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Efficient Cooperative MAC and Routing in Wireless Networks

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ABSTRACT

Cooperative communication refers to the collaborative processing and retransmission of the overheard information at those stations surrounding the source. It exhibits various forms at different protocol layers and introduces many opportunities for cross layer design and optimization. To fully reap the benefits of cooperative communications in wireless networks, the entire protocol stack - physical, MAC, and routing protocols - should be carefully redesigned or reengineered. In this paper, we first propose a cooperative MAC protocol by enhancing IEEE 802.11 DCF with minimal modifications to maximize the benefit of cooperative diversity. Its performance is compared to that of an existing cooperative MAC and legacy 802.11 DCF protocols and shown to be superior. We also propose a cluster based cooperative routing protocol which has minimal control overhead and time consumed in establishing the cooperative paths. Through extensive simulations, the performance of the proposed protocols are evaluated and compared to other combinations of MAC and routing protocols.

Keywords: Cooperative MAC, Cooperative Routing, End-to-End Delay, Energy Efficiency, Cross-Layer Design

1 Introduction

Cooperative networking has recently received significant attention as an emerging network design strategy for future wireless networks to cost-effectively provide multimedia services. In cooperative networking, individual network nodes cooperate to achieve network goals in a coordinated way. Cooperative transmission, which is a form of distributed spatial diversity, can offer more reliable communications, increased network capacity, extended coverage area, and more efficient communication. However, the higher layer protocols of cooperative networks must be properly designed to realize the advantages [1-3].

Most cooperative transmission schemes involve two phase of transmission: a coordination phase, where nodess exchange their own source data and control messages with each other and/or the destination, and a cooperation phase, where the nodes cooperatively retransmit their messages to the destination. In Figure 1, in the coordination phase (i.e., Phase I), the source node broadcasts its data to the relay nodes and the destination node and, in the cooperation phase (i.e., Phase II), the relay nodes forward the source's data (either by themselves or by cooperating with the source) to enhance reception at the destination. The nodes may interchange their roles as source and relay at different instants in time. To

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enable such cooperation among nodes, different relay technology can be employed depending on the relative node locations, channel conditions, and transceiver complexity. Decode-and-forward, amplify-and-forward, coded cooperation, and compress-and-forward are some of the basic cooperative relaying techniques.

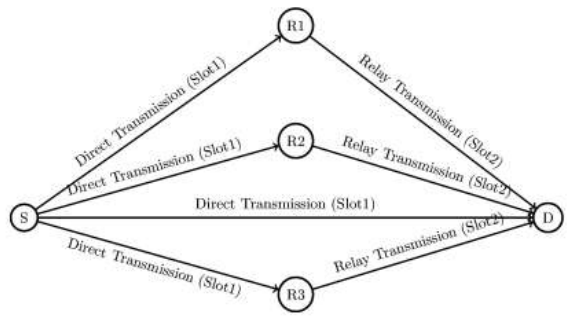

Figure 1: Cooperative Communication

The innovation of cooperative communications is not confined only to physical layer. It is available in various forms at different higher protocol layers. The cooperative MAC protocols developed in the recent years show how the benefits of cooperative diversity can be achieved by modifying the IEEE 802.11 distributed coordination function (DCF) [4-11]. Routing algorithms which are based on the cooperative communications are known as cooperative routing algorithms [12-15]. These approaches perform well in physical, MAC or Network layer separately; however, the performance can be further improved by using cross-layer methods. The cross layer approaches proposed in [16-18] consider the cross-layer optimization of physical and MAC layers.

While cooperative communication can improve network performance, it can also incur considerable overhead. This overhead includes : (i) signaling and network control overhead for cooperating entities selection and coordination; (ii) additional required resources such as bandwidth for relay transmission; (iii) energy consumption at the cooperating entities; (iv) time consumed in selecting the cooperating entities and establishing the cooperative paths; and (v) the overall added complexity to the communication and networking process [3]. Reduction of these various forms of cooperation overhead will have great impact on the cooperative network performance.

In this paper, we propose a cooperative MAC protocol for multihop networks. The proposed protocol is backward compatible with the legacy 802.11 DCF protocols. The protocol requires minimum modification to the data packet header and control packets. The simulation results show that the proposed MAC protocol achieves significant throughput improvement compared to CoopMAC (Liu et al (2007)) and IEEE 802.11 DCF protocols in single hop networks. We study the TCP performance in a multihop wireless network with the proposed cooperative MAC for channel access and show improved performance over that using legacy 802.11 DCF. We also propose a cluster based cooperative routing protocol which reduces the overhead involved in route establishment and maintanance. Extensive simulation results show that in a multihop network, the proposed cooperative MAC and cluster based routing protocols increase the end-to-end throughput and packet delivery ratio.

The rest of the paper is organized as follows. A brief description of the related works in cooperative network protocols is given in Section 2. The proposed MAC and routing protocols are presented in Section 3 and Section 4, respectively. Simulation results are discussed in Section 5. Conclusion and future work are presented in Section 6.

2 Related Work

The Cooperative MAC (CoopMAC) protocol for wireless LANs [6-8] is based on the idea of transforming a slow one-hop transmission into a faster two hop transmission, thereby decreasing the transmission time for the traffic being handled. Pei et al [16] studied how the physical layer cooperation can be integrated with the MAC sublayer for dramatic improvements in throughput and interference. The CoopMAC protocol with diversity combining is introduced in this article. When receiver combining is enabled, the relay can forward packets at a rate equal to or greater than the one that it adopts in CoopMAC where combining is not possible. Liu et al [6] verified by analysis and simulations that CoopMAC for infrastructure WLAN can achieve substantial throughput and delay performance improvements over legacy IEEE 802.11.

Korakis et al [7] extended CoopMAC into the ad hoc network environment. The implementation of CoopMAC and its performance and challenges in a real environment were reported in [8]. In [19], the authors have extended the saturation throughput analysis of CoopMAC to the non saturated network case. In [18], the authors have proposed a MAC protocol design for distributed cooperative wireless networks. They focused on beneficial node cooperation by addressing two fundamental issues of cooperative communications, namely, when to cooperate and whom to cooperate with, from a cross-layer protocol design perspective. Taking account of protocol overhead, they explored a concept of cooperation region, whereby beneficial cooperative transmissions can be identified. To increase network throughput, they proposed an optimal grouping strategy for efficient helper node selection, and devised a greedy algorithm for MAC protocol refinement.

The authors of [5] have developed rDCF protocol which enables packet relaying in the ad hoc mode of 802.11 systems by requesting each station to broadcast the rate information between stations explicitly. The rDCF exploits the physical layer multi-rate capability by enabling the sender, relay and receiver nodes coordinate to decide what rate to use and whether to use a relay node. Through simulation, the delay and throughput performance were investigated but not the energy efficiency.

Adam et al [9] have presented a Cooperative Relaying Medium Access protocol (CoRe-MAC) as an extension to CSMA/CA which addresses resource reservation, relay selection, and cooperative transmission while keeping the overhead in terms of time and energy low. They analyzed the efficiency of this protocol for packet error rate, throughput, and message delay in a multihop network. In the case of unreliable communication links, performance improvement occurs. However, for good SNR between source and destination, CoRe-MAC has similar performance as the standard CSMA/CA.

In [20], the authors have proposed a cooperative relaying without the symbol-level synchronization constraint, called Distributed Asynchronous Cooperation (DAC). With DAC, multiple relays can schedule concurrent transmissions with packet-level (hence coarse) synchronization. The receiver then extracts multiple versions of each relayed packet via a collision resolution algorithm, thus realizing the diversity gain of cooperative communication. They also designed a simple MAC protocol to exploit the benefit of DAC, and a generic approach to incorporate DAC relaying into existing routing protocols.

Cooperation may not be beneficial in certain scenarios, and hence it is crucial to develop adaptive MAC that uses cooperation only when it is needed. The authors Shan & Zhuang [17] have shown that cooperation is beneficial only when the source-destination link has a low transmission rate and/or the payload length is large enough compared to the signaling overhead for cooperation. In general, the cooperation decision at the MAC layer depends on the link quality measurements and achieved throughput. Hence, cross layer design between the PHY and MAC layers is required. MAC protocol should address the challenging issue of how to schedule the transmissions from the cooperating entities and their neighbors to avoid collisions.

The routing protocol in a cooperative network should be designed to use all cooperating entities between the source and destination nodes. A route from the source to destination becomes a sequence of cooperative links. The routing problem can be viewed as a multi-stage decision making; at each stage, the decision is to select the transmitting and receiving set of nodes [21]. The two major challenges in developing a cooperative routing protocol are the high computational complexity and the increased interference in the presence of multiple flows. Cross-layer design between the routing and MAC protocols can be beneficial to resolve the multi-flow throughput degradation issue of cooperative routing.

A novel decentralized cross-layer multi-hop cooperative protocol, namely, Routing Enabled Cooperative Medium Access Control (RECOMAC) was proposed in [22]. The protocol architecture makes use of cooperative forwarding methods, in which coded packets are forwarded via opportunistically formed cooperative sets within a region, as RECOMAC spans the physical, MAC and routing layers. Randomized space-time coding is exploited at the physical layer to realize cooperative transmissions, and cooperative forwarding is implemented for routing functionality, which is submerged into the MAC layer, while the overhead for MAC and route set up is minimized. However, it is not compatible with the conventional architecture with non-cooperative transmissions.

The problem of transmission-side diversity and routing in a static wireless network was studied by Amir et al [12]. They formulated the problem of finding the minimum energy cooperative route using dynamic programming (DP). The optimal algorithm, namely, Cooperation along the Minimum Energy Non-Cooperative Path (CAN), turned out to be computationally intractable. Hence, they proposed two suboptimal algorithms, CAN-l , and Progressive cooperation (PC-l).

Two cooperation-based routing algorithms, namely, Minimum-Power Cooperative Routing (MPCR) algorithm and Cooperation Along the Shortest Non-Cooperative Path (CASNCP) algorithm were proposed by Ibrahim in [13]. The MPCR algorithm takes into consideration the cooperative communications while constructing the minimum power route. The CASNCP algorithm is similar to CAN-l and PC-l, as it finds the shortest path route (SPR) first and then applies cooperative communications upon the SPR to reduce the transmission power.

In [14], the authors have proposed two MAC protocols (Repetition coding with maximal ratio combining MAC (MRC - MAC), Space time coding MAC(STC MAC)) and two routing protocols (Cooperative Routing Protocol (CRP), Enhaced CRP (E-CRP)). MRC-MAC is the MAC protocol to support repetition coding with MRC at the physical layer. STC-MAC is the MAC extension to support space-time coding. In the MRC-MAC and STC-MAC protocols, they assume that each hop's source, destination and two relay nodes are known to the MAC layer. CRP is based on the widely used AODV routing protocol in wireless ad-hoc networks.

The performance evaluation through simulation shows the need to incorporate adaptive decision whether to invoke cooperative relaying on each hop.

In [15], the authors have proposed and investigated a new distributed cooperative routing algorithm that realizes minimum power transmission for each composed cooperative link, given the link BER constraint at a certain target level. The key contribution of the proposed scheme is to bring the performance gain of cooperative diversity from the physical layer up to the networking layer.

The above mentioned cooperative routing protocols are all designed based on minimization of the total transmitted power. Other link costs including delay, bandwidth and link life time need to be considered. Cross layer designs to resolve the multi flow throughput degradation issue with cooperative routing also need to be addressed.

3 Cooperative MAC Protocol for Multihop Networks (M-CMAC)

We propose a cooperative MAC protocol for multihop networks. Like CoopMAC [6], in our protocol also, high data rate stations assist low data rate stations in their transmission by forwarding their traffic. A helper is selected such that two fast hop transmissions replaces one slow hop transmission. The helper with the best two hop transmission rate, which is having minimum delay for data transmission from source to helper and from helper to destination, is considered as the best helper and selected as neighbor node for that particular source-destination pair. It is assumed that the location information of the nodes are known so that the euclidean distance between every pair of nodes can be computed. Since the data rate of a link is related to the distance between the nodes, the computed distances can be easily converted to the corresponding data rates. Every node in the network maintains a cooperative table (CT) of potential helpers, which contains the MAC address of all destinations that can be reached through a single hop transmission, the direct euclidean distance to the destination, the MAC address of the helper (if a helper is present), and the total distance through the helper. If no helper is available, the helper address is same the destination address. A simple example network is shown in Figure 2, and Table 1 shows the format of CT for the network shown in Figure 2.

It is backward compatible with legacy 802.11 DCF, and has minimal modification to the data frame (MAC Protocol data unit) header and the RTS-CTS control frames. When a source node has data to send, it checks in its CT whether a helper exists for that particular destination. If a helper exists, then the source sends an RTS message to the helper, reserving the channel for a duration corresponding to single hop transmission. The format of RTS message used in our proposed protocol is shown in Figure 3.

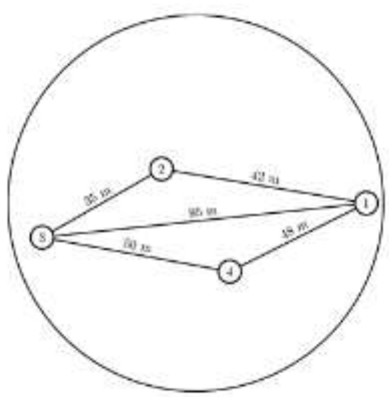

Figure 2: Helper Selection in M-CMAC Protocol

Table 1: Cooperative Table at Node 3

MAC Address of Destination	Helper Address	Direct Distance	Distance via Helper
1	2	95	77
2	2	35	-
4	4	50	-

The source saves the address of the destination node in the helper address field and the helper address is stored as the destination address. When an RTS message is received, the nodes will check the helper address field and destination address field. If the helper address field is different, then the node infers that it has to act as a helper for another node. If the helper is willing to forward the data, then it will send a CTS back to the source. The source will send the data packet to the helper if the CTS message is received. The format of MAC-PDU header is shown in Figure 4. The address of the helper is entered in the Destination address field and the original destination's MAC address is stored in the Address 3 field. Source address is saved in the Source Address field. When this packet reaches the helper, it checks the Destination address field of the MAC header and address in the field Address 3. If both are different, then the helper will copy its own address to the Source address field and the address in Address 3 field is stored in the Destination Address field. It also sends an ACK to the source to indicate the success of packet reception. Then the helper will send an RTS message to the destination and reserves the channel for single hop transmission. When this RTS message is received, the destination will send a CTS back to the helper. The helper then forwards the packet received from the source, to the destination. The destination will send an ACK to helper if the packet is received.

Frame Control	Duration	Source Address	Destination Address	Helper Address

Figure 3 : RTS Frame Format

Unlike CoopMAC, where the channel is reserved for two hop transmissions and therefore the neighbors of source, helper and destination have to defer their transmissions until then, in our protocol, the reservation is for one hop each time. Thus there is increased number of parallel transmissions (i.e., channel resuse) in the case of our protocol.

Frame Control	Duration	Source Address	Destination Address	Address 3	Sequence Contro	Address 4

Figure 4: MAC PDU Header Format

4 Cluster Based Cooperative Routing (CBCR) Protocol

We propose a cluster based cooperative routing protocol with the multi-hop data forwarding function realised at the link layer, where we have cooperative links (using M-CMAC described in Section 3). We use the term cluster to denote a group of nodes that can communicate with each other through a single hop transmission, and the term routing relays to denote the nodes within each cluster that forwards the packet to the next hop. A routing relay belongs to two or more clusters at the same time. The protocol involves two stages: routing relay selection phase and data forwarding phase.

4.1 Routing Relay Selection Phase

Every node in the network broadcasts periodical beacon messages to inform its presence to the neighbors. The beacon message carries the nodes's MAC address. Each node builds a relay table which includes all the neighbouring nodes it can communicate with. Each node will broadcast its neighbor list to its neighbors if any entry in the list has changed since the last broadcast. The first column of the relay table of any node X contains the MAC address of the neighboring nodes of node X. The row corresponding to each neighboring node contains the MAC addresses of all the neighbors of the neighboring node.

The routing relays are selected independently by each node, based only on its own relay table. A node is selected as relay if it connects the highest number of nodes, i.e., the longest row, or it connects nodes that are not connected by the previously selected relay nodes. Let {N } denotes the set of all nodes that are within the single hop transmission range of Node X and {D} denotes the set of all nodes that can be reached through the nodes in N . Let count represents the number of elements in {N }. {B} is the set of routing relays and R i denotes the node in the first column of row i. The algorithm to find the routing relay is explained in Algorithm 1. Before applying the algorithm, the table has to be sorted in the decreasing order of the number of neighboring nodes. ie, the details of the neighboring node that has the maximum number of neighbors is placed first. If two or more nodes have the same number of neighbors, then they are arranged in the increasing order of MAC address.

Algorithm 1 : Relay Selection Algorithm

1: Initialize {B} = R 1 .

2: {D} = {D} − { Neighbors of R 1 }

3: if {D} = Ø then goto 11

4: else

5: i ← 2

6: while ({D} = Ø & i ⩽ count + 1) do

7: if ({D} ∩ { Neighbors of R i }) = Ø then

8: {D} = {D} − ({D} ∩ { Neighbors of R i })

9: {B} = {B} ∪ R i

10: i ← i +1

11: End

For the multi hop network shown in Figure 5, the contents of the relay table for Node 3 is given in the Table 2. Node 8 and Node 6 are selected as the routing relays by Node 3.

4.2 Data Forwarding Phase

When a node has a packet to send, it first checks whether the destination is in the same cluster. If the destination is in the same cluster, then it checks if a helper exists for this particular destination. If a helper exists, then the packet is transmitted to the helper. If no helper is available, then the packet is transmitted directly to the destination.

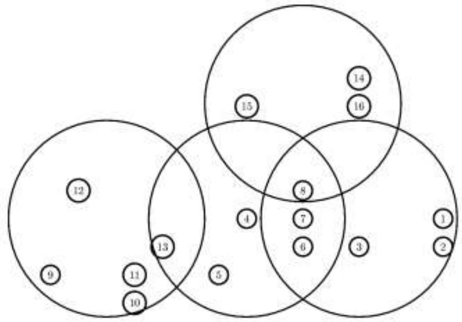

Figure 5: Cluster Selection in CBCR Protocol

If the destination belongs to a different cluster, then it searches the relay table to find if the destination can be reached through any of the routing relays. If the destination can be reached through any routing relay, the packet is forwarded to the routing relay. The packet is send to the routing relay via a helper, if a helper node exists for this routing relay. Otherwise, it is forwarded directly to the routing relay.

Table 2: Structure of Relay Table at Node 3

MAC Address of Node	Neighbor Nodes					
3	1	2	6	7	8	
1	2	3				
2	1	3				
6	3	4	5	7	8	
7	3	4	5	6	8	
8	3	4	6	7	15	16

If the destination cannot be reached through any of the routing relays, then the node multicasts the packet to all the routing relays.

5 Simulation Results

The proposed M-CMAC protocol described in Section 3 and the proposed CBCR protocol described in Section 4 have been implemented in the NS2 network simulator. Performance evaluation using these implementations are discussed in this section. A network topology of 1000 x 1000 square meter is considered. Nodes are uniformly and independently distributed at random locations. Simple path loss model is considered for wireless channel and IEEE 802.11g parameters are used for the experiments. The data rates for different transmission ranges as per IEEE 802.11g are shown in the Table 3. The simulation parameters are listed in Table 4

Table 3: Rate vs Range

Data Rate (Mbps)	6	9	12	18	24	36	48	54
Maximum Range (Meter)	100	84	77	63	51	39	34	26

Table 4: Simulation Parameters

MAC Header	240 bits
RTS	208 bits
CTS	112 bits
ACK	112 bits
Data Rate for MAC Header	6 Mbps
Slot Time	20 µs
SIFS	10 µs
DIFS	50 µs
CWMin	31 slots
CWMax	1023 slots
Rety Limit	6

5.1 Performance of M-CMAC Protocol

Any node in the network can act as source node and all the nodes which are in the transmission range of a given source node are considered as destinations. Distance between the source and destination nodes are calculated and recorded as direct one hop distance in the cooperative table of the given source node. Since data rate of link is related to distance between the nodes, a helper is selected such that two fast hop transmissions replaces one slow hop transmission. The helper with the best two hop transmission rate which is having minimum delay for data transmission from source to helper and from helper to destination, is considered as best helper and selected as neighbor node for that particular source-destination pair. Figure 6 shows the relationship between the number of nodes and the overall throughput for legacy 802.11 DCF, CoopMAC and the proposed M-CMAC at a fixed payload size (1000 bytes). For 802.11 DCF network, as number of nodes increases, the throughput of network increases linearly. For CoopMAC and M-CMAC protocols, as the number of nodes increases, the availability of helpers for forwarding data packets increases and hence these protocols have better throughput compared to 802.11 DCF. This increase in throughput is due to the increase in availability of helper nodes which results in faster two hop transmission instead of single one hop transmission. The proposed M-CMAC protocol has significantly higher throughput than the CoopMAC, because of the increased channel reuse as mentioned in Section 3.

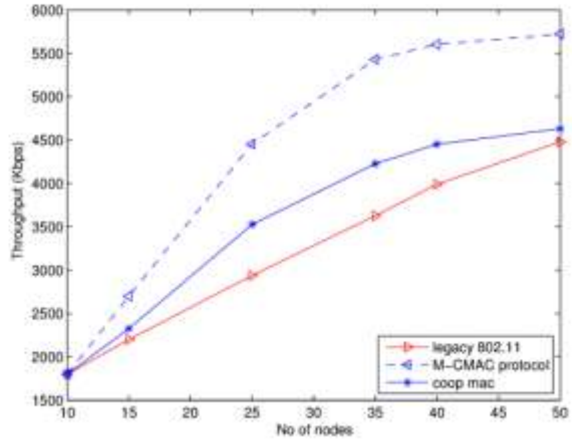

Figure 6 : Throughput vs Number of Nodes

The relationship between throughput and packet size is shown in Figure 7. When the packet size is smaller, throughput of the network is low. As the packet size increases, the throughput increases linearly and then saturates for a packet size above 1200 bytes. Again, asignificant improvement with the M-CMAC protocol over the CoopMAC is obvious.

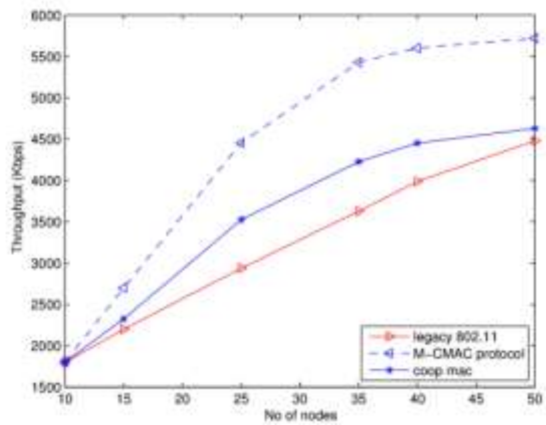

Figure 7: Throughput vs Packet Size

It is observed that the proposed protocol for adhoc networks can achieve significant throughput compared to CoopMAC and legacy 802.11 protocols. This increased throughput is due to the increased number of parallel transmissions (channel reuse) in the network. In CoopMAC, the channel is reserved for two hop transmission and therefore the neighbors of source, helper and destination have to defer their transmissions for the corresponding durations. Also in CoopMAC, the neighbors of the source node will set the NAV for a duration corresponding to the time for direct transmission between source and destination. The probability for RTS collisions are also higher for CoopMAC. In the case of our protocol, the nodes which are not in the transmission range of source and helper can transmit packets parallelly, when the source is sending packets to the helper. The nodes which are not in the transmission range of destination and helper can transmit packets parallelly, when the helper forwards the packet to the destination.

Figure 8 presents the cumulative distribution function for the packet delay in single hop adhoc network. The simulation is for a network of 40 nodes with a packet size of 1500 bytes. 16 nodes are generating packets at a rate of 1 Mbps. We can see that the delay of our protocol is significantly lower than that of legacy 802.11. This is because both M-CMAC and the CoopMAC decrease the transmission time of slow rate frames and thus more frames can be transmitted in a given period of time, a fact that decreases the queuing and service time of the frames. CoopMAC has better delay performance than the proposed protocol. This is due to the fact that contention for the medium has to be performed twice in the proposed protocol (from source to helper and helper to destination) when compared to single contention in CoopMAC.

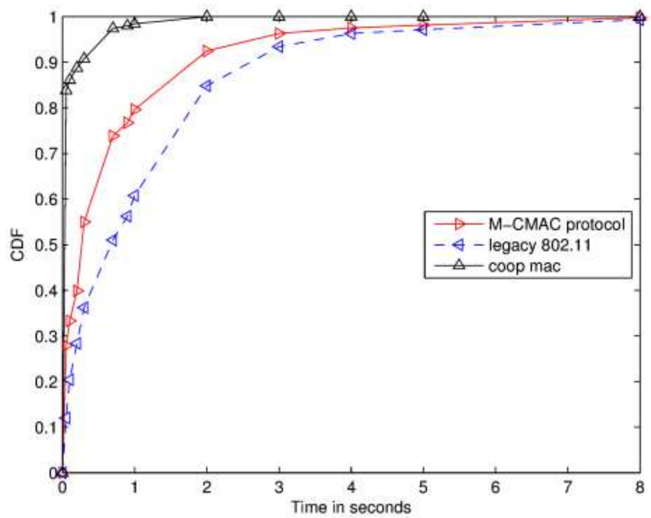

Figure 8 : CDF of Delay

The performance of UDP over the prooposed MAC protocol for multihop networks is shown in Figure 9. We considered random network topology with varying number of nodes, 40 percentage active sources, 1500 bytes packets, and AODV routing protocol.

In [23], the authors study TCP performance in a multihop network using IEEE 802.11 DCF for channel access. They show that for a given network topology and flow patterns, there exists an optimal window size at which TCP achieves highest throughput via maximum spatial reuse of channel. However, TCP grows its window size beyond the optimal value, leading to throughput reduction. The relationship between TCP window size and throughput over the proposed protocol in multihop wireless networks for random network topologies were investigated (which are not shown in this paper). The relationship between packet size and throughput for 2 and 4 active TCP flows are shown in Figure 10. Our proposed M-CMAC provides significant increase in TCP throughput conpared to 802.11 DCF, in all the cases.

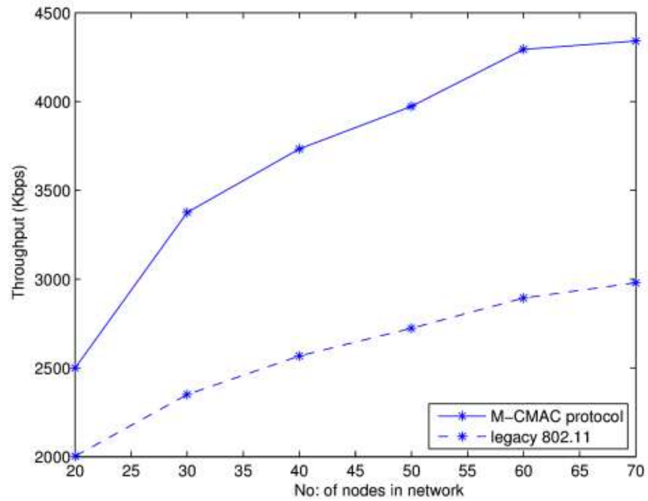

Figure 9: UDP Performance

5.2 Combined Performance of M-CMAC and CBCR Protocols

The number of nodes are varied from 10 to 100 for the following results. Source nodes are assumed to generate CBR traffic of 0.5 Mbps, and 512 bytes packet size is considered. Only 20 percentage of the total nodes are generating traffic. The destination nodes are randomly chosen.

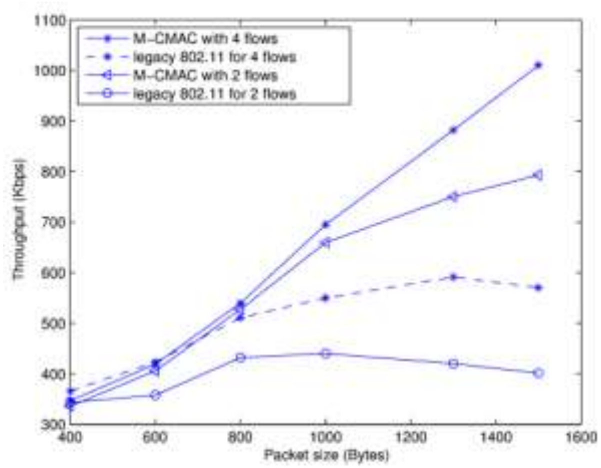

Figure 10 : TCP Performance with varying Packet size (bytes)

The performance of four combinations of MAC and routing protocols are compared : (i) AODV routing and legacy 802.11 MAC protocols; (ii) AODV routing and the proposed M-CMAC protocols; (iii) Proposed CBCR and legacy 802.11 MAC protocols; (iv) Proposed CBCR and the proposed M-CMAC protocols. Throughput versus number of nodes for the different combinations of the protocols are shown in Figure 11. From the figure, we can see that higher throughput can be achieved in a multi hop network by combining cluster based cooperative routing protocol and the proposed cooperative MAC protocol. The maximum throughput is obtained when the number of nodes is around 70. After that the throughput decreases.

For the remaining experiments, we considered only the proposed M-CMAC at the link layer, and compared the performance of the proposed CBCR with AODV. The average end-to-end delay for a packet is shown in Figure 12. The total delay is slightly higher for the proposed routing protocol. The proposed routing protocol achieves better packet delivery ratio compared to AODV routing protocol. This is shown in Figure 13.

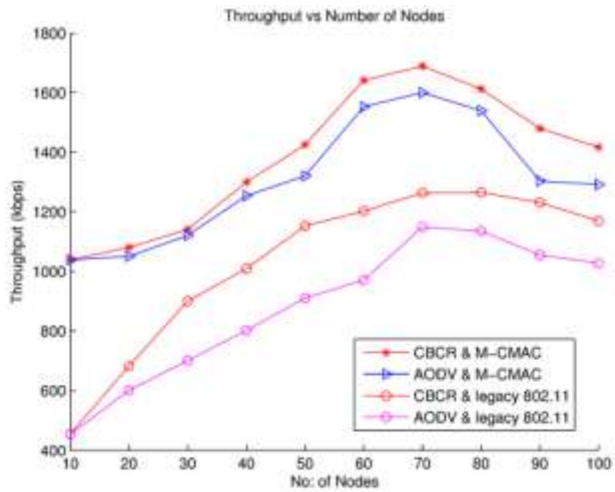

Figure 11: Throughput vs Number of Nodes

The variation of the per node energy consumption with number of nodes is illustrated in Figure 14. As the number of nodes increases, the per node energy consumption decreases. It is also observed that, compared to AODV, the energy consumption for CBCR is low and this reduction is more prominent with large number of nodes. The distribution of energy consumption in the network and its variation with number of nodes are illustrated in Figure 15 and Figure 16 for AODV and CBCR respectively. The nodes are divided into 4 bins based on energy consumption: ie < 25%, 25 − 50%, 50 − 75%, ⩾ 75% of their initial energy. Z axis shows the number of nodes falling in each bin. It is observed that, in the case of AODV, as the number of nodes increases, majority of nodes fall under the category of 50 − 75% energy consumption, and only a small number of nodes fall under the other categories. In contrast, in the case of CBCR protocol, with large number of nodes , the number of nodes consuming 50 − 75% of their initial energy and those consuming 25 − 50% of their initial energy approach same values. In other words, the energy consumption is more uniformly distributed in the network, thus avoiding the premature death of some nodes and enhancing the lifetime of the network.

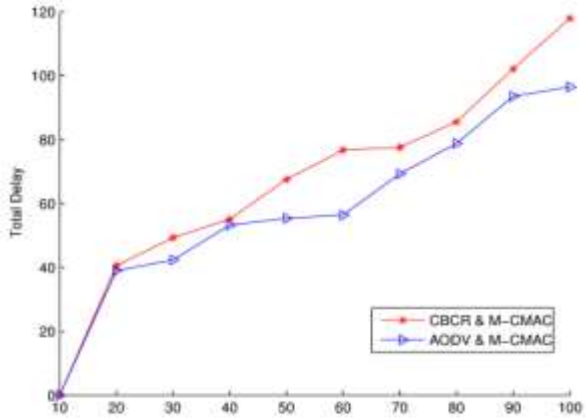

Figure 12: Average End to End Delay

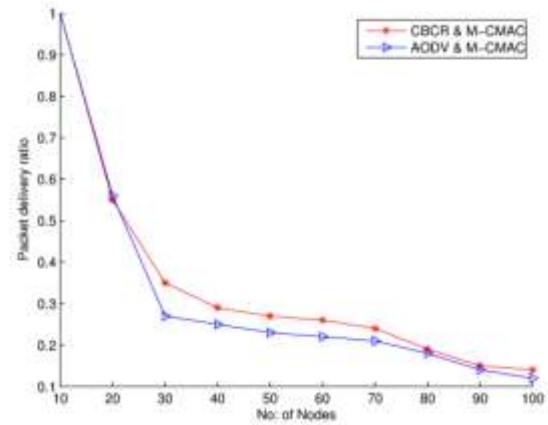

Figure 13: Packet Delivery Ratio

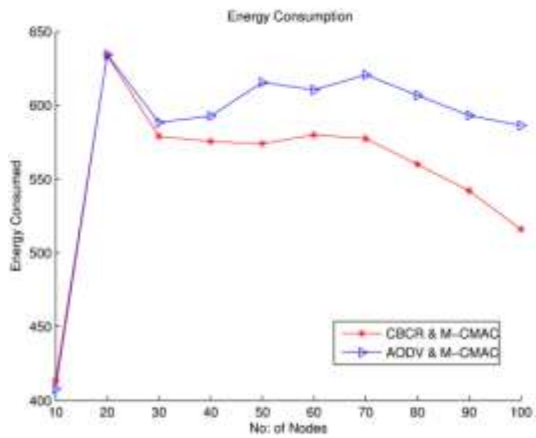

Figure 14 : Energy Consumption

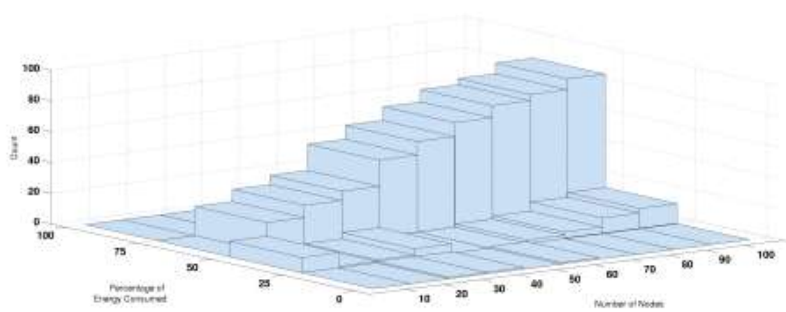

Figure 15 : Energy Distribution for AODV

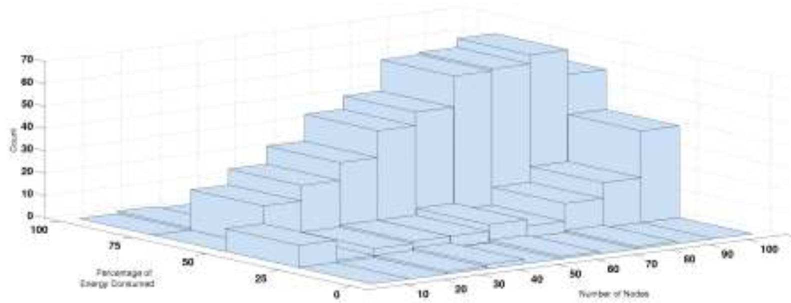

Figure 16 : Energy Distribution for CBCR

6 Conclusion

To extend the benefits of cooperative diversity at the physical layer to the higher layers of the cooperative wireless networks, we proposed an IEEE 802.11 DCF compatible cooperative MAC protocol and a minimal overhead cooperative routing protocol. Through extensive simulations, performance of the proposed protocols were evaluated in terms of throughput, delivery ratio, end-to-end delay and energy distribution. The delay performance is expected to be much better in actual network deployment, as the proposed routing protocol gets rid of the extra processing by the network layer routing protocols. This performance gain cannot be evaluated through simulation. The comparison of the proposed cooperative routing protocol with minimal energy cooperative routing protocols in the literature is the future work.

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