Single Channel Versus Multichannel MAC Protocols for Mobile Ad Hoc Networks

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ABSTRACT

MAC layer protocol which is a sub layer of data link layer has become an interesting research topic in Mobile Ad hoc Networks (MANET). Being affected by the physical layer and providing service for the upper layers, several schemes have been proposed to improve the deficiencies in this important layer. Although several single channel schemes came into design and tried to achieve a high quality of service scheme, most of them, if not all, were not successful due to hidden and exposed terminal problems and the fairness issue. On the other hand, the multichannel schemes were almost successful in solving these problems and providing a better and more reliable MAC protocol for the users. In this paper, we will make a thorough investigation among these protocols and will demonstrate why multichannel schemes outperform single channel ones and the best solutions to benefit from all these factors in order to achieve a reliable MAC protocol.

Keywords: MANET, Single channel, Multichannel, MAC, Wireless network

I. INTRODUCTION

Ad hoc networks are one of the most important and interesting discoveries that served humanity to perform their tasks much simpler. Although wireless networks (Wi-Fi) were successful in providing good services using infrastructure mode, utilizing a structure with smaller devices and having more abilities was expected. These networks use an infrastructure-less based scheme, that is, without a base station for example, where nodes can act as a sender, receiver or even a router.

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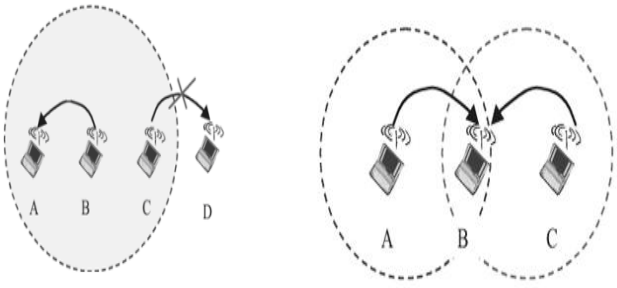
Although Mobile Ad-Hoc Networks (MANET) was successful in demonstrating a modern topology for application use, the infrastructure-less based property and the unique structure of these networks allowed several problems to occur in different network layers. MAC layer which is one of the most important layers was faced with some problems that forced the designers to propose several schemes providing more reliable protocols. Besides the famous hidden and exposed terminal problems, fairness issue and the power consumption were additional factors to be considered in designing these schemes. Single channel MAC protocols were the earliest schemes that authors proposed to overcome these problems. IEEE 802.11 [1], the standard for wireless LAN, proposed an Ad hoc version of itself referred to as "*DCF*" which was based on virtual carrier sensing and the physical carrier sensing. Having the hidden and exposed terminal problem, the protocol was not successful in providing a good service for MANET. The protocol was designed for single-hop networks where in MANET multi-hop networks play an important role in end-to-end transmissions. Other single channel schemes came into design to solve these problems but most of them were not successful in a complete elimination of these obstacles and therefore, the authors came into conclusion that using additional channels may help solving these problems. The multichannel MAC protocols were proposed to alleviate these problems by using more than one channel in order to avoid collision and provide a better fairness among the nodes. The authors also proposed schemes to integrate the property of power saving plus the additional channels to save the energy consumption of the nodes while solving the collision problems.

In the following, we will go through the design issues of MAC layer protocols. In section 2, we will talk about the classification of the MAC layer protocols and how different schemes solve the problems in ad hoc networks. In section 3 we will make a comparison between the single channel and multichannel schemes based on the MAC layer issues. In section 4, we will discuss a better solution for a reliable MAC protocol and finally in 5, we will conclude our discussion.

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

A. Hidden and exposed terminal problems

These two problems have become a major issue in MANET. The two scenarios below will illustrate how they cause problems in Mobile Ad hoc networks. We will explain the problems briefly as follow and explain the relationship between these problems and the advent of multichannel schemes. In fig.1 (a), Node B is trying to transmit to Node A and Node C decides to transmit to Node D. Since Node C can sense Node B, it will not transmit though it can send without causing problem. Here bandwidth waste (less spatial reuse) becomes an important issue and Node C will starve from transmission while its window size increases.



(a) Node C is exposed to Node B (b) Node A is hidden to Node B

Fig.1 . Hidden and exposed terminal problems

This scenario is what that is referred to as the "*exposed terminal problem*". Another scenario as Fig.2 (b) depicts is when Node A is trying to send to Node B, and meanwhile Node C which is out of the transmission range of Node A, is trying to transmit to Node B as well. Hence, a collision will occur at the receiver (Node B). This is referred to as *"hidden terminal problem"* in which significantly decreases the throughput. In the literature, several schemes have been proposed to solve the hidden and exposed terminal problems [2] [3] where they were categorized as Employing multiple channels, schemes with synchronization and so forth.

B. Fairness issue

Another important factor that should be considered in designing MAC protocols is to make sure if all the nodes have access to the channel in order to transmit their data. Since most of the single channel schemes rely on the back-off procedure, if the nodes have collision once transmitting to a certain receiver, they will go through the back-off time and will try to retransmit after a certain amount of time. Since this duration is different for different nodes, some nodes may have more chance to transmit than others and they will be favored in data transmission. This will result in starving among the unlucky nodes and long contention window size. Therefore, designing good strategies for back-off procedures and providing fair chances among nodes to access the channel is one of the important aspects in MANET.

C. Power consumption issue

Mobile devices are battery dependant and are operated with not a long time battery lives. Therefore, saving power is an important concern for increasing the efficiency of the networks. In order to have an efficient power saving protocol, several factors should be considered. First of all, collisions which are one the most common problems in MAC layer protocols should be prevented or become lessened since they will cause costly retransmissions. Secondly, the transceivers should be kept in standby mode when they are not transmitting since they consume a lot of power. This is referred to as *"power management"* schemes where the nodes will go through sleep and awake cycles. For the third reason, nodes should use sufficient power instead of maximum power for control and data transmissions. This is referred to as *"power control"* schemes where they are operated with varying the transmission power.

D. Physical layer effect

As equation 1 demonstrates, In order for a node to receive a transmitted signal from other nodes correctly, the SINR (signal to interference and noise ratio) should exceed a certain threshold β, that is,

$$\mathrm{SINR}_i = \frac{P_i}{\sum_{k \neq i}^{n} P_k + N} \geq \beta, \qquad (1)$$

Where P_i is the received signal power and (P_k + N) is the Joint interference power. This is referred to as the *"capture effect"* which improves the channel utilization significantly if being implemented correctly. Recent research has been conducted to improve the wireless communication area and to overcome the physical layer problems such as fading that reduces the efficiency of the network. MIMO (multiple input multiple output) and space time coding improved the physical layer by increasing the data rate and decreasing the power consumption of the network. Directional transmission also is another method to decrease the interference along with higher throughput.

II. MAC LAYER PROTOCL CLASSIFICATIONS

In this section, we will talk about the single channel and multichannel approaches and discuss the way they solved these problems in MANET and what problems they might have themselves as to need to be solved in future.

A. Single channel schemes

The earliest protocols that were designed to implement as a MAC layer protocols were the single channel schemes.

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Using one channel to share all the information (control signals and the DATA), these schemes faced a lot of problems that decreased the efficiency of the entire network. As discussed above, IEEE 802.11 DCF [1] is one of the earliest and most famous protocols to run on MANET. Not being efficient in multi-hop ad hoc networks due the hidden and exposed terminal problems, the authors proposed other schemes to be replaced. The Multiple Access with Collision Avoidance (MACA) [4] on the other hand, did not use the carrier sensing option and instead, it used the RTS/CTS/DATA handshake to reserve and use the channel. Although this protocol was a simple design, the control channel collisions made the scheme not effective in the MAC layer. Similar to IEEE 802.11 [1], this protocol did not have a fair treatment among nodes and did not work in multicasting scenarios.

B. MACA-BI protocol and the control overhead solution

MACA by invitation (MACA-BI) [5] is a receiver initiated MAC protocol which is based on the MACA scheme. Instead of sending the RTS from the sender, the receiver will initiate the transmission by sending an RTR (Ready-To-Receive) signal to select the sender. Hence it uses a two way handshake RTR-DATA instead of the three way one in MACA [4] and will reduce the number of control channels and reduce the overhead. This protocol relies on the predictable data pattern networks where receiver needs to select the sender based on a certain traffic prediction pattern. In the networks where the traffic pattern is not defined, the performance of this protocol will be same as MACA [4]. This is illustrated in Figure 2.

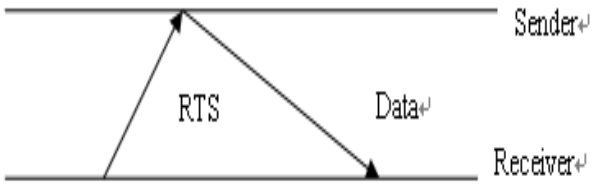


Fig.2. MACA-BI mechanism

C. MACAW protocol and the fairness solution

MACA for wireless LANs is another single channel schemes which tried to improve the performance of MACA [4] protocol. A five handshake RTS/CTS/DS/DATA/ACK has been used in this protocol which leads to alleviation of the hidden and exposed terminal problem and better fairness. By using a different back-off approach (MILD), this protocol allowed the nodes to access the channel in a fair manner which is more desirable in ad hoc networks. For multicasting, The Multiple Access with Collision Avoidance for Wireless (MACAW) [6] uses a special control channel called MRTS to use the channel. However, multicasting remains an unsolved problem for single channel protocols. Figure 3 illustrates the performance of this protocol.

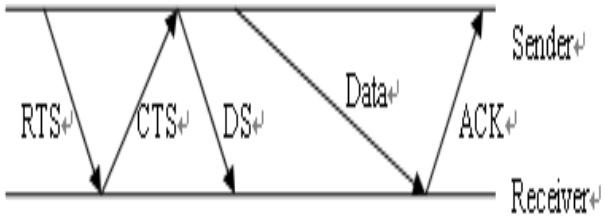


Fig.3. MACAW handshaking mechanism

D. Multichannel schemes

Since the single channel schemes did not completely solve the nature problems of MANET, the authors developed new methods to treat these issues in a better way. The hidden and exposed terminal problems are one of the most important issues here that single channel schemes were not able to eliminate though they slightly alleviated them. Below, the paper will classify the protocols by their efficiency of solving the important factors to design the MAC layer protocols. Due to the space limitation, we only selected the most important schemes that were efficient in solving these problems though other schemes had modern ideas to overcome these problems.

E. Busy tone schemes solving the hidden and exposed terminal problems

These schemes rely on a out-of-band signal to reserve the channel and by doing so, they will avoid the hidden and exposed terminal problems. Busy Tone Multiple Access (BTMA) uses a centralized control method using a base station. The base station senses the transmission and sends out the busy tone to reserve the channel for the ongoing transmission. All other nodes that hear the tone will defer their transmission. The protocol does not seem to be efficient in ad hoc networks since it uses the busy tone in a centralized based manner. RI-BTMA (Receiver Initiated BTMA) sends a preamble packet from the sender to the intended receiver. Right after, the receiver will send the busy tone to reserve the channel and to get ready to receive the data from the transmitter. The busy tone will do the same work as BTMA does except that it is transmitted from the receiver while for BTMA the base station will transmit the signal. Since the performance of RI-BTMA is dependent on the slotted manner and it needs synchronization among the slots, it cannot perform well in ad hoc networks. DBTMA [7] (Dual Busy Tone Multiple Access) DBTMA [7] divides the main channel into two sub channels where one is for data transmission and the other one is for transmitting control signals. Here, two out-of-band busy tones are being utilized in order to avoid the interference

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

from other neighbors: *BTt* (the transmit busy tone) is used to reserve the channel for the sender which is transmitting the data and *BTr* (the receive busy tone) is used for the receiver in order to receive the data without any interference. This protocol seems to be effective in terms of solving the hidden and exposed terminal problems. Nonetheless, DBTMA [7]requires additional channel and transceivers, that is, two narrow-bandwidth transmitters for setting up separate busy tones. Moreover, there is no acknowledgment received by sender to indicate the recipient of the packet. However, DBTMA [7] outperforms FAMA-NCS [8] and MACA [4] significantly that justifies the higher cost of the complex hardware.

F. Schemes with a common control channel solving the fairness and the exposed terminal problems

The multichannel schemes without a common control channel will not use a separate channel to transmit the singles. Instead, they will combine the handshaking process by using both the channels for control and data transmissions. The Interleaved Carrier Sense Multiple Acess (ICSMA) [9] protocol, divides the BW into two channels where the RTS and data will go on one channel and the CTS and ACK will be transmitted in the other channel. The handshaking process is interleaved between these channels which will prevent the exposed terminal problem and will treat the nodes in a fair way. It will also allow two simultaneous transmissions between two nodes which lead to higher throughput. The cost here is the additional channel usage with the limited bandwidth in ad hoc networks. As figure 4 illustrates, another protocol which is pretty similar to this protocol is called JMAC (Jamming-Based Multiple Access Control) [10]. This protocol was proposed to solve the famous hidden and erroneous reservation problems (exposed terminal problem) and allows more concurrent transmission/receipt as well. The idea of this protocol is to divide the shared medium into two channels and use jamming signal to reserve the channel. In this protocol, the source starts to transmit RTS/DATA at one channel (S) and the destination will send back RTS/ACK at the other channel (R). To reserve the channel, the jamming signal is sent on both S and R channels from the sender and receiver respectfully. The jamming signal contains no data and hence no decoding needed. The purpose of jamming the channel is pretty similar to the reservation function of RTS/CTS in IEEE 802.11. The difference is that the region will be jammed for the amount of time needed and not more depending on the result of RTS-CTS exchange. This protocol allows concurrent transmission/receipt without causing collision and hence, increases the throughput of the network. The authors demonstrated that this protocol solves the hidden and exposed terminal problems though the channel division in case of RTS/CTS/DATA/ACK has some costs compare to one channel schemes.

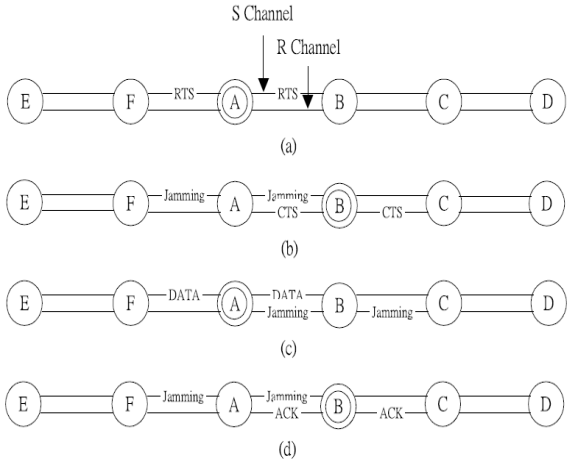


Fig. 4. Frame exchange and the transmission of jamming signal in the JMAC protocol.

G. Multichannel schemes solving the power option

As mentioned before, the ad hoc nodes are battery operated and the way they consume energy and the amount of power being saved is an important issue in these networks. The power option comes with the protocol so that the nodes save their energy while transmitting and therefore, improve the network efficiency. Although there are single channel schemes like PCM (Power control medium access control) use a power saving method to use the required amount of energy for transmission, but our focus here is on multichannel schemes since they will solve other aspects of MANET in addition to the power. PAMAS [12] (Power aware medium access control with signaling) uses a signaling channel for the RTS/CTS transmission and uses a second channel for data sharing. When the receiver is receiving the data, it transmits a busy tone on the signaling channel so that all the nodes around power off their transmission based on certain situations while not affecting the throughput. The drawback of this scheme is the radio transmission turnaround time which causes delay in the network.

DCA-PC [13] (Dynamic channel assignment with power control) uses one channel for control signals and N channels for data transmission. The channels are assigned dynamically based on need using an RTS signal where the receiver will pick the selected channel and send the information with the CTS signal. Each host has two transceivers in order to listen to both the channels simultaneously. The hidden terminal problem is solved since one of the transceivers always listen on the signaling channel. Power control schemes is being used here where the control packets are sent with a maximum power and the data packets are sent using the required amount of power. Therefore, the power is being saved while avoiding the

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hidden terminal problem. This scheme does not work well in the scenarios where the bandwidth is equal among the channels. For instance, if we have three channels, 33% of the total bandwidth will be dedicated to the control channel which is costly.

III. MULTICHANNEL Vs SINGLE CHANNEL MAC PROTOCOLS

Single channel MAC schemes were designed for MAC layer protocols in mobile ad hoc networks. Although they were partially successful in providing a fair service for the MAC layer, most of them did not solve the nature problems of MANET due to the single channel usage and the collision happened at the receiver. For instance, MACAW [6] proposed a good method to treat the nodes in a fair way and to alleviate the hidden and exposed terminal problems. Nonetheless, the usage of one channel and control channel overhead causes collision to happen for the exposed terminal nodes. On the other hand, the multichannel schemes demonstrated better abilities to avoid the hidden and exposed terminal problems and higher throughput due the usage of more than one channel in their network. However, depending on different situations, different schemes may be used to gain the expectations based on the need. For example, in the networks where the bandwidth is really limited the multichannel schemes may not be efficient and therefore the single channel schemes will be more useful. Hence, each protocol can be used based on the network traffic, available bandwidth, power level, and the mobility of nodes. Table 1 compares the performance of different MAC protocols with regards to different issues.

Table 1. Link utility performance comparison between MAC protocols

MAC protocols	Hidden and exposed issues	Fairness	Power saving	Cost
MACA	Not solved	Poor	Not considered	Possible Control Signal Collision
MACA-BI	Partially solved	Poor	Not considered	Predictable pattern
MACAW	Partially solved	Fair	Not considered	Control overhead
DBTMA	Solved	Average	Not considered	BW
ICSMA	Solved	Good	Not considered	BW
PAMAS	Partially solved	Average	Good	BW
DCA-PC	Solved	Average	Good	BW

IV. Best Solution towards a Reliable MAC Protocol

Since MAC layer is an important layer providing service for the network layer, designing a MAC protocol with acceptable performance and less error is critical. Since the hidden and exposed terminal plus the fairness issues are almost solved by the multichannel schemes, combining the power options will also help the protocols to save the power being used. On the other hand, using the directional antennas will lead to less interference and higher throughput in the network. Further studies are being done on the performance of these antennas and once become cheaper with smaller hardware; they may be integrated with the multichannel schemes to solve the interference and the channel fading affecting the mobile ad hoc networks.

V. CONCLUSION

This paper discussed the comparison between the single channel and multichannel MAC protocols considering several factors affecting the design of the MAC layer. We realized that the single channel schemes did not perform well in the MAC layer due to the hidden and exposed terminal problems and the multichannel schemes solved these problems with the cost of additional channel usage. We also observed that in order to have a better scheme a combination of power aware options, directional antenna hardware and the multichannel schemes can be a good solution to a better performance in MANET.

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ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)