Mac Protocols in Mobile Ad Hoc Networks

Nermin Makhlouf and Pavel Vajsar

***Abstract*—Mobile Ad hoc NETwork (MANET) is a wireless network of mobile nodes connected by wireless link without a central control. The Medium Access Control (MAC) protocol is one of the important issues in such network, thereby the presented paper will discuss the MAC protocol used in MANET depending on IEEE 802.11 standard which known as Distributed Coordination Function (DCF).However, the limitation of MANET is that, the collision increases with the rise of nodes number. Therefore paper study the MAC protocol using directional antennas to reduce the collisions, increase the range of transmission and largely reduce the interference between the directions. However, the main problem of using directional antennas is caused by frequent node mobility. So the movement plays a vital role in wireless Ad hoc networks to predict the location of MNs.**

***Keywords*—Mobile Ad hoc network, MAC.**

I. Introduction

The popular Carrier Sense Multiple Access/Collision Detection (CSMA/CD) MAC method is used for wired network. In CSMA/CD, when a node wants to send over the network, first it sense the wire medium whether it's idle or busy. If it's idle, the node sends its data with sensing the medium continually. Otherwise, the node delays its transmission to avoid a collision with existing packets. While in the wireless networks, the signal strength is inversely proportional to the square distance from the transmitter node, thus nodes, which are out of transmitter's range, can't sense the transmitted signal causing problems as illustrated in fig.1. There are three nodes A, B, C. Node B is within the range of each nodes A and B, node C is out of the range of A. Node A wants to send to B, wherefore node A waits until the medium is idle, then A starts transmitting to B. Node C wants to send to node B while B is receiving data from A. But C can't sense the transmitted signal from A, thus C starts transmitting to B causing collision at node B. This problem is called "hidden- terminal problem". Another problem is illustrated in fig.2, there are four nodes A, B, C, D. Nodes B and C are within the range of both nodes A and D, but D is out of A's range. While node B is transmitting data to node A, node C wants transmitting data to D. But C senses the transmitted signal from A, thus C delays its transmission to D. Even through a transmission from C does not interfere with the reception at node A, this case is called "exposed terminal problem".

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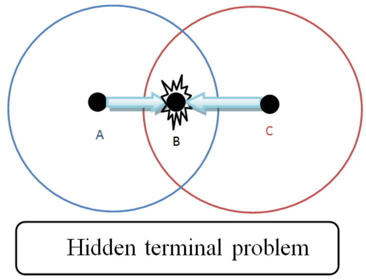

Fig. 1. Illustration of hidden terminal problem

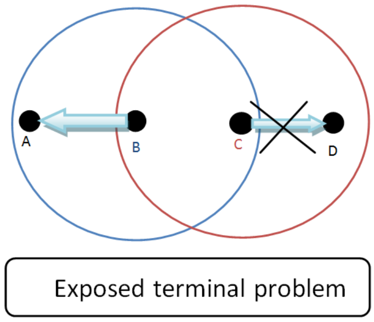

Fig. 2. Illustration of exposed terminal problem

II. Multiple Access Collision Avoidance (MACA) protocol

The Multiple Access Collision Avoidance (MACA) protocol doesn't fully solve the problem of CSMA/CD. It uses two additional packets, Request To Send "RTS" and Clear To Send "CTS", to reduce the collision at receiver. These packet are shorter than data packets, however, they contain the length of the data frame that will follow. Let us conceder an example with four nodes A, B, C, D as shown in fig.3. The node A wants to send data to the node B, so A broadcasts a RTS packet then B replay to A by sending a CTS packet. At node C the CTS packet collides with a RTS packet sent from D, so C doesn't replay to the RTS from D. But A starts sending data to B after A receives CTS from B. The node D sends another RTS packet because it didn't receive a CTS from C and then C responses to D by sending back a CTS packet which may collide with data packet at B node if the data reception isn't complete. We notice there is no acknowledge for receiving the data, thus the retransmission is started by higher layer (transport layer) [1].

The wireless LANs use the MACA protocol, but they use additional control packets like ACKnowledgement packet (ACK) which is received by the sender from the receiver node after data reception is complete. Thus, the arrangement of transmitted packets is (RTS-CTS-DS -ACK).

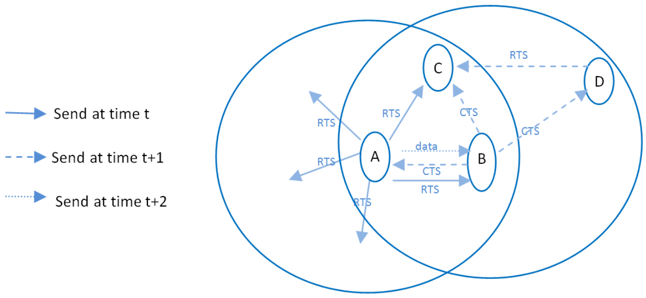

Fig. 3. Illustration of RTSCTS mechanism

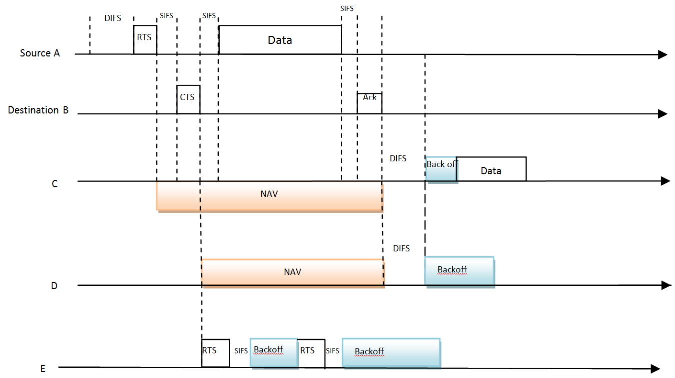

Fig. 4. CSMA/CA mechanism

III. IEEE 802.11 MAC SCHEME FOR MANET

The IEEE 802.11 standard determines DCF which is used for infrastructureless network like MANETs so we focus on DCF type. DCF is a combination of CSMA and MACA so it's called (CSMA/CA). It uses the (Data, ACK) sequence packets, but when the data packet is long it uses (RTS, CTS, Data, ACK) sequence packets. Each node has a timer called Network Allocation Vector (NAV) contains a time value. This time is the duration of the transmission to another node, as shown in fig.4, node A wants to send to node B. A senses the medium:

- If node A receives a signal weaker than a certain value called Carrier Sense Threshold (CST) for a specified time called Distributed Inter Frame Space (DIFS), the medium is idle and A broadcasts RTS packet, which includes information about the duration of the following transmission, fig.4. B receives RTS, and then if the medium is idle for a time called Short Inter Frame space (SIFS), destination B replays to A by sending CTS packet which includes the same information of duration. The other nodes, which can sense either RTS or CTS (i.e node C and D), set their NAV timer according to the duration information to prevent from access the medium as long as NAV $>$ 0, therefore the probability of collision is decreased. When source A receives CTS packet, A starts sending data after time interval SIFS. Then if destination B receives data correctly, B sends ACK packet to A after time interval SIFS.
- If node A receives a signal stronger than CST, A senses the medium busy, A delays its transmission for time known as backoff time. The initial backoff time is chosen randomly in the range $(0, CW-1)$, where $CW_{min} \leq CW \leq CW_{max}$ is contention window, therefore probability that two nodes choose the same value of CW is low. Then the backoff timer is decreased as long as the medium is idle, and it is stopped when the medium is busy. When the backoff timer reaches zero, the source node is allowed to send the data frame.

Fig.4 shows that node E wants to send data to D, while there is transmission between A and B. E is out of the ranges of both A and B. Wherefore E senses the medium idle for time longer than time interval DIFS. Then E sends RTS to D which isn't allowed to access medium because of NAVs CTS. E doesn't receive CTS from D after interval time SIFS, this means the medium isn't free. Therefore E chooses the backoff time randomly, in term of time slots. The backoff timer begins decreasing until it reaches zero, then D will retransmit RTS. D will double the backoff time (CW) at each retransmission depending on algorithm of Binary Exponential Backoff (BEB). But if the failure of transmission reaches to the maximum $CW_{min} = CW_{max}$, the node ignores the packet and CW will return to CW_{min}. Therefore we can notice that exposed-terminal problem isn't solved [2].

IV. DIRECTIONAL ANTENNAS IN MANET

Typically, a MANET [3] uses omnidirectional antenna, it means each node can transmit and receive signals from all directions. Using directional antennas improves the MAC protocol for MANET, where it reduces the interference between the directions because the antenna sends the most energy of signal in the right direction. And it increases the throughput and the range of transmission, and solves the exposed terminal problem [4].

A. *The Node with antenna Model*

It is supposed a MANET of n Mobile Nodes (MNs) [5], each MN has directional antennas with non-overlapping directions and all nodes use the same wireless channel. The antennas cover all directions (2π rad). The MN is supplied with a system for defining its position and speed, such as a Global Position System (GPS) which also provides a synchronized clock, and the MN has a Location Table (LT) in which the location information of its neighbors is stored temporarily; however, at the beginning the LT is empty. We assume an idle MN listens to the medium using all antennas; this is called Omni-Listen (OL) mode. But when a MN listens using a directional antenna, this is called Directional-Listen (DL) mode. The MNs update their Directional NAV (DNAV) when they receive either a Directional RTS (DRTS) or a Directional CTS (DCTS) packet.

1) MAC protocol using Directional antennas: A Location and Mobility Aware (LMA) MAC protocol is adapted for MANETs with directional antennas, because when there is a transmission between two nodes, the radiations of antennas have to be adjusted according to their location predictions. The

LMA MAC protocol assumes that all MNs move at constant speeds and angles during a short period of time and the style of kth content in the LT is [6]:

$$LT(k) = (Timestamp(k), NodeID(k), \quad (1)$$
$$Position(x_k, y_k), Movingangle(\alpha_k), Speed(S_k), TTL_k)$$

Where $1 \leq k \leq n, TTL_k$ is Time To Live of k^{th} content, $TTL_k = 0$ at each registration of LT(k) and then TTL_k is increased with time. When it exceed a certain threshold T, the LT(k) is deleted from the MN"s LT.

When a MN intends to start a new transmission, it uses either an Omni-listen/ Omni- RTS (OL/ ORTS) or a Directional-listen/ Directional- RTS (DL/DRTS) depending on the current information in its LT. Figs.5,6 and 7 illustrate the LMA MAC protocol where the medium is idle, node A wants to send data to B, and As LT doesnt have any information about the location of its neighbors. A sends an ORTS packet which includes location information of A: the time instant of ORTS transmission (t_k), the node ID_a, the current position $(P_A(t_r) = (x_a(t_r), y_a(t_r)))$, the moving angle (α_A) as shown in fig.7 and speed (S_A)

All As neighbors (B, C, D), which listen ORTS, will register As information in their location tables, so Bs LT, Cs LT and Ds LT will be updated as:

$$LT_B(A) = LT_C(A) = LT_D(A) = (t_r, ID_A, P_A(t_r), \quad (2)$$
$$(\alpha_A), (S_A), TTL_A)$$

Where the value of TTL_A is zero at every update of LT(A). And then destination B responses by sending a DCTS, where the direction of CTS is calculated as follow:

$$\theta(t_c) = tan^{-1}\frac{y_B(t_c) - y_A(t_c)}{x_B(t_c) - x_A(t_c)} \quad (3)$$

Where t_c is the time moment of sending DCTS from B to A, while $P_A(t_c)$ is calculated from $P_A(t_r)$ as:

$$P_A(t_c) = \begin{cases} x_A(t_c) = x_A(t_r) + S_A cos\alpha_A(t_c - t_r) \\ y_A(t_c) = y_A(t_r) + S_A cos\alpha_A(t_c - t_r) \end{cases} \quad (4)$$

The DCTS from B also includes the location information of B, thus A will update its LT as:

$$LT_A(B) = (t_c, ID_B, P_A(t_c), \alpha_B, S_B, TTL_B) \quad (5)$$

Node C receives DCTS from B, and then C updates its LT and sets its DNAV timer, thus C will not be allowed to access medium within this direction. But node C can start sending to any node which is out of DNAV range and is in the Cs LT. Now each of A and B is aware of the location of the other. The directional data transmission is started according to transmission angle θ_{data} from node A to node B where θ_{data} is computed as:

$$\theta_{data}(t_i) = tan^{-1}\frac{y_A(t_i) - y_B(t_i)}{x_A(t_i) - x_B(t_i)} \quad (6)$$

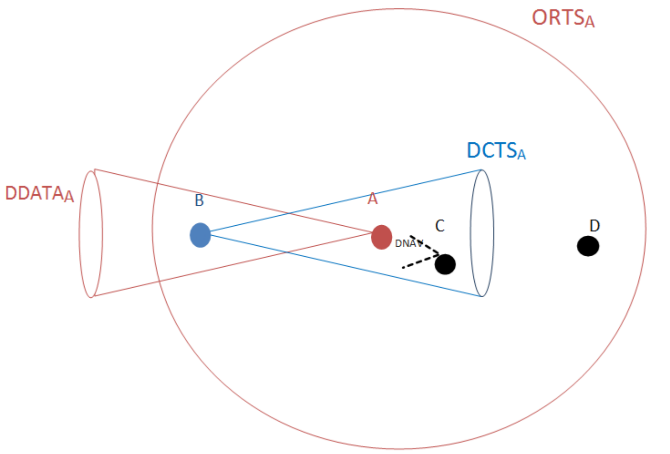

Fig. 5. MAC protocol using directional antennas the transmission direction

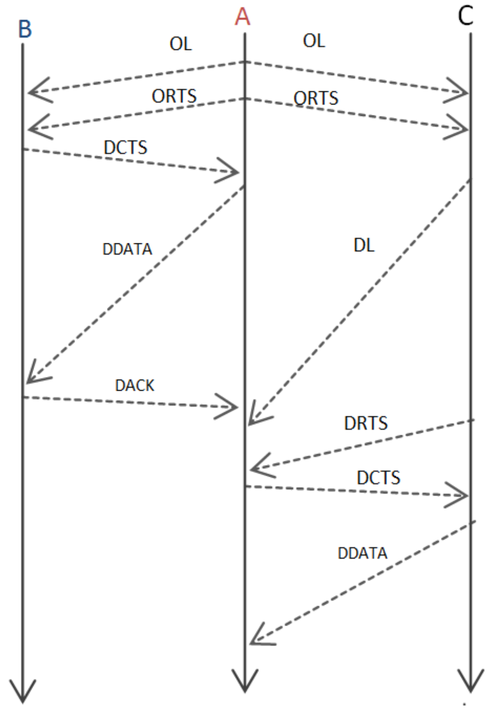

Fig. 6. MAC protocol using directional antennas the arrangement of transmission depending of the time

Where t_i ranges between the starting and the stopping time instants for data transmission, so $\theta_{data}(t_i)$ changes with time depending on MNs movement, and it can be adapted on the basis of existing antennas. The position of nodes at t_i is calculated using their LTs as:

$$P_A(t_i) = \begin{cases} x_A(t_i) = x_A(t_r) + S_A cos\alpha_A(t_i - t_r) \\ y_A(t_i) = y_A(t_r) + S_A cos\alpha_A(t_i - t_r) \end{cases} \quad (7)$$

$$P_A(t_c) = \begin{cases} x_B(t_i) = x_B(t_c) + S_B cos\alpha_B(t_i - t_c) \\ y_B(t_i) = y_B(t_c) + S_B cos\alpha_B(t_i - t_c) \end{cases} \quad (8)$$

After obtaining the transmission angle, the antenna beams of nodes A and B are pointed to the predicted direction and

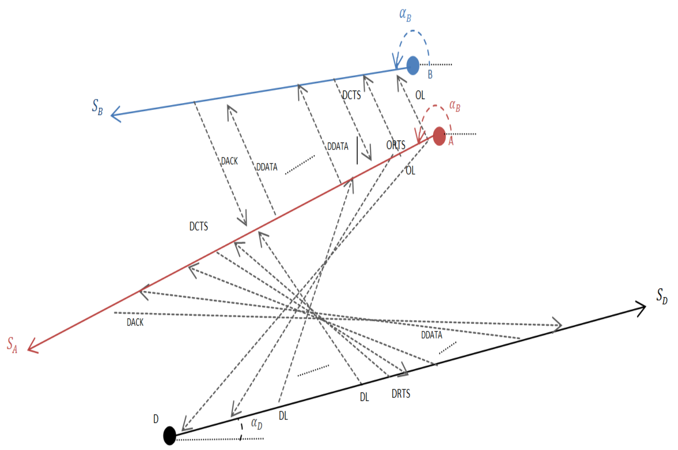

Fig. 7. The LMA MAC mechanism depending on movement direction

begin transmission. If the data transmission is completed, node B will send directionally ACK to node A. During the Transmission from node A to node B (T_{A-B}), node D may want to send data to node A, however, node D knows the As position from $ORTS_A$. Therefore node D listens to node A directionally and holds transmission medium directionally. Node D takes into account the change of As position over time to compute the current transmission angle $\theta(t)$. When transmission (T_{A-B}) is completed, node D senses medium idle using DL mode and then it sends DRTS packet to node A after the ending of backoff time, where the transmission angle for RTS is computed at the time moment of sending it (t'_r) as:

$$\theta(t'_r) = tan^{-1}\frac{y_D(t'_r) - y_A(t'_r)}{x_D(t'_r) - x_A(t'_r)} \tag{9}$$

Where $P_A(t'_r)$ is calculed from $P_A(t_r)$ as following:

$$P_A(t'_r) = \begin{cases} x_A(t'_r) = x_A(t_r) + S_A cos\alpha_A(t'_r - t_r) \\ y_A(t'_r) = y_A(t_r) + S_A cos\alpha_A(t'_r - t_r) \end{cases} \tag{10}$$

And then the transmission sequences between nodes A and D comply similarly with the previous transmission T_{A-B}. The predicted position by LMA MAC protocol could be inaccurate because the speed and moving angle during the data transmission can be changed. This protocol can be enhanced by using the Directional Beacon (DB) mechanism which makes the MNs get the update of mobility information via DB after any change of one nodes moving angle or speed. For example, when node B change its moving angle at t_m during T_{AB} the DB will distribute this modified mobility information to Bs neighbors within the transmission range (e.g., node A). Therefore node A will calculate transmission angle $\theta_{data}(t_m)$ depending on the update information.

V. Conclusion

This paper has studied the MAC protocol in MANETs and how can improve the MAC protocol by using directional antennas. The collisions among the MNs could be decreased based on the proposed LMA MAC protocol, where the MN can predict the location of its destination, and then it adjusts its antenna beam to the predicted direction of desired receiver in order to begin transmitting. Thereby the frequency reuse and the interference are enhanced. Moreover, this protocol could have more accurate of predicted location by using the DP mechanism, even if the MNs continually move during the data transmission.

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