Bandwidth Constrained Multicast Routing for TDMA-Based Mobile Ad Hoc Networks

Xu Zhen and Zhou Long
School of Electric & Electronic Engineering, Wuhan Polytechnic University, Wuhan, China
Email: [1]xuzhen@whu.edu.cn, [2]profzh@126.com

***Abstract*—Multicasting, which is a one-to-many communication, is motivated by the increasing importance of real-time and multimedia applications with different QoS requirements. The QoS metric considered in this work is the bandwidth. We approach this problem by assuming a common channel shared by all hosts under a TDMA (Time Division Multiple Access) channel model. In this paper, we propose a new TDMA-based QoS multicast routing algorithm--PSLCB, which aims at minimizing the number of forwarders so as to reduce bandwidth consumption. Simulations results show that compared with ODMRP, our proposed QoS routing algorithm improve packet delivery ratio and reduce end-to-end packet delay.**

***Index Terms*—slot, multicast, bandwidth, routing**

I. Introduction

Mobile ad hoc networks (MANETs) are developing rapidly as a new technology in recent years that have attracted much researcher's attention because of its potential applications in various fields, including last-mile broadband Internet access. Mobile ad-hoc networks consist of wireless hosts that communicate with each other, in the absence of a fixed infrastructure. Due to considerations such as radio power limitations, power consumption, and channel utilization, a mobile host may not be able to communicate directly with other hosts in a single-hop fashion. A multi-hop scenario occurs, where the packets sent by the source host are retransmitted by several intermediate hosts before reaching the destination host.

In this paper we discuss the multicast routing algorithm with QoS support for MANETs. Multicast routing is an effective way to communicate among multiple hosts in a network. In multicast communication, a single source node sends a message or information to a group of receivers simultaneously, and send it only once, even if it needs to be delivered to a large number of receivers. Multicasting protocols try to minimize the consumption of network resources taking advantage of the fact that some parts of the paths from the source to the destinations can be shared by multiple destinations. The larger the path shared, the lower overall bandwidth consumption is obtained. For resource-limited wireless network, multicast communication make full use of wireless broadcast advantage and has been widely applied in multimedia applications with different quality-of-service (QoS) requirements, e.g., audio/video conferencing and long-distance consultation.

In the recent years, the need to support real-time applications, such as audio or video transmissions, is getting more and more. QoS-support routing protocol[1] is becoming important as well. QoS routing is to find routes that have sufficient resources to meet the QoS requirements of connections. There are several QoS requirement, such as packet loss rate, delay, bandwidth etc. The paper focuses its discussion on bandwidth, because it is one of the most critical requirements for real time application. The bandwidth requirement is measured as the number of slots in one frame. Multicast routing is to find a multicast tree, which is rooted from the source node and spans all destination nodes. The multi-constrained QoS-based multicast routing algorithm has been proved to be NP-hard problem[2]. Because the global information is needed for these algorithms, however the global information is difficult even impossible to get in MANETs. The NP-hard problems drive the researchers to use heuristic techniques to get optimization solutions. In MANETs, the available bandwidth of a wireless link depends not only on the traffics carried by its neighboring links, but also on how well transmissions on its neighboring links are scheduled at the MAC layer, thus the paper present a heuristic timeslot assignment algorithm to solve the interference problem and reuse timeslots as soon as possible. In addition, the mobility of nodes in the MANETs may bring the change of network topology, therefore, the paper adopt the distributed scheme. Finally, this paper presents a bandwidth-aware multicast routing algorithm, which try to reduce bandwidth consumption for achieving better network performance by minimizing the number of forwarders in a tree. To seek routes with QoS constraints efficiently, one-off call admission is required for call setup and resource reservation. If no such a route can be found, the connection request should be rejected.

The rest of this paper is organized as follows. Related work is presented in the next section. Section III presents the formulation of the problem, and describes an interference model. Section IV designs an interference-aware timeslot assignment algorithm. Section V gives a QoS multicast routing algorithm with required bandwidth. Simulation results are presented in Section VI. Section VII concludes the paper.

II. Related Work

Manuscript received December 15, 2012; revised February 25, 2013.
doi: 10.12720/jcm.8.3.161-167.

In a MANET, the radio is inherently a broadcast medium, and transmissions among neighboring nodes may interfere with each other because of contention for the shared wireless channel. This interference makes an important impact on the performance of a MANET[3]. In the past year, many researchers have been on developing solutions for interference problem. Currently, there are following ways used most extensively to alleviate interference. (1)TDMA-based MAC protocol, which schedules the links in the network by assigning them different slots. In the literature [4], Jian Tang, Guoliang Xue and Christopher Chandler present an optimal bandwidth allocation algorithm to allocate timeslots along the found paths for connection requests with unit bandwidth requirements. (2)CDMA-over-TDMA, which assigns each node with an orthogonal code to eliminate the interference among different transmissions, and neighboring links share the same timeslot. (3) Multiple radios are tuned to non-overlapping channels. IEEE 802.11 can support 12 radios. Krishna Ramachandran and Elizabeth M. Belding in the literature [5] model the interference between the routers using the multi-radio conflict graph, and present an interference-aware channel assignment algorithm and protocol that address the interference problem in the wireless mesh networks. (4)CSMA-based MAC protocol. Nodes contend the shared channel at the same time with their neighboring nodes. The literature [6] proposes bandwidth-constrained routing problem (BCRP) under CSMA-based or contention-based CDMA MAC protocols.

The multicast protocol is a primitive communication operation for sending the same message from a source node to a group of destination nodes. It is very significant for many wireless and mobile applications. There are many existing multicast protocols such as MAODV (Multicast Ad-hoc On-Demand Distance Vector)[7], Core Assisted Mesh Protocol(CAMP)[8] and ODMRP (On-Demand Multicast Routing Protocol)[9] protocols for wireless ad hoc networks. However, these multicast protocols do not explicitly provide the QoS function. In the recent years, several QoS multicast routing protocol have been proposed. In the literature[10], a QoS multicast protocol, named M-CAMP, was proposed, which adopted a measurement-based approach for estimating the bandwidth availability from the server to the clients. Then, probe packets were sent along the multicast tree to test if the network satisfied the bandwidth requirement. However, the admission control schemes are not effective enough to avoid QoS violation. The literature [11] proposes a QoS Multicast Routing protocol (QMR). QMR is a mesh-based protocol which is established on-demand to connect group members and provides QoS paths for multicast groups. The QMR protocol integrates bandwidth reservation function into a multicast routing protocol with the assumption that available bandwidth is constant and equal to the raw channel bandwidth. QMR contains mechanisms that provide hybrid fix-reservation and shared-reservation bandwidth to guarantee QoS multicast routing. The literature [12] proposes a bandwidth-efficient multicast routing protocol for ad-hoc networks. In order to achieve low communication overhead and high multicast efficiency, the proposed protocol employs the following mechanisms: (1) on-demand invocation of the route setup and route recovery processes to avoid periodic transmissions of control packets, (2) a new route setup process that allows a newly joining node to find the nearest forwarding node to minimize the number of forwarding nodes, and (3) a route optimization process that detects and removes unnecessary forwarding nodes to eliminate redundant and inefficient routes.

III. Problem Definition

The paper represents a MANET with a undirected network graph $G(V, E)$ where V represents the set of nodes corresponding to routers in the network and E represents the set of links between the nodes. The undirected edge $e(u, v)$ in G corresponds to a wireless link between node u and v in the network if $d(u, v)$ is within the transmission range, where $d(u, v)$ is the Euclidean distance between node u and v. node n_i has a set of neighbors $NB_i = \{n_j \in V: (n_i, n_j) \in E\}$. In addition, all nodes are assumed to have the fixed reception and carrier-sense ranges.

The aim of our work is to develop a novel multicast routing by exploiting the slot reuse capability. The MAC sub-layer in our model is implemented by using a TDMA channel model, for which each frame is divided into a control subframe and a data subframe. The bandwidth is partitioned into a set of time slots $S = \{s_1, s_2, ..., s_M\}$, M is the number of slots in a data subframe. TS_i is defined as a set of data slots which node n_i is using to send data currently, RS_i is a set of data slots which node n_i is using to receive data. $\overline{TS_i}$ is a set of available timeslots for node n_i. TS_{ij} is a set of available timeslots for link $e(n_i, n_j)$. TS_{ij}' is a set of timeslots for link $e(n_i, n_j)$ selecting for transmission, that is TS'_{ij} will be occupied by link $e(n_i, n_j)$.

It is difficult to design a QoS routing on TDMA-based MANETs. Because the use of a slot for a link depends on the status of its two-hop neighboring links, which may bring hidden terminal problem and exposed terminal problem.

A. Hiddden Terminal Problem

In Fig. 1, the node A does not know the existence of node C. Similarly, node C does not know the existence of node A. The node A intends to transfer packet to the node B. At the same timeslots, the node C should be conveyed to node B too. So the collision of packet will take place in node B.

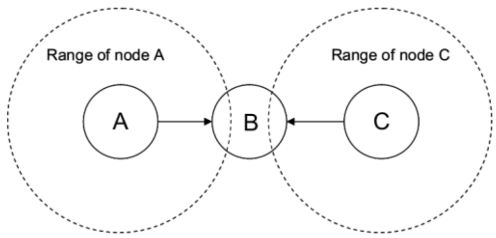

Figure 1. Hidden terminal

B. Exposed Terminal Problem

In Fig. 2.When node A should transfer the package to node B, will transfer the information of one RTS first, then node B will be passing one CTS back and telling node A to begin to transfer. But node C is received to CTS, so node C can not transmit the package to node D.

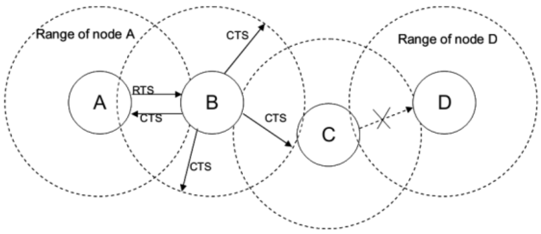

Figure 2. Exposed terminal

If QoS routing protocol only considers the hidden-terminal problem, then no three adjacent links are allowed to share the same free time-slots. This limitation can be overcome if the exposed-terminal problem is also taken into consideration, such that it is possible that no two adjacent links share the same time slots. In the paper, the hidden terminal and exposed terminal problem should be taken into consideration in order to efficiently reuse the slot.

Supposed that a QoS route is constructed between source node S and destination node D. the bandwidth requirement is two slots. The slot {6} has been taken by link *e*(B, E), and slot{7, 8} has been reserved for link *e*(C, D). The path *P* {S->A->B->C->D} is taken as a QoS route. In the view of intra-flow interference, let link *e*(S, A) take slots{1, 2} for traffic transmission. As the hidden terminal, node B can't take slot {1, 2}. Slot {6} has been used by itself. So node B only choose two slots from slots {3, 4, 5, 7, 8}. let link *e*(A, B) take slots{3, 4} for traffic transmission, thus link *e*(B, C) only take slots{5}, and can't meet the bandwidth requirement. But if link *e*(S, A) take slots{7, 8}, and link *e*(A, B) take slots{1,2}, thus the slots {3, 4, 5} are available for link *e*(B, C). Therefore, the path *P* can satisfy the bandwidth requirement. In fact, if neighboring link has traffic to transmit, it must bring the interference to the ongoing route *P*. If link *e*(S, A) have taken slots{4} for another traffic, link *e*(B, C) and link *e*(A, *B*) can't use slot {4}, or else interference problem will occur. Based on above consideration, let link *e*(B, C) take slots{3, 5}, interference problem will be avoided, and QoS requirement also are met.

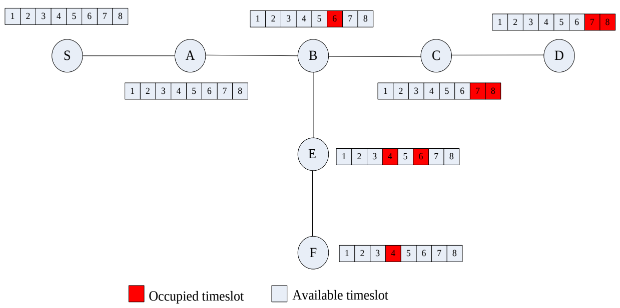

Figure 3. An example for hidden terminal and exposed terminal

The above problems are often encountered when we are designing a QoS routing protocol for TDMA-based MANETs. In the paper, the interference from intra-flow and inter-flow is taken into consideration, and a novel slot assignment scheme is proposed to alleviate the interference problem.

IV. INTERFERENCE-AWARE TIMESLOT ASSIGNMENT

Our main focus in this paper is how to schedule the communication links such that no two links in the same timeslots interfere with each other. In the section, the paper employs a distributed algorithm to achieve an ideal timeslot assignment scheme. Centralized algorithms are quite practical in static wireless networks. However the topology of MANET is dynamic, so it is inefficient to update the coloring using a centralized algorithm. Now, distributed approaches have become prevalent in MANETs.

Our distributed timeslot assignment algorithm assigns timeslots for the links as follows: (1) No central control, the algorithm run in parallel in every node in the network; (2) Nodes in the network exchange local information with its neighbors, and every node knows timeslots information the links in its interference range use; (3) The least conflict timeslots have priority.

Lemma 1. For link *e*(*A*, *B*), a slot *t* can be used by node *A* to transmit traffic to node *B* without causing a collision, the following three constraint should be satisfied:

1. Slot *t* is not yet scheduled to send or receive data in either *A* or *B*.
2. For any one-hop neighbor *C* of *A*, slot *t* is not scheduled to receive data in *C*. Slot *t* can be scheduled (or reused) to send data in *C*, but cannot send data to any of the other one-hop neighbors of *A*.
3. For any one-hop neighbor *D* of *B* , slot *t* is not scheduled to send data in *D*. Slot *t* can be scheduled (or reused) to receive data in *D*, but cannot receive data from any of the other one-hop neighbors of *B*.

$$\begin{cases} t \notin TS_A,\ t \notin RS_A,\ t \notin TS_B \quad and \quad t \notin RS_B \\ t \notin RS_C, \quad \forall C \in NB_A \\ t \notin TS_D, \quad \forall D \in NB_B \end{cases} \tag{1}$$

Theorem 1. For link *e*(*A*, *B*), if node *A* can transmit traffic to node *B* at slot *t*, the following three constraint should be satisfied.

$$\begin{cases} FT1 = \{t \notin TS_A,\ t \notin RS_A,\ t \notin TS_B \quad and \quad t \notin RS_B\} \\ FT2 = \{t \notin RS_C, \quad \forall C \in NB_A\} \\ FT3 = \{t \notin TS_C, \quad \forall D \in NB_B\} \end{cases} \tag{2}$$

Thus, the available set of slots TS_{AB}={$FT1 \cap FT2 \cap FT3$}.

Take Fig.4 for an example, node *A* and *C* are neighbor of node *B*, node *B* intends to transmit data to node *C*. node *B* analyse its one-hop neighboring slot information, RS_A={5}, TS_B={4}, RS_B={6}, TS_C={2}, RS_C={7},

TS_D={8}. According to Theorem 1, $\overline{TS_B}$ ={1, 3, 5, 8}∩{1, 2, 3, 4, 6, 7, 8}={1, 3, 8}. TS_{BC} = {1, 3, 8}∩{1, 2, 3, 4, 5, 6, 7}
={1, 3}.

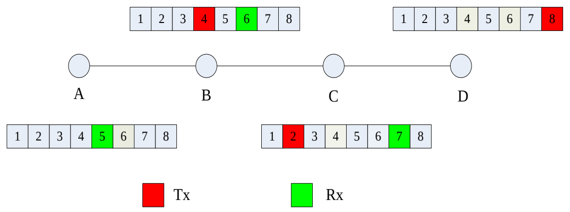

Figure 4. An example of slot assignment

Theorem 1 may decide the slot for a link. However, time slot assignment for a route is NP-hard problem. Based on the interference model, a three-hop timeslot assignment scheme is introduced. Three adjacent links on a route can't share the same timeslot.

Theorem 2. If the route is interference-free scheduled, then any three consecutive links on the route are assigned different timeslots.

$$\overline{TS_{AB}} \cap \overline{TS_{BC}} \cap \overline{TS_{CD}} = 0 \quad (3)$$

Generally, the interference range is twice of transmission range. If link *e*' and link *e* don't interfere with each other, two end points on the link *e*' can't be in the interference range of link *e*, which is denoted by the union of the interference range of the two end points on the link *e*. therefore three consecutive links must be assigned different timeslots.

For three consecutive links, upstream node can't know slots of downstream node, it is necessary for a node backward to determine the slots for the previous third link in order to meet the bandwidth requirement, i.e. which slots among available slots for upstream link depend on the slot selection of downstream link. It is obvious that continuous three-hop slot assignment schemes can alleviate interference problem, but it is still possible that a bandwidth-aware route can't be found. Actually, the best way to find an optimum slot selection for all nodes in a route to satisfy the QoS requirement is to collect all available slots information of all nodes in the route to the destination, and the destination decides the slots scheduling. But it is time-consuming. Therefore, the least conflict slot first assignment scheme is also introduced. In the scheme, the slots with the least conflict with the next two links are preferable to be selected. Because a slot can be used just once for three continuous links, or else the available slots in the next two links may be insufficient to satisfy the QoS requirement.

In Fig. 3, *e*(*A*, *B*), *e*(*B*, *C*) and *e*(*C*, *D*) can't use the same slots. *e*(*C*, *D*) has use slot {7, 8}, then *e*(*A*, *B*) and *e*(*B*, *C*) only use other slots. *e*(*B*, *E*) and *e*(*E*, *F*) has use slot 6 and slot 4 respectively, then *e*(*A*, *B*) and *e*(*B*, *C*) also can't use slot {4, 6} based on continuous three-hop slot assignment principle. *e*(*S*, *A*) is beyond three hop of *e*(*C*, *D*) and *e*(*E*, *F*), thus *e*(*S*, *A*) may select two slots from slots{4, 7, 8} according to the least conflict slot first assignment.

V. Bandwidth-Aware QoS Routing

Our work aims to minimize the number of forwarders. The number of forwarders in a multicast tree is equal to the number of non-leaf node. To reduce the number of hosts participating in packet forwarding can maximize global efficiency in bandwidth consumption. In our proposed protocol, the path between the source and the destinations share the non-leaf nodes as soon as possible to minimize the non-leaf nodes.

The paper assumes that a connection only uses a single multicast path for transmission, i.e. a flow can't be split. To provide a bandwidth *B* on a given path, it is necessary that every node along the multicast route find at least *B* slots for transmission to its downstream neighbor, and these slots do not interfere with other transmissions.

In our proposed protocol, a route setup process is invoked when a new node joins a multicast group. During the route setup process, every destination node try to find the nearest forwarding node of the multicast group, and the path between the nearest forwarding node and itself is bandwidth-satisfied.

For a multicast group, *s_id* is the source of the new flow, *d_list* is the set of the destination nodes of the new flow, *b_req* is the bandwidth requirement for the new flow. Our proposed protocol intends to establish a bandwidth-satisfied multicast tree for the new flow. ψ is a subset of the *d_list* and ξ is the set of members in the multicast tree. Initially, set ψ = { } and ξ= { *s_id* }.

Without loss of generality, assume that *d_list* ={d_1,d_2,…,d_N}, where N is the number of destination nodes in the multicast group. When d_1 want to become a member of the multicast group *G*, the multicast group *G* only include *s_id*, then d_1 broadcasts a JOIN packet, which include the parameters: *s*, *b_req*, *node_list* and *slot_lis*,*TTL*. *s* is d_1; *b_req* is bandwidth requirement for the new flow; *node_list* is a list of nodes it has traversed. Its initial value is {d_1}; *slot_list* records the slot assignment information on the path. Its initial value is {$\overline{TS_{d_1}}$ }. TTL is the limited hop number.

Destination node d_1 flood JOIN packet to its neighbor node. The intermediate node *F* receives JOIN packet from d_1, if it has been in *node_list*, it will discard JOIN packet. Otherwise, it will reduce TTL by 1, and assign slots for links between node d_1 and *F* according to slot assignment algorithm. Slot assignment algorithm is described as follows.

Without loss of generality, assume that continuous tree links: link $e(n_{m-1}, n_m)$, $e(n_m, n_{m+1})$ and $e(n_{m+1}, n_{m+2})$. node n_{m+2} receive an JOIN packet from node n_{m+1}, and check the available slots $\overline{TS_{m+1}}$ from *slot_list*. node n_{m+2} calculate $TS_{m+1,m+2}$ based on $\overline{TS_{m+1}}$ and the transmit slot sets its neighbors are using. If $TS_{m+1,m+2}$ can meet bandwidth requirement, it will determine which slots are to be used for the link $e(n_{m-1}, n_m)$ based on the least conflict slot first assignment principle. Therefore, $TS'_{m-1,m}$ can be determined. If $TS'_{m-1,m}$ and $TS_{m+1,m+2}$ can not meet the bandwidth requirement *b_req*, node n_{m+2} will discard the JOIN packet. Otherwise, node n_{m+2} collect its one-hop neighbor slot information and calculate the available slots $\overline{TS_{n_{m+2}}}$ based on *FT1* and *FT2*, *then* append $\overline{TS_{n_{m+2}}}$ into *slot_list*. In addition, append itself into *node_list*, and then forward the updated JOIN packet to its neighbors.

If node *F* is on the multicast group, it will be responsible for the determinations of the slots selections for the previous three links. If the slots on these three links can meet the bandwidth requirement *b_req*, then the path between d_1 and *F* is bandwidth-satisfied. Node *F* will receive more than one JOIN packets from node d_1, and the first received JOIN packet does not necessarily have the smallest hop count. Therefore, in our proposed protocol, node *F* waits until it receive a preset number of JOIN packets, and then choose a JOIN packet with the smallest hop count. Further node *F* send REPLY packets back to node d_1, following the path that the selected JOIN packet has traversed in reverse direction. REPLY packet includes the parameters: *s* and *node_list*. *s* is node *F*; *node_list* is the list of nodes traversed by the selected JOIN packet. Node d_1 also receive more than one REPLY packets from nodes on the multicast group *G*, node d_1 waits until it receive a preset number of REPLY packets, and then choose a REPLY packet with the smallest hop count. Finally node d_1 send RESERVE packet is sent along the path P_1 that the selected REPLY packet has traversed, and the links on the path P_1 will reserve *b_req* slots. Update $\psi = \{ d_1 \}$ and $\xi = \{ s\_id \cup P_1 \}$.

Similarly, when d_2 want to join the multicast group *G*, d_2 broadcasts a JOIN packet, the intermediate node *F* receives JOIN packet from d_2 will check whether the path between d_2 and itself is bandwidth-satisfied or not. If the path can't meet bandwidth requirement, the JOIN packet will be discarded. If *F* is not on the multicast group *G*, it will append itself and its slot into *node_list* and *slot_list* respectively. If node *F* is on the multicast group, it will become candidate for forwarder of node d_2. A candidate F_i which is closest to d_2 is selected as forwarder. P_2 is the shortest path between F_i and d_2, which is included in the multicast group *G*. Update $\psi = \{ d_1, d_2 \}$ and $\xi = \{ s\_id \cup P_1 \cup P_2 \}$. The execution for other destination nodes is very similar. When all destination nodes are added into multicast group *G*, the execution will terminate until a new node joins a multicast group. Then $\psi = \{ d_1, d_2, \ldots d_N \}$ and $\xi = \{ s\_id \cup P_1 \cup P_2 \cup \ldots \cup P_N \}$. ξ represents a bandwidth-satisfied multicast tree which connects *s_id* with all destination nodes.

Algorithm 1 Slot assignment of the intermediate node

/* continuous link $e(n_{m-1}, n_m)$, $e(n_m, n_{m+1})$ and $e(n_{m+1}, n_{m+2})$ */
If ExistInNodelist(n_{m+2}) || RREQ.TTL=0 then
    Discard the JOIN packet
Else
    $TS_{m+1,m+2} = \overline{TS_{m+1}} \cap \{ \bigcup TS_{NB_{n_{m+2}}} \}$
    If $TS_{m+1,m+2} \geqslant b\_req$
        Assign slots for $e(n_{m-1}, n_m)$
        Add itself into *node_list*
        Update JOIN packet
        If n_{m+2} is not a member of multicast group G
            Forward JOIN packet
        Else
            Determinate the slots for the previous three links
            Send REPLY packet
        End If
    Else
        Discard JOIN packet
    End If
End If

Fig. 5 describes an example of establishing a bandwidth-satisfied multicast tree that connects source node *s* with three destination node d_1, d_2 and d_3. Initially, $\psi = \{ \}$ and $\xi = \{ s \}$. d_1 want to join the multicast group, and broadcast a JOIN packet. Node *s* send REPLY packet to d_1, then d_1 choose a shortest route to group *G*, i.e., d_1-I1-*s*, and reserve *b_req* slots. $\psi = \{ d_1 \}$ and $\xi = \{ s \cup \{d_1, \text{I1}, s\} \}$. d_2 want to join the multicast group, and broadcast a JOIN packet. Node I1 and *s* send REPLY packet to d_2, then d_2 choose a shortest route to group *G*, i.e., d_2-I3-I1, and reserve *b_req* slots. $\psi = \{ d_1, d_2 \}$ and $\xi = \{ s \cup \{d_1, \text{I1}, s\} \cup \{d_2, \text{I3}, \text{I1}\} \}$. d_3 want to join the multicast group, and broadcast a JOIN packet. Node I3 and d_2 send REPLY packet to d_3, then d_2 choose a shortest route to group *G*, i.e., d_2-I4- I3, and reserve *b_req* slots. Update $\psi = \{ d_1, d_2, d_3 \}$ and $\xi = \{ s \cup \{d_1, \text{I1}, s\} \cup \{d_2, \text{I3}, \text{I1}\} \cup \{d_3, \text{I4}, \text{I3}\} \}$. ξ represents a tree that connects *s* with d_1, d_2 and d_3. Then the bandwidth-satisfied multicast tree with minimal number of forwarders is established.

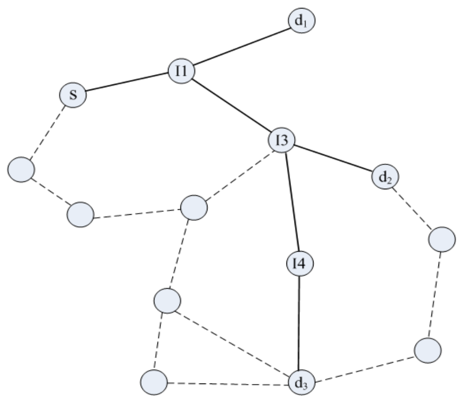

Figure 5. A bandwidth-satisfied multicast tree

VI. SIMULATION

In this section, we present the details of the simulations that we perform to evaluate the performance of our proposed protocol which refers to well known multicast routing protocol-ODMRP. We use NS-2 as a network simulator. The paper mainly considers a mobile ad hoc network with 30 nodes randomly placed in an area (1000m×1000m). Each node is equipped with an IEEE 802.11 wireless interface. A traffic load between a pair of source-destination is generated by varying the number of packets per second on the constant bit rate - CBR. Each packet is 1024bytes in size. The packet size is large enough to test whether the algorithm is capable of driving the applications with high bandwidth demand. The number of slots of the data frame is assumed to be 16 slots. The bandwidth requirement is 2 slots. The default radio parameters is adopted that the transmission range is 200 meters.

In the paper, we propose a bandwidth-aware routing protocol(PSLCB), and success rate, end-to-end delay and overhead will become our performance evaluation metrics. These performance metrics are commonly used to examine the capability of a multicast algorithm. Success rate can be defined as the value of successful QoS route requests divided by the total number of QoS route requests from source to destination. Overhead is the number of transmitted packets, including the control and data packets, when delivering the same amount of data. End-to-end delay is the interval from the time that the multicast is initiated to the time that the last host receives its multicasting, which is used to measure the maximum time a packet travel from source to destination.

Fig. 6 shows the performance results of success rate vs number of destination nodes. It is observed that our protocol achieves more success rate than ODMRP. When the multicast group size is very small, PSLCB works slightly better than ODMRP. As the number of destination nodes increases, PSLCB and ODMRP obtain much lower success rate. Nevertheless, the advantage of PSLCB becomes apparent. As the number of destination nodes increases, the interference between the links and the load of links will increase, causing packets to be delayed and dropped, but PSLCB can alleviate the interference by efficiently reuse the slots and efficiently use bandwidth resource to reduce the load on the links, therefore PSLCB will outperform ODMRP.

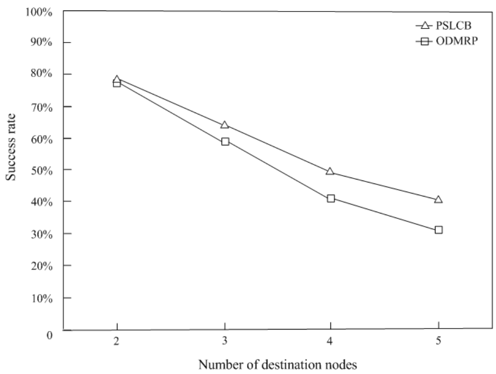

Figure 6. Success rate vs number of destination nodes

Fig. 7 shows the performance results of end-to-end delay vs the number of destination nodes. It is observed that the greater the number of destinations nodes is, the higher end-to-end delay will be. Nevertheless, PSLCB has lower end-to-end delay. Because the greater the number of destination nodes, the more the load on the links in the network, which cause packets to be delayed. PSLCB is bandwidth-aware route, which try to minimize the forwarder to maximize global efficiency in bandwidth consumption, therefore PSLCB will outperform ODMRP.

Fig. 8 shows the performance results of overhead vs the number of destinations. It is observed that the greater the number of destination nodes is, the higher the overhead will be. The reason is the more the destination nodes added, the more the control packets needed. The result also shows that PSLCB has higher overhead than ODMRP. This is because that extra control packet of our approach is needed to construct bandwidth-aware multicast routing.

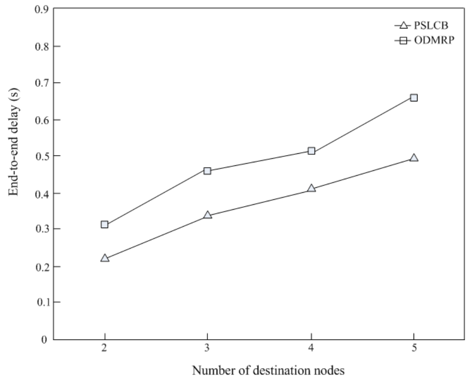

Figure 7. End-to-end delay vs number of destinations

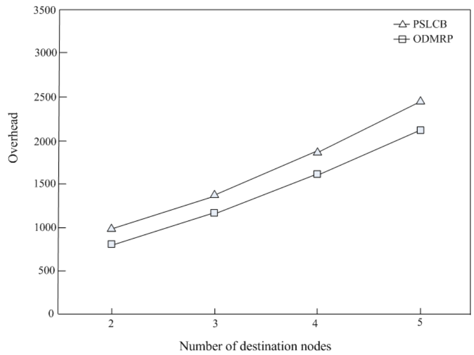

Figure 8. Overhead vs number of destinations

VII. CONCLUSION

In order to solve interference problem among links, the TDMA channel model is adopted in the paper. Both of the hidden-terminal and exposed-terminal problems are taken into consideration in order to possibly exploit the slot reuse capability. The paper also proposes a distributed slot assignment algorithm to satisfy the bandwidth constraint of connection request, and further proposes a bandwidth-constrained QoS multicast route from a source to a set of destination nodes. It constructed multicast trees with the objective of minimizing the total number of forwarders, in addition to bandwidth satisfaction. In the simulations our QoS multicast routing protocol-PSLCB can increase packet delivery ratio and reduce average end-to-end packet delay.

ACKNOWLEDGMENT

This work is partially supported by the National Natural Science Foundation of China under Grant No.60970117 and 61075015, Educational Commission of Hubei Province of China under Grant No.Q20111707.

REFERENCES

[1] C. X. Zhu and M. S. Corson, "QoS routing for mobile ad hoc networks," in *Proc. of IEEE INFOCOM*, 2002.

[2] V. P. Kompella, J. C. Pasquale, and G. C. Polyzos, "Multicasting for multimedia applications," in *Proc. of IEEE INFOCOM*, 1992, pp. 2078-2085.

[3] R. Sollacher and M. Greiner, "Impact of interference on the wireless Ad-Hoc networks capacity and topology," *Wireless Network*s, vol. 12, no. 1, pp. 53–61, 2006

[4] J. Tang, G. L. Xue, and C. Chandler , "Interference-aware routing and bandwidth allocation for QOS provisioning in multihop wireless networks," *Wireless Communications and Mobile Computing*, vol.5, no. 8, 2005.

[5] K. N. Ramachandran, E. M. Belding, and K. C. Almeroth, "Interference-aware channel assignment in multi-radio wireless mesh networks," in *Proc. of IEEE INFOCOM*, 2006.

[6] C. Y. Chiu, Y. L. Kuo, and E. H. K. Wu, "Bandwidth-constrained routing problem in wireless ad hoc networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 19, no. 1, pp. 4-14, 2008

[7] E. Royer and C. Perkins, Multicast Ad-hoc On-Demand Distance Vector (MAODV) Routing, draftietfmanet-maodv-00.txt, 2000.

[8] J. Garcia-Luna-Aceves and E. Madruga. "The core assisted mesh protocol," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 8, 1999.

[9] Y. Yi, S. Lee, W. Su, and M. Gerla, On-Demand Multicast Routing Protocol (ODMRP) for Ad-hoc Networks, draft-yi-manet-odmrp-00.txt, 2003.

[10] E. Pagani and G.P. Rossi, "A framework for the admission control of qos multicast traffic in mobile ad hoc networks," in *Proc. 4th ACM International Workshop on Wireless Mobile Multimedia*, 2001, pp. 2-11.

[11] M. Saghir, T. C. Wan, and R. Budiarto, "Load balancing qos multicast routing protocol in mobile ad hoc networks," *AINTEC, Lecture Notes in Computer Science*, K. Cho Ed., P.Jacquet, Springer-Verlag, vol. 3837, 2005, pp. 83–97.

[12] T. Ozaki, J. B. Kim, and T. Suda, "Bandwidth-efficient multicast routing for multihop, ad-hoc wireless networks, " in *Proc. of IEEE INFOCOM*, 2001, pp. 1182-1191.

[13] Z. Xu, C. H. Huang, and Y. Chen, "Interference-aware QOS routing in wireless mesh networks," in *Proc. of IEEE MSN*, 2008, pp. 95-98.

[14] Y. Wang, W. Z. Wang, X. Y. Li, and W. Z. Song, "Interference-aware joint routing and tdma link scheduling for static wireless networks," *IEEE Transactions on Parallel and Distributed Systems*, 2008.

[15] W. Z. Wang, Y. Wang, X. Y. Li, W. Z. Song, and O. Frieder, "Efficient interference-aware TDMA link scheduling for static wireless networks," in *Proc. of ACM MobiCom*, 2006.

[16] Meghanathan and Natarajan, "Minimum Hop vs. Minimum Edge Based Multicast Routing for Mobile Ad Hoc Networks," *Advances in Wireless, Mobile Netowrk and Applications*, vol. 154, 2011, pp. 1-10.

[17] W. H. Hsu, J. H. Chen, and S. C. Yeh, "A novel Delay-Based Multicast Routing Protocol in ad hoc wireless networks," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 7, no. 4, pp. 211-220, 2011.

[18] E. Astier, A. Hafid, and S. Aljahdali, "An efficient mesh-based multicast routing protocol in mobile ad hoc networks," *Wireless Communications & Mobile Computing*, vol. 12, no. 9, pp.822-836, 2012.

[19] R. C. Biradar and S. S. Manvi, "Review of multicast routing mechanisms in mobile ad hoc networks," *Journal of Network and Computer Applications*, vol. 35, no. 1, pp. 221-239, 2012

Xu Zhen is an associate professor of the School of Electric & Electronic Engineering, Wuhan Polytechnic University where he has been since 2009. He received a M.Sc. degree in mechanical and electronic engineering from Wuhan University of Technology in 1999 and a Ph.D. degree in computer science from wuhan University in 2009.

Zhou Long is a professor of the School of Electric & Electronic Engineering, Wuhan Polytechnic University where he has been since 1998. He received a Ph.D. degree from Huazhong University of Science & Technology in 1998. From 2001 to 2004, he was a postdoctoral researcher in Huazhong University of Science & Technology.

.