A Distributed Slots Reservation Protocol for QoS Routing on TDMA-Based Mobile Ad Hoc Networks

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***Abstract*— The paper presents a distributed slots reservation protocol (DSRP) for QoS routing on TDMA-based mobile ad hoc networks. According to one-hop neighboring information, Slot Decision Policy (SDP) is proposed to select the time slots in order to construct a route satisfying the QoS requirement. The hidden-terminal and exposed-terminal problems are solved as well. In addition, a slot adjustment mechanism is proposed to adjust the slots in a mobile host if slot conflict occurs in the reservation period. Route maintenance is also provided to maintain a route when the network topology is changed. By the simulation results, the proposed protocol can not only increase the search of a route with bandwidth requirement guaranteed but also raise the throughput and efficiency of the network.**

I. INTRODUCTION

A mobile ad hoc network (MANET) is an infrastructure-less network consisting of numbers of mobile hosts (MHs) communicating with one another via relaying messages among MHs through multihop wireless links. The main challenges of a MANET are its fast changing of topology and the lack of a global information. An MH has only its neighboring information due to its transmission capability, such as transmission range, battery power, and so on. These result in the difficulty of developing an efficient routing protocol for MANETs. A routing protocol for MANETs should not only be capable of finding a route for the communicating MHs but also tolerating highly dynamic changing of topology. A large number of researches on routing for MANETs could be found in the literature such as AODV, DSR, TORA, and so on [1], [2], [3]. Most of them try to find a shortest route between the source and the destination. However, they did not take quality-of-service (QoS) requirement into consideration. In addition to find a route from a source to a destination, a QoS routing for MANETs should also guarantee the end-to-end QoS requirement of the route, such as bandwidth needs, delay constraints, and so on. Recently, QoS routing protocols on MANETs have been studied extensively [4], [5]. QoS routing in MANETs is becoming an important issue.

In [6], a QoS routing protocol on CDMA over TDMA channel model is proposed. This protocol constructs the QoS route path depending on one-hop neighbors information. The hidden terminal problem is covered by assigning different codes for the concurrent transmissions within two-hop distance. The cost of the code assignment should be counted into the protocol as well. However, the code assignment is not discussed in the paper. Due to the high cost of using CDMA model, some researches investigate to find the QoS route only on the TDMA channel model [4], [5].

A TDMA-based bandwidth reservation protocol for QoS routing in MANETs is proposed in [4]. This protocol can solve the hidden-terminal and exposed-terminal problems by taking two-hop neighbors' slots usages into consideration. Each host maintains the two-hop neighbors' slots usages to select the appropriate slots for each link of the route. If there are many slots to select for a link, random policy is adopted. It has a high possibility that the protocol can not find any route satisfying the QoS requirements, even there exists a QoS route. On the other hand, the QoS routing protocol proposed in [5] is also based on the TDMA channel model. The protocol maintains one-hop neighboring information for the selection of slots in order to find a QoS route. A route maintenance mechanism for reconstructing a route when the route is broken is described as well.

In this paper, a Distributed Slots Reservation Protocol (DSRP) for QoS routing on TDMA-based mobile ad hoc networks is proposed. The hidden-terminal and exposed-terminal problems are taken into consideration as well. Slots reuse is the main concept of the protocol. The main differences of the DSRP from the [5] are slots reuse and slots adjustment mechanism. The slots that have least conflict with other MHs or have been used by other MHs are used first if they are valid to use. Thus, the successful rate to find a QoS route can be increased correspondingly. A slots adjustment mechanism is to adjust the slots usages of an MH to tolerant more routes passed by when the slots in an MH have been reserved or used by another route. Doing so can increase the successful rate of discovering a QoS route. Route maintenance is to maintain the connectivity of the QoS route and improve the efficiency of the route. Extensive experiments are performed to verify the superiority of the proposed protocol. The proposed protocol does outperform than the existing methods in call success rate and average delay time.

The rest of this paper is organized as follows. Section II presents the system model and describes the challenges in designing the QoS routing protocol on TDMA-based mobile ad hoc networks. Section III describes the Distributed Slots Reservation Protocol (DSRP), including slots selection policies, QoS route discovery, QoS route reservation, and QoS route maintenance. Simulation results are presented and analyzed in Section IV. Section V concludes the paper.

II. PRELIMINARIES

A. The System Model and Terminology

The paper proposes a Distributed Slots Reservation Protocol (DSRP) for QoS routing on TDMA-based mobile ad hoc networks. In TDMA-based channel model, time is divided into slots. Several slots form a frame. To distinguish the phases for control and data packets, a frame is generally divided into two subframes. One is the *control* subframe for control packets and another is the *data* subframe for data packets. Each slot can be used for one packet transmission.

Some technical terms used throughout the paper are defined as follows. Let $\mathcal{N}$ be the set of MHs. Suppose $A, B \in \mathcal{N}$. If A and B are within each other's transmission range, A and B are neighbors of each other, and vice versa. Let NB_A denote the neighbors of A. $NB_A = \{B \in \mathcal{N} \mid B$ is within the transmission range of $A.\}$. If B is a neighbor of A, there is a link between A and B, and vice versa. The link is denoted $\overline{AB}$. Here, the link refers to the bidirectional link. Unidirectional link is not under the scope of the paper. Let $\mathcal{L}$ be the set of links. $\mathcal{L} = \cup_{A \in \mathcal{N}}\{\overline{AB} \mid B \in NB_A\}$. Therefore, a mobile ad hoc network can be as a graph $\mathcal{G} = (\mathcal{N}, \mathcal{L})$, where $\mathcal{N}$ and $\mathcal{L}$ are defined as above.

Let n be the number of data slots in a data subframe and $\mathcal{T}$ the set of data slots in a data subframe. TS_A is defined as a set of data slots which A uses to send, RS_A a set of data slots which A uses to receive, and $FS_{\overline{AB}}$ a set of data slots for the link $\overline{AB}$ that A can use to send to B and B can use to receive from A. Note that the time slots discussed in the paper all mean the data slots, if no otherwise is notified.

B. Challenges of QoS Routing on TDMA-Based MANETs

It is difficult to design a QoS routing on TDMA-based mobile ad hoc networks. There are a lot of challenges to be conquered, such as the hidden terminal problem, exposed terminal problem, and the slots shortage problems. The challenges of QoS routing on TDMA-Based MANETs are briefly described as follows.

- ***Hidden and Exposed Terminal Problems —***
  Suppose A, B, and $C \in \mathcal{N}$. If $B \in NB_A$ and $B \in NB_C$, but $A \notin NB_C$ and $C \notin NB_A$, A and C are hidden terminals to each other. Under the circumstance, it will cause collisions if A and C send to B simultaneously due to the invisibility of hidden terminals. The hidden terminal problem is known to be a serious problem in multihop mobile ad hoc networks since it will cause collisions and further degrade the system throughput. On the other hand, the exposed terminal problem is explained as follows. Suppose A, B, C, and $D \in \mathcal{N}$. Assume that B wants to send to A ($A \in NB_B$) and C wants to send to D ($D \in NB_C$). If $C \in NB_B$, $A \notin NB_C$, and $D \notin NB_B$, the two communications (B sends to A and C sends to D) do not interfere with each other and can occur simultaneously. However, according to CSMA (Carrier Sense Multiple Access), one, either B or C, is inhibited from transmitting to its destination due to its exposure to another. The exposed terminal problem is viewed as a source of an inefficiency of the network.
  Take Fig. 1 as an example. Suppose S sends to B in slots $\{1,2\}$. B receives from S in slots $\{1,2\}$ and forwards to E in slots $\{3,4\}$. If E forwards to G in slots $\{1,2\}$, the collision will occur at B. This is the hidden terminal problem. Therefore, when an MH wants to transmit, it should take the hidden terminal problem into consideration in order not to collide with others. On the contrary, if C wants to send to A, C can reserve slots $\{3,4\}$ to send even B has used slots $\{3,4\}$ to send. This is the exposed terminal problem. When an MH wants to transmit, if it can consider the exposed terminal problem and use the slots that its neighbors have used, the others MHs can have more free slots to use.
  Thus, solving the exposed terminal problem can not only increase the network efficiency but also increase the successful rate of QoS routes findings.
- ***Slots Shortage Problems —***
  In addition to the hidden and exposed terminal problems, slots shortage problems are also a big challenge in designing a QoS routing on TDMA-based MANETs. Slots shortage problems mean the problems that there should exist at least one route from the source to the destination which satisfies the QoS requirement. However, for the sake of inappropriate slots selection, the route that originally exists can not be discovered now. The slots shortage problem caused by inappropriate slots selection will affect not only on the discovery of self route but also the discoveries of the neighboring routes.

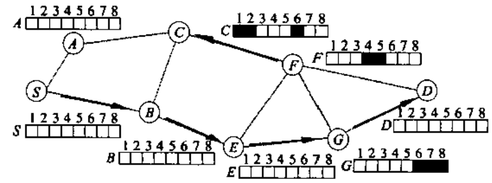

Fig. 1. The exposed terminal and slots shortage problems.

Slots Shortage for Self Route (SSSR): The slots shortage problem for self route (SSSR) is that there actually exists a QoS route between the source and the destination. But if the slots are selected inappropriately in any link of the route, this may cause the route which can not satisfy the QoS requirement between the source and the destination.
As shown in Fig. 1, suppose S wants to construct a QoS route to D and the QoS requirement is 2 slots. The slots $\{6,7,8\}$ in G have been used. Take the route $P : S \rightarrow B \rightarrow E \rightarrow G \rightarrow D$ as an example. Assume S uses slots $\{1,2\}$ to transmit to B and B uses slots $\{3,4\}$ to forward to E. Slots $\{3,4\}$ in E should be used to receive from B. E can not use slots $\{1,2\}$ to forward to G due to the hidden terminal problem. As a result, E has no sufficient slots to forward to G. Under such a circumstance, the route P can not satisfy the QoS requirement. On the contrary, for the same route P, if S uses slots $\{5,6\}$ to transmit to B and B uses slots $\{7,8\}$ to forward to E, E can use slots $\{1,2\}$ to continuously forward to G and G uses slots $\{3,4\}$ to forward to D. Therefore, the route P can satisfy the QoS requirement.
Slots Shortage for Neighboring Routes (SSNR): Slots shortage problem may affect the neighboring routes. Consider the same example discussed above. Suppose the slots in black color are used. For the same route P, according to the previous result, S, B, E, and G use slots $\{5,6\}$, $\{7,8\}$, $\{1,2\}$, and $\{3,4\}$ to transmit to B, E, G, and D, respectively. If there is a neighboring route P' from F to C, the QoS requirement is also 2 slots. One can easily observe that there is no sufficient slots for F to transmit to C. However, if S, B, E, and G respectively use slots $\{7,8\}$, $\{5,6\}$, $\{3,4\}$, and $\{1,2\}$ to transmit to B, E, G, and D instead, F can have enough slots ($\{7,8\}$) to transmit to C. Thus, not only P but also P' can satisfy their QoS requirements.
Taking slots shortage problems into consideration not only can increase the successful rate of route discovery but also the network throughput. So slots shortage problems are important issues in designing a QoS routing protocol on TDMA-based MANETs.

III. DISTRIBUTED SLOTS RESERVATION PROTOCOL (DSRP) FOR QOS ROUTING

The Distributed Slots Reservation Protocol (DSRP) is an on-demand slots reservation protocol for QoS Routing on TDMA-Based Mobile Ad Hoc Networks. When a source S wants to communicate with a destination D, the *Route Discovery Phase* will be initiated by S to search a QoS route to D. During the *Route Discovery Phase*, slot decision policy (SDP) decides which slots would be used in a link. On receiving the RREQ packet, *Route Reservation Phase* will be initiated by D to reserve slots for the route by replying a route reply (RREP) packet destined to the S. However, the slots that have been decided to reserve during *Route Discovery Phase* may be reserved by other requests during *Route Reservation Phase*. Hence, instead of rediscovering a new route, slot adjustment scheme will be initiated to coordinate the slots scheduling of the conflict MH with its one hop neighbors' scheduling. This is the main concept of DSRP, and the details will be described as follows.

A. QoS Route Discovery Phase

Let W, X, Y, and Z be MHs. Suppose Z receives a broadcast packet RREQ from Y, and this RREQ packet has not been received before. RREQ packet carries some routing information about *source id, destination id, current MH id, unique id, Path, bandwidth requirement(BR)*, and FS. $Path$ is the partial path that has been discovered so far, and *unique id* is for each route to avoid endless loop. FS records two information. One is free slot sets in the previous two contiguous links ($FS_{\overline{WX}}$ and $FS_{\overline{XY}}$) and temporary free slots set of $Y(FS_Y)$. Another is the slot utilization rates of $FS_{\overline{WX}}$, $FS_{\overline{XY}}$, and FS_Y. Then FS_Z and $FS_{\overline{YZ}}$ will be calculated similar to [4]. $SIP1 = \{t \in \mathcal{T} \mid t \notin TS_Y, t \notin RS_Y, t \notin TS_Z, \text{ and } t \notin RS_Z\}$, $SIP2 = \{t \in \mathcal{T} \mid t \notin RS_C, \forall\, C \in NB_Y, C \in \mathcal{N}\}$, and $SIP3 = \{t \in \mathcal{T} \mid t \notin RS_C, \forall\, C \in NB_Z, C \in \mathcal{N}\}$. If $FS_{\overline{YZ}}$ satisfies the QoS requirements, and there are three MHs recorded in $Path$ before Z ($P: W \rightarrow X \rightarrow Y \rightarrow Z$), Z will decide which slots would be used in $\overline{WX}$ ($FS_{\overline{WX}}$).

The principle of slot decision policy is that the slots with the least conflict in the next two links are preferable to be selected. If the slots which are also available in the next two contiguous links are selected, the available slots in next two contiguous links will be lessened. Then slots shortage could be happened in the next two link. Therefore, by this principle of slot decision policy, the probability of SSSR problem will be decreased.

However, number of the slots with the least conflict in the next two links may be more than bandwidth requirements. Instead of randomly choosing slots to send, DSRP takes the slots utilization rate into consideration to pick up more suitable slots for using. The slots with higher utilization rate have higher priority to be selected. By this way, the slots reuse rate can be increased, more routes can exist at the same time in the network, and the SSNR problem will be mitigated.

If Z is the destination MH, the slots in $\overline{XY}$ and $\overline{YZ}$ would be also decided by least conflict and most reuse slots decision policy, and call Route Reservation function to reserve slots. The detailed procedures are shown in Algorithm 1 and Algorithm 2.

B. QoS Route Reservation Phase

Let M and N be MHs. When M receives the RREP, it checks that if itself is listed in Path of RREQ or not. If M is in Path, it reserves the relative slots and sends the RREP packet to the source along the $Path$.

Unfortunately, if the slots which M has decided to reserve are reserved by other requests, M will collect slots information in $SA\_members$ to decide which slots could be used by broadcasting SA_REQ. SA_REQ is similar to RREQ packet, and $SA\_members$ are the neighboring MHs of M. After receiving free slots information in SA_REP from $SA\_member(N)$, *Slot_Adjustment_Alogorithm()* will be used to decide which slots would be used ($US_{\overline{MN}}$). Finally, M sends SA_EXE packet which contains $US_{\overline{MN}}$ to $SA\_members$ for reserving slots. The detailed procedure is shown in Algorithm 3, and *SAA* will be described in next subsection.

1) Slots Adjustment Algorithm(SAA): The *SAA* is a branch-and-bound technique. The jammed MH will construct a slots adjustment tree according to its 1-hop neighboring slots information. The tree node will be branched to several children if it has the possibility for slots adjustment. The tree node will be pruned if there exists another tree node whose level is lower than itself. Finally, each path from the root to the leaf is a valid adjustment. The shortest path is the final solution. If there are also many solutions with the same level, we choose the path with least nodes to be a solution.

A{1, 2, 3, 5, 6}
B{3, 4, 9, 10}
C{3, 4, 5, 6}
D{7, 8, 5, 10}
Y{1, 3, 5, 7}

(a) Slot conflict status

Y1 - Y3 - B3 - B9
Y1 - Y3 - B3 - B10
Y1 - Y5 - C5 - C4 - B4 - B9
Y1 - Y5 - C5 - C4 - B4 - B10
Y7 - Y3 - B3 - B9
Y7 - Y3 - B3 - B10
Y7 - Y5 - C5 - C4 - B4 - B9
Y7 - Y5 - C5 - C4 - B4 B10
Y7 - D7 - D10

(b) The solution of slots conflict

Fig. 2. An example of Slots Adjustment Algorithm.

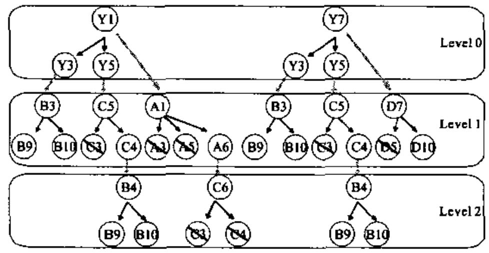

Fig. 3. The tree of the Slots Adjustment Algorithm.

Take Fig. 2(a) as an example. The circled slots are reserved beforehand, and there is a slot collision in slot 1 between Y and A (Y_1 and A_1). There are two solutions to prevent from slot collision in slot 1. One is Y chooses slots 3 and 5 instead. *SAA* which is shown in Fig. 3 solves the slots collision problem by establishing a tree. The root is Y_1 and the children of Y_1 are Y_3 and Y_5. If Y_3 is taken into consideration to replace Y_1, another slot collision will happen between Y_3 and B_3. In order to prevent from the second slot collision, B_9 and B_{10} could be chosen. So by *SAA*, B_3 is a child of Y_3 and a parent of B_9 and B_{10}. Therefore, from root to leaf node, $Y_1 \rightarrow Y_3 \rightarrow B_3 \rightarrow B_9$ and $Y_1 \rightarrow Y_3 \rightarrow B_3 \rightarrow B_{10}$ are two possible solutions of adjustment.

Another solution is A picks up slot 3, 5 and 6 instead. However, A_3 collides with B_3, the solutions of adjustment is discussed before, and the height of $Y_1 \rightarrow Y_3 \rightarrow B_3 \rightarrow B_9$ is shorter than $Y_1 \rightarrow A_1 \rightarrow A_3 \rightarrow B_3 \rightarrow B_9$. So A_3 will be pruned. Similarly, A_5 is pruned as well. Likewise, all of the possible solutions are shown in Fig. 2(b). Finally, the adjustment $Y_7 \rightarrow D_7 \rightarrow D_{10}$ will be chosen.

C. Route Maintenance

We establish a QoS route to send after route constructing process. However, networks topology changes any times, so that routing path may break by MH moving out the transmitting range. If a MH X detects the forward node leaving, a route maintenance scheme will be initiated to search a new route. This searching a maintenance route scheme is similar to DSRP. At beginning, X broadcasts MT_REQ packet to search a new route. If the destination MH receives the MT_REQ packet, it will reply a MT_REP packet to establish partial route. Else X will send a MT_ERR packet to source MH by unicast for re-initiating DSRP to discover a new route. After a period of time, the other MHs in original route behind X will release time

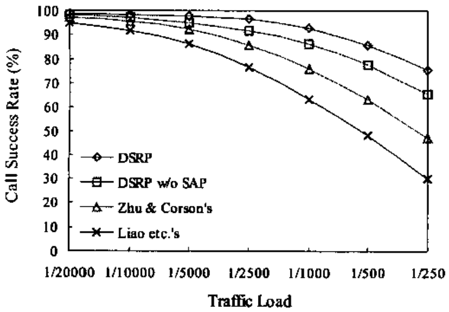

Fig. 4. Call success rate vs. traffic load.

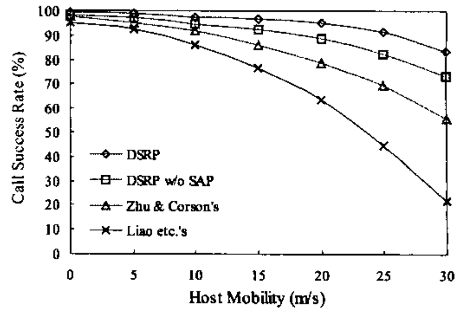

Fig. 5. Call success rate vs. mobility.

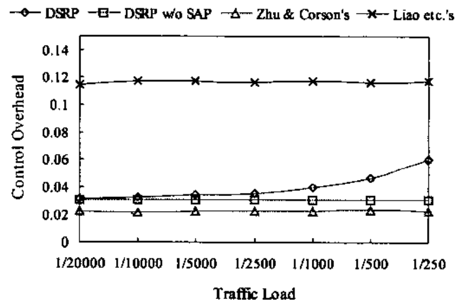

Fig. 6. Control overhead vs. traffic load.

slots reserved for previous link for others using.

IV. SIMULATION RESULTS

We have developed a simulator to evaluate the performance of DSRP comparing with related work [4], [5] from several aspects. There are 30 MHs in 1000m $\times$ 1000m area. The transmission range is 300 meters, the transmission rate is 11 M bit/s, and the QoS bandwidth requirement is 2 slots. Each frame has 16 data slots, and each time slot is 5 ms. The source-destination pairs are generated randomly, and the total simulation time is 1000 sec.

A. Call Success Rate

The call success rates of different protocols(DSRP, DSRP w/o SAP, Zhu & Corson's, and Liao etc.'s) are compared under various traffic loads in Fig. 4. DSRP w/o scheme is DSRP without slot adjustment scheme, and the mobility is 10m/s. When the traffic is light, most of slots are free in each MH. So the call success rates with different bandwidth requirements are almost upward 98%. However, when the traffic becomes heavy, the slots in each MH are used frequently. Then the route will be without enough slots to use. So the call success rates will decrease. In consideration of slot conflict and slot reuse, DSRP is better than others.

The Fig. 5 is shown the call success rates of different protocols in various mobility. The traffic load is 1/5000(ms/frame) . Under slow mobility, the calls by each protocol are almost successfully if there exist the routes. As the mobility increases, the routes break easily because network topology changes quickly. So the performances of all the protocols decrease. However, DSRP, DSRP w/o SAP, and Zhu & Corson's are with route maintenance or route adjustment mechanisms. The routes will be reconstructed quickly. Therefore, the calls of Liao etc.'s is the worst. But the route maintenance of DSRP and DSRP w/o SAP reconstruct routes more efficient than Zhu & Corson's. So the calls of Zhu & Corson's is lower than DSRP and DSRP w/o SAP. The SAP adjusts the slots when the faults occurred by slots reservation in route establishing process. So the DSRP performs better than DSRP w/o in call success rates.

B. Control Overhead

The control overhead is defined as the number of control packets for transmitting a unit of data successfully. The simulation results are shown in Fig. 6. As the traffic increasing, the control overhead of all the protocols almost do not grow up apparently except DSRP. That means that no matter the traffic in the networks is slight or heavy, the number of control packets for constructing a route is stable.

Liao etc.'s needs to maintain two-hop slots information, but others just maintain slots information of one-hop neighbors. Therefore, the control overhead of Liao etc.'s is the highest. The route adjustment scheme executed need some control packets. So the control overhead of DSRP is more than Zhu & Corson's and grows up with traffic increasing.

C. Average Delay Time

The simulation result of average delay time is shown in Fig. 7. Delay time is the time which constructing a successful route needs. In Fig. 7, the average delay time of all protocols are stable except DSRP. The Liao etc.'s could discover a route by two-hops neighboring information, but DSRP and Zhu & Corson's are only by one-hop neighbors information. So more calculation and decision are needed. Therefore, the delay time of Liao etc.'s is the fewest. DSRP considers more factors in slots decision than Zhu & Corson's. Then the calculation and decision time of DSRP is more than Zhu & Corson's. However, the difference is similar. The average delay time of DSRP also grows up with traffic increasing. The reason has been discussed in the subsection of *C*.

V. CONCLUSIONS

In this paper, we proposed a new QoS routing protocol, named as the distributed slots reservation protocol (DSRP), which can provide an efficient bandwidth reservation QoS routing for ad hoc networks. By DSRP, each node discovers the route just only by one-hop neighboring information. We also consider slot reuse to increase more paths in the networks. Except for the basic functions of routing protocol, we still propose an enhanced functions such as slots adjustment and route maintenance. The simulation results show that the call success rate and average delay time in DSRP are better than the related work. Therefore, DSRP works well for QoS routing on TDMA-based mobile ad hoc networks.

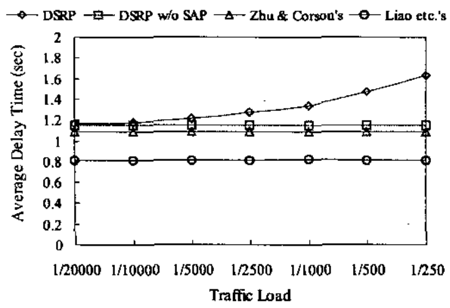

Fig. 7. Average delay time vs. traffic load.

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APPENDIX

Algorithm 1 Route_Discovery

/* Suppose Z receives a broadcast packet RREQ from Y */
if this RREQ has been received before **then**
  Exit this procedure
else
  $FS_Z = SIP1 \cap SIP2$.
  $FS_{\overline{YZ}} = FS_Y \cap SIP3$.
  if $FS_{\overline{YZ}} \geq BR$ **then**
    Add Z in $Path$.
    if more than three MHs recorded in $Path$ **then**
      $US_{\overline{WX}} = SDP(\overline{WX})$
    end if
    Broadcast RREQ
    if $Z = D$ **then**
      $US_{\overline{XY}} = SDP(\overline{XY})$
      $US_{\overline{YZ}} = SDP(\overline{YZ})$
      $Route\_Reservation()$
    end if
  end if
end if

Algorithm 2 SDP

/* $\overline{MN}$ is a parameter from calling function */
switch $\overline{MN}$ **do**
  case $\{\overline{MN} == \overline{WX}\}$
    $US_{\overline{MN}} = FS_{\overline{WX}} - FS_{\overline{XY}} - FS_{\overline{YZ}}$
    if number of slots in $US_{\overline{MN}} < BR$ **then**
      $US_{\overline{MN}} = [(FS_{\overline{WX}} \cap FS_{\overline{XY}}) \cup (FS_{\overline{WX}} \cap FS_{\overline{YZ}}) - (US_{\overline{WX}} \cap US_{\overline{XY}} \cap US_{\overline{YZ}})] \cup US_{\overline{MN}}$
    end if
  break
  case $\{\overline{MN} == \overline{XY}\}$
    $US_{\overline{MN}} = FS_{\overline{XY}} - FS_{\overline{YZ}}$
  break
  case $\{\overline{MN} == \overline{YZ}\}$
    $US_{\overline{MN}} = \phi$
  break
end switch
if number of slots in $US_{\overline{MN}} < BR$ **then**
  $US_{\overline{MN}} = FS_{\overline{MN}}$
else
  select slots in $US_{\overline{MN}}$ by highest slot utilization rates
  return($US_{\overline{MN}}$)
end if

Algorithm 3 Route_Reply

/* When M receives the RREP and detects */
if slots are jammed **then**
  M broadcasts SA_REQ
end if
if N receives the SA_REQ packet **then**
  if N is in $SA\_members$ **then**
    if N is a sender for M **then**
      $FS_{\overline{MN}} = SIP1 \cap SIP2$
    else
      $FS_{\overline{MN}} = SIP1 \cap SIP3$
    end if
    Reply SA_REP to M
  end if
end if
if M receives the SA_REP from N **then**
  if M is a sender for N **then**
    $FS_{\overline{MN}} = FS_{\overline{MN}} \cap SIP3$
  else
    $FS_{\overline{MN}} = FS_{\overline{MN}} \cap SIP2$
  end if
  $US_{\overline{MN}}$ = *Slot_Adjustment_Alogorithm()*
  Broadcast SA_EXE for $SA\_members$ to reserve slots
end if