Technical Issues and Challenges involve in designing a MAC protocol for Wireless Ad hoc Network

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***Abstract* — Wireless Ad hoc Networks have received significant attention in recent years due to their easiness to setup and their potential applications in many domains. Such networks can be useful in situations where there is not enough time or resource to configure a wired network. The shared media used by wireless networks, grant exclusive rights for a node to transmit a packet. Access to this media is controlled by the Media Access Control (MAC) protocol. These protocols are of significant importance since the wireless communication channel is inherently prone to errors and unique problems such as the hidden-terminal problem, the exposed-terminal problem, deafness and signal fading effects etc. Although lots of researcher has been performed research on these MAC protocols and presented various issues involved in it. Through this paper an attempt is done to present all relevant challenges/issues that may occur while designing a MAC protocol. A classification of MAC protocols and their brief description, based on their operating principles with different antenna modes and important features are discussed in this paper. Traditional MAC protocols in ad hoc networks employ omni-directional antennas. Recently, directional antennas have emerged as an alternative due to their capability of spatial reuse, low probability of detection, robustness to jamming, and other beneficial features which increases coverage range and subsequently network capacity in the communication network. Different antenna modes with their functionality and working technology are discussed. Finally, a comparison study of both omni-directional and directional MAC protocols based on their characteristics and underlying features is presented and conclude the paper.**

Keywords- MAC, antenna, channel, RTS/CTS, hidden & exposed terminal

I. INTRODUCTION *(HEADING 1)*

Wireless communication is the transfer of data from one place to another through electromagnetic waves like radio, microwave and infrared waves. It is a mode of communication that uses free space instead of wires where data can be exchanged in less time and people far away from each other can easily communicate at any time e.g., use of online chatting, cell phones, e-mails etc [1]. The system that enables wireless data communication is called the wireless network. It consists of either computers, laptops, notebooks, routers, switches, cell phones, portable phones, PDA's, related operating systems / software, access points (AP), base stations (BS), antennas or towers etc. Various types of wireless networks being used now days are as; infrastructure-based WLAN, wireless Ad-hoc network, wireless personal area network (WPAN), wireless cellular network, satellite system, television network and wireless sensor network (WSN) etc. Internetworking provides centralized support, connectivity, reliability, network management, and flexibility for all types of wireless networks by introducing special network technologies in between different layers of OSI model [2]. Among these entire layers MAC layer plays vital role in wireless communication. MAC belongs to layer 2; the Data Link Control layer (DLC) of the ISO OSI reference model that establish a reliable point-to-point or point–to-multipoint connection between different devices over wired or wireless medium to transfer data between two or more nodes of the network. MAC layer takes responsibilities of error correction for anomalies occurring in the physical layer, framing, physical addressing, flow controls and also address issues caused by mobility of nodes and an unreliable time varying channel [3]. Each type of network uses slightly different techniques and algorithms from each other in all aspects including MAC algorithms as well. It allows several users simultaneously to share a common medium of communication in order to gain maximum of channel utilization with minimum of interference and collisions [4]. MAC algorithm is similar to traffic regulations in the highway. Several vehicles cross the same road at a time but rules required to avoid collision e.g., follow the traffic lights, building the flyovers etc [5].

Wireless ad hoc networks are slightly different to the wireless network as in wireless network a central coordinator or access point exists in the network and all the connections are done through this central node where to configure a network in ad hoc mode, every couple of nodes can communicate with each other independent of the central coordinator by sharing a common radio broadcast channel [4] [5]. However the radio spectrum is limited, the bandwidth available for communication in such network is also limited [7]. That's why access to this shared medium should be controlled in such a manner that all nodes receive fair share of the available amount of bandwidth, and that the bandwidth is utilized efficiently [1] [6]. Since ad hoc wireless network needs to address unique issues which are discuss in the next section, a different set of protocols is required for controlling access to the shared medium in such network and these are nothing but only MAC protocols [6] [7].

The rest of this paper is organized as follows; Section II emphasizes the peculiar issues and challenges involve in designing MAC protocols. Section III gives brief description of different MAC protocols proposed for ad hoc networks listing their technical features, functionality, enhancement and issues. Finally section IV concludes the survey on various MAC protocols with a comparison of investigated protocols and provides a future direction to researchers for open issues that have not been studied thoroughly.

II. General Issues and Challenges of MAC Algorithms in Ad hoc Network

A. Bandwidth Efficiency

Bandwidth is a very crucial resource in wireless networking; that's why the MAC protocols must be design in such a way that the limited bandwidth should utilized in an efficient manner [6]. This approach kept the involved control overhead as minimum as possible and protect the network from extra over loaded [7] [8].

B. Mobility of nodes

As nodes in ad hoc networks are mobile most of the times, it can affect performance (throughput) of the protocol in some scenarios [7]. The bandwidth reservation made or the control information exchanged may end up being of no use if the node's mobility is very high. Therefore the design technology of MAC protocol must take this mobility factor into consideration so that the wastage of reserved bandwidth can be minimized and the performance of the system is not significantly affected due to node mobility [9].

C. Hidden and Exposed terminal problem

These problems are very unique to wireless networks. Hidden terminal problems are refers to the collision of a packet at a receiving node due to the simultaneous transmission of those nodes that are not in the direct transmission range of the sender, but are within the transmission range of the receiver [7] [8]. Collision occurs when both nodes transmit packets at the same time without knowing about the transmission of each other [9].

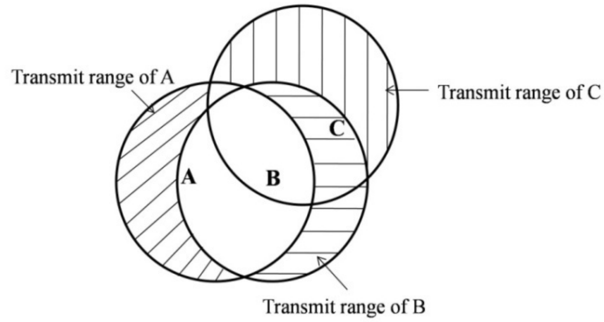

Figure 1: Illustration of the hidden and exposed terminal problems.

As illustrated in Fig. 1, node B is within the range of nodes A and C, but A and C are not in each other's range. Let us consider the case where A is transmitting to B. Node C, being out of A's range, cannot detect carrier signal and may therefore send packet to B, thus causing a collision at B. This is referred to as the hidden-terminal problem, as nodes A and C are hidden from each other.

The exposed terminal problem refers to the inability of a node, which is blocked due to transmission by a nearby transmitting node, to transmit to another node [7] [9]. Let us now consider another case where B is transmitting to A. Since C is within B's range, it senses carrier signal and decides to defer its own transmission. However, this is unnecessary because there is no way C's transmission can cause any collision at receiver A. This is referred to as the exposed- terminal problem, since B being exposed to C caused the latter to needlessly defer its transmission.

D. Quality ob Service (QoS) Support

Qos refers to the capability of a network to provide better services to selected network traffic over various technologies. In ad hoc networks QoS support is essential for supporting time-critical traffic session such as in military communication [8]. The QoS parameters such as bandwidth, throughput, delay, and jitter require reservation of resources like network bandwidth, buffer space and processing power. The inherent mobility of nodes in ad hoc wireless networks makes such reservation of resource a difficult task and become complicated to provide QoS support in real-time applications [6]. Therefore MAC protocols for ad hoc networks must have some kind of a resource reservation mechanism that takes into consideration the nature of wireless channel and the mobility of nodes [9].

E. Error probe shared broadcast channel

Radio channels are the only communication medium for the nodes in wireless networks [7]. Though radio channel is broadcast in nature but only one node at a time can start transmission and can access channel if its transmission do not affect any ongoing session i.e. when a node is receiving data, no other node in its neighborhood, apart from the sender, should transmit [8]. Since several nodes may contend possibility of packet collision is quit high in wireless network. Therefore the MAC protocols should provide the grant of accessing the channel in such a way that collisions are minimized [9].

F. Fairness

Fairness refers to the ability of the MAC protocols to provide an equivalent share or weighted share of the bandwidth to all competing nodes. Fairness can be either node-based or flow based [10]. The former attempts to provide an equal bandwidth to all competing nodes where the later provides an equal share for competing data transfer session. In ad hoc wireless network fairness is important due to the multi-hop relying done by the node [5]. An unfair relying load for a node results in draining the resources of that node much faster than that of the other nodes.

G. Time synchronization

Absolute synchronization in between nodes for bandwidth (time slots) reservation is a very important issue of ad hoc networks. To achieve this synchronization among nodes exchange of control packets is required [7]. Control packets carried the carrier signal between sender, receiver and intermediate nodes in the networks which help them by providing the knowledge about the ongoing session [6]. However a particular amount of available bandwidth is used in the exchange mechanism of these control packets which may lead to an enormous wastage of network services. Therefore while designing a MAC protocol it should be keep in mind that the control packets must not consume too much of network bandwidth [4].

H. Distributed Operation

Fairness Unlike cellular network, ad hoc wireless network do not have central coordinator to distribute bandwidth fairly among nodes [10]. Therefore nodes must be scheduled in a distributed fashion for gaining access to the channel and for this exchange of control information among nodes is required [11]. Therefore the MAC protocol design should be fully distributed and must make sure that the additional overhead incurred due to this control information exchange is not elevated [7].

I. Degradation of battery power

Battery power is the key resource to keep an ad hoc network alive for a long time [2]. Each and every node in the ad hoc network is constrained with limited power supply and each transmission reduces the power at the nodes, causes early degradation in lifetime of the network [3]. Therefore the MAC protocols must design in such a way that power should utilized in efficient manner and introduced some controlling technique so that the network gain capability for controlling transmission power [11].

J. Location Dependent constrain

The load on the wireless channel varies with the number of nodes present in a given geographical region. This makes the contention of the channel high when the number of nodes increases. The high contention for the channel results in a high number of collisions and a subsequent wastage of bandwidth [7] [8]. A good MAC protocol should have built-in mechanism for distributing the network load uniformly across the network so that the formation of regions where the channel contention is high can be avoided [12].

III. OVERVIEW OF MAC ALGORITHMS WITH THEIR DESIGN CHALLENGES

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A. Antenna Modes

Define Wireless networking works by sending radio transmissions on specific frequencies where listening devices can receive them with the help of special radio transmitters and receivers respectively. Antennas are key components in these radio communication systems that convert electric power into radio waves, and vice versa [9]. Typically antenna system has two separate capabilities or modes to transmit or receive signals: Omni and directional. This may be envisioned as two separate antennas; an omni-directional and a steerable single beam antenna i.e. directional. The existing MAC protocol used in ad-hoc community is well tuned for omni-directional antennas. These antennas radiate the signals in all directions (360 degree) resulting in a circular transmission/reception pattern and the signal is received by all the neighboring nodes (those within transmission range) surrounding the sender [12] [13].

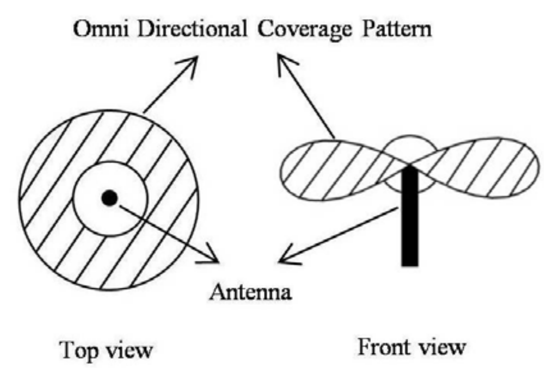

Figure 2: Omni Directional Antenna Coverage

The major issue arise in such transmission is wastage of energy associated with the transmission signal of all direction except the receiver [11]. As a packet is usually intended for a specific receiver, it is not necessary for all the surrounding nodes to receive the signal. Such transmission pattern adds no advantage because the receiver gets only a small part of the energy of the omni-directionally transmitted signal. In fact, the remaining wasted energy also possibly interferes with other ongoing transmissions [12]. Therefore a special mode of antenna is needed that can focus the beam only towards the receiver and the nodes that are not in the direction of the receiver are free to go ahead with their communication. Such antennas which have the ability to focus the beam in a particular direction are termed as Directional Antennas [13]. By using Directional Antennas, a node may able to selectively receive signals only from a certain desired direction. This enables the receiver node to avoid interference that comes from unwanted directions and reduce the chance of collision between multiple packets resulting in the increase of effective network capacity [14].

Directional antennas are mainly of two types: single beam antennas and multi beam antennas. In single beam antenna, there is only one beam active at a given time because of only one transceiver [13]. Figure 3(a) shows the single beam antenna. Due single transceiver, multiple transmission/reception is not possible. On the other hand, the multi beam directional antenna can forms multiple beams in any direction [13] [14]. Figure 3(b) shows the multi beam directional antenna where simultaneous transmissions or receptions are possible. However it is not possible that at a same time some beams transmit data and others receive data.

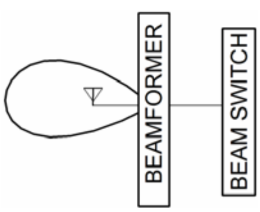

Figure 3(a): Single-beam Directional Antenna

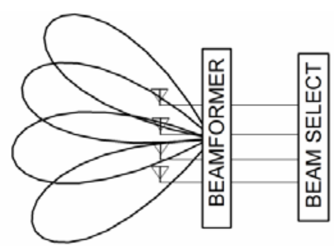

Figure 3(b): Multi-beam Directional Antenna

The major advantage of directional antenna over omni-directional antenna in ad hoc networking is spatial reuse, as there can be multiple transmissions in the same neighborhood without the destruction of the transmitted packets[9]. Spatial reuse is the capacity of having concurrent transfers between multiple source and destination pairs sharing the same frequency channel at a same time [15]. On the other hand, the directional transmission increases the signal energy towards the direction of the receiver resulting in the increase of the coverage area [8] [14]. These two benefits widely lead in the increase of the channel capacity.

Unfortunately, directional transmissions cause some serious challenges in an ad-hoc environment and those are the increase of the instances of hidden terminal problem, the problem of deafness, problem of the determination of neighbors' location and interference caused by higher gain [15]. Since the first one is known to us, let move to other challenges. Deafness refers to the inability of a receiver node that is locked in a particular sector for a particular signal, and did not response / hears other signals that arrive in further sectors [10] [16]. In particular, deafness can cause destructive interactions with upper layers, like multiple retransmissions may fail causing a node to think that the connection is lost due to mobility and triggering a route discovery search[16]. The third is a natural problem that arises from the fact that for the transmission of a packet, the transmitter must know the location of the receiver to turn over the beam to the appropriate direction [14]. Finally in the fourth challenge the problem arise due to higher gain of directional antennas that produce larger range of signal. At a given distance, the strength of the focused beam is much higher than the strength of the omni-directional beam [17]. If the signal is able to reach longer, there may adverse effects of interference caused to other ongoing communications in that direction [18]. Considering the above issues the researchers need to develop new techniques in the directional antenna to design efficient / healthy MAC protocols [7] [18].

B. Omnidirectional MAC protocols

i. IEEE 802.11 DCF

IEEE 802.11 Distributed Coordinated Function protocol is the primary medium access control (MAC) technique. This protocol is based on carrier sense multiple access with collision avoidance (CSMA/CA) scheme with binary slotted exponential back-off technique. IEEE 802.11 DCF requires every station to perform a Carrier Sensing activity to determine the current state of the channel (idle or busy). If the medium is found to be busy, the station defers its transmission. Whenever the channel becomes idle for at least a Distributed Interframe Space (DIFS) time interval, a Collision Avoidance mechanism is needed to resolve collision between stations. In such mechanism [7] a back-off interval is used where before initiating transmission, every node S chooses a random back-off counter value from a range [0, CW], where CW is called a contention window. Node S decrements the back-off counter value by 1 after every idle slot time and when its value reaches 0, node S can transmits the packet. If the transmission from S collides with some other transmission, the CW becomes double and this process continues at each unsuccessful transmission until the CW reaches its maximum threshold value CW_{max}. After reaching CW_{max} , node S chooses a new back-off counter value and attempts retransmission [6]. In one word we can say, the back-off counter is decremented as long as the channel is sensed idle, “frozen” when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for more than a DIFS. The station transmits when the back-off time reaches 0.

The major challenge occur in this technique is inability to overcome hidden & exposed terminal problem [19]. Here the sender station only senses the state of the channel. In a typical ad hoc network, the sender and receiver station may not be near to each other at all times. In such situation, the packets transmitted by a node are prone to collisions at the receiver due to simultaneous transmission by the hidden terminals. Further the bandwidth utilization in CSMA protocol is less because of the exposed terminal problem.

ii. MACA

It extends for multiple access collision avoidance protocol and was proposed as an alternative solution of the issues arise in traditional carrier sense multiple access protocol. MACA does not make use of carrier-sensing for channel access. It uses two additional signaling packets: the request-to-send (RTS) packet and clear-to-send (CTS) packet [7]. When a packet wants to transmit a data packet, it first transmits a RTS packet to the intended receiver. On receiving the RTS packet, if the receiver node is not involving with other transmission and ready to receive the data packet, then reply back the sender node by sending a CTS packet [7] [20]. Once the CTS packet is received by the sender without any error, it starts transmitting the actual data packet. This whole mechanism is depicted in figure 4 [20].

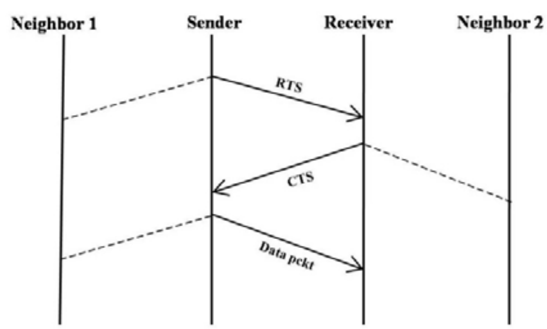

Figure 4: Packet transmission in MACA

Neighbor node hears the transmission of the RTS packet by the sender and defers its own transmission till the sender could receive the CTS packet [21]. Both CTS & RTS packets carry the expected duration of the data packet transmission. If no CTS packet is heard by the node during its waiting period, it is free to transmit packet, once the waiting interval is over. Thus, Exposed terminal problem is solved in MACA. Similarly, a node near receiver, upon hearing the CTS packets, defers its transmission till the receiver receives the data packet. Hence, the hidden terminal problem is also overcome in MACA [18].

Like IEEE 802.11 DCF, MACA too used binary exponential back-off (BEB) algorithm to determine lost / corrupt packets and to retransmit new packets. In this technique, if a packet transmitted by a node is lost, then the node back off for a random interval of time before retrying a new transmission. Each time a collision is detected, the node doubles its maximum back off window.

Major challenge faced by MACA is the other nodes involve in transmission suffer starves flows due the BEB algorithm used in it [7]. For example, consider figure 5 where node B and C wants to communicate with node A and B respectively and that's why both node B and C keep generating a high volume of traffic.

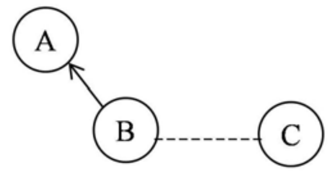

Figure 5: Example of issue occur in MACA

Say B succeeds capturing the channel first and starts transmitting packet. At the same time C keeps trying sending its packet to B but failed every time since B is involved with A and thus C keeps incrementing its back-off window according to BEB algorithm. As a result, the probability of node C acquiring the channel keeps decreasing, and over a period of time it gets completely blocked [20] [21].

iii. MACAW

It is also a Media Access Protocol for Wireless LAN and introduces more optional control frames and an improved BEB algorithm to overcome some shortcomings arises in MACA. The BEB algorithm in MACAW is modified by launching a packet header as an additional field to carry the current back-off counter value of the transmitting node so that on receiving the packet the receiver node can copy this value into its own back-off counter [7] [22]. This process helps to allocate bandwidth in a fair manner. Secondly the back-off counter value reset mechanism is modified by introducing a mathematical computation to avoid the large variation in the back-off values. In this technique, a Multiplicative Increase and Linear Decrease (MILD) back-off mechanism is used where upon a collision; the back-off is increased by a multiplicative factor and upon a successful transmission, it is decremented by one [7] [23]. It eliminates the rapid adjustment in the back-off counter values and helps to provide a quick escalation in the back-off values at high contention time.

On the other hand, a five-way handshaking communication is introduced in MACAW instead of three-way handshaking like MACA by adding two more control packets; DS (Data sending) and ACK (Acknowledgement) to relieve expose node problem [22]. In this problem an exposed node say C became blocked due to its unnecessary increased back-off counter values. In figure 6 the RTS packet send by C to D is became useless as CTS packet from D gets colloid at C with transmitted by node B.

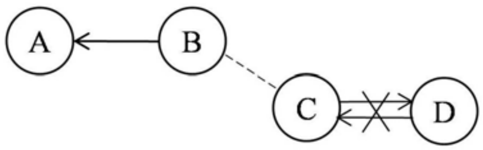

Figure 6: Exposed node problem example

Therefore to solve this problem DS control packet is send by source node before transmitting the actual data packet. This DS packet carries information about the duration of the actual data packet transmission that could be used by the exposed nodes for updating information they hold regarding the duration of the transmission. An exposed node, overhearing the DS packet, understands that the previous RTS-CTS exchange was successful, and so defers its transmission until the expected duration of the DATA-ACK exchange [24].

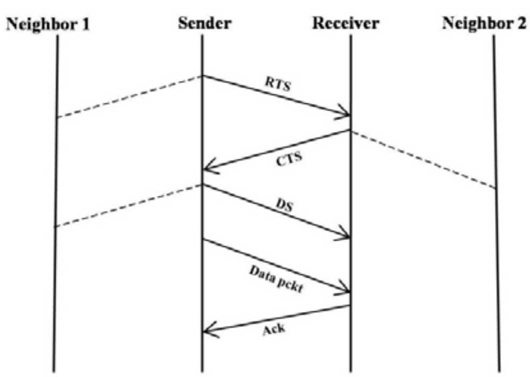

Figure 7: Data Packet Transmission in MACAW

The challenges that a network designer may face while designing MACAW is increased traffic load [7] [22]. The addition of ACK packet in every basic message's RTS-CTS exchanged may increase the load of the traffic required for the completion of the data packet transmission. Instead of adding this, ACK's could be piggy-backed onto the subsequent CTS packets. Whenever the queue for a stream at a station had more than one packet in it, the sending station would not request the ACK but would merely wait for the piggy-backed acknowledgment on the next CTS [23] [24].

iv. FAMA

challenges that It extends for Floor Acquisition Multiple Access protocol and is based on a channel access discipline which consists of a carrier sensing operation and a collision avoidance dialog between the sender and the intended receiver of a packet [7] [25]. The objective of a FAMA protocol is to allow a station to acquire control of the Floor (channel) dynamically, and in such a way that no data packets ever colloid with any other packet. This can be viewed as a form of dynamic reservation. A FAMA protocol requires a station who wishes to send one or more packets to acquire the channel before transmitting the packet queue [26]. The channel is acquired using control packets that are multiplexed together with the data packets in the same link in such a way that, although control packets may colloid with others, data packets are always sent free of collision.

A floor acquisition strategy based on RTS-CTS exchanged can be addressed by two variants: either by packet sensing or carrier sensing [27]. The first variant corresponds to using the ALOHA protocol for the transmission of RTSs; the second consists of using a CSMA protocol to transmits RTSs. A station sends CTS after receiving an error- free RTS addressed to it. When a station receives error-free CTS, it knows that the channel has been acquired by the station to which the CTS is addressed. After the channel has acquired the channel holder is able to send data packets free of collision over the channel [25].

To ensure the floor acquisition is enforced among competing senders hidden from one another and who have requested the floor i.e. sent an RTS, the CTS sent by a receiver is guaranteed to inform any hidden sender that did not hear the RTS being acknowledged. In this way, FAMA overcome hidden terminal problem [26] [27].

v. DBTMA

A floor In ad hoc networks, the hidden and the exposed terminal problems can severely reduce the network capacity on the MAC layer. Using RTS-CTS control packets the above discussed protocols attempt to relief this problem but could not completely succeed. Consequently a new MAC protocol, DBTMA (Dual Busy Tone Multiple Access) is proposed [28], where the single communication channel is splits into two sub-channels; Data channel and Control channel. Control channel is responsible to send RTS-CTS packet and through Data channel the actual data is transmit [7] [29]. Along with RTS-CTS control packets, two narrow-bandwidth tones are also introduced in this protocol; BT_t (Transmit Busy tone) and BT_r (Receive Busy Tone), indicate whether the node is transmitting RTS packets or receiving data packets, respectively. The BT_t provides protection for the RTS packets to increase the probability of successful RTS reception at the intended receiver [28]. On the other hand, BT_r acknowledge the RTS packet and provide continuous protection for the transmitted data packets. All nodes sensing any busy tone are not allowed to send RTS requests to their intended destination. When BT_r signal is sensed, a new node sending the RTS packet is required to abort such transmission immediately [29].

When a sender node say X in the figure 8 has a data packet to send, then first it sense the channel whether the BT_t and BT_r signals are active or not. If none of the busy tone signals is present (which means that no one in node X's transmission area is receiving data packet or sending RTS packets), it turns on its signal, sends an RTS packet to the receiver node say Y. By the end of the RTS transmission, node X turns off its BT_t signal. On receiving the RTS packet, Y first turns on its BT_r signal and reply node X by sending a CTS packet. The BT_r signal of Y is continuously ON until it receives data packet successfully. Node X monitoring the BT_r signal sends the data packet to node Y. On successful reception of the data packet, node Y turns OFF the BT_r signal ending the communication. Indeed, the RTS-CTS packets and the both busy tone signals solve the hidden- and the exposed-terminal problems [7] [28].

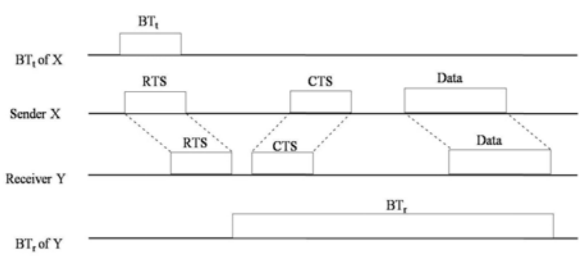

Figure 8: Control packets & Data packets transmission in DBTMA

Since DBTMA used extra two out-of-band busy tones addition to normal RTS/CTS packets, exposed terminals are able to initiate new transmission, because they do not need to listen to the shared channel to receive the acknowledgment from their intended receivers [24]. Furthermore, the hidden terminals can reply to RTS requests by simply setting up it's receive busy tone. When RTS/CTS dialogues are used on the single channel, such as in the MACA, MACAW schemes, the hidden terminals cannot send their replies [7]. Unfortunately, extra hardware is required by the DBTMA scheme as two busy tone transmitters and sensing circuits need to be incorporated into each communication node to manage the interference between busy tone and data signal. Therefore careful hardware design in DBTA may help to minimize the effect of possible interference [29].

C. Directional MAC protocols

i. DMAC 1

When a sender Although omni-directional antenna based MAC protocols somehow overcome the hidden and exposed terminal problem, a large portion of network capacity is wastage by reserving the wireless channel for a long time when a node differs its transmission and remain blocked until its neighboring nodes complete their won transmission. To use the network capacity efficiently, directional antennas are applied to the MAC protocols on a per-antenna basis [30]. The key feature in Directional MAC1 (DMAC1) scheme is usage of directional antenna for sending RTS packet in a particular direction, and omni-directional antennas for sending CTS packet in all directions [31]. Secondly, DMAC1 protocols apply one important logic where if one directional antenna at some node may be blocked, other directional antennas at the same node may not be blocked, allowing transmission using the unblocked antennas. This property results in network performance improvement when using directional antennas [30] [31].

Figure 9 show how wireless bandwidth efficiency of the MAC protocols can be improved by using a directional antennas. In this figure, assume that node Q has a data packet for node R, and also assume that no other data transfers are in progress (so none of the antennas are blocked). In this case, node Q sends a directional RTS (DRTS) packet including the physical location information of Q, in the direction of node R. Thus, node P does not receive the DRTS from node Q even though node P also exists within Q's transmission range. If node R receives the DRTS packet from Q successfully, it then returns an ornni-directional CTS (OCTS) reply. Two location informations are included in the OCTS packet: location of the node sending OCTS (node R's location in Figure 9) and location of the sender of the corresponding DRTS packet (node Q in Figure 9). After the successful exchange of DRTS and OCTS packets, a data packet is sent by node Q using a directional antenna. When node R receives the data packet, it immediately sends an ACK to node Q using a directional antenna.

At the same time if node S, which is a neighbor of R, wishes to transmit data to node T. The directional antenna of node S that points towards node R is blocked, since node S would have received on his directional antenna the OCTS sent by node R to node Q. However, the blocked antenna is different from the directional antenna that point towards node T. Therefore node S can send a DRTS packet towards node T. But node S must knows that its data transmission to node T would not interfere with the other on-going data transfer from Q to R, S sends a DRTS control packet to T. As a result, DMAC1 for directional antennas can improve performance by allowing simultaneous transmissions that are disallowed when using only omni-directional antennas [32].

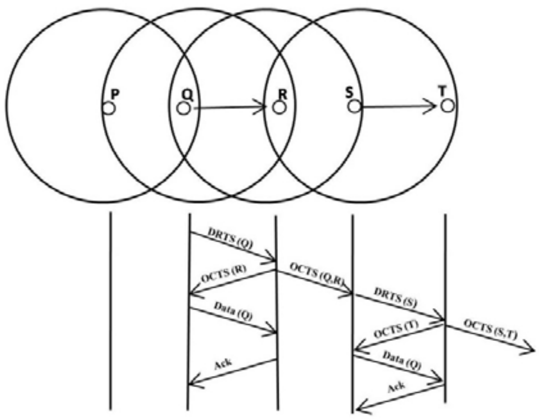

Figure 9: Data transmission between nodes in DMAC 1 scheme

The big issue with DMAC1 scheme is that, finding the intending receiver location and direction to initiate communication [30] [31]. Therefore many researchers took GPS support to identify neighbor location.

ii. DMAC 2

The big Directional Media Access Protocol 2 (DMAC2) [33] exploits the ability of the sender and receiver node to determine the direction of the arriving frames in order to know each other's location. Since the nodes are continuously moving and there is no centralized control, a node is not normally aware of the exact location of its neighbors [32]. The task of finding the sequence of nodes through which to route a packet to the intended destination is performed by the routing protocol. Hence, for every data packet that is to be transmitted, the MAC is concerned with only the destination for that hop, as specified by the routing layer. The key feature of this scheme is, RTS and CTS exchange is omni-directional, whereas Data and Acknowledge packets are directional [32] [33]. Let us assume that an idle node listens to ongoing transmissions on all its antennas. Any node that wishes to send a data packet to a neighbor first sends an omni-directional RTS packet addressed to the destination. Consider the following figure 10 where A wanting to send a data packet to B, first transmits an RTS packet to B. This is transmitted on all antennas of A, as it does not know the direction of B at the start. If B was in standby and receives the RTS packet correctly, it responds by transmitting a CTS packet, again on all directions (antennas). However, B notes the direction from which it received the RTS packet by noting the antenna that received the maximum power of the RTS packet (antenna 2). Similarly A estimates the direction of B while receiving the CTS packet, and if the RTS-CTS handshake is performed successfully, proceeds to transmit the data packet on the antenna facing D (antenna 4). All the neighbors of A and B, who hear the RTS-CTS dialog, use this information to prevent interfering with the ongoing data transmission [26] [33].

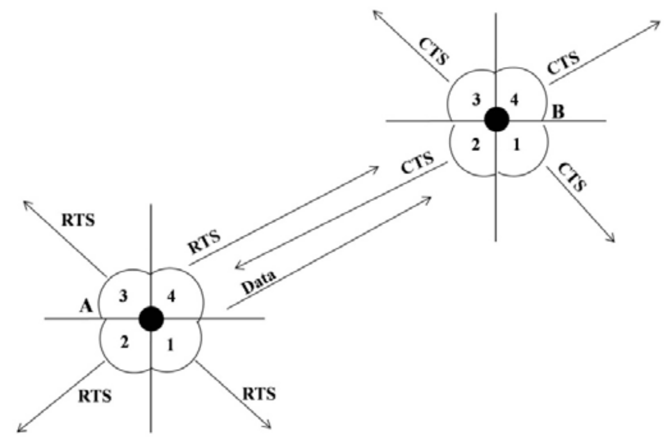

Figure 10: Data packet transmission between nodes in DMAC2 scheme

In contracts to DMAC1 protocol, it accomplishes location tracking in an on-demand manner, instead of in a pro-active manner which can overcome the location finding problem and improves the throughput performance in the network [28]. However, the major issues arise in such protocol is frequent node movement due to dynamic nature of ad hoc network which changed network topology very often. Therefore some mechanism like GPS can be applied to capture node's speed to resolve change in topology.

iii. DMAC 3

In contracts Directional MAC 3 (DMAC 3) [34] addresses the hidden node problem and node deafness by employing a novel scheme of selective circular directional transmission of both RTS and CTS, where these packets are transmitted only through the antennas with neighbors. In this protocol a node used directional antenna that provides coverage around it by a total of *M* non-overlapping beams [31]. A node can transmit and receive in any of these *M* antenna beams. DMAC 3 does not rely on prior availability of neighbors' location; instead it employs a self-learning algorithm to determine the presence or absence of nodes in given directions [32] [34]. Initially it carries out a continuous process of learning to determine through which a given neighbor can be reached. For this, DMAC 3 relies on the use of broadcasting. Nodes send "hello packets" to their one hop neighbor time to time to know its location. At last all network nodes will eventually determine their neighbors during the learning phase. Besides determining all particular neighbors of a node, this process also allows a node to determine if some of its sectors have any neighbors at all [34]. After knowing neighbor's location a sender node first transmitted a RTS frame always in the sector where its intended neighbor is located. Upon reception of a RTS packet as shown by step (1) in Figure 11, the receiver waits for a period of time equal to SIFS and sends back a CTS as shown by step (2) to the respective sender. Only after the RTS/CTS handshake is completed and the channel is reserved in their direction, both sender and receiver nodes simultaneously initiate the circular directional transmission of their RTS and CTS packets respectively, to inform their neighboring nodes. This is clearly seen in Figure 11 through step (3).

To carry out DATA transmission in a synchronize way, the sender node S and receiver node R includes a special time unit in both of their RTS and CTs frame respectively. Through these time units, node R is able to determine the exact point of time when node S will have finished its circular directional transmission of RTS and hence will start transmitting DATA and similarly node S can precisely tell the moment node R will be ready and waiting for DATA transmission. Once the circular RTS/CTS transmission is completed, sender sends the actual data packet to the receiver through the reserved direction. On getting the data packet correctly, receiver replies the sender by an acknowledgment packet. Both scenario is revealed by step (4) and (5) in figure 11 respectively.

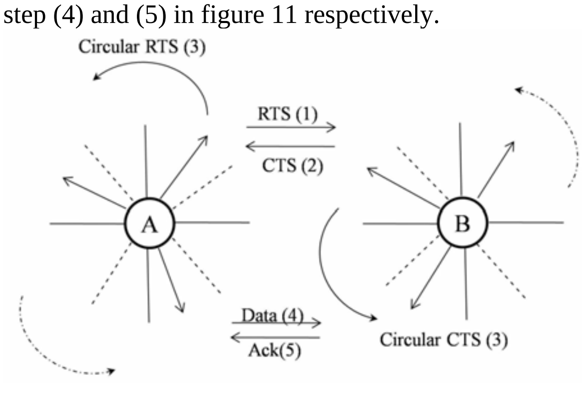

Figure 11: Data packet transmission between nodes in DMAC3 scheme

In DMAC 3 protocol, a directional antenna of M beams is used to produce high coverage around the node, but for all these antenna beams a single MAC buffer is used which may lead an issue called self-induced blocking [33] [34]. If a packet for a particular antenna beam is blocked, the node will not be able to transmit in any other directions until the blocked packet is successfully transmitted and it should wait for becoming the medium to be idle which reduces overall throughput of the system. Therefore to overcome this problem MAC layer has introduces multiple buffers for each corresponding antenna [34].

iv. DMAC4

Directional antenna increases spatial reuse and the range of the communication. With these advantages the directional communication brings new set of challenges as hidden and deaf node problems. The fact behind these problems is unawareness of the vicinity of communicating nodes about their communication. The deafness problem occurs when a destination node doesn't reply due to its beam pointed away from the sender's direction or the other communication is going on in same sector. On the other hand hidden node problems cause by unheard RTS/CTS and asymmetry in gain of the antenna.
To solve these problems Alam et al. [35] proposed a new Directional MAC (DMAC4) protocol which takes advantage of the multi beam smart antennas. Through these multi beam antenna, a node can simultaneously transmit/receive a packet to/from all the directions around it (360^0) through all the beams. But it can either transmit or receive at a time. So the antenna needs to set in transmission or reception mode. With multiple beams, DMAC4 employees a scheme of simultaneous transmission of RTS/CTS packets to its neighbors, and the transmission of neighbor information packet (NIP) to nodes that just completed their communication. The purpose of transmitting NIP is to inform those nodes about other ongoing communications in the network [34] [35].

When a node has a packet to transmit, first of all it sends RTS towards the intended receiver. After the receiver receives RTS, replies with CTS to the sender. After successful RTS/CTS handshake, the intended communicating nodes again transmit RTS and CTS to its vicinity through it's all remaining beams. Then they start DATA communication. During the communication the remaining beams will block their transmission and reception. The idle node sets DNAV for the beam when it overhears a packet. The DNAV will be updated after every overheard packet [32] [35]. The whole working mechanism is clearly depicted in the following figure 12.

In the figure node A and B starts communicating by sending RTS and CTS packet to each other. After the successful RTS/CTS handshake, A and B transmit RTS and CTS to their neighbors through their remaining beams. During AB's communication, two other nodes say C and D also want to start their communication and this becomes unaware for node A and B. After the completion of transmitting RTS/CTS to all neighbors, actual data transmission between A and B was held and they complete their communication while the node pair C and D is still communicating. Node E and node F who are idle (knows about both communication) generates NIP for node A and B and send them. After getting the packet, node A and B set their DNAV for the remaining duration of communication of nodes CD. The DNAV will be updated after every overheard packet.

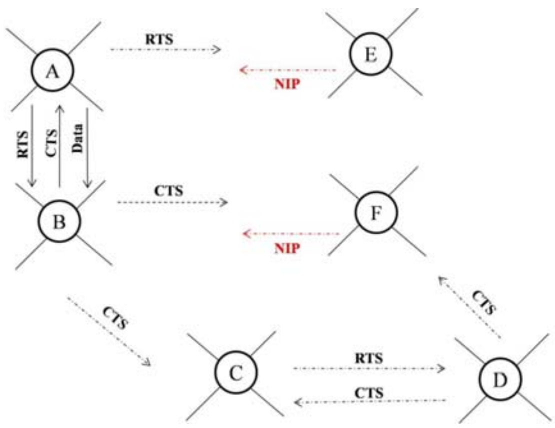

Figure 12: Data packet transmission between nodes in DMAC4 scheme

Although DMAC 4 overcomes the problem of deafness and hidden terminal but NIP generation and neighbour information table updating, increases the packets overhead which is an important issue and need to be handle at the time of designing the protocol [35].

A comparison study of above discussed protocols is presented in the following Table I based on their various features, characteristics and issues.

IV. CONCLUSION

This study presented a broad overview of the research work conducted in the field of wireless ad hoc network with respect to MAC protocols. We have discussed the characteristics, architecture, functionality, working principle, issues involve with various MAC protocols and identified their salient features. In particular, we have looked some special design issues associated with different MAC protocols which are very important to keep in mind before designing them. However omni-directional and directional antenna model related to MAC protocols are discussed and the advantages, disadvantages using these models are examined. Unique challenges like mobility, channel utilization, collision resolution, power conservation, bandwidth efficiency etc. are observed with respect to both omni-directional and directional MAC protocols and it is found that directional MAC protocols are more effective compare to omni-directional MAC protocols, as they introduce spatial reuse and high coverage range for the communication.

TABLE I. CHARACTERISTICS COMPARISION OF DIFFERENT MAC PROTOCOLS

Protocol	**Basic Protocol**	**Antenna mode**	**Channel Utilization**	**Hidden problem**	**Exposed problem**	**Deafness Problem**	**Backoff Algorithm**	**Ack used**
IEEE 802.11 DCF	--------	OMNI	POOR	YES	YES	YES	YES	NO
MACA	IEEE 802.11	OMNI	FAIR	YES/NO	YES	YES	BEB	NO
MACAW	MACA	OMNI	GOOD	NO	YES	NO	MILD	YES
FAMA	MACA	OMNI	GOOD	YES	YES	NO	BEB	NO
DBTMA	MACA	OMNI	VERY GOOD	NO	NO	NO	BEB	NO
DMAC1	IEEE 802.11	DIR	GOOD	YES	NO	YES	BEB	YES
DMAC2	IEEE 802.11	DIR	GOOD	YES	YES	YES	BEB	NO
DMAC3	IEEE 802.11	DIR	VERY GOOD	NO	NO	NO	BEB	YES
DMAC4	IEEE 802.11	DIR	VERY GOOD	NO	YES	NO	BEB	NO

Unfortunately, directional transmissions increase the hidden terminal problem, the problem of deafness and the problem of determination of neighbors' location. However two improved directional MAC protocols: DMAC 3 and DMAC 4 succeed to overcome these issues by introducing directional RTS/CTS and multi beams antennas with large coverage around the nodes. Unfortunately, high mobility behaviour of the nodes may lead network failure by causing topology break and need to include some re-route discovery techniques to solve such problem.

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