. Yuan, B. Zheng, W. Lin and C. Dai, An opportunistic cooperative mac protocol based on cross-layer design, 2007 International Symposium on Intelligent Signal Processing and Communications Systems, ISPACS 2007 - Proceedings, 2008, pp. 714-717.
- [10] J. Jang, A study on a cooperative MAC protocol at ad hoc networks, KIMICS, vol. 13, no. 8, Aug. 2009, pp. 1561-1570.

- [11] J. Jang, A study on a network coding enabled cooperative MAC protocol at ad hoc networks, KIMICS, vol. 13, no. 9, Sep. 2009, pp. 1819-1828.
- [12] Bletsas A., Khisti A., Reed D. P., A simple distributed method for relay selection in cooperative diversity wireless networks, based on reciprocity and channel measurements, IEEE 61st Vehicular Technology Conference, VTC 2005-Spring, vol. 3, Dec. 2005, pp. 1484-1488.
- [13] N. Li, N. Cheng, Y. Cai and X. Xu, Performance Analysis of a Cooperative MAC Based on Opportunistic Relaying for Ad Hoc Networks, 2010 International Conference on Wireless Communications and Signal Processing, Oct. 2010, pp. 1-6.
- [14] T. Korakis, Z. Tao, Y. Slutskiy and S. Panwar, A Cooperative MAC protocol for Ad Hoc Wireless Networks, Fifth Annual IEEE International Conference on Pervasive Computing and Communications Workshops, May 2007, pp. 532-536.
- [15] NS Manual, <http://www.isi.edu/nsnam/ns>.
- [16] S. Moh, C. Yu, A Cooperative Diversity-Based Robust MAC Protocol in Wireless Ad Hoc Networks, IEEE Trans. Parallel and distributed system, vol. 22, no. 3, Mar. 2011, pp. 353-363.