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A Distributed Channel Reservation Multiple Access Protocol for Multihop Mobile Ad Hoc Networks

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Abstract- **A novel multichannel MAC protocol, namely distributed channel reservation multiple access protocol, is presented for efficient channel sharing in multihop mobile ad hoc networks. It flexibly employs request-to-send and clear-to-send (RTS/CTS) dialogue on a common channel and selects conflict-free traffic channel to accomplish the transmission of data packet based on a novel channel selection scheme. The acknowledgment (ACK) packet for the data packet transmission is replied to the sender over another common channel, which effectively eliminates the influence of exposed terminal problem. The influence of hidden terminal problem is also greatly reduced because most of possible packet collisions on a single channel are avoided due to traffic load balance on multiple channels. In addition, any communication pairs within locality can take full advantage of multiple traffic channels without collisions and the spatial reuse of same channel are extended to neighboring communication pairs even within 2 hops from them. Finally, performance comparison of the proposed protocol with the CAM-MAC protocol is provided, and simulation results show that it outperforms the CAM-MAC protocol on total channel utilization, average channel utilization and average packet delay.**

Keywords: multihop mobile ad hoc networks, multiple access, channel reservation, collision avoidance.

I. INTRODUCTION

Mobile ad hoc network can be instantly setup when needed and can operate without relying on any existing infrastructure in the present of node mobility [1]. One of its key problems lies in the design of a medium access control (MAC) protocol, which deals with efficient channel resource sharing for multiple nodes during communications. Recent years, many MAC protocols applied in mobile ad hoc network have been studied intensively [2, 3]. IEEE 802.11 DCF [4] based on collision avoidance is a widely used single-channel MAC protocol, which includes CSMA/CA protocol and RTS/CTS protocol. Compared with the CSMA/CA protocol, the RTS/CTS protocol employs RTS/CTS handshake mechanism to decrease transmission collisions from the transmission time of long data packet to that of RTS mini-packet mostly due to hidden terminal problem [2] caused by the application of carrier sensing. This mechanism can partly weaken the influence of exposed/hidden terminal problem and prevent costly data packet collisions when every node in the locality of the sender and the receiver hears at least one control packet and defers transmission appropriately. In multihop ad hoc networks, however, this assumption does not hold, in general. Neighboring nodes are usually unable to receive the control packets because they are masked by ongoing transmissions from other nodes near them [5]. This means the exposed/hidden terminal problem can not generally be avoided, even under perfect operating conditions, such as negligible propagation delay, no channel fading, and no node mobility. In addition, as the increase of the mobile nodes, it will suffer severely collisions.

To achieve better channel sharing performance for a large number of mobile nodes with burst traffic, the design of multichannel MAC protocol is a good solution. By exploiting multiple channels, we can resolve exposed/hidden terminal problems easily just by using different channels and avoid data packet collisions with control packet by adopting split phase or dedicated control channel. The multichannel protocols have been proposed for wireless ad hoc networks can be classified into three types: channel hopping, split phase, and dedicated control channel [6]. In the first kind of protocol, the transceiver of all the mobile nodes hop to each channel based on common hopping sequence or its unique hopping sequence, and exchange data packets after handshaking on current channel or recipient's current channel [7, 8]. In the multichannel MAC protocols with split phase [9, 10], active nodes contend to reserve their wanted channel on a default channel during control phase and then transmit their data packets on the negotiated channel, which does not support traffic transmission during control phase on other channels. In addition, both of these two kinds of protocols need time synchronization, which is very difficult for wireless mobile ad hoc networks with distributed and multihop feature. Among them, the multichannel MAC protocols with dedicated control channel are proved to be the best.

Dynamic channel assignment (DCA) MAC protocol [11] is a typical dedicated control channel MAC protocol, in which each node exchange RTS/CTS packets on one control channel to select free traffic channel for transmitting data packet based on channel status (i.e., busy or free) recorded by itself. To achieve accurate channel selection, it employs two half-duplex transceivers on each node (Control transceiver will operate on control channel, while data transceiver will dynamically switch to one of the data channels).

In cooperative asynchronous multichannel MAC (CAM-MAC) protocol [12], idle nodes obtain channel usage information by overhearing transmissions in their locality on control channel and a cooperation mechanism to facilitate information sharing among nodes is proposed. It uses 4-way handshakes on dedicated control channel to

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confirm channel selection, and idle nodes send INV (invalid) packets to help their neighbors on traffic channel selections, both of which consume a lot of channel resource for the purpose of accurate reservation and easily result in heavy control traffic and severely contention collisions. Both of DCA and CAM-MAC do not solve the exposed terminal problem.

To solve these problems, a novel multichannel MAC protocol, namely distributed channel reservation multiple access (DCRMA) protocol, is presented for efficient multiple access in multihop mobile ad hoc networks. The rest of the paper is organized as follows. Section II introduces the network model of wireless multihop mobile ad hoc networks. Section III then presents the proposed protocol, followed by simulation results and discussion in Section IV. Conclusions are finally drawn in Section V.

II. NETWORK MODEL

Each mobile node has only one set of half-duplex transceiver and a unique identifier (ID). There are multiple channels (say N_{CH}) for use, herein, two of them are used for common channels (say CCH_1 and CCH_2), and the others are used for traffic channels (say TCH_0, TCH_1, …, TCH_{NTCH-1}), where N_{TCH} is the number of traffic channels and equal to (N_{CH}-2). Every node keeps a channel usage table to record TCH status (i.e. idle or busy) and necessary parameters (i.e. expiry timer of busy status). Usually every node senses CCH_1 for reception when it is not transmitting or receiving any packets and record TCH usage in the channel usage table by overhearing RTS/CTS packet on CCH_1. It is assumed that there are both sender's ID and recipient's ID in RTS and CTS mini-packets.

Assume that once a node receives a packet, it can immediately reply corresponding packet without any delay, i.e. there is no processing time during any event handling processes of nodes. Let t_p represent the signal propagation time of packet transmission from a node to its neighbors and t_{rt} represent the receiving-to-transmitting turn-around time of wireless transceivers, then after a node transmits the last bit of a packet to its neighbors, it will receive the first bit of response packet from its neighbors in a short interval τ, where $\tau=2t_p+t_{rt}$. For the purpose of only considering MAC performance, it is assumed that the failure of packet reception is only caused by the transmission overlapping of multiple packets on the same channel at the same time and not by channel link errors.

Node can obtain their 1 and 2-hop information by overhearing the control channel.

III. DCRMA PROTOCOL

A. Basic Protocol Description

In the DCRMA protocol, when a node A (i.e. sender A) wants to send data packets to some node B (i.e. recipient B), it will sense CCH_1 for a while. If CCH_1 is busy, node A will wait until CCH_1 becomes idle. If the channel is idle for some random contention window (CW) interval, it will send an RTS mini-packet on CCH_1 to its recipient B in which it designates an available traffic channel TCH_i by an ID-based channel selection scheme described in the following. If node B receives the entire RTS packet successfully and decides that the designated traffic channel TCH_i is also idle by checking its channel usage table, it will tune its transceiver from reception status to transmitting status to transmit a CTS mini-packet on CCH_1. If successful, node A will transmit its data packet on their selected traffic channel TCH_i. On receiving the data packet successfully, node B will return an acknowledgment (ACK) mini-packet on CCH_2 to indicate its successful reception of the data packet. Fig. 1 shows the principle of the DCRMA protocol.

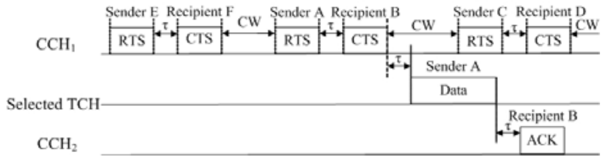

Figure 1. Principle of the DCRMA protocol.

B. Channel Selection Scheme

In the DCRMA protocol, an ID-based channel selection scheme is proposed. Assume that one of node C and D is one hop apart from one of node A and B. After sender A initiated a data transmission session (includes RTS, CTS, data and ACK packets) with its recipient B, sender C initiates another data transmission session with its recipient D. Then three kind of TCHs for sender C and its recipient D are defined, i.e. their default TCH, unused TCHs and conflict-free TCHs.

Default TCH of sender C and its recipient D is defined as the jth TCH (i.e. TCH_j), where $j=[(ID_C+ID_D)/2] \bmod N_{TCH}$. In the same way, the default TCH of sender A and its recipient B is the ith TCH (i.e. TCH_i), where $i=[(ID_A+ID_B)/2] \bmod N_{TCH}$.

Because sender C knows any node pair (say X and Y) within its neighbors and 2-hop nodes, it also knows the default TCH_k of node X and Y, where $k=[(ID_X+ID_Y)/2] \bmod N_{TCH}$. Let $\Phi_{adjacent}$ be the set of all the default TCHs used by X and Y, and Φ_{TCH} the set of all the TCHs. Then the set of unused TCHs is $\Phi_{unused}=\Phi_{TCH}-\Phi_{adjacent}$. The unused TCHs of sender C are the TCHs that is not its default TCH and are not used by its adjacent neighbors (include 1-hop and 2-hop neighbors which one of them is 1 hop away from sender A or recipient B).

Relative to already-existed data transmission session of sender A and its recipient B, the conflict-free TCHs of sender C and recipient D are TCH_{CF1}, TCH_{CF2}, TCH_{CF3}, and TCH_{CF4}. Where, $CF_1=[(ID_A+ID_C)/2] \bmod N_{TCH}$, $CF_2=[(ID_B+ID_C)/2] \bmod N_{TCH}$, $CF_3=[(ID_A+ID_D)/2] \bmod N_{TCH}$ and $CF_4=[(ID_B+ID_D)/2] \bmod N_{TCH}$. They are conflict-free because that it is not possible for any communication pair between node A, B, C and D to use these TCHs (except occasional cases) while sender A and its recipient B, and sender C and its recipient D initiate data transmission sessions, respectively.

Therefore, in the proposed ID-based channel selection scheme, after the beginning of data transmission session between sender A and its recipient B, sender C and its recipient D selects available channel for data packet transmission without collisions in the order of the following steps.

Step 1: The default TCH of sender C and its recipient D is selected at first if it is available.

Step 2: Otherwise, choose one of their available unused TCHs.

Step 3: Otherwise, one of their available conflict-free TCHs, i.e. TCH_{CF1}, TCH_{CF2}, TCH_{CF3}, and TCH_{CF4}, is selected in that order.

Step 4: At last, sender C and its recipient D backoff to avoid possible collisions with sender A and its recipient B just as RTS/CTS mode of IEEE 802.11.

C. Solution of Exposed Terminal Problem

The method that an ACK packet is sent over a dedicated channel CCH_2 other than traffic channel effectively eliminates exposed terminal problem which is introduced by the using of control packets transmission. As shown in Fig. 2, communication pairs A, B and C, D can use the same traffic channel to complete their data packets transmission.

Assume that while sender A initiated a data transmission session with its recipient B, sender C initiates another data transmission session with its recipient D. Thus node C is an exposed terminal of node A. Traditionally, the ACK packet transmission is completed on the traffic channel used by data packet transmission. In this scenario, collisions will occur if the two communication pairs use the same traffic channel as shown in Fig. 3. Node A can not receive the ACK packet correctly. However in our protocol, sender A and its recipient B, and sender C and its recipient D can use the same traffic channel to transmit data packet at the same time, because as shown in Fig. 4 node A will receive ACK packet on the dedicated channel CCH_2, which totally avoids the collisions described above. In the same way, while sender B initiated a data transmission session with its recipient A, sender D initiates another data transmission session with its recipient C, both of them can use the same traffic channel to transmit data packets without collisions.

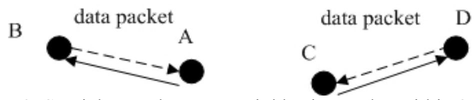

Figure 2. Spatial reuse between neighboring nodes within 2 hops.

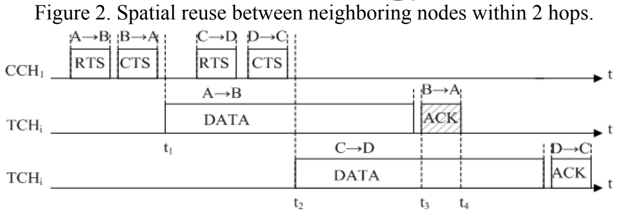

Figure 3. Collisions of ACK packet on node A due to exposed terminal problem.

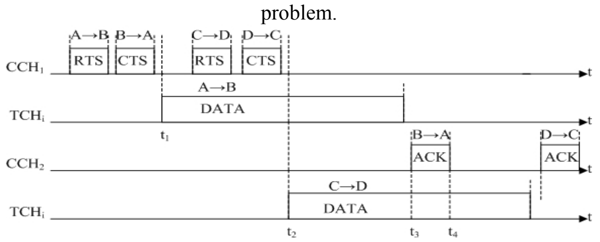

Figure 4. Collision avoidance of ACK packet transmission on node A.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

The scenario that 50 nodes are randomly distributed in the area of 1×1 km is considered in simulation. We simulate 10 different topologies under the same scenario and obtain the average value as the final simulation results. By this means, the mobility of mobile nodes is considered. We also simulate the performance of DCRMA-RF protocol and DCRMA-C1 protocol, in which in the former, a free traffic channel is selected randomly from all the traffic channels, and in the later there is only one dedicated channel CCH_1.

We use three performance metrics to evaluate a multihop mobile ad hoc network, i.e., total channel utilization, average channel utilization, and average packet delay.

Let R_b be the data rate of a traffic channel, and $R_{b\text{-}CCH}$ and $R_{b\text{-}TCH}$ the data rate of CCH and TCH, respectively. Let L_{PKT}, L_{RTS}, L_{CTS} and L_{ACK} be the length of data, RTS, CTS and ACK packets, respectively, and t_{PKT}, t_{RTS}, t_{CTS} and t_{ACK} their transmission time. The parameters of CAM-MAC protocol are set in the same way. All the parameter setting in the DCRMA protocol is according to the rules of the CAM-MAC protocol. In addition, in the DCRMA protocol, we assume that the sum of $R_{b\text{-}CCH1}$ and $R_{b\text{-}CCH2}$ is equal to the $R_{b\text{-}TCH}$, so that we can guarantee that both the two protocols always share the same bandwidth on control channel. The detailed simulation parameters are listed in Table I and II.

TABLE I
PARAMETERS FOR ETF MAC PROTOCOL

N	R (km)	R_b (Mbps) on CCH_1	R_b (Mbps) on CCH_2	R_b (Mbps) on TCH	L_{RTS}, L_{CTS} (bit)	L_{PKT} (bit)	L_{ACK} (bit)
50	0.2	0.75	0.25	1	162	4000	105

TABLE II
PARAMETERS FOR CAM-MAC PROTOCOL

N	R (km)	R_b (Mbps) on CCH&TCH	L_{PRA}, L_{PRB} (bit)	L_{INV} (bit)	L_{CFA}, L_{CFB} (bit)	L_{NCF}, L_{ACK} (bit)	L_{PKT} (bit)
50	0.2	1	169	177	81	65	4000

B. Performance Comparison on Channel Selection Schemes

Fig. 5, 6 and 7 show performance comparison of the DCRMA protocol with the DCRMA-RF protocol on total channel utilization, average channel utilization per channel and average packet delay respectively.

From Fig. 5 and 7, we can see that with the increase of N_{TCH}, total channel utilization increases and average packet delay decreases. When the N_{TCH} is 6 or more, both the total channel utilization and average packet delay become almost the same. The reason is that with the increase of offered load, the control channel becomes to be fully loaded and the offered load that could be distributed reaches its maximum.

From Fig. 6 we can see that with the same offered load, average channel utilization suffers greater degradation with the increase of the number of TCHs. The reason is that once the exchanges of control packets on CCH_1 becomes saturation, the total offered load that can be distributed to accommodate on all the traffic channels reaches maximum, more traffic channels result in less channel sharing on each traffic channel and cause resource wastage. In the scenario, the average number of neighbors of a node is about 5 and from the figure, when N_{TCH} is 2, the average channel utilization is the largest among all the N_{TCH} value. It means that for the case that there are 3 communication pairs within channel sharing locality and spatial reuse can be available for its adjacent area, 2 traffic channels is the most efficient for utilization on each traffic channel.

The figures also show that our channel selection scheme outperforms random traffic channel selection scheme on taking full usage of traffic channels. Compared with the DCRMA protocol, the DCRMA-RF protocol suffers lower total channel utilization, lower average channel utilization and higher average packet delay in the same way. This is because in the DCRMA-RF protocol, the sender randomly chooses a free traffic channel from all the traffic channels, which may cause a lot of wastage in channel resource, while in the DCRMA protocol the sender can flexibly select any conflict-free traffic channel based on the ID-based channel selection scheme and take full usage of all the available traffic channels. In addition, if N_{TCH} is 2 or more, there will be still a lot increase in total channel utilization of the DCRMA protocol, but less increase in that of the DCRMA-RF protocol as shown in figure 5.

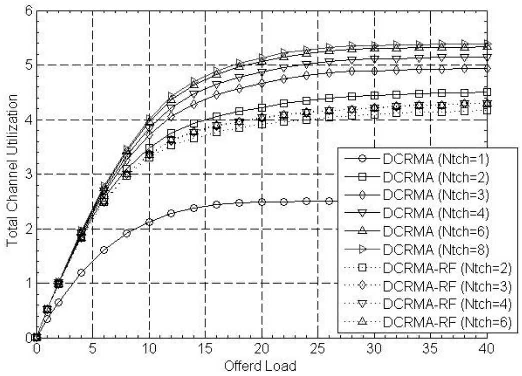

Figure 5. Compared with DCRMA-RF on total channel utilization.

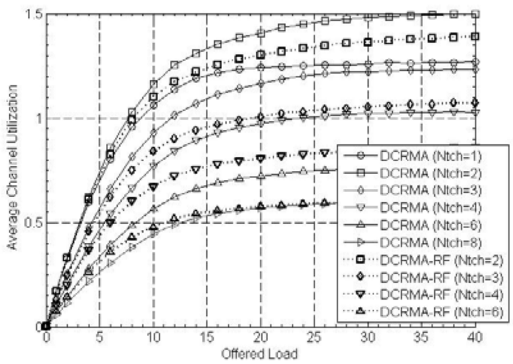

Figure 6. Compared with DCRMA-RF on average channel utilization.

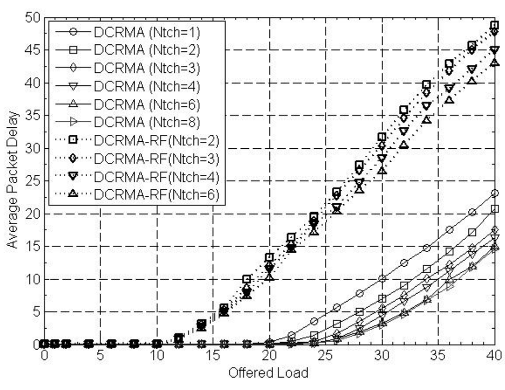

Figure 7. Compared with DCRMA-RF on average packet delay.

C. Performance Comparison on ACK Transmission Schemes

From the Fig. 8, 9 and 10, simulation results show that the DCRMA protocol outperforms the DCRMA-C1 protocol on total channel utilization, average channel utilization and average packet delay in the same way. Because the method that ACK packet is sent over CCH_2 other than traffic channel used by data packet transmission effectively eliminates exposed terminal problem and the spatial reuse of same channel are extended to the neighboring communication pairs even within 2 hops. As shown in Fig. 2, two neighboring communication pairs in locality can send data packets on the same traffic channel at the same time without collisions.

D. Performance Comparison with CAM-MAC Protocol

Fig. 11, 12 and 13 show performance comparison of the DCRMA protocol with the CAM-MAC protocol on total channel utilization, average channel utilization and average packet delay. In the simulation, we change the N_{TCH} to observe its influence on performance metrics. We can see that with the same parameters, the DCRMA protocol outperforms the CAM-MAC protocol on all the performance metrics. There are two reasons for that. Firstly, the DCRMA protocol simply uses 2-way handshakes to make a channel reservation for later data transmission, while CAM-MAC uses 4-ways handshakes to complete the contention before data transmission and during the procedure, idle nodes may issue INV packets to cooperation with the sender and receiver in traffic channel selection, both of which increase control overhead greatly and result in much easier transmission saturation on control channel. Secondly, in the DCRMA protocol, it uses a dedicated channel CCH_2 to transmit the ACK packet, which effectively eliminates exposed terminal problem introduced by the use of control packets transmission. In addition, using this method spatial reuse of same traffic channel is extended to the communication pairs which are within 2 hops. This case is illustrated in fig. 2, 3 and 4, the communication pair A, B and C, D can transmit data packets using the same traffic channel at the same time without collisions.

At high load, the DCRMA protocol will suffer little performance degradation due to better collision avoidance feature and better channel usage efficiency while the CAM-MAC protocol suffers a lot.

V. Conclusion

In this paper, we proposed an ID-based channel selection scheme, by adopting which we can effectively select conflict-free channel to complete the transmission of data packet. The use of another common channel for ACK packet transmission effectively eliminates the influence of exposed terminal problem which means that any communication pairs within locality can take full advantage of multiple TCHs without collisions and the spatial reuse of same channel are extended to other communication pairs even within 2 hops from them. Finally, simulation results show that the proposed protocol has better performance than the CAM-MAC protocol.

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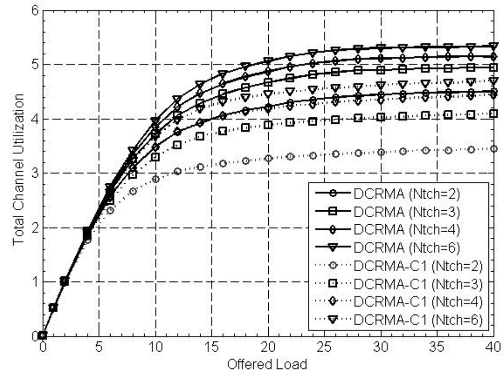

Figure 8. Compared with DCRMA-C1 on total channel utilization.

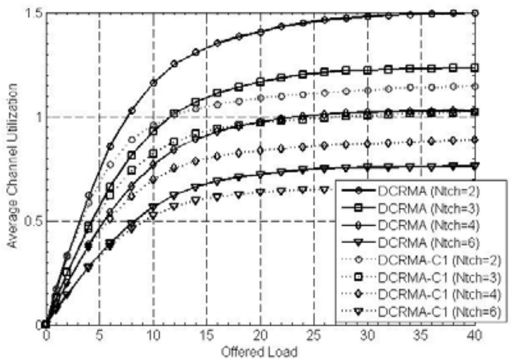

Figure 9. Compared with DCRMA-C1 on average channel utilization.

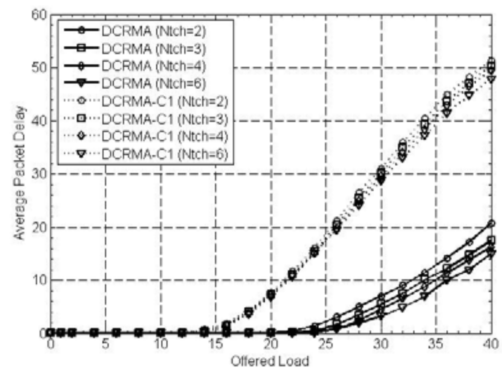

Figure 10. Compared with DCRMA-C1 on average packet delay.

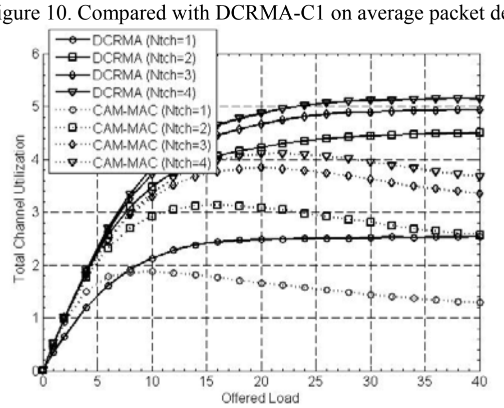

Figure 11. Compared with CAM-MAC on total channel utilization.

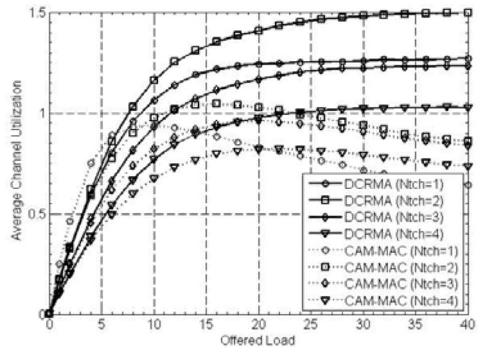

Figure 12. Compared with CAM-MAC on average channel utilization.

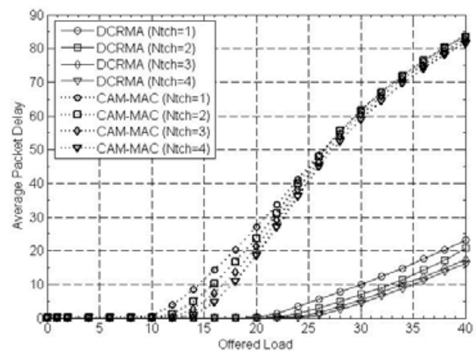

Figure 13. Compared with CAM-MAC on average packet delay.