Cooperative Medium Access Protocols in Wireless Networks A Survey

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ABSTRACT: *Cooperative communication is a new paradigm in the area of wireless communication. It promises spatial diversity by virtual antenna array. The efficient designing of Medium Access Control (MAC) protocol is necessary for gaining advantage of the cooperation gained at physical layer. Cooperative MAC layer protocol are designed considering three important features : Benefit of Cooperation, Selection of Best Relay(s) and Relay Selection Scheme. Cooperative MAC layer can provide benefits like increased data rate and throughput, reduced delay, improved energy efficiency, improved coverage area and improved transmission reliability. At the same time it has to deal with continuously changing wireless channels, overhead due to implementation of protocol, node mobility and interference due to cooperation. In this survey, a broad overview of existing protocols is given in accordance with the networks they are used and common issues involved in designing of cooperative MAC protocol.*

Key Words*: Cooperative MAC protocol, Energy Efficiency, Relay Selection, Throughput, IEEE 802.11*

Summary
In this paper, we have reviewed various cooperative MAC protocols in terms of performance improvement. Most of the protocols are considering either data rate or energy efficiency improvement. One parameter is improved at the cost of other parameter. This encourages us to design new cooperative MAC protocol which should consider improvement in both the parameters with the help of optimization techniques.

I. Introduction

Wireless networks are gaining popularity in every field of life. The number of mobile devices, which are capable of accessing cellular networks and ad hoc networks, are increasing at rapid rate. The devices and applications are consuming data never imagined before. The wireless networks are expected to be throughput efficient, energy efficient. At the same time wireless channels are vulnerable. So the detrimental effect of wireless channel will force wireless network to underperform. MIMO is capable of providing improved channel capacity and transmission reliability by employing spatial diversity. But implementation of MIMO technology in mobile devices is still a challenge. The minimum distance between multiple antennas and power consumption of multiple antennas are prime concern in the implementation of MIMO in mobile devices [1].

Cooperative wireless communication can provide an alternative way of achieving spatial diversity by employing virtual antenna array. Cooperative communication uses the neighboring nodes as relay and forms virtual antenna array. Wireless channels are broadcasting in nature. Cooperative communication takes advantage of this characteristic. The nodes in the vicinity of transmitter and receiver will overhear the communication. The nodes will work as relay to provide better path between transmitter and receiver than direct communication. Cooperative communication can provide either transmission reliability or improved data rate. Cooperative communication can improve data rate and throughput, coverage and energy efficiency and reduce delay.

At physical layer cooperative communication employs various relaying strategies like Amplify and Forward (AF), Decode and Forward (DF) and Compress and Forward (CF) [2]. In AF, the relay receives the data from transmitter, amplifies it and retransmits to the receiver. The receiver combines the data received from the transmitter and relay. In DF, the relay receives and decodes the data transmitted by the transmitter. Then it will re encode the data and transmit towards receiver. In CF, the relay will receive data from the transmitter and then it will transmit the compressed version of received signal towards the receiver. The AF and DF are the main relaying strategies used by researchers across the world.

The performance of cooperative wireless communication should be carefully studied at MAC layer and cross layer otherwise advantages at physical layer will get reduced or even in worst case cooperative communication can be disadvantageous. Cooperative communication will increase protocol overhead due to selection of relay. The interference will also increase as three nodes are involved in relay communication compared to direct communication [3]. Hence careful design of cooperative MAC layer protocol will be important for the cooperative communication as it has critical impact on the network performance.

II. Classification of MAC Protocol

MAC protocols are generally classified into three categories:

1) Reservation based MAC protocols
2) Contention based MAC protocols
3) DCF (IEEE 802.11)

In reservation based MAC protocols, the resources are reserved for communication before the communication initiates. So it provides fairness, limited delay and guaranteed QoS. For implementation of reservation based protocols knowledge of network topology is essential. Time synchronization between each node is necessary for this protocol. TDMA is widely used as reservation protocol. It allocates time slots to various users for transmission of their data. It is not a good candidate for dynamic network.

Contention based protocols do not reserve resources for any devices. The devices will compete for getting access of the channel. ALOHA and CSMA are the examples of contention based protocols. In ALOHA the devices will transmit at any time (PURE ALOHA) or at starting of every new slot (Slotted ALOHA). In CSMA the users will scan the channel before transmitting. If the channel is free it will transmit otherwise it will scan the channel after sometime. Contention based protocols are good choice for dynamic networks [4].

DCF (Distributed Coordinate Function) is the MAC protocol version used by 802.11 ad hoc networks. It is based on CSMA/CA (collision avoidance). Every node will set a back off timer for transmission. When the timer reaches zero, it will scan the channel if the channel is idle for more than DIFS time the node will transmit the data. It uses RTS/CTS to avoid collision during transmission. The source node transmits RTS to the destination. The destination receives RTS and responds with CTS if it is ready for reception. The nodes which are in the vicinity of either source or destination will be aware of this communication. So they will hold their back off counter till the communication finishes. The counter will start once the channel becomes idle. DCF is an ideal candidate for MAC protocols based on 802.11 ad hoc networks.

III. Cooperative MAC Layer Protocols

Cooperative MAC protocol design should carefully consider three important questions [5] :

1. Beneficial Cooperation
2. No. of Relays involved in Cooperation
3. Relay Selection Strategy

Cooperative communication can provide many advantages but it adds extra protocol overhead due to two or more links for transmitter compared to just one link in direct communication. When relay is added to facilitate communication it also adds interference to the network. So the nodes near to relay cannot communicate, which were permitted to communicate in direct communication.

i. Beneficial Cooperation

Cooperative communication is beneficial when looked at physical layer. But careful MAC consideration is needed. The addition of relay for communication will increase interference and protocol overhead to employ that relay. After considering above two points, decision of cooperation should be taken only if it improves the Quality of Service of the network.

ii. No. of Relays involved in Cooperation

One or more than one relay can be employed for the purpose of relaying. The more the relay involved in relaying the more is the advantage of spatial diversity. But at the same time, these relay will need network resources to forward the data. The MAC layer will consume finite protocol overhead in employing multiple relay. So, single relay or multiple relay is a trivial question. Literature suggests that selection of best relay will provide almost equal benefits as multiple relays.

iii. Relay Selection Strategy

Cooperative MAC protocol will have many relay available for cooperation. From this it has to select the best relay for successful implementation. The relay selection is generally dependent upon the parameter we need to improve i.e. if we need better throughput and delay performance then relay with best channel condition should be selected. For better energy efficiency relay with higher residual energy should be selected.

Table I provides an comprehensive survey on the existing MAC protocols based on various important parameters like network scenario, research objective, cooperative strategy, cooperation decision taking authority, no. of relays involved in communication and type of relay selection.

The research objective of most of the cooperative MAC protocols is centered towards improvement in single parameter i.e. data rate, throughput, delay, energy efficiency, coverage parameter. While achieving this goal most of the researchers have ignored other parameter.

Thanasis Korakis et. al. proposed COOPMAC protocol. This protocol is considered to be pioneer in the area of cooperative wireless communication. Each node will manage a Coop table. In contains essential details of potential relay nodes, which will be used when node wants to communicate. The protocol performs well in terms of throughput for both light load and heavy load condition [6] .

Chungaung Shi et al., proposed CAC-MAC. It is a cross layer MAC protocol. The best relay will be selected based on channel condition accessed from RTS and CTS. It employs four difference transmission modes i.e. basic access, RTS/CTS, Cooperative transmission and receiver MRC. The protocol achieves higher network throughput and delay performance compared to direct transmission [7].

Pei Liu et. al. proposed STIC-MAC, which employed multiple relay for cooperative communication. The protocol used space time coding for parallel transmission of data by all relay in single time slot. The protocol has shown significant improvement in throughput and delay. The protocol performs well under mobility constraint [8].

Sanghoon Kim and Wayne Stark proposed SRMAC. It is a cross layer MAC protocol, which utilizes cooperation only if it is beneficial. This protocol considers combined effect of physical layer and MAC layer. The authors have demonstrated effect of number of relay employed in cooperation. They have also demonstrated significance of relay location in single hop network. The MAC protocol shows significant improvement over direct transmission [9].

Xiaoyan Wang and Jie Li have proposed DEL-CMAC protocol. Each neighboring device in vicinity of transmitter and receiver will take relaying decision based on its ability to improve the overall energy efficiency and network lifetime. The protocol shows significant improvement in energy efficiency and network life time. But this improvement is achieved at the cost of network throughput [10].

Eftychia et al. have proposed a new idea of cooperation at MAC layer. The SCD2D-MAC protocol considers social connectivity between users and energy level of individual user for selecting relay. The social connectivity is important feature for consideration as social known user can easily agree for cooperating other user data [11].

H. R. Shamna and Jacob Lillykutty have improved two tradeoff parameters i.e. throughput and energy efficiency. To achieve this goal they have used optimization. The simulation results are showing significant improvement in network lifetime, energy efficiency and network throughput compared to other protocol [12].

Table I. Comparison of Existing Cooperative MAC Protocols

Name	Network Scenario	Research Objective	Cooperative Strategy	Cooperation Decision	Relay Number	Relay Selection Scheme
COOPMAC (2009)	WLAN	Throughput Improvement	Repetition Based, Proactive	Transmitter	One	Preselect, Historical Info
CAC-MAC (2012)	WLAN	Throughput Improvement	Repetition Based, Reactive	Relay	One	Contention, Back off
STICMAC (2012)	WLAN	Throughput Improvement	Space time code, Proactive	Relay	Random	Qualification
SRMAC (2013)	WLAN	Throughput Improvement	Repetition Based, Reactive	Relay	One	Contention, Fast Back off
DEL-CMAC (2015)	WLAN	Network Lifetime & Energy Efficiency Improvement	Repetition Based, Reactive	Relay	One	Contention, Back off
SCD2D MAC (2016)	D2D	Energy Efficiency Improvement	Repetition Based, Reactive	Receiver	One at a time	Contention, Back off
DCMAC (2017)	WLAN, Multihop	Network Lifetime & Energy Efficiency Improvement	Repetition Based, Reactive	Relay	One	Contention, Back off

IV. Conclusion

In this paper, we have reviewed various cooperative MAC protocols in terms of performance improvement. Most of the protocols are considering either data rate or energy efficiency improvement. One parameter is improved at the cost of other parameter. This encourages us to design new cooperative MAC protocol which should consider improvement in both the parameters with the help of optimization techniques.

V. References

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