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A New Exposed-terminal-free MAC Protocol for Multi-hop Wireless Networks

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Abstract

This article presents a new multichannel medium access control (MAC) protocol to solve the exposed-terminal (ET) problem for efficient channel sharing in multi-hop wireless networks. It uses request-to-send and clear-to-send (RTS/CTS) dialogue on a common channel and flexibly opts for conflict-free traffic channels to carry out the data packet transmission on the basis of a new channel selection scheme. The acknowledgment (ACK) packet for the data packet transmission is sent back to the sender over another common channel thus completely eliminating the exposed-terminal effects. Any adjacent communication pair can take full advantage of multiple traffic channels without collision and the spatial reuse of the same channel is extended to other communication pairs which are even within 2 hops from them. In addition, the hidden-terminal effect is also considerably reduced because most of possible packet collisions on a single channel are avoided due to traffic load balance on multichannels. Finally, a performance comparison is made between the proposed protocol and other typical MAC protocols. Simulation results evidence its obvious superiority to the MAC protocols associated with other channel selection schemes and traditional ACK transmission scheme as well as cooperative asynchronous multichannel MAC (CAM-MAC) protocol in terms of four performance indices: total channel utilization, average channel utilization, average packet delay, and packet dropping rate.

Keyword: wireless networks; multiple access; channel reservation; exposed terminal

1. Introduction

Wireless networks, such as satellite networks, high altitude platform based (HAP-based) networks, highly dynamic air-based self-organizing networks, mobile ad hoc networks and wireless sensor networks, have found wide application in communication. One of the key problems is multiple access, also known as medium access control (MAC), which deals with channel resource efficiently shared by multiple nodes in communication, such as communication among multiple ground stations or mobile users through a satellite, and communication between HAP and aircraft or among aircraft and unmanned air vehicles (UAVs). Currently, there are many multiple access protocols proposed to solve the problem about common channels shared by multiple nodes in wireless networks[1-2]. Most of them adopt random access mechanism or hybrid mechanism integrating random access with other access methods. As a typical example of the random access protocols, the request-to-send and clear-to-send (RTS/CTS) distribution mode of IEEE 802.11 MAC protocol[3] uses the RTS/CTS handshake mechanism to decrease the transmission collision time of long data packet to that of RTS mini-packet mostly caused by the hidden-terminal problem[1] in the context of multi-hop architecture, broadcasting-characterized wireless medium and the application of carrier sensing. As a typical hybrid access protocol in wireless networks, the user-dependent perfect-scheduling multiple access (UPMA) protocol[4] adopts random collision resolution scheme for active nodes to contend for access channel and acquire polling services without colliding with the help of centralized access points or cluster-heads selected by local nodes according to a clustering algorithm, i.e. channel access-based self-organizing clustering algorithm[5]. However, this kind of protocols is not efficient for mobile wireless networks due to overload in exchanging control packets to select cluster-heads thus over-exhausting power resource in cluster-heads to control traffic relay. As one of other kind of reservation protocols, the self-organizing time division multiple access (STDMA) protocol[6], which is adopted as the standard of very high frequency (VHF) digital link (VDL) mode 4 for air-based com-

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munication networks serves to be the only multiple access protocol supporting communication between air-based nodes or between air-based and ground-based nodes. However, it needs strict synchronization on the basis of global navigation satellite system (GNSS), which greatly increases complexity of the system, and what is more, other mobile nodes can not make immediate use of released slots when data burst transmission is required in a communication session. In addition, random reservation and collision avoidance scheme does not fit in with the presence of high traffic load and a profusion of active mobile nodes. Newly arrived active nodes due to mobility and hidden-terminal problem can cause severe packet collision even after successful reservation. Furthermore, the exposed-terminal (ET) problem caused by transmission of CTS and acknowledgment (ACK) packets[1] will greatly waste channel resource that nodes can otherwise use.

To improve the channel sharing performance for a multitude of mobile nodes with bursting traffic, developing a multichannel MAC protocol seems like a good solution. In general, current multichannel MAC protocols for wireless networks can be categorized into three sorts according to whatever mode it is with: channel hopping, split phase and dedicated control channel[7]. Of them, the multichannel MAC protocols with dedicated control channel prove the most ideal. In the first kind of multichannel MAC protocols, the transceiver of all the mobile nodes hops to each channel on the basis of common hopping sequence or its unique hopping sequence, and exchange data packets after handshaking on current channel or recipient's current channel[8-10]. In the multichannel MAC protocols with split phase[11-14], active nodes contend for reserving their wanted channels on a default channel during control phase and then transmit their packets on the negotiated channel during data phase. However, it does not support traffic transmission during control phase on other channels. In addition, both aforesaid kinds of protocols need a stretch of time to attain synchronization, which is very difficult to meet for wireless networks with distributive and multi-hop features.

As a typical MAC protocol with a dedicated control channel, the dynamic channel assignment (DCA) MAC protocol[15] is characterized by each node exchanging RTS/CTS by way of handshake on one control channel to select free traffic channel for transmitting data packet based on channel status, busy or free, recorded by the node. To ensure accurate channel selection, it is equipped with two half-duplex transceivers on each node.

In a cooperative asynchronous multichannel MAC (CAM-MAC) protocol[16], idle nodes obtain channel's usage information by monitoring transmissions in their locality and a cooperation mechanism is provided to facilitate information sharing among nodes. During channel reservation on the dedicated control channel, it uses 4-way handshakes to confirm channel selection and idle nodes send invalid mini-packets (INVs) to help their neighbors on traffic channel selections, which both consume a lot of channel resource for the purpose of accurate reservation and easily result in heavily-loaded control traffic and severely contending collision. In addition, both DCA and CAM-MAC protocols are in no position to solve the exposed-terminal problem.

To solve these problems, this article puts forward a new protocol, called exposed-terminal-free (ETF) MAC protocol, to achieve efficient channel sharing in multi-hop wireless networks.

2. Network Model and Assumptions

Each mobile node has only one set of half-duplex transceivers and a unique identifier (ID). There are multiple channels, N_{CH} channels, in use. Of them, two channels, CCH_1 and CCH_2, are used as control channels while the others, $\mathrm{TCH}_0, \mathrm{TCH}_1, \cdots, \mathrm{TCH}_{N_{\mathrm{TCH}}-1}$, are as traffic channels, where N_{TCH} is the amount of traffic channels equal to ($N_{\mathrm{CH}}-2$).

Each node has a channel usage table to record the status of traffic channels within its transmission range. In order to provide necessary information for selecting the proper traffic channel, the table of a node should contain current status of the traffic channel (busy or idle), ending time of the busy status, the IDs of the sender and the recipient with their hops from the node. In general, every node senses control channel CCH_1 for reception when it is not transmitting or receiving any packet, records TCH usage status in its channel usage table by overhearing RTS/CTS packets on CCH_1 and sets an ending time for the busy status of TCH usage. Upon reaching the ending time, the status of the TCH becomes idle. In addition, if the recipient indicated in the RTS packet is in the transmission range, it neglects the RTS packet to wait for the associated CTS packet.

Assume that once a node receives a packet, it immediately sends back a corresponding packet without any delay, which means leaving no processing time in the event handling processes of nodes. Let t_{p} be the signal propagation time of packet transmission from a node to its neighbors and t_{rt} the receiving-to-transmitting switch time of wireless transceivers, then after a node transmits the last bit of a packet to its neighbors, its recipient will deliver the first bit of response packet in a short interval τ, where $\tau=t_{\mathrm{p}}+t_{\mathrm{rt}}$. While taking into account MAC performance only, it can be supposed that the failure of packet reception is merely blamed for the transmission overlapping of multiple packets on the same channel at the same time rather than for channel link errors.

Generally, there are both sender's ID and recipient's ID in RTS and CTS mini-packets. Therefore, node can obtain its 1-hop and 2-hop nodes by overhearing RTS and CTS packets transmitted on the control channel CCH_1.

Let $R_{\text{b-CCH1}}$, $R_{\text{b-CCH2}}$ and $R_{\text{b-TCH}}$ be the data rate of CCH_1, CCH_2 and TCH, respectively; L_{PKT}, L_{RTS}, L_{CTS} and L_{ACK} the lengths of data, RTS, CTS and ACK packets; t_{PKT}, t_{RTS}, t_{CTS} and t_{ACK} their transmission time, respectively.

3. ETF MAC Protocol

3.1. Basic protocol description

In the ETF MAC protocol, when a node or a sender A wants to send data packets to another node or recipient B, it will sense CCH_1 at first. If CCH_1 is busy, node A will wait until CCH_1 becomes idle. If it is idle, after waiting for some random contention window interval (CW in Fig.1), which can be computed with binary exponential backoff algorithm in IEEE 802.11 MAC protocol or other backoff algorithms, it will send an RTS mini-packet on CCH_1 to the recipient B in which it designates an idle traffic channel TCH_i through a channel selection scheme, which will be described in the following. After successful receipt of the entire RTS packet, the node B checks if the designated traffic channel TCH_i is idle in its own channel usage table and if it is, it will change its transceiver from reception status into transmitting status to deliver a CTS mini-packet on CCH_1. If successful, node A will transmit its data packet on their selected traffic channel TCH_i. On successful receipt of the data packet, node B will return an ACK mini-packet on CCH_2 for confirmation. Fig.1 shows the principle of the ETF MAC protocol.

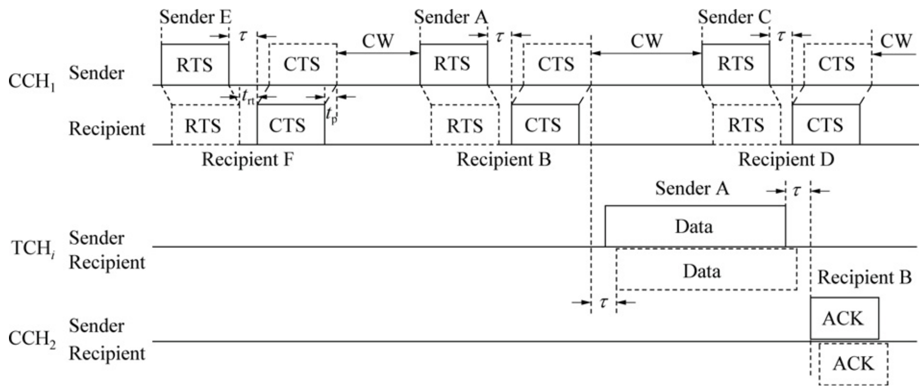


Fig.1 Principle of ETF MAC protocol.

3.2. Channel selection scheme

Assume that at least one of the nodes C and D is 1 hop away from one of nodes A and B. After sender A initiates a data transmission session (includes RTS, CTS, data and ACK packets) to its recipient B, sender C initiates another data transmission session to its recipient D. Then there are three kinds of TCHs for sender C and its recipient D to opt for: default TCHs, unused TCHs and conflict-free TCHs.

Default TCH for sender C to its recipient D is denoted by the jth TCH, i.e. TCH_j, where $j=[(ID_C+ID_D)/2] \bmod N_{TCH}$. In the same way, the default TCH for sender A to recipient B 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 1-hop and 2-hop nodes, it also knows the default TCH_k of nodes X and Y, where $k=[(ID_X+ID_Y)/2] \bmod N_{TCH}$. Let Φ_{TCH} be the set of all the TCHs, and $\Phi_{adjacent}$ the set of all the default TCHs of X and Y, then the set of unused TCHs is $\Phi_{unused}=\Phi_{TCH}-\Phi_{adjacent}$. The unused TCHs of sender C are those that are not its default TCHs and nor are used by its 1-hop and 2-hop nodes which are also 1 hop away from sender A or recipient B.

Apart from already existing data transmission session of sender A to its recipient B, the conflict-free TCHs of sender C to its 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, except the TCHs that have occasionally been occupied by other neighboring communication pairs, it is impossible for any communication pair consisting of either node A or B and either node C or D to use these TCHs when sender A and C initiate different data transmission sessions.

Therefore, in the proposed channel selection scheme, after the start of data transmission session from sender A to its recipient B, sender C and its partner-recipient D can choose available channel for data packet transmission without colliding by following the order of the following steps.

Step 1 The default TCH for sender C to its recipient D is chosen first if ready for use.

Step 2 If not, choose one of the unused TCHs, if available.

Step 3 If not, one of the available conflict-free TCHs should be chosen in the order of TCH_{CF1}, TCH_{CF2}, TCH_{CF3}, and TCH_{CF4}.

Step 4 If neither of TCHs can be used, it is necessary to await its default TCH to be available.

In addition, there are two rules governing a node to decide whether a traffic channel can be used or not. Firstly, check the channel usage table to find whether the status of the traffic channel is idle. Secondly, check the channel usage table to see whether a TCH can be used by two neighboring communication pairs at the same time. This will be explained later.

3.3. Solution to exposed-terminal problem

For sender A to its recipient B and sender C to its recipient D, if any communication pair between the node of A and B and the other node of C and D is at least 2 hops away from each other, their data transmission sessions do not collide even if they use the same channel at the same time.

Because of multichannel application, most of possible packet collisions on a single channel are avoided due to traffic load balance on multiple channels. In addition, any adjacent communication pairs can take full advantage of multiple TCHs without colliding and the spatial reuse of the same channel are extended to other communication pairs which are even within 2 hops from them.

The method that an ACK packet is sent over a dedicated channel CCH_2 other than traffic channel completely eliminates ET problem induced by the ACK packets transmission. As shown in Fig.2, in the case of successful exchange of RTS/CTS packets, sender A and its recipient B on one side, and sender C and its recipient D on the other can use the same traffic channel to accomplish their data packets transmission. So can sender B and its recipient A on one side and sender D and its recipient C on the other.

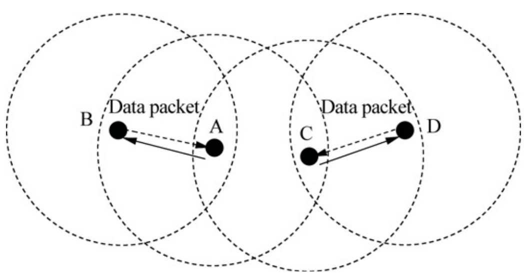
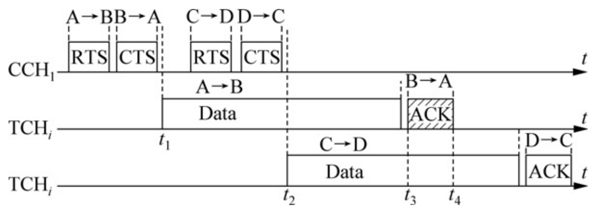
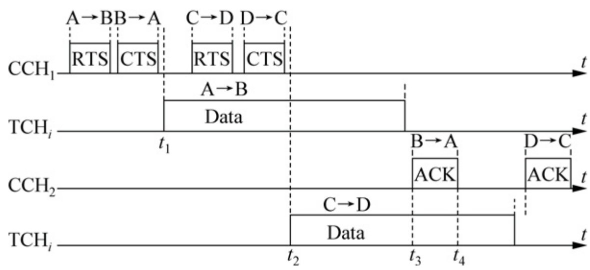


Fig.2 Exposed-terminal problem and spatial reuse between neighboring communication node pairs within 2 hops.

Assume that while sender A initiates a data transmission session to its recipient B, sender C begins initiating another data transmission session to its recipient D, then node C is an exposed-terminal of node A. Traditionally, the ACK packet transmission is conducted on the traffic channel used by data packet transmission. In this case, collision will occur if the two communication pairs use the same traffic channel (see Fig.3(a)), making node A unable to receive the ACK packet correctly. However, in our protocol, sender A and its recipient B on one side, and sender C and its recipient D on the other can use the same traffic channel to transmit data packet at the same time because, just as Fig. 3(b) shows, node A will receive ACK packet on the dedicated channel CCH_2, which is helpful to completely avoid the above described collision.



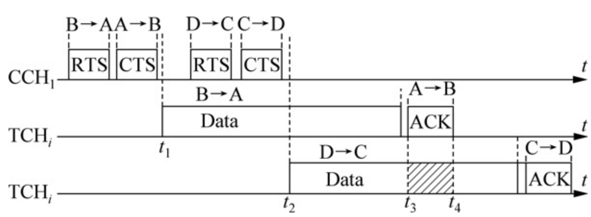
(a) Collision of ACK packet transmission on node A due to ET



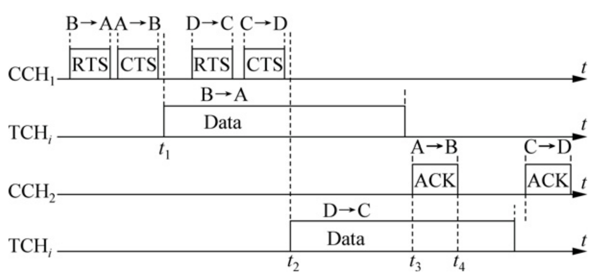
(b) Collision avoidance of ACK packet transmission on node A

Fig.3 Collision and collision avoidance of ACK packet transmission on node A.

The same is true of the case with sender B and its recipient A on one side and sender D and its recipient C on the other. To contrast, by the traditional scheme where the ACK packet transmission is carried out on the traffic channel used by data packet transmission, collision will occur if the two communication pairs use the same traffic channel (see Fig.4(a)) making node C unable to receive the data packet correctly. In the proposed protocol, both neighboring communication pairs can use the same traffic channel to transmit data packets without collision. Because node A transfers ACK packet on CCH_2, it totally does away with the transmission collision on node C (see Fig.4(b)).



(a) Collision of data packet transmission on node C due to ET



(b) Collision avoidance of data packet transmission on node C

Fig.4 Collision and collision avoidance of data packet transmission on node C.

4. Performance Evaluation

In this section, an evaluation is conducted on the performance of the ETF MAC protocol with channel selection schemes ETF-S1 and ETF-S2 as well as ACK packet transmission scheme ETF-C1 by using the OPNET modeler. In the ETF-S1 protocol, only the default channel is selected by a communication pair. In the ETF-S2 protocol, one channel is randomly selected from all the free traffic channels. In the ETF-C1 protocol, there is only one dedicated channel CCH_1, through which the ACK packets could be transmitted on the same traffic channel as is used by data packet transmission. Besides, a comparison between the proposed protocol and the CAM-MAC protocol is also made.

In order to evaluate multiple access performance of MAC protocols, four performance indices are used: total channel utilization, average channel utilization, average packet delay, and packet dropping rate. The total channel utilization of a multi-hop wireless network is defined as the proportion of the time used to successfully transmit data packets on all the TCHs in the network to the total simulation time. The average channel utilization as the total channel utilization averaged over the sum of the channels used in the network. The average packet delay as the average duration from the generation time of a data packet to the time of its reception by its recipient. The packet dropping rate as the ratio of discarded data packets due to transmission collision to the total generated packets. Assume that the packet generation process of a node follows Poisson process, let λ be the number of packets generated at a node per second, $N_{\text{received\_PKT}}$ the number of all the successfully received data packets, t_{sim} the total simulation time, D_i the delay time of the ith successfully received data packet and $N_{\text{dropped\_PKT}}$ the number of discarded data packets due to transmission collision. Then the transmitted load is equal to ($N\times\lambda\times t_{\text{PKT}}$), and the performance indices are expressed by

$$\text{Total channel utilization}=\frac{t_{\text{PKT}}\times N_{\text{received\_PKT}}}{t_{\text{sim}}}$$

$$\text{Average channel utilization}=\frac{t_{\text{PKT}}\times N_{\text{received\_PKT}}}{t_{\text{sim}}\times N_{\text{CH}}}$$

$$\text{Average packet delay}=\frac{\sum_{i=1}^{N_{\text{received\_PKT}}} D_i}{N_{\text{received\_PKT}}}$$

$$\text{Packet dropping rate}=\frac{N_{\text{dropped\_PKT}}}{N_{\text{dropped\_PKT}}+N_{\text{received\_PKT}}}$$

4.1. Simulation environment

In simulation, suppose that N nodes in R transmission range are randomly distributed in the area of 1×1 km. Ten different situations will be simulated under the same condition and average values obtained as the final results.

Let L_{PRA}, L_{PRB}, L_{INV}, L_{CFA}, L_{CFB} and L_{NCF} be the lengths of PRA, PRB, INV, CFA, CFB and NCF packets in the CAM-MAC protocol, respectively. Generally, the data rate of dedicated control channel $R_{\text{b-CCH}}$ is the same as that of $R_{\text{b-TCH}}$. For the purpose of fairly comparing the ETF protocol with other dedicated control channel MAC protocols, assume that the sum of $R_{\text{b-CCH}_1}$ and $R_{\text{b-CCH}_2}$ in the ETF protocol equals the data rate of dedicated control channel in other multichannel MAC protocols, which also equals $R_{\text{b-TCH}}$. In addition, to avoid ACK packet collision on CCH_2, the ratio of $R_{\text{b-CCH}_1}$ to $R_{\text{b-CCH}_2}$ is set to be 3:1. For instance, if $R_{\text{b-TCH}}$ is set to be 1 Mbps, then $R_{\text{b-CCH}_1}$ can be set to be 0.75 Mbps and $R_{\text{b-CCH}_2}$ to be 0.25 Mbps. Table 1 and 2 list the detailed parameters in simulation.

Table 1 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	4 000	105

Table 2 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	4 000

4.2. Performance comparison of channel selection schemes

Figs.5-8 show performance comparison between the ETF MAC, the ETF-S1 and the ETF-S2 protocols in terms of above-cited four indices.

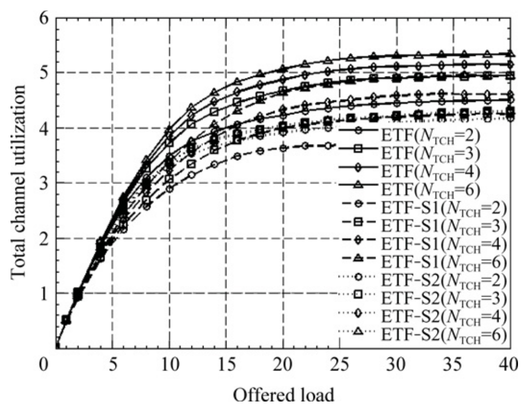


Fig.5 Compared with ETF-S1 and ETF-S2 on total channel utilization.

From Figs.5-8, it is observed that, with the same N_{TCH}, lower transmitted loads would be in large part unlikely to induce packet collision, which would result in lower packet delay, lower packet dropping rate and more achievable transmitted traffic loads. Increasing transmitted load would lead to slower increase in

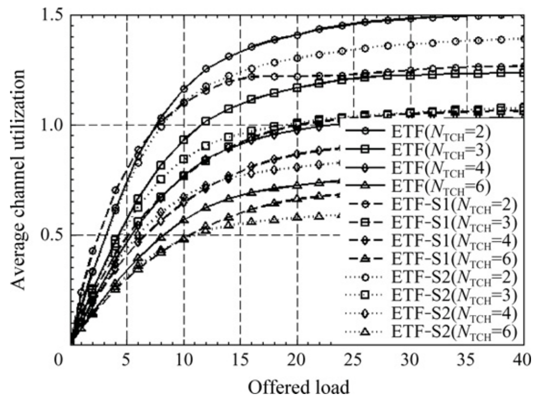


Fig.6 Compared with ETF-S1 and ETF-S2 on average channel utilization.

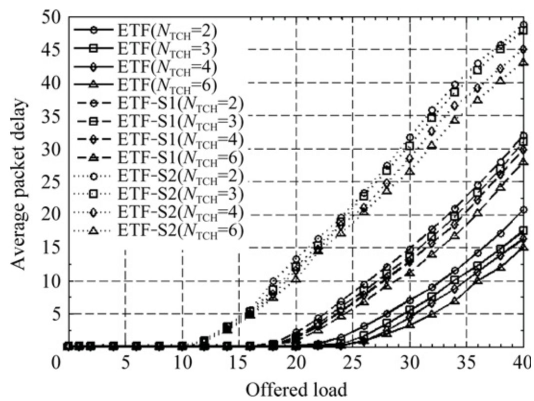


Fig.7 Compared with ETF-S1 and ETF-S2 on average packet delay.

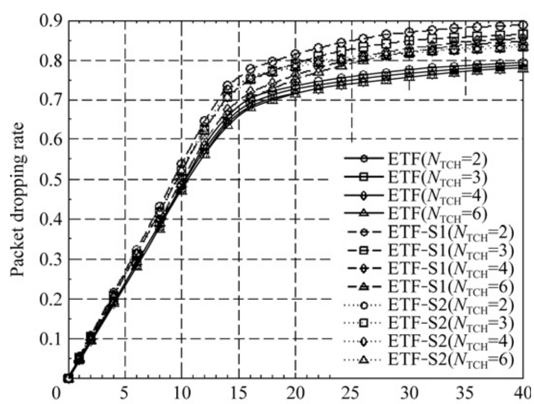


Fig.8 Compared with ETF-S1 and ETF-S2 on packet dropping rate.

channel utilization because a lot of nodes having data packet to transmit contend for reserving channels and severe packet collision on CCH_1 would cause unsuccessful reservation on traffic channel resource. When the transmitted load increases to 20-25 (see Fig.5), the channel utilization reaches the maximum and the average packet delay begins to rise exponentially. Since then, further increasing transmitted load would no longer improve channel utilization. This could be attributed to the saturated control channel CCH_1 and the transmitted loads that could be distributed to reach the maximum.

From Fig.6, it is observed that, with the same transmitted load, average channel utilization tends to decrease with the number of TCHs increasing. The reason is that once the exchange of control packets on CCH_1 becomes saturated, the total transmitted load on all the traffic channels reaches maximum, and the increase of the number of traffic channels results in less channel sharing on each traffic channel and causes resource wastage. In this case, the average number of neighbors of a node is about 5. From Fig.6, of all the possible values that N_{TCH} could be assumed, N_{TCH}=2 allows the average channel utilization to attain the maximum, which means that, with three adjacent communication pairs and spatial reuse available for its adjacent area, two traffic channels are the most efficient for utilization on each traffic channel. On the other hand, with the increase of N_{TCH}, the number of free traffic channels and the possibility that a traffic channel is idle if needed becomes larger, which results in the larger possibility of successful reservation on CCH_1. This would augment the entire channel utilization when N_{TCH} increases (see Fig.5). In addition, increase in N_{TCH} would significantly improve the entire channel utilization of the ETF MAC protocol as shown in Fig.5. However, this effect is not clear for the ETF-S2 protocol.

Figs.5-8 also evidence that the ETF MAC protocol outperforms the ETF-S1 and the ETF-S2 protocols in terms of all performance indices with the same N_{TCH}. For the ETF-S1 protocol, the scheme that provides only one default traffic channel for a sender to choose causes a lot of channel resource waste especially when there are many usable traffic channels. It is interesting that random free channel selection scheme in the ETF-S2 protocol shows worse performance than the proposed channel selection scheme which provides all kinds of free traffic channels to choose in a certain order. It can be ascribed that, by random free channel selection scheme, many active nodes might be more likely to select the same one free traffic channel thus resulting in unsuccessful reservation than by the channel orderly selection scheme, and the proposed channel selection scheme avoids possible conflicting channel selection results in advance. Therefore, these simulation results show that compared with other traffic channel selection schemes, the proposed channel selection scheme has considerably improved the multiple access performance.

4.3. Performance comparison of ACK transmission schemes

Figs.9-12 show performance comparison between the ETF MAC protocol and the ETF-C1 protocol in terms of above-cited four indices. It can be observed that the ETF MAC protocol noticeably outshines the ETF-C1 protocol in terms of all the performance indices. This is because the fact that, in the ETF-C1 pro-

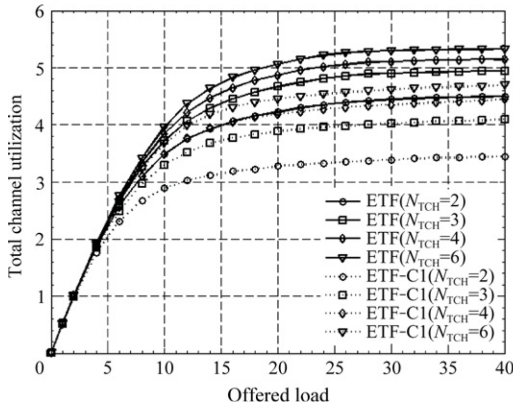


Fig.9 Compared with ETF-C1 on total channel utilization.

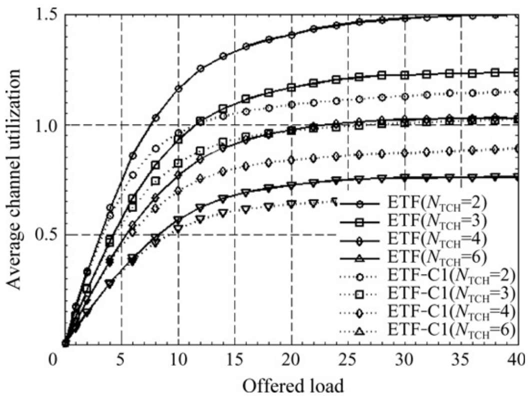


Fig.10 Compared with ETF-C1 on average channel utilization.

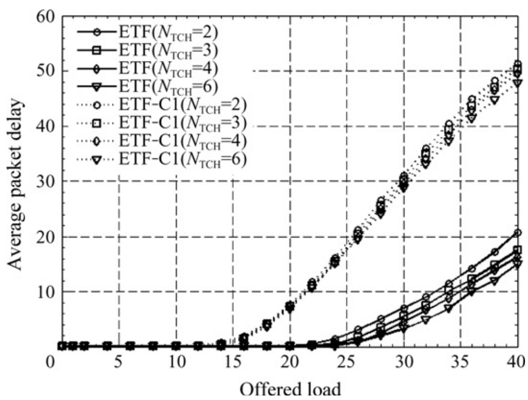


Fig.11 Compared with ETF-C1 on average packet delay.

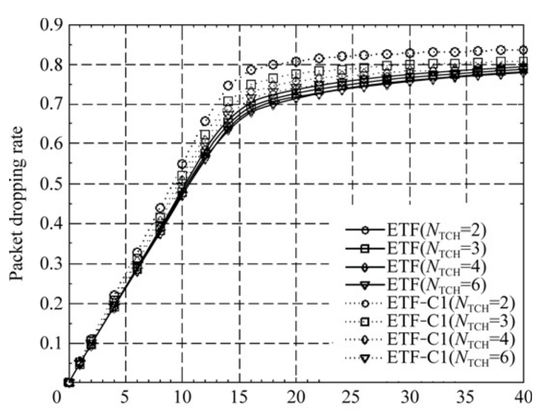


Fig.12 Compared with ETF-C1 on packet dropping rate.

tocol, the method that ACK packet is delivered on CCH_2 instead of traffic channels thoroughly settles the ET-induced problem and the spatial reuse of the same channel can be extended to the neighboring communication pairs even within 2 hops. As shown in Fig.2, two neighboring communication pairs can send data packet on the same traffic channel at the same time without packet collision.

4.4. Performance comparison of CAM-MAC protocol

Figs.13-16 show performance comparison of the ETF MAC protocol with the CAM-MAC protocol in terms of four indices. From Figs.13-16, it can be noticed that, with the same parameters, the ETF MAC protocol outperforms the CAM-MAC protocol in respect of all the aforesaid indices. This might be explained by two reasons: ① The ETF MAC protocol simply uses a 2-way handshake to realize a channel reservation for later data packet transmission while the CAM-MAC protocol requires a 4-way handshake to complete the contention before data packet transmission and uses idle nodes to issue INVs to avoid conflicting selection of traffic channel, which inevitably increases control workload and easily results in transmission saturation on control channel. ② The ETF

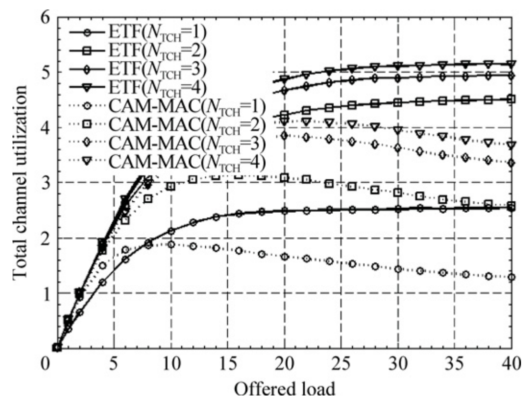


Fig.13 Compared with CAM-MAC on total channel utilization.

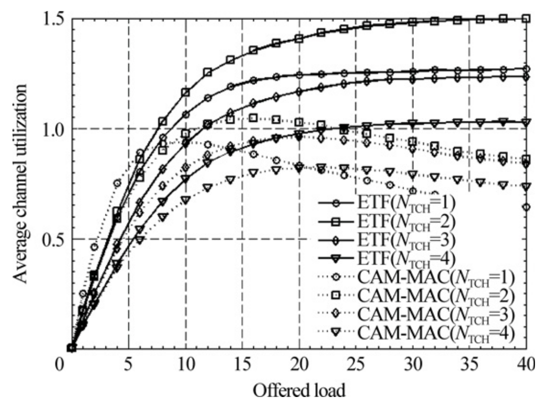


Fig.14 Compared with CAM-MAC on average channel utilization.

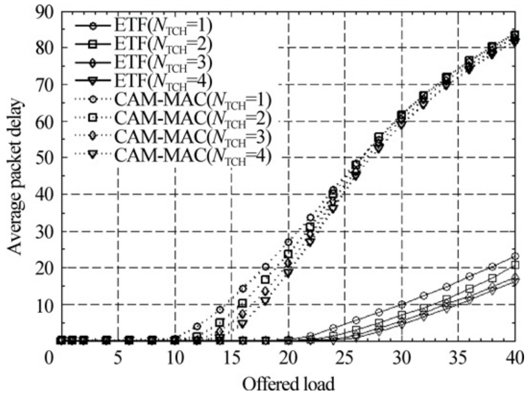


Fig.15 Compared with CAM-MAC on average packet delay.

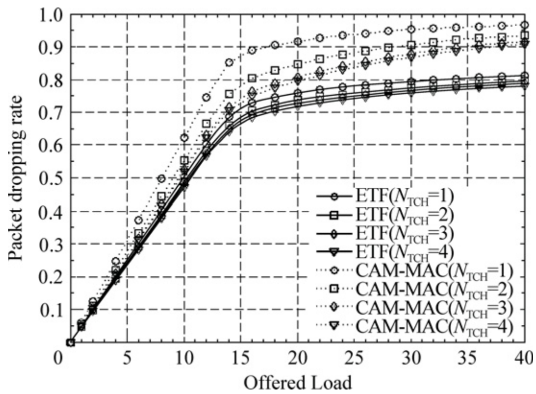


Fig.16 Compared with CAM-MAC on packet dropping rate.

MAC protocol uses a dedicated channel CCH_2 to transmit ACK packets, which completely eliminates the ET problem caused by the ACK packet transmission. Therefore, the spatial reuse of the same traffic channel can be extended to two communication pairs even within 2 hops, which leads to amelioration of multiple access performance. Figs.2-4 give out a firm testament to the above inference.

With transmitted loads increasing, there is no degradation of performance that could be found in ETF MAC protocol thanks to its stronger ability to avoid collision and better channel utilization efficiency. This is contrary to the CAM-MAC protocol in the same case, where the performance would be hurt a lot.

5. Conclusions

This article presents a new multichannel multiple access protocol, called ETF MAC protocol, for efficient channel sharing in multi-hop wireless networks. It employs a flexible RTS/CTS dialogue on a common channel and selects conflict-free traffic channel to realize the data packet transmission based on a novel channel selection scheme. The use of another common channel for ACK packet transmission completely eliminates the influences of exposed-terminal problem. Simulation results have shown the advantages of the proposed protocol over the MAC protocols associated with other channel selection schemes and traditional ACK transmission scheme as well as the CAM-MAC protocol.

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