무선 Ad hoc 네트워크에서의 공간재이용을 위한 매체접근제어프로토콜

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A Media Access Control for Spatial Reuse in Wireless Ad hoc Networks

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요 약

무선 Ad hoc 네트워크에 지향성 안테나를 사용함으로써 간섭의 영향 감소, 공간재이용(spatial reuse) 증가, 그리고 통신용량 증가 등의 장점을 실현할 수 있다. 그러나 기존의 IEEE 802.11 MAC 프로토콜은 무지향성 안테나를 고려하여 설계되었기 때문에 기존의 MAC 프로토콜을 지향성 안테나를 탑재한 무선 Ad hoc 네트워크에 적용할 경우 그 장점을 효율적으로 제공할 수 없다. 본 논문에서는 최적의 공간재이용을 통한 성능향상을 달성하기 위한 MAC 프로토콜을 제안하였으며, 시뮬레이션을 통하여 기존의 MAC과 통신효율과 종단간 지연을 비교하였다.

ABSTRACT

Using directional antenna in wireless network can offer many advantages including significant decrease of interference, increase of spatial reuse and possibility of improving network capacity. However, existing 802.11 MAC is designed for use of omni-directional antenna then those advantages can not be shown in that MAC protocol when it uses directional antenna. In this paper, we present a MAC protocol specifically designed for directional antenna to achieve spatial reuse and improve capacity of MAC protocol. Simulation result shows the advantages of our proposal in comparison with existing MAC in terms of end-to-end delay and network throughput.

키워드

Ad hoc Networks, Directional Antenna, Medium Access Control, Spatial Reuse

Ⅰ. Introduction

A wireless network is without fixed base stations or any wireline backbone infrastructure. The nodes use peer-to-peer packet transmissions and multihop nodes to communicate with one another. The networks topology is continuously changing due to frequent node movements and hence dynamic nodes protocols are required to established and maintain the nodes. In literature, terms such as multihop wireless networks and packet radio networks are used to describe such networks. Such networks are very useful in military and other tactical applications such as law enforcement, emergency rescue or exploration missions, where cellular infrastructure is unavailable unreliable. There is considerable interest in using wireless networks in commercial applications as well where there is a need for

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application communications services without the presence of a fixed infrastructure.

The fundamental MAC protocols, such as the 802.11 MAC [1], are primarily designed for a single-hop and omni-directional antennas [2] wireless environment, where nodes typically form a clique and communication always takes place over a single wireless hop and equipped with omni-directional antennas. In such a single-channel [3] environment, the 802.11 MAC contention resolution mechanisms focuses primarily on ensuring that only a single sender-receiver node pair receives collision-free access to the channel at any single instant. The 802.11 MAC does not seek to exploit the spatial diversity inherent in multihop networks, where different sets of nodes are able to concurrently communicate with different sets of neighbors. By exploiting this spatial diversity, we should be able to significantly increase the number of concurrent transmissions [4] by distinct sender-recipient node pairs that are spaced sufficiently apart. An 802.11 MAC protocols in a multi-channel environment, it is easy to occur collisions because of hidden nodes and exposed nodes. So in 802.11 MAC protocol, we must guarantee that all neighbors of the data recipient are idle through the entire data transmission. By using control gap [5], the MAC layer can allow for neighbors to be engaged in concurrent transmissions, as long as their transmissions are align with the first pair.

This paper is organized as follows. In section 2, we discuss related work on modified MAC protocol to improve spatial reuse. In section 3, we proposed a new MAC protocol utilizing control gap. In section 4, we compare the performance of our proposed protocols with IEEE 802.11. And section 5 presents a brief summary.

Ⅱ. Related Works

Some researchers in the past have addressed challenges to improve wireless spatial reuse [1, 3, 6, 7, 9-12].

A. Chandar and A. Acharya in [1, 3], has presented that IEEE 802.11 DCF uses a 4-way distributed handshake mechanism (RTS/CTS/DATA/ACK) to resolve contentions between notes. A node reserves the channel for data transmission by exchanging RTS/CTS messages with the target node. When a node wants to send packets to another node, it first sends an RTS packet to the destination. The receiver, on processing the RTS, replies by sending a CTS packet to the sender. RTS and CTS packets include the expected duration of time for which the channel will be in use. Other neighbors that overhear these packets must defer their transmission for the duration specified in the packets. But 802.11 MAC does not permit concurrent transmission in two nodes which are either neighbors or have a common neighboring node. The following observation must be supported by any wireless MAC to avoid collisions at a receiver: If any node is currently a transmitter, there can be only one receiver node in the transmitter's one-hop neighborhood. Conversely, if any node is a receiver, only one node in its one-hop neighborhood is allowed to be a transmitter.

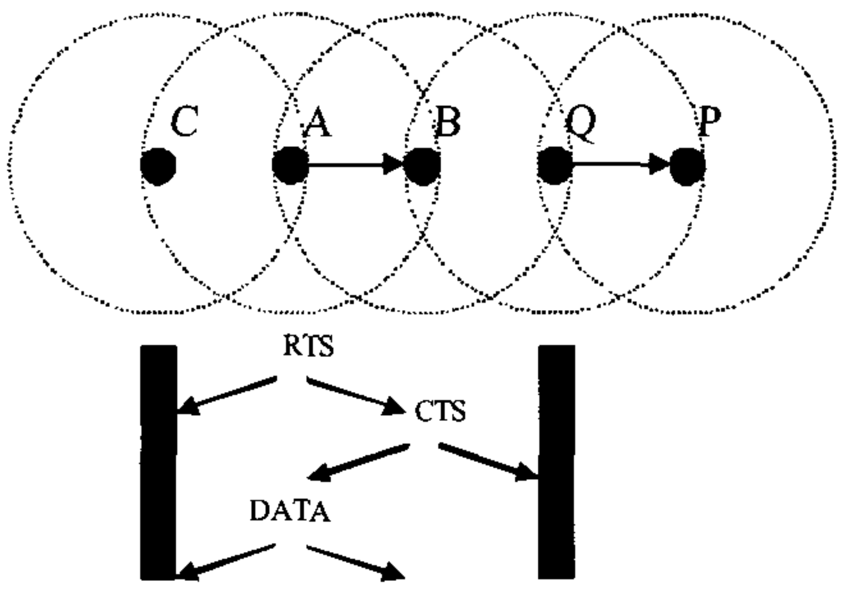

Fig. 1. MAC protocols

Consider Fig. 1 node A broadcasts a RTS packet for its intended receiver, node B. If node C hears the RTS successfully, it replies with a CTS packet so that A can start transmitting data packets upon receiving the CTS. Note that both RTS and CTS packets contain the proposed duration of data transmission. Since nodes are assumed to transmit using omni-directional antennas, all nodes within radio range of A and B will hear one or both of those control packets (nodes C and Q), these nodes must wait for the duration of data transmission before they can transmit anything themselves. Thus, the area covered by the transmission range of sender (node A) and receiver (node B) both in reserved for the data transfer from A to B, to prevent collisions. So transmission of A to B and Q to P cannot occur simultaneously.

Y. Ko, V. Shankarkumar and N. Vaidya [7] proposed MAC protocol using directional antenna to permit concurrent transmission. In this MAC protocol, transmitter sends a directional RTS and the receiver responses omni-directional CTS. They assume that the transmitter knows the receiver's location, so it transmits directionally the RTS to it. They propose an alternative of that scheme in case of lack of information for the location of the receiver. In this case the RTS is transmitted in omni mode in order to seek the receiver.

M. Takai. J. Martion, A. Ren and R. Bagrodia [9] proposed Directional Virtual Carrier Sensing in which they use directional RTS and CTS transmission. For the operation of this scheme they assume that the receiver's location is known by the transmitter. In the opposite situation, they propose the omni-directional transmission of RTS. They also propose a cache scheme where they maintain information about the location of their neighbors, which is updated every time a node receives a frame.

Ⅲ. The Proposed MAC Protocols

3.1 Determine the Position of Pairs

A wireless network without fixed base stations or any wire line backbone infrastructure. The nodes use peer-to-peer packet transmissions and multi-hop to communicate with one another. However the networks topology is continuously changing due to frequent node movements. Before the communication, we need to determine the position of communication pairs.

We assume that the radio transceiver in each mobile node is equipped with M directional antennas [10]. Each of the antennas has a conical radiation pattern, spanning an angle of 2π/M radians. The M antennas in each node are fixed with non-overlapping beam directions, so as to collectively span the entire plane. We use the convention for numbering the antennas from 1 to N as shown in Fig. 2, with numbers increasing clockwise starting from the horizontal (3 o'clock) position.

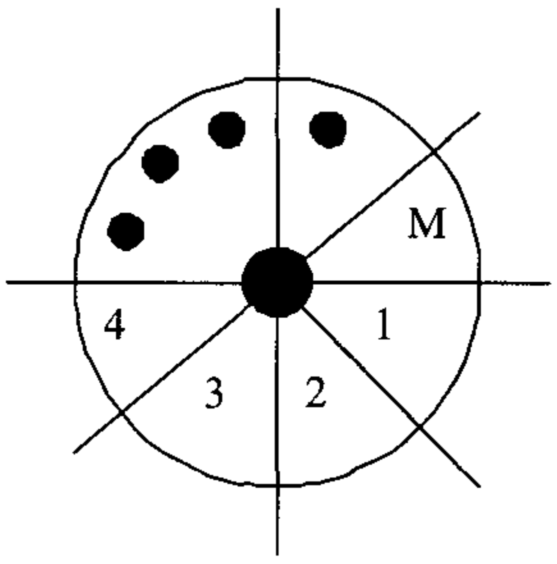

Fig. 2. A node with M beams

The proposed MAC protocol is illustrated in Fig. 3. The key feature that has been added in the adaptation is a mechanism for the transmitting and receiving nodes to determine the directions of each other. Before the data packet being transmitted, the MAC must be capable of finding the direction of the receiver node. Similarly, as we require the receiver to use directional antennas as well, the receiver node must also know the direction of the transmitter before it receives the transmitted data packet. Any node that wishes to transmitted data packet to a neighbor first sends an omni-directional RTS packet. The receiver receives the RTS packet, and it will estimate the position of the transmitter. After that the receiver sends directional CTS packet at that direction. When transmitter receives CTS packet from receiver, it can estimate the position of receiver. For example, in Fig. 3 A wanting to send a data packet to B, it first transmits an RTS packet to B. This transmission utilizes omni-directional RTS (ORTS), as it does not know the position of B at the start. If B receives the RTS packet successfully, it can estimate the position of A, then responses a direction CTS (DCTS) to A. When A receives the CTS, A also can know the position of B. After this, A can transmit data to B using directional antennas, and B reply ACK to A, again on directional antennas.

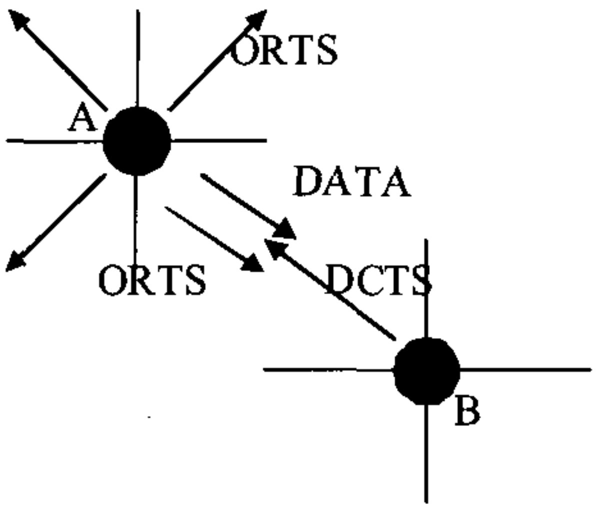

Fig. 3. An example of determining position

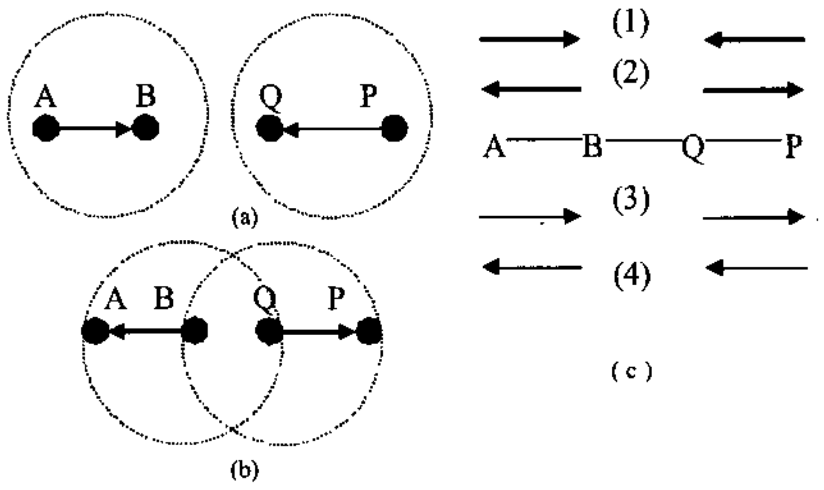

Fig. 4. 802.11 MAC's failure to exploit spatial reuse

3.2 Utilize a Control Gap

Now consider Fig. 4 where Q and B are one-hop neighbors, and A's transmission range does not include Q (and vice versa), and P's transmission range does not include B (and vice versa). It is clear that the transmission patterns shown in cases (3) and (4) shown in Fig. 4c are impossible: B's transmission to A would collide with P's transmission at Q (case 3) and A's transmission to B would collide with Q's transmission. Next consider the case when two receivers are neighbors: packet transfers A-to-B and P-to-Q, as shown in Fig. 4a (case 1 in Fig. 4c). Since A's transmission range does not include Q and P's transmission range does not include B, the two transmissions should be allowed to proceed in parallel. However, the 802.11 MAC does not support such parallel transmissions: when B sends a CTS in response to A's RTS, Q is aware that B has reserved the channel for CTS interval. If now P sends a RTS to Q, Q cannot respond with a CTS to P since it is aware of an existing channel reservation that would overlap with P's data transmission. A similar situation exists for the scenario in Fig. 4b (and case 2 in Fig. 4c): although B and Q should be able to transmit to A and P respectively at the same time, 802.11 does not permit such parallelism, as the transmission of the first RTS prohibits the second sender from sending out any RTS during the entire interval RTS.

Use the propose MAC protocol mentioned above, nodes can determine the position of each pair. To solve the problem of case1 and case2 in Fig. 4, the modified MAC protocol utilized spatial diversity for putting control gap [3]. Because of a node reverting between a transmitter and receiver roles multiple times during a packet transfer without a precision, the 802.11 MAC precludes the possibility of concurrent transmissions by two neighboring nodes that are either both senders or both recipients. In addition, in the 802.11 4-way handshake mechanism, neighbors cannot initialize to be a transmitter while a node pair is transmitting a packet, until the original 4-way handshake is completed. Therefore, only two neighbors being either both transmitters or both receivers and a gap which between the RTS/CTS exchange and the subsequent DATA/ACK exchange allows other neighboring pairs to exchange RTS/CTS messages within the control phase gap of the first pair, and subsequent pairs to align their DATA/ACK transmission phases with that of the first pair, modified MAC can support concurrent transmissions. The control gap is put in place by the first pair (A-to-B). A subsequent RTS/CTS exchange by a neighboring pair (P-to-Q) does not redefine the gap; subsequent pairs instead use the remaining portion of the control gap to align their data transmission with the first pair. Consequently, one-hop neighbors exchange the roles between transmitters and receivers in unison at explicitly defined instants and neighbors synchronize their reception periods. Thus this protocol avoids the problem of packet collisions.

In Fig. 5, corresponding to case2 in Fig. 4a, B sends a RTS to A, where B is called the master node and RTS sets up the master transmission schedule. If Q overhears this RTS and Q has a packet to transmit, it will set up an overlapping transmission to P, where Q is called the slave node and sets the slave transmission schedule, aligning the starts of the DATA and ACK phases.

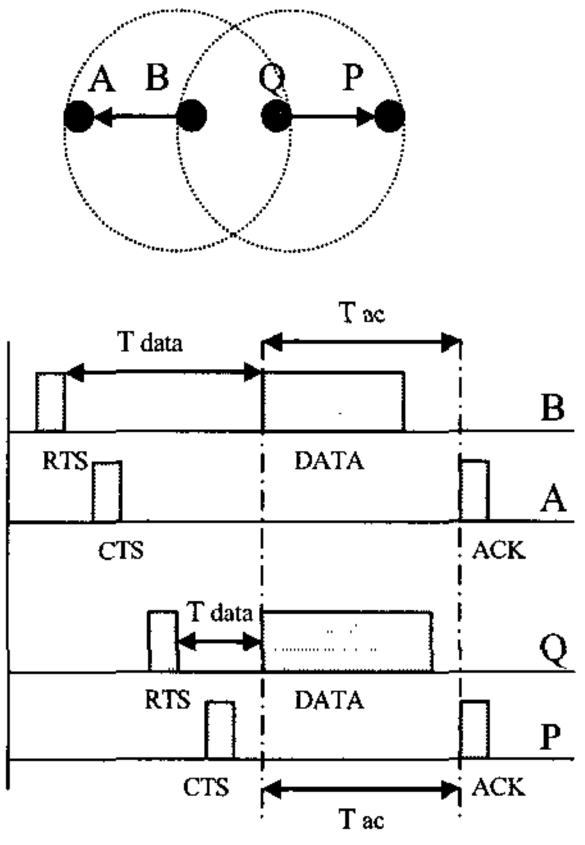

Fig. 5. Control gap MAC (a)

In Fig. 6, corresponding to case2 in Fig. 4a, when Q receives an RTS from P, it sends a CTS that alters the suggested transmission schedule by P to align it with the previously schedule transmission A to B. The RTS message is further enhanced to carry a bit which we call the inflexible bit, which indicates to the RTS receiver whether the transmission schedule proposed in the RTS message can be changed: if the bit is set, then this schedule cannot be changed. When a node receives a RTS where the inflexible bit unset, it may change the proposed schedule by modifying the TDATA and TACK of the RTS, and sending back the modified values on the CTS. When Q has overheard the CTS from B and is aware of a scheduled reception in its neighborhood. Thus, when it receives a RTS from P with the inflexible bit unset, it responds with a modified TDATA and TACK interval (shown as t1 and t2) so that Q's reception of data from P overlaps with B's reception.

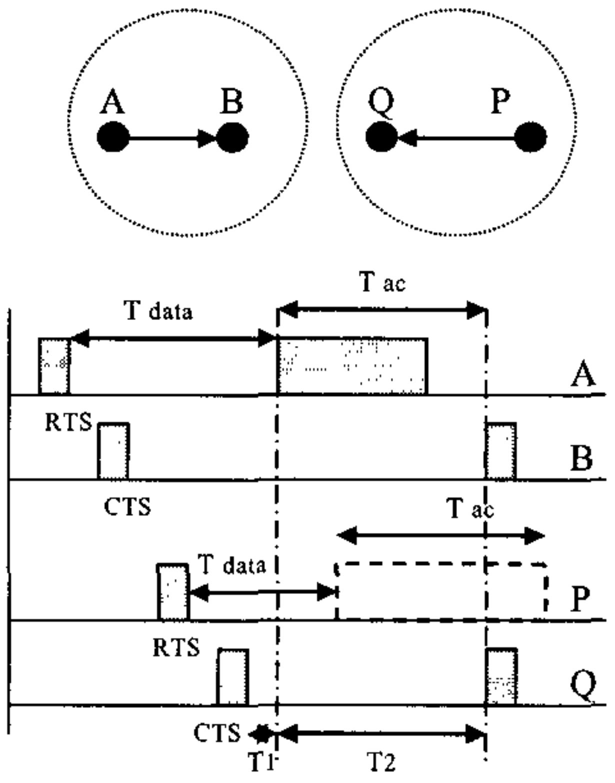

Fig. 6. Control gap MAC (b)

3.3 Two Master Transmission

In Fig. 7, Y is neighbor of Q and B, but Q is not a neighbor of B. The two transmissions A-to-B and P-to-Q have been scheduled, so Y has two masters, B and Q. When X sends a RTS to Y, the data transmission from X to Y must align with data transmission from P to Q, and Y's ACK align with B's ACK to A. In general, if a node has more than one master, it has to align the proposed DATA transmission with that of the master with earliest DATA transmission and align the ACK with that of the master with the latest ACK. Thus, all master recipient nodes other than the master with the latest ACK are blocked from scheduling any further receptions till the master transmission with the latest ACK, completes.

To solve this problem, we modified the MAC for utilize directional antennas and control gap together. When recipient receives ORTS from transmitter, it then returns DCTS to reply. In Fig.6, this means P has another data to transmit to Q before Y sends its ACK to X aligned with the ACK from B to A, and Q can schedule further reception from P by responding a DCTS to P, which will not interfere with Y's reception of data.

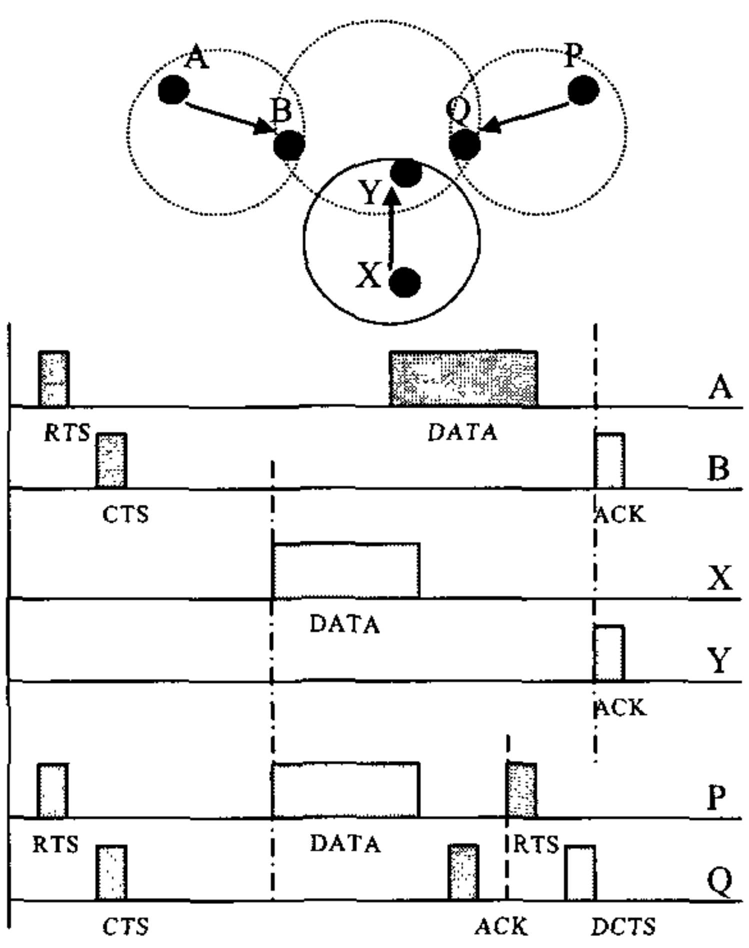

Fig. 7. Directional and Control gap MAC

3.4 Duration Period for Master Transmission

There is a details related to the implementation of the protocols. There is the necessary to attention this detail.

In MAC 802.11 protocol, the duration period is:

Duration period= RTS trans time+ SIFS+ CTS trans time+ SIFS+ Data trans time+ SIFS+ ACK trans time.

In proposed MAC protocol, the duration period of one pair is: Duration period (proposed) = RTS trans time+ Tdata of master (Fig. 5) + Tack+ ACK trans time. Where Tdata of master equates SIFS+ CTS trans time of master + SIFS+ RTS trans time of slave+ SIFS+ CTS trans time of slave+ SIFS. We can find a conclusion from these two equations that Tdata of master + Tack> 3SIFS + CTS trans time + Data trans time. So this protocol can be applied only if the packet size is greater than a certain threshold, which means this protocol only for large packets transmission.

Ⅳ. Performance Analysis

To evaluate the performance of our MAC protocol, our simulation uses QualNet [8], a discrete-event network simulator that includes a rich set of detailed models for wireless networking.

The following scenarios are configured for the performance evaluation of proposed protocol. We defined the parameter values in our simulation according to IEEE802.11 [13]. The nodes are placed over a 1500m×1500m flat terrain and SNR is 10.0dB as default value of simulation. We design the simulate model with the ring topology, as Fig. 8. This layout consists of an equal number of nodes, placed in inner and outer concentric circles, with all the inner nodes form a clique. While 802.11 does not allow more than one transmission at any given time for the concentric ring. The inner nodes form a clique, and the outer nodes are aligned with the inner nodes.

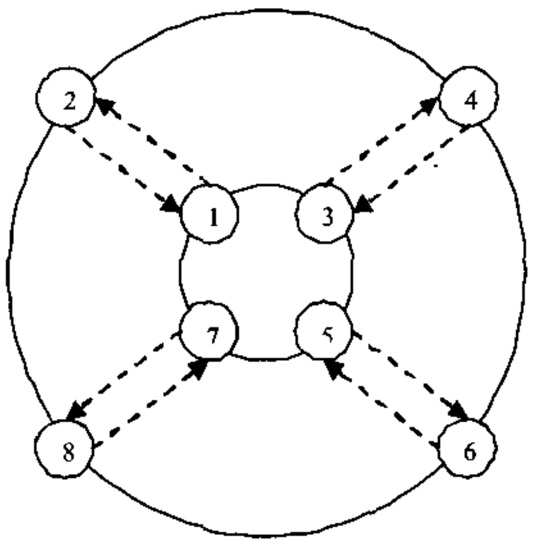

Fig. 8. Ring Topology

We defined frame size is 2304 bytes because of maximum MSDU (MAC Service Data Unit) on [13]. For the length of control gap, as we know, the control gap is between the RTS/CTS exchange of the first pair of communication nodes. It is exploited by other pairs of nodes to complete their own RTS/CTS exchange and to align their data transfer with the DATA and ACK packets of the first pair. If the length of control gap is small, other pair of nodes can not exchange their RTS/CTS completely, thus throughput is low. Whereas the length of control gap is very big, after other pair of nodes exchanging their RTS/CTS completely, they are need to wait for a long time before exchanging DATA, so it decreases the performance of throughput. Fig. 9 shows the optimal length of control gap. When the length of control gap is small, throughput is very low. With the increasing of length of control gap, throughput arises. For 4, 8 and 12 nodes, they get the peak of throughput at 320bytes, 640bytes and 704bytes, respectively. After that, there is a gradual decline reduction of throughput. We can see when the length of control gap at 640 bytes, the throughput for 8 and 12 nodes is similar, but after that it gets different throughputs between them. According as the different throughputs between 4, 8 and 12 nodes, we chose the length of control gap at 640bytes.

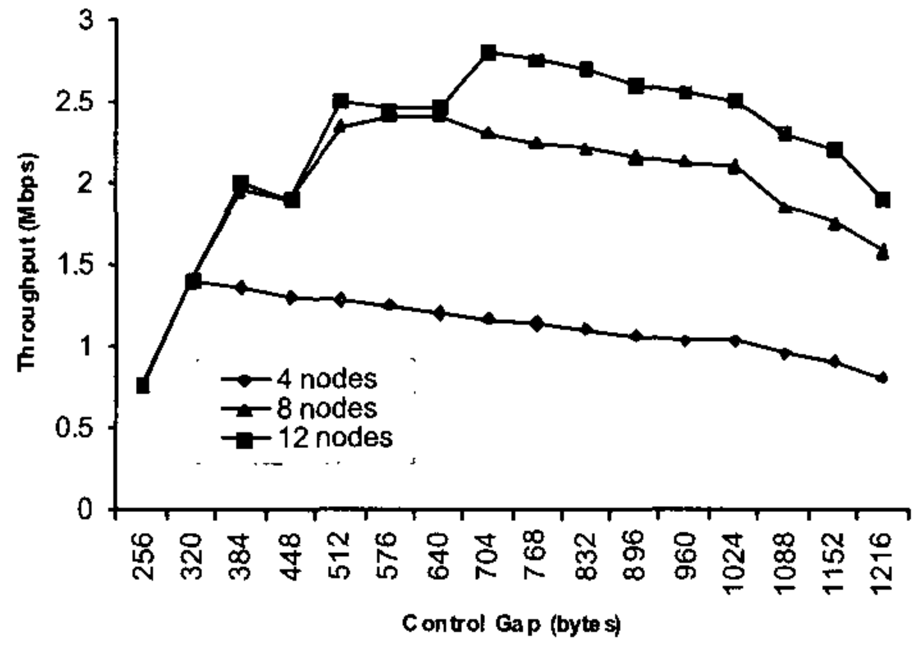

Fig. 9. Choice of Control Gap Length

This paper we evaluate the performance compared with the performance of IEEE 802.11 MAC. The main performance of this protocol is throughput and end-to-end delay. We first evaluate the throughput performance in Fig. 10. We can see the cumulative throughput for a traffic pattern with inner nodes. In the omni configuration, each node transmits and receives frames with the original IEEE 802.11. Because of in this situation, RTS/CTS reserve the use of channel and other neighbors that overhear these packets must defer their transmission. In another word, only one transmission can be allowed. Thus the performance of throughput is almost the same. While using our proposed protocol, we allow more than one transmission. Thus, the throughput of our protocol can give higher performance of throughput than 802.11. But there is a drop in throughput when the number of nodes exceeds 12. This caused because when the outer nodes get too crowded, an outer node comes within the carrier sense range of other inner nodes and schedule infeasible concurrent transmissions.

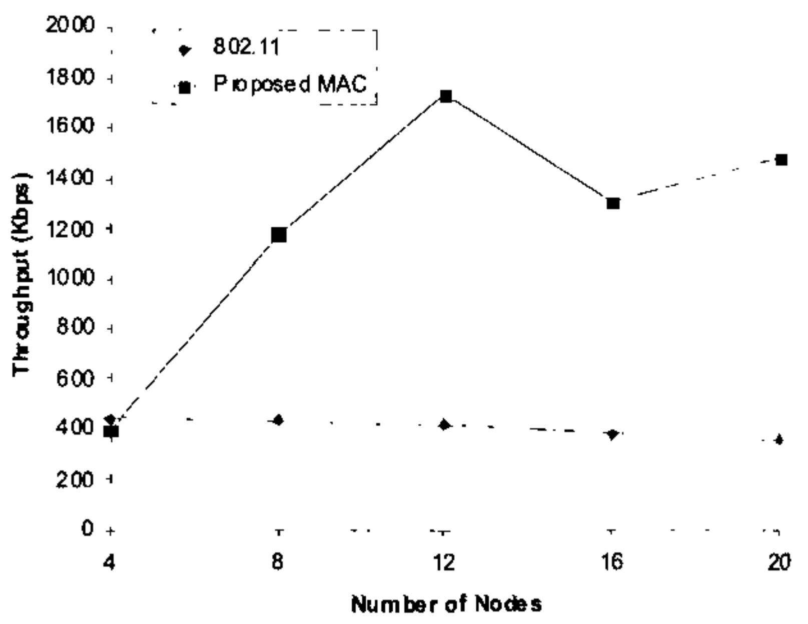

Fig. 10. Throughput in 802.11 & Proposed MAC

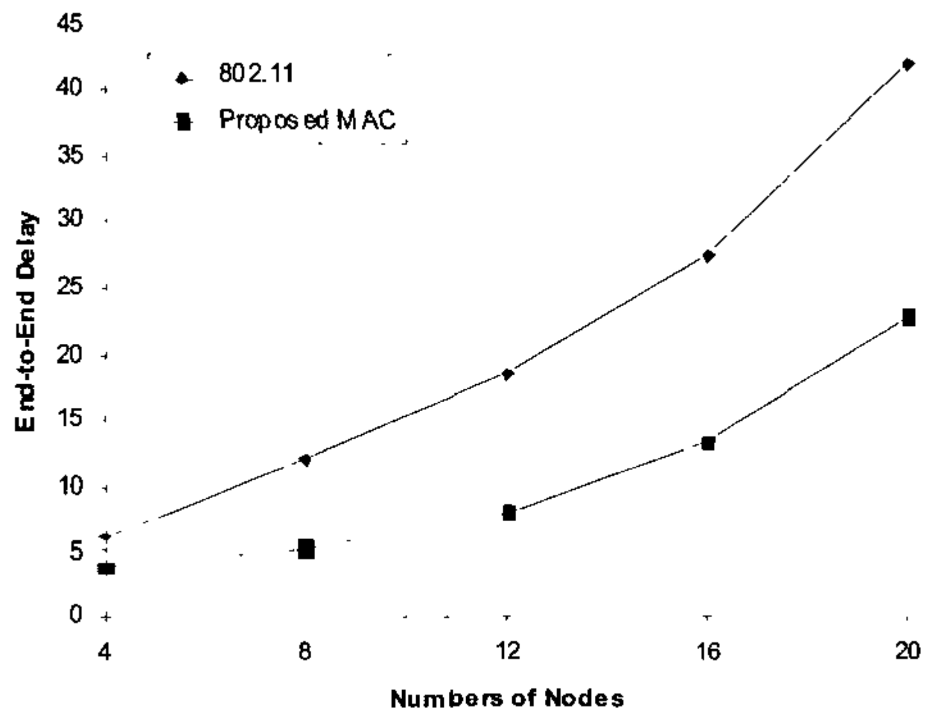

Fig. 11. Average End-to-End Delay

Then we evaluate the performance of average end-to-end delay. In Fig. 11, with the increasing of the number of the nodes, the average of end-to-end delay with 802.11 MAC protocol increased quickly. While the increscent average of end-to-end delay of proposed protocol is low. In this figure, it shows that the proposed protocol can reduce the average end-to-end delay caused by concurrent transmission.

V. Conclusions

In this paper we first discuss the disadvantage of 802.11 MAC which has limited to support for spatial reuse. Then we propose a new MAC protocol which address the position determination of pairs by ORTS and DCTS and improve the performance of spatial reuse by a control gap which set between the RTS/CTS and DATA/ACK packets. This gap realizes two pairs of neighbor nodes transmit DATA at the same time. Moreover, it allows two masters concurrent transmissions which achieve further improvement of the spatial reuse. Finally, we use the QualNet to evaluate the performance of our proposed MAC protocol in comparison with 802.11 protocols. The results show the potential for significant throughput improvement and average end-to-end delay decline. In subsequent work, performance studies on a larger and random network topology are needed to exhaustively show the performance features of our proposed protocol.

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