# A Quality of Service Aware Multi-Path Routing for TDMA-Based Ad Hoc Networks

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**Abstract:** Recently, provision of quality-of-service (QoS) in an ad hoc network is a challenging task. In this paper, we propose a QoS aware multi-path routing for time division multiple access (TDMA)-based ad hoc networks. Our protocol has a new capability of establishing multiple sub-paths, evern for a single session connection. Each of sub-paths is capable of providing the QoS in terms of the number of time slots. Time slot assignment is essential to provide the calculated bandwidth in TDMA-based ad hoc networks. Our protocol adopts the maximum-bandwidth-first-based time slot assignment algorithm. We evaluate the performance of the protocol through simulations.

**Keywords:** ad hoc networks; QoS routing; TDMA; multi-path serach

## 1 Introduction

A mobile ad hoc network (MANET) consists of wireless nodes that communicate with each other, in the absence of a fixed wireless network infrastructure. Nodes cooperate to forward packets with each other, thus a node can communicate with another node by multi-hop. Node mobility causes unpredictable topology changes, the design of quality of service (QoS) routing protocol is more complicated than traditional networks.

The ability to provide QoS support is dependent on how well the channel resources are managed by the protocol at the MAC layer. In order to guarantee the QoS of multimedia flows whose bit rate is almost constant, the time division multiple access (TDMA)-based medium access control (MAC) that reserves the required network bandwidth for the routes is more suitable than the contention-based MAC that the current 802.11 does. The TDMA-based MAC implementation and QoS routing technique using TDMA-based bandwidth reservation has become a hot topic.

Recently, TDMA is studied as the MAC layer protocol to satisfy the QoS ruquirments of an application[1-4]. A TDMA-based bandwidth reservation protocol for QoS routing in a wireless mobile ad hoc network is proposed in[1]. Distributed Slot Reservation protocol that comprises of several strategies for dynamic bandwidth allocation to be used in QoS routing for TDMA-based ad hoc networks is proposed in[2]. A QoS routing protocol that is based on reservation pool is presented in[3]. A framework for joint topology-transparent scheduling and QoS routing is proposed in[4].

Scheduled-based MAC protocols can be categorized into two categories: topology-dependent scheduling and topology-transparent scheduling. The former is a conflict-free scheduling that maximizes the system performance by using network topology information. In the assumed TDMA model[5], the use of a time slot for a link depends on the status of its 2-hop neighboring links. TDMA-based QoS routing protocols in [2,5] are inevitable to take the slot assignment and interference into consideration. QoS routing in TDMA/CDMA-based ad hoc networks has been investigated in [6]. The use of a time slot on a link only depends on the status of its 1-hop neighboring links. The topology-transparent scheduling can guarantee single-hop QoS support without the overhead due to the recomputation of transmission schedules when the network topology changes[4]. When the bandwidth requirements is high or the network resource is rare, Multi-path QoS routing protocols are developed to provide QoS support if the uni-path QoS serach cannot find a single path that meets the bandwidth requirement[7-10].

In a MANET, different bandwidths for a route can be obtained by different time slot assignment algorithm. Our research adopts an effective time slot assignment algorithm by which more available bandwidth for a route can be obtained. This time slot assignment algorithm is integrated with a multi-path routing protocol of TDMA-based MANE.

## 2. Background

### 2.1 Network Model

The TDMA channel model is assumed to be time-slotted. The transmission time scale is organized in fixed-length frame, each of which consists of a control subframe and a data subframe. The data subframe consists of $N_D$ fixed-length data slots, indexed from 0 to $N_D$ - 1, is used to transmit data packets to its 1- hop neithbors for QoS flows. The control subframe contains $N_C$ fixed-length control slots, indexed from 0 to $N_C$ -1, and is used by each node to transmit control packets to its 1-hop neighbors. Figure 1 shows a TDMA frame structure.

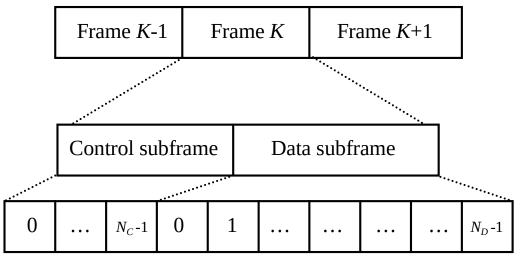


**Figure 1. TDMA frame structure**

## 2.2 TDMA-Based Bandwidth Reservation

In the QoS routing protocol[5], the flow estimates the available bandwidth in the network by broadcasting the control message. If the route that satisfies the bandwidth requirement, the flow reserves the slots for nodes in the route. Jawhar[1] proposed the DSR-based QoS routing protocol. Available bandwidth in the network is also estimated during the normal DSR-based route search process.

In the Dynamic Range Resource Reservation Protocol[11], the flow dynamically changes the amount of bandwidth reservation according to the available network bandwidth. When *Src* wants to searches for the route to *Dst* that satisfies the bandwidth requirement (required number of slot), it broadcasts the *QREQ* to the network. The requirement have a range, described as [$B_{min}$, $B_{max}$]. The *PATH* field in the *QREQ* contains the list of links that *QREQ* went through. *NH* filed contains the slot in which the latest forwarder of the *QREQ* can send data without colliding with the other neighbor nodes' communication. $B_{Cur}$ is the current allocated number of slots to the *PATH*. The node that receives duplicate *QREQ* will discard it. Otherwise, it allocates the slots to link from forwarder to itself, and adds the result to the *PATH* filed. Then, it updates the $B_{Cur}$ and *NH* field, and broadcasts the QREQ.

If the allocated number of slots is less than $B_{Cur}$, the link may become the bottleneck. The node tries to allocate more slots to link by releasing the slots of the links that allocate more slots. When the node can not allocate more than $B_{Min}$, it steals the slot from other neighbor flow and try to allocate $B_{Min}$ to the link.

Figure 2 shows the this Downgrade process. Flow 1 has already reserved the slots for N5 and N6 that are the neighbors of N3 and N4. A QREQ has been forwarded through the *Src*, N1, N2, and N3 before N4 receives it. When N3 forwards the QREQ, N3 adds its neighbor node list and those flow's slot allocation information to the QREQ. If N4 can not allocate enough slots to link N3-N4, N4 checks the neighbor flow's information. If the neighbor flow reserves more than those $B_{min}$, N4 tries to steal these surplus sltos and allocate them to link N3-N4. If there are several neighbor flows, N4 chooses the slot that has the minimum number of flows involved with Downgrade process. However, the actual slot release/reservation is not performed here, and only the result of Downgrade process is added to DN-PATH field of the QREQ.

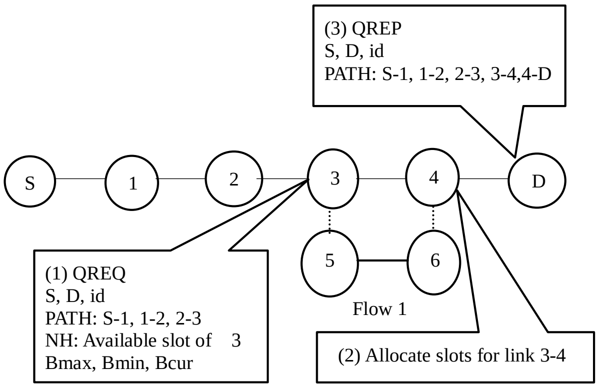


**Figure 2. The slot reservation of Dynamic Range Resource Reservation**

## 2.3 Multi-Path QoS Routing

When the network becomes congested, it will be difficult to find a proper route that satisfy the application's bandwidth requirement. In this case, multi-path QoS routing schemes that sums up the bandwidth reserved by several paths. H. Wu[6] and Y. S. Chen[7] extended DSR- based routing protocol to the multi-path communication.

When *Dst* receives a QREQ, it waits for receiving the other QREQs. If *Dst* received several QREQs, those PATHs that is included in the QREQs become multi-path candidate paths. However to estabblish multi-path communication, it is necessary to avoid the collision of slot reservation among the paths. In the On-Demand, Link-State, Multi-Path QoS Routing Protocol[7], *Dst* selects multiple paths from *Src* to *Dst* for the communication , and the sum of available bandwidth of these paths can satisfy the application's bandwidth requirement. In [7], *Dst* may choose multiple no-disjoint paths that have the same intermediate nodes, which may bring about the slot reservation collision. The reasion is that the same intermediate nodes of multiple seleced paths may reserve the same slot above one time.

## 3. Our Protocol

Our multi-path QoS routing protocol is an on-demand one based on source routing. It consists of multi-path QoS routes discovery, multi-path QoS routes selection


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and multi-path QoS routes reservation.

### 3.1 Definitions and Formulations

In order to avoid the slot reservation collision that exists the multiple QoS routes, we suppose that *Dst* is in charge of the slot allocation of the route. When *Dst* recieives a QREQ from *Src*, every link bandwidth will be achieved. The number of common free slots between two adjacent nodes denotes the link bandwidth between them.

With proper algorithm for slot assignment, free slots of every link of a route can be assigned without conflict, and the number of assigned slot of every link of the route is equal. The number of available slots is denoted as the route bandwidth. The purpose of slot assignment is to assign as many slots of every link as possible in order to achieve the maximum route bandwidth.

Suppose that a route is consists of $K$ links. Formula (1) denotes every link bandwidth of the route is equal. Where a $(i, j)$ shows the result of slot assignment on slot $j(1 \leq j \leq N_D)$ of link $i$ $(1 \leq I \leq K)$. When the value of $a(i, j)$ is 1, which represents the slot $j$ is assined for the link. When the value is 0, which represetns the slot $j$ is not assined for the link. Formula (2) is to maximize the bandwidth of the route.

$$\sum_{j=1}^{N_D} a(1, j) = \sum_{j=1}^{N_D} a(2, j) = ... = \sum_{j=1}^{N_D} a(K, j) \qquad (1)$$

$$\mathrm{B}_{\mathrm{route}} = \mathrm{Max}(\sum_{j=1}^{N_D} a(i, j)) \qquad (2)$$

In the TDMA channel model, a same slot can not be assigned in three successive links of the route to avoid the slot reservation conflic. Formula(3) shows this case.

$$\mathrm{a}\,(i - 1, j) + \mathrm{a}\,(i, j) + \mathrm{a}\,(i + 1, j) \leq 1 \quad (2 \leq I \leq K - 1,\ 1 \leq j \leq N_D) \qquad (3)$$

$$\mathrm{s}\,(i, j) + \mathrm{a}\,(i, j) \leq 1 \quad (1 \leq i \leq K,\ 1 \leq j \leq N_D) \qquad (4)$$

Formula(4) means that only free slots of every link can be assigned. Where s $(i, j)$ denotes the status of the slot $j$ $(1 \leq j \leq N_D)$ of the link $i$ $(1 \leq i \leq K)$. It has two values: 0 an 1. The value of 0 represents that this slot is free, and 1 represents that this slot is not free and can not be assigned to link. According to these formulas, optimal slot assignment with maximum available bandwdith can be obtained at the *Dst*.

### 3.2 QoS Route Discovery

When *Src* wants to searches for the route to *Dst* that satisfies the bandwidth requirement B, it broadcasts the *QREQ* to the network. The *QREQ* contains the following information: (Src, Dsc, id, PATH, NH, B). The *PATH* field records the link information and link bandwidth that QREQ went through. At the first, the *PATH* is null. The *NH* field records slot status information of neighbor nodes of the nodes in *PATH*.

When the intermediate node $j$ in the network receives the *QREQ*, it will discards the *QREQ* if it has received the same *QREQ*. If it is not contained in NH, it will discars the *QREQ*. Otherwise, it determine the link bandwidth between the forwarder $i$ of the *QREQ* and itself according to the slot status information in *NH*. As long as the link bandwidth is not null, the bandwidth on link $(i, j)$ will be appended in the *PATH* and the slot status information of neighbors of $j$ will be appended in the *NH*. Because we suppose that *Dst* is in charge of slot reservation avoiding collision, the intermediate node will not allocate slots or perform the downgrade process the during the *QREQ* goes through.

### 3.3 Multi-Path QoS Routes Selection

Whe *Dst* receives the first *QREQ*, it continues to try to receive the other *QREQ*s during pre-determined time $T$. Then *Dst* adopts the following maximum-bandwidth-first-based slot assignment algorithm to maximize the reservable slots on the first discovered PATH, whereas the convential slot assignment is performed at the intermediate nodes in local searching process. This global treatment of our proposal makes its assignment better approximation than convential method. The basic principles of the maximum-bandwidth-first-based slot assignment algorithm are as follows:

The slot assignment is started from the bottleneck link that has the smallest number of link bandwidth and is continued in other links towards both neighbor links. If the number of the bottleneck link $n$ is above 1, then select the first bottleneck link in the PATH as the start link $s$. Otherwise, the bottleneck link is the start link $s$.

Slot assignment is tried assuming a initial value of available bandwidth. If the assignment trial becomes infeasible, the initial value is decremented by 1 and the assignment trial is repeated until it becomes feasible. Suppose that $w$ is the available bandwidth of the route by the following expression, and set it as the initial value of $w$. In Formula (5), $g$ denotes the number of free slots on start link $s$.

$$w = \mathrm{g}/3 \qquad (5)$$

In order to begin the slot assignment from the starting link $s$, *Dst* selected $w$ slots on starting link according to the order of their free times in five successive links. The slot of the fewest free free times will be chosed first. The slots which are used by its one-hop and two-hop neighbor nodes will be not chosed. The slot information of one-hop and two-hop neighbor nodes will be achieved by the *NH* field of *QREQ*.

In the following pseudo-language description, $i$ denotes the No. of the link in which the assignment is being done (initial value is $s$); $K$ is the number the links of the route; b is the available bandwidth of the route.

```
BEGIN
    if (n = 1) s = No. of bottleneck; else s = min (No. of the bottlenecks);
    w = g/3;
    LABLE1:  i = s;
    LABLE2:  select_w_slots;
    if (select_w_slots = TRUE)
    {
  delete above selected w free slots on link i-2, i-1, i+1,i+2;
  if (i != K)
  {    i =i+1;          i is not the last link of the route
       LABLE3:    select_w_slots;
       if (select_w_slots = TRUE)
       {
           delete above selected w free slots on link i-2, i-1, i+1,i+2;
           if (i = K)       // i is the last link of the route
           {     b = w;   exist(0);
           }
           else { i =i +1;   //assign slot on the latter link
                 goto LABLE3;
           }
       }
       else {                     //can not assign w slot
       w = w-1;                  //w decremented by 1
        LABLE1;
    }
  }
  else
  {
       i=i-1;            // assign slot on the former link
       goto LABLE3;
    }
  }else
  {    w=w-1;
       goto LABLE2;
  }
END
```

If the the available route bandwidth $b$ is above the bandwidth requirement B, our protocol is a uni-path QoS routing protocol. Otherwise, *Dst* tries to wait for the next arrived QREQ. When the second QREQ arrived, *Dst* with the global slot informtion can find available route bandwidth b' by using the maximum-bandwidth-first-based slot assignment algorithm described above. It is noted that in order to avoid the slot reservation conflict of neighboring links in different routes, the slot assignment information for the first route will be considered during the slot assignment for the second QREQ.

If the sum of $b$ and $b'$ can satisfy the bandwidth requirement B, multi-path QoS routes selection and reservation ends. Otherwise, *Dst* waits for the third QREQ.

## 4 Simulations

The effectiveness of our proposed protocol is demonstrated by using C. The network topology and parameters description as follows. The transmission range is 30m and network area is 200m × 200m. There are 20 control slots with 0.1ms slot length and 16 data slots with 5ms slot length in a frame. Assume that *Src* and *Dsc* are selected at random. Average communication duration is 600sec and average flow arrivial interval is 120, 60 and 30sec, respectivly. The bandwidth requirement is 500Kps and 2.5Mbps, respectivley.

The dynamic range resource reservation protocol (DRRR), Multi-Path DRRR (MP-DRRR) and our protocol were implemented by extending the current DSR protocol. The simulation was executed 20 times.

Figure 3 shows the average total transmitted data $T$ in each traffic condition. $T$ is defined as $T=\sum_{i=1}^{N} T_i / N$. $T_i$ means total data of flow $i$. $T_I$ is defined as improvement ratio of $T$ compared to DRRR.

In Figure 3, Multi-path DRRR doesn't increase $T_I$. On the contrary, our protocol could find more available bandwidth, and $T_I$ is increased. In our protocol, when the average number of flows is 5, $T_I$ is the 12%. However the more the average number of the flows increase, the more $T_I$ decreases because the available bandwidth decreased when the network becomes congested. However, our protocol has higher $T_I$ in each traffic condition.

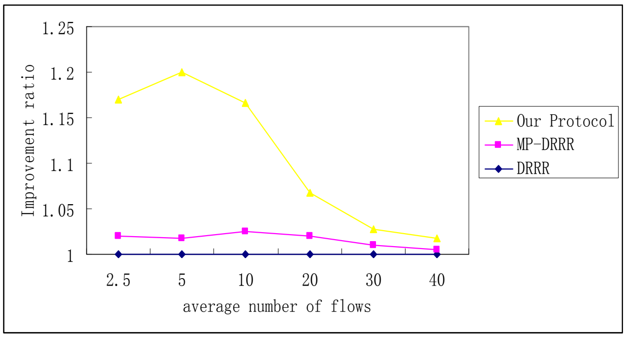


**Figure 3. The Total Transmitted Data**

## 5 Conclusions

In this paper, we propose a novel QoS aware multi-path routing protocol for TDMA-based ad hoc network. This new scheme contains the following features that work to improve the performances: the bandwidth-guaranteed routing, the multi-path search and selection, and the maximum-bandwidth-first-based slot assignment method. The method proposed in this paper is a simple basic one. Other issues such as exploring the possible advantages in terms of QoS multicast routing are left for future work.


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## Acknowledgement

This work has been supported by The Young and Middle-aged Elitists' Scientific and Technological Innovation Team Project of the Institutions of Higher Education in Hubei Province (No. 200902), Key Scientific Research Project of Hubei Education Department (No. B2009 1904).

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