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Prepare Tone: Enhancing Broadcast-Packet Transmission of Multiple Rendezvous Mac Performance in Multiple-Channel Ad Hoc Network

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Abstract

Multiple Rendezvous approaches utilized multi-channel which was only with a single transceiver radio may enhance Mac throughputs of multi-channel ad hoc network no less than that of other approaches which need extra radios or hardware for time synchronization. However, for the media-access methods of Multiple Rendezvous, nodes in ad hoc network should be listening on different channels to preserve the control packets of any data transmission with none-interference each other. Therefore, for any broadcast data packet or multicast data packet, it should be transmitted to its destinations like a set of single-cast data packets. And then other performances of ad hoc network as routing may be reduced by the high overload of broadcast packet. In order to reduce the transmission number of a broadcast packet, a method of using prepare tones (single-cast tone and broadcast tone) before data-packet transmission is presented, we called it PTMC (Prepare Tone for Media-access Control). In the method of PTMC, any broadcast packet will be send out only once to preserve it can reach any idle destination, which is not sending or receiving any data-packets at that time, nevertheless any single-cast packet will be matched and send out just as MAXM done. Simulation results among PTMC, MAXM and SSCH show: If every broadcast packet was send to potential receivers one by one, the throughputs of ad hoc network routed by AODV and media controlled by MAXM or SSCH may not be improved as the available channel number is increasing, for reasons of the routing discovery time increasing. Using PTMC to solve this problem, whatever data-traffics or available channels are provided, the throughput of PTMC will be better than the other two. Thus with available channels increasing, the throughput of PTMA is improved.

Keywords: Ad hoc; Media Access Control Protocol; Multi-Channel; Multiple Rendezvous; Broadcast; Throughput;

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1. Introduction

In wireless ad hoc network, MAC protocols address the problem of controlling access to the transmission medium in a broadcast network. Due to higher contentions and collisions, the performance of many presented single-channel MAC protocols as IEEE 802.11[1-5] is decreased quickly with the number of mobile hosts increasing by reasons of only one common channel shared by mobile hosts. To relieve this problem, using multi-channel protocols for parallel transmission on distinct channels is an efficient method for improving the throughputs, reducing data delays[6,7] and supporting QoS (quality of service) easier than single-channel MAC protocols [8]. However, the key limitation of multi-channel MAC protocols for ad hoc networks is that the sender and the receiver have to find each other's channel before communication with one another.

According to how devices agree on the channel to be used for transmission and how they resolve potential contention for a channel, Jeonghoon Mo[9] compared performances of these multi-channel mac approaches and differed them into four variations: Dedicated Control Channel, Common Hopping, Split Phase and Multiple Rendezvous.

Besides characteristics of Multiple Rendezvolus, MCMAC[10],SSCH[11],BTMC[12],SNDR[13],and MAXM[14] have enhanced the throughputs of multi-channel adhoc network by handling deadlock or matching problems as Fig.1(a)and(b) shown. Therefore, whatever access algorithms are adopted, some performances of ad hoc network as routing may be reduced by the high overload of broadcast packet as Fig.1(c)shown.

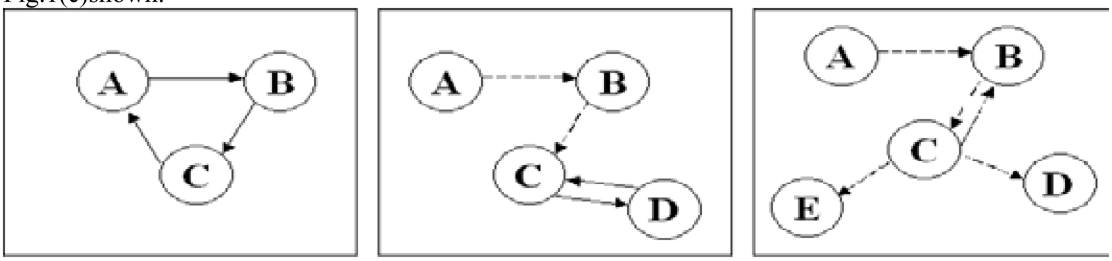

Fig. 1 (a) deadlock problem (b) matching problem (c) broadcast problem

- Dead Lock problem: Assumed shift-time is the shortest slot which consumed by every node tuning its channel, in Fig.1(a). When A, B, C attempt to send packet to each other at a same shift-time slot, none packet will be send out.
- Matching problem: In Fig.1(b), when Sender A tunes its channel to Receiver B which intends to send packets to busy node C (Note node A, B and C are on different channels), any packet from A to B will not be send out until transmissions between C and D end. Thus, wireless resource between the two matched transceiver pair (node A and B) is wasted.
- Broadcast problem: In Fig.1(c), when Node C wants to send a broadcast packet to Node B, D and E, for the reason of these three nodes in different channels, one transmission may not send the packet to all destinations.

In this paper, we propose an efficient multi-channel MAC protocol, named PTMC, for ad hoc networks. PTMC is a scheduled-access protocol which can be implemented easily. The idea of PTMC is to state all idle nodes on a common channel and start an received-control packet-received progress like MAXM done from two kinds of 'prepare tone'.

In section 2 and 3, the reason of problems of deadlock, matching and broadcast handled/solved by PTMC will be inllustrated. In section 4, a simulation among PTMC, MAXM and SSCH has been done. Simultation result shows PTMC is efficient.

2. PTMC protocol

Similar with MAXM, PTMC is presented as a two-dimension plane ad hoc network model.

- The topology of nodes can be described as an undirected graph. Each point described a node in an ad hoc network and an edge described two points can communicate with each other.
- Any node can only occupy one channel in a frame slot.
- Let data-transfer-speed of each channel constant be H.
- Whenever a node tunes its channel, it can work such action as send, receive or monitor after shift-time out only.

Compared with MAXM, PTMC used a special-channel to transmit two new control signals, such as single-cast prepare tone and broadcast prepare tone which similar with 'IDLE-TONE' used by MAXM. In this protocol, they are all used to control the progress of packet transmission with 'IDLE-TONE' together. In section 2.2, we will illustrate the assignments of these signal durations. Nevertheless, all these signals will be never interfered to any other packets.

2.1. Receiver-based Transmission Strategy

Then in PTMC, packet transmissions are refered to Receiver-based Strategy. A node that intends to send packet to a destination will tune its transceiver to the channel of the destination first. An intended sender will listen for the frame-start signal issued by the destination to initiate the frame.Thus it is possible for more than one intended senders to wait for the same destination. Hence, the receiver has to decide and announce the intended sender that could obtain the permission to send packet in this frame.

The definitions of states of nodes in an ad hoc network and their working progress are shown in Fig.2. Any node in this network run obeyed the following states under the following condition ①-⑥:

- idle state: When a node doesn't have transmission or intend to send or receive, we say the node is at idle state. Once the node stays at this state, there must be satisfied with one of the two conditions. The one is that the buffer of higher layer arrived packet is empty. The other is that in backoff slot once the receiver of the following sending packet is busy, we also call those nodes waiting for next attemptation are at idle state.

①when a node at idle state has packets to send out, after sending out a prepare tone, the node will change its state to intended-send state.

②when a node at idle state receive a prepare tone, the node will change its state to intended-receive state.

- intended-send state: When a node is intending to detect whether the receiver of the following sending packet is busy, we say the node is at intended-send state.

③ when a node is at intended-send state, if its destination of the sending packets allows it to send packet, the node will change its state to sending state. On the contrary, the node will change its state to intended-receive state.

- intended-receive state :When a node is intending to detect whether there are packets that will be send to it, we say the node is at intended-receive state.

④ when a node is at intended-receive state, if it found there is one or more than one nodes want to send packet to it, the node will select one node as its sender, then the node will change its state to receiving state. While none packet is detected to send to it, the node will change its state to idle state.

- sending state: When a node is sending packets to a receiver through its transceiver radio, we say the node is at sending state.

⑤ when the sending state of a node is out, the node will change its state to intended-receive state.

- receiving state :When a node is receiving packets which are send to it through its transceiver radio, we say the node is at receiving state.
  ⑥ when the receiving state of a node is out, the node will change its state to intended-receive state.

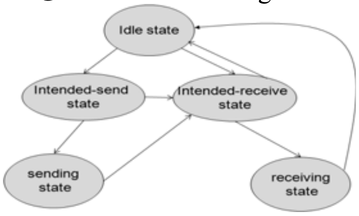

Fig.2 node state of PTMC

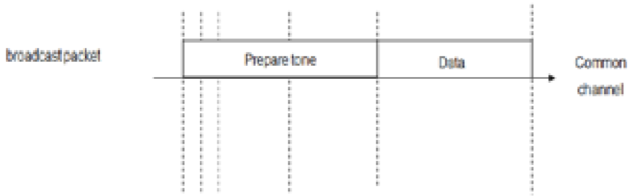

Fig.3 the frame structure of broadcast packet in PTMC

2.2. Frame Structure of PTMC

Fig.3 described the frame structure of a broadcast packet, as prepare tone and Data. Fig.4 described the frame structure of a single-cast packet. Every part of the frame structure defined as below must be send out under CSMA mode:

- single-cast prepare tone: A signal which is not interfered with any data packets can be detected form the common channel. The duration of a single-cast prepare tone is set to twice durations of shift-time in PTMC.
- idle tone: Another signal can both be detected and break on any data channel. The duration of idle tone is set to be longer enough to eliminate any channel error, like the eifs_time difined by IEEE802.11(b).
- broadcast prepare tone: A signal which is like single-cast prepare tone. But the duration is equal to the sum of single-cast prepare tone, twice durations of shift-time, twice the duration of idle tone and the duration of part A of single-cast packet.

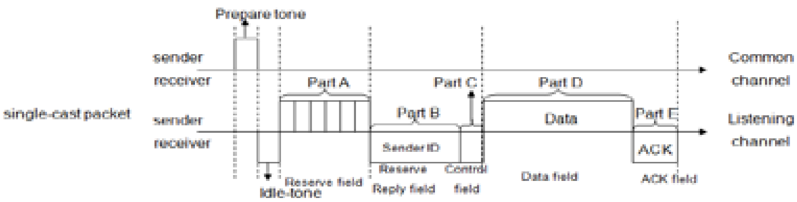

Fig.4 the frame structure of single-cast packet in PTMC

- Reserve field, Reserve reply field, Control field, Data field, ACK field are defined as MAXM done.

2.3. Protocol Behavious

- At the Receiver Side

In PTMC, when node B is an idle node and hearing a single-cast prepare tone on common channel. At the same time B will tune to its listening channel and change its state to intended-receive state. If the channel is idle, B should send out an Idle-tone immediately under CSMA mode, other status B should tune back to common channel and change its state to idle state.

After successfully sending Idle-tone, B detects Part A in the reserve field received. If any reservation bit of Part A is not zero, B should select a sender whose reservation bit is not zero and set 1 at the relative position in reserve reply field. If all reservation bits of Part A are zero, B should tune back to common channel and change its state to idle state.

After successfully sending out reserve reply field, B should change its state to receiving state, and wait for a Data packet arrived. If Data packets arrived and received correctly, B should reply ACK on its listening channel. If Data packets timeout, B should tune back to common channel and change its state to idle state.

After successfully sending out ACK, B should terminate the frame and tune back to idle state.

On the other hand, if the node B is at idle state and hearing a broadcast prepare tone on the common channel. After the duration of broadcast prepare tone, B should do nothing except waiting for a Data packet until the broadcast packet arrived or timeout.

- At the Sender Side

In PTMC, if node A is at idle state and it has data packet to send out, whether the demand of data transmission by node A is for the new packet arrived from higher-layer protocol or a data packet backoff ending, node A needs to listen on the common channel first. If the channel is idle, A should send out a prepare tone under CSMA mode on common channel immediately.

If the following packet is a broadcast packet, after broadcast prepare tone is over, A should send this packet on common channel.

If the following packet is a single-cast packet, after single-cast prepare tone is over, A should tune to the receiver's listening channel and change its state to intended-send state.

If the channel is busy, A should make a new backoff time for the following packet and change it to intended-receive state, other status A should wait for an Idle-tone arrived. If the Idle-tone timeout, A should make a new backoff time for the following packet and change to intended-receive state.

After Idle-tone arrived, A should break Idle-tone and set its reservation bit in Part A to 1, then wait for the reserve reply field of Part B. If Part B timeout or the transmission is not permitted by the receiver, A should make a new backoff time for the following packet and change it intended-receive state.

If the reserve reply field arrived and the receiver permits transimission, A should change its state to sending state and send out the singlecast data packet immediately.

After sending out the singlecast data packet, A should wait for ACK. If ACK arrived correctly, A should tune back to common channle and change its state to idle state for next transimission. Other status, A should make a new backoff time for the following packet, and also change its state to idle state.

3. Properties of PTMC

3.1. deadlock free

In PTMC, all 'prepare tone's are send on common channel under CSMA mode. Thus we know that if any two neighboring nodes send out prepare tone at the same time, the contention between two prepare tones will be detected and avoided. That is to say, there must exist a strict sequencing between any two prepare tones from neighboring nodes, in a word, every prepare tone has none overlaps in time sequence. Thus, if some nodes has been in deadlock status like Fig.1(a) shown, we can sure that there must exist an order that Node A, B and C tune to intended-send state. In this section, we assumed that Node A earliest changes to intended-send state at slot TA, Node B changes state at slot TB and Node C at slot TC. Therefore, it is obviously that there must exist such TA, TB and TC that are satisfied with equations (1) and (2), such as following,

$$TB > TA + 2*shift\text{-}time \quad (1)$$

$$TC > TB + 2*shift\text{-}time > TA + 2*shift\text{-}time \quad (2)$$

Then, at timet2=TA+2*shift-time+eifs-time has timed out, node A could detect Idle-tone and tune to intended-received state. Before time t2, node A has tuned its radio to its listening-channel and send out idle tone. As the equations (1) shown, at time t2 Node C can detect the idle tone of A and C will communicate with A. That is to say, by PTMC, the deadlock problem will be broken.

3.2. maximal matching

In PTMC, difference between any two neighboring nodes changing to intended-send state is at least twice of shift-time. Thus, once some nodes have wasted wireless resource like Fig.1(b) shown, we can sure that there must exist a slot that both node A and B are being at intended-send state.

At first, if TB described the time that Node B changed its state to intended-send state is earlier than the time of Node A changing to intended-send state. As the same as avoiding deadlock, after time TB+2*shift-time, Node A will communicate with Node B.

Secondly, if TB is later than TA, different states of Node B at TA are discussed as below,

B at idle state: After TA, B accepts a prepare tone and changes to intended-receive state, at TA +shift-time, Node B can communicate with Node A.

B at intended-received state: if the Idle-tone of Node B is not broken, the communication will be connected between Node A and Node B. On the contrary, if the Idle-tone of Node B is broken, B will tune to another node and communicate with it, that is to say, none wireless resource is wasted.

B at receiving-state or sending-state: As the assumption, node B must terminate communication before time TA+2*shift-time+eifs-time and changes its state to intended-receive state, idle state and intended-send one by one. Then Node A can detect the Idle-tone of Node B before time t2, that means a communication will be built correctively between A and B.

According to the Sheng-Hsuan's investigation[14,15] of maximal matching algorithm which proposed by Hsu-Huang[16] in MAXM, we have also proven that PTMC can make a Maximal set of matching transceiver pairs.

3.3. broadcast to any idle neighbors

In fact, if node A had sending a broadcast-tone in time interval of [TA,TB], PTMC can ensure all neighboring nodes which doesn't communicate with the other one in interval [TA,TB]can receive the broadcast packet from Node A restrictively. We first assumed that Node B is any neighboring node of Node A, different states of Node B at TA are discussed as following,

B at idle state: After TA, Node B receives a broadcast prepare tone, in this duration, B will do nothing until received the broadcast packet.

B at intended-send state or intended-receive state: if Node B doesn't communicate with the other node, before time of TA+2*shift-time+2*eifs-time, B will back to idle state and receive broadcast prepare tone.

4. Simulation

4.1. Environment of simulation

In this section, the Average Throughput (bits/sec) is used to evaluate the performance of Multi-channel ad hoc network routed by AODV[17] protocols. Average Throughput is the data quality successfully received by the node per unit time. In the simulations, we set 40 mobile nodes obeyed radonmess way points in scenes of ad hoc network by OPNET.

In scene 1, MAXM is used as media-access algorithm. SSCH is used in scene 2 and PTMC is in scene 3. In all scenes, a random number generator is used to assign pairs for channel shifts like SSCH done; then all scenes which set data packets coming from higher-layer are obeyed Poisson distribution, λ_A is their parameter that means the rate of package arrived. All data packet sizes are obeyed with exponential distribution, λ_S is their parameter. The control parameters are shown in Table. 1.

Table 1. An example of a table

Parameter	Classic data	Range / others	Parameter	Classic data	Range / others
Data arrived rate λ_A	15 packets/sec	5~20	Maximum long-retry numbers	4	Fixed
The length of packets λ_S	2048 bits	1024~4096	Average move speed	5 m/s	Fixed
Available Channels	10	3~40	Power	0.005 w	Fixed
Channel shift slots	100 us	Fixed	Receive threshold	-95db	Fixed
Channel Speed	1M bits/sec	Fixed	Network Area	10^6 m ^{2}	Fixed
Maximum short-retry numbers	7	Fixed			

4.2. Simulation results

Fig.5 has shown the trend of throughput varied with the parameter change. Two phenomena are objective, one is in any case the application by PTMC will never be lower than by previous protocols; the other one is when the number of available channels nears to node count, the throughputs of MAXM scenes and MCCE scenes will be limited by some bottleneck.

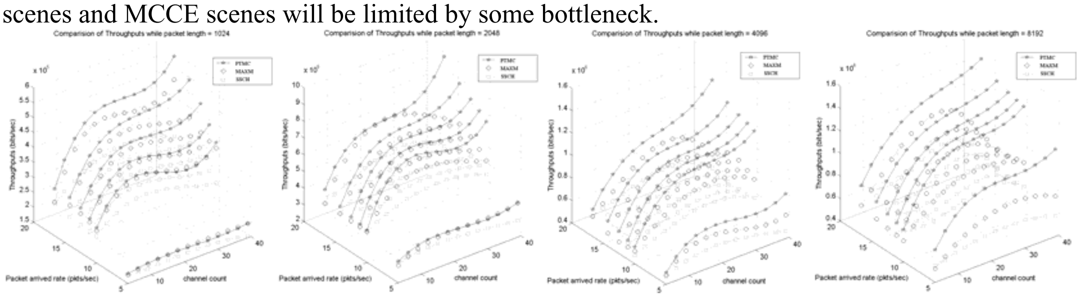

Fig.5. Comparision of Throughputs

In Fig.6, the trend of RouteDiscovery time describes an objective phenomenon that with the number of available channels increasing, overload of RouteDiscovery time in MAXM and SSCH would not reduce, while that in PTMC would decrease continuously.

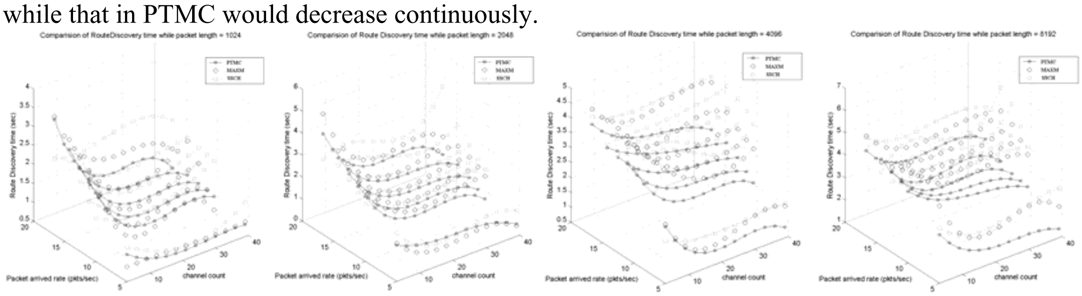

Fig.6. comparison of routing discovery time

5. Conclusion

In previous Multiple Rendezvous MAC protocols, the transmission of broadcast packets will due to mass protocol cost in an ad hoc network. The root reason is that any broadcast packet could not be transmitted to all of receivers only by one transmission. While PTMC is a new protocol used an algorithm of transmitting ‘prepare tone’ on common channel can make a broadcast packet can arrive all idle neighbors only by one transmission. The simulation results have shown, when the available channels are more in an ad hoc network, PTMC can reduce the cost of the ad hoc network routed by AODV and improve the throughput of network finally.

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