***I.J. Wireless and Microwave Technologies*, 2011, 3, 46-53**
Published Online June 2011 in MECS (http://www.mecs-press.net)
DOI: 10.5815/ijwmt.2011.03.08

Available online at http://www.mecs-press.net/ijwmt

A QoS Multicast Routing in TDMA-Based MANET Using Directional Antennas

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Abstract

In this paper, a quality of service (QoS) multicast routing protocol in mobile ad hoc networks (MANET) using directional antennas has been presented. Many important applications, such as audio/video conferencing, require the quality of service guarantee. Directional antenna technology provides the capability for considerable increase in spatial reuse, which increases the efficiency of communication. This paper studies TDMA-based timeslot allocation and directional antennas, and presents an effective algorithm for calculating bandwidth of a multicast tree. We also propose a novel DSR-based QoS multicasting routing agrotithm. The simulation result shows the performance of this routing protocol in terms of call success rate.

Index Terms: Directional antennas;TDMA;QoS; multicast routing

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 transmit data using an omnidirectional antenna that radiates its power equally in all directions. Directional antennas allow a node transmit data in a particular direction. At the same time, a receiving node can focus its antenna in a particular direction. Directional antenna technology provides the following advantages: (1) a smaller amount of power can be used; (2) other nodes can use the surrounding area in the other directions to transmit, which increases the spatial reuse; (3) route has shorter hops and smaller end-to-end delay [1]. A MultiBeam Adaptive Array (MBAA) system is used in [2] and is capable of forming multiple beams for simultaneous transmissions or receptions in different directions.

Multicasting is a basic one-to-many communication way. A multicast group contains a special node which is responsible for transmitting data packets to the other nodes in the same group. Pushed by real-time applications with quality of service (QoS) requirements, a.g., audio/video conferencing and distance education, QoS multicast routing protocol for multimedia communication has been presented in [3].

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Quality of service is more difficult to guarantee in wireless networks, especially for real-time multimedia application. There are several parameters of QoS, such as packet loss rate, delay, bandwidth etc. In order to meet the QoS requirements of the applications, multicast protocols are required to construct multicast trees with QoS guaranteed. We focus its discussion on bandwidth, because it is one of the most critical requirements for real time application. This paper presents an effective algorithm for calculating multicast tree bandwidth and QoS multicast routing. When a new flow with QoS bandwidth requirement is initiated, a QoS route request package (QREQ) is flooded for determining a bandwidth-satisfied route. Destination nodes collect path information from source node and send it back to source node. The source node determines the construction of multicast tree according to the path information from the destination nodes.

2. Related Work

Unlike in wired networks, calculation of path bandwidth in infrastructure-less TDMA based MANET, additional constraints have to be considered. The mode of operation is half duplex. This is because an antenna cannot send or receive at the same time. Radio interference problem must be addressed. In a frame consisting of fix numbr of time slots, each of which can be used by a node for sending or receiving packets. In order to address radio interference problem, a node can use a particlular time slot only if the neighbouring nodes which are one or two hops awary do not use the same time slot. For a given node, each slot is marked as either “Free” or “Reserved”, where “Free” means the slot is not used by the node and any adjacent nodes, and is available for allocation. “Reserved” means that the slot has been reserved for a QoS path. Consider a path from source to destination in Figure 1. Fig.1 (b) shows slot status for five nodes. *Link bandwidth (LB)* is defined as the element number in set of slots that are marked as “Free” in end nodes of a link. Fig. 1(c) shows common free slots for links in path. *Path bandwidth (PB)* is defined as the minimum link bandwidth along the path. In MANET, path bandwidth cannot be found directly from link bandwidth and is an NP-complete problem [7].

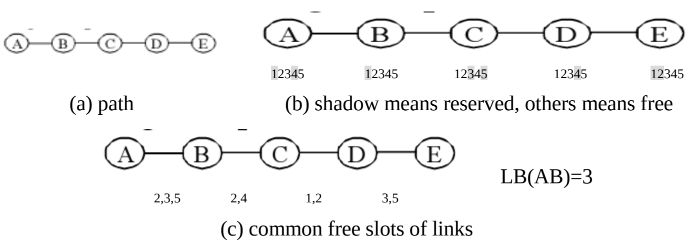


Fig 1. A simple path and time slot status

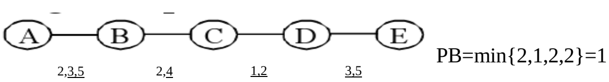


Fig 2. Slots schedule (Underline means allocated)

Finding path bandwidth in TDMA-based MANET explained below. In Figure.2, allocate slots {1,2} and {3,5}to link(C,D) and link(D,E) because there are not common slots on continuous links. Then allocate slot {4} to link(B,C) because node C cannot send and receive at the same slot {2} simultaneously. At last, allocate slots {3,5} to link(A,B). The path bandwidth is the minimum link bandwidth allocated along the path. The bandwidth of path(ABCDE) is one slot.

There are a limited number of multicasting proposals devised for MANET enviroment. YuhShyan Chen et al. propose a hexagonal-tree QoS multicasting protocol [3]. Ke et al. present a multi-constrained QoS-based multicast routing algorithm using the advantage of wireless notwork [4]. Zhao et al. have proposed a reliable multicast routing which is a multicast routing algorithm based on link quality based metric (link cost) [5]. Furthermore, Han and Guo in [6] have studied the problem of collision-free multicast in multi-channel wireless network, and present two heuristic-based algorithms with the aim of reducing both the interface redundancy and the multicast latency. These protocols use the omnidirectional antennas mode.

It is assumed that a MultiBeam Adaptive Array (MBAA) antenna is capable of broadcast by adjusting the beam width [2]. Figure.3 shows a node equipped with an MBAA antenna array with 4 beams. Fig. 3 (a) shows the transmission mode and Fig.3 (b) shows the reception mode. Suppose two nodes *x* and *y* are neighbors. If *x* want to transmit data to *y*, *x* must orient its transmitting beam in the direction of *y* and *y* must orient its receiving beam in the direction of *x*.

Jawhar and Wu present the slot allocation rules for directional antennas [1]. A data slot *t* is free and can be allocated to send data from node *x* to neighbor *y* if the following conditions are satisfied:

1) *x* don't receive in *t*, and *y* don't send in *t* by any antennas.

2) Neighbors of *x* don't receive in *t*, from *x* where neighbors is in the same angular direction as *y*.

3) Neighbors of *y* don't send in *t*, from *y* where neighbors are in the same direction as *x*.

There are a limited number of routing protocols using directional antennas. Jawhar and Wu research the resource scheduling in wireless networks using directional antennas in [1]. Bazan and Jaseemuddin propose the routing and admission controls for wireless Mesh networks with directional antennas in [8]. YuhShuyan and Shin advice a shoelace-based QoS routing protocol for mobile ad hoc networks using directional antenna in [9].

(a) Transmission mode (b) Reception mode

Fig 3. Transmission pattern of antenna

3. Definition and Suppossion

This paper represents a static multi-hop wireless network with an undirected network graph G (*V*, *L*) where *V* represents the set of nodes and *L* represents the set of links between the nodes. In wireless networks, the interference range (R_I) is twice of transmission range (R_T). Suppose there are a source node *S* and a set of receiver nodes *R*. Our purpose is to find the set *T* in G which connect the source node *S* to each receive node $r_i \in R$ ($1 \le i \le m$). Given a multicast tree $t \in T$, $l(v_i, v_j) \in t$ is an link in multicast tree *t*, we give the following definitions.

Definition 1: The available bandwidth of a multicast tree is defined as the minimum path bandwidth in the tree.

$$\text{bandwidth}(T) = \text{Min}\{\text{path bandwidth}_i\} \qquad (1 \le i \le m) \tag{1}$$

Definition 2: Delay of a multicast tree is the maximum delay in the tree.

$$\text{delay}(T) = \text{Max}\{ \sum_{l_i \in PATHs} delay(l_i) \} \tag{2}$$

Definition 3: The network cost of a multicast tree is defined as the total cost of all the paths in the tree.

$$\text{cost}\ (T) = \sum_{i=1}^{m} \cos t(Path_i) \quad (3)$$

Definition 4: The cost of a multicast tree is the consumed network resource in all paths. The consumed network resource in a path is defined as the reserved path bandwidth times the total hop number in path.

$$\text{cost}(Path_i)=\text{path bandwidth}_i \times \text{hop number of Path}_i\ (1 \le i \le m) \quad (4)$$

Based on the previous definition, the problem can be fomulated as follows. Given a graph G (V, L), our work is to find a tree T, such as the following conditions are satisfied.

1) bandwidth(T)$\geq B$ (B is the minimum bandwidth requirement of a multicast tree);
2) delay(T)$\leq D$ (D is the maximum delay requirement);
3) cost(T) is the minimum.

Definition 5: The bandwidth of link l is the sum of the path bandwidth of the current connections that use link l. If the path is interference-free scheduled, then any three consecutive links on a path are not assigned same time slots.

Definition 6: For any slot t, any interference-free link scheduling must satisfy the following condition, where l_1, l_2 and l_3 are three consecutive links. T(l_i,t) denotes whether link l_i use slot t to transmit data.

$$T(l_1,t) + T(l_2,t) + T(l_3,t) \leq 1 \quad (5)$$

4. Our QoS Multicast Routing Protocol

4.1. Data Structures

Let each node x maintains three tables: send table (ST), receive table (RT) and hop-count matrix (H). $ST_x[i,j]$ and $RT_x[i,j]$ contain slot status for the 1-hop or 2-hop neighbor i of x for sending and receiving data. If slot j of node i has been reserved for sending or receiving data, ST=1 or RT=1; If slot j has been allocated, ST=0 or RT=0; otherwise, ST=-1 or RT=-1.

The hop-count matrix $H_x[i, j]$ contains information about x's 1-hop and 2-hop neighborhood. $H_x[i, j]$=1 if node i has node j as a neighbor; otherwise, $H_x[i, j]$=0. The above three tables also contain angular groups field. The entry $A[a]_i^j$ denotes the set of angular groups to which the ath sending/receiving antenna is pointed. $A[a]_i^j$ =null indicates that the ath antenna for node i is not used during slot j.

4.2. Our QoS multicast routing Protocol

QoS multicast routing requires finding routes from a source node to a group of destination nodes with QoS requirement. When a source node S wants to send data to a group of destination nodes with a bandwidth requirement of b slots and maximal delay bound D, it broadcasts a QREQ(S, *Destination_Set*, id, b, x, $PATH$, NH, TTL) to all of its neighbors. Where *Destination_Set* is a set of destination nodes, id is identity of request, x is a node currently relaying the QREQ, $PATH$ is path together with the available slots that has been discovered, and NH is a list of next-hop nodes of node x, together with the format $((h'_1, l'_1), (h'_2, l'_2) \ldots (h'_n, l'_n))$. TTL is the delay bound. h'_i has potential to serve as the- next hop of node x, along with a list of slot l'_i.

When an intermediate node *y* receives a QREQ from node *x*, it will decide whether QREQ has been received according to *S* and *id*. If yes, it will drop the QREQ. If *y* has been in *PATH*, it will drop the RREQ. If node *y* is not a node in *NH*, it drops the RREQ. If value of *TTL* is 0, it drops the RREQ. Otherwise, it will reduce *TTL* by 1, adds itself into *PATH*, and also adds its free time slots into *PATH*. Node *y* creates two temporary tables, ST_{temp} and RT_{temp}, as follows copy all entries in ST_y into ST_{temp}, and copy all entries in RT_y into RT_{temp}. Assign $ST_{temp}[h_j, t]$ = $ST_{temp}[h_{j+1}, t]$ =0 for each slot *t* in the list l_i (i=m, m+1). In order to avoid hidden terminal problem, the same slot can't be allocated to three consecutive links (l_m, l_{m+1}, l'_{temp}). Let NH_{temp}=null.

For every neighbor *z* of *y* do *L*=select_slot(*y*, *z*, *b*, ST_{temp}, RT_{temp}) if *L* is not null then NH_{temp}=NH_{temp}|(*z*, *L*). The procedure select_slot (*y*, *z*, *b*, ST_{temp}, RT_{temp}) denotes find *b* free slots from link (*y*, *z*) according to the ST_{temp} and RT_{temp}. If *L* is null then discards the QREQ, because node *y* cannot find one neighbor to extend next hop such that link bandwidth is smaller than *b*. It mainly relies on slot allocation rules for directional antennas to do the selection. For every slot *t*, if the following three conditions hold, *t* is an available slot that allocated to link (*y*, *z*). $A_y^w \wedge A_y^z \neq \Phi$ denotes that *y*' neighbor *w* is in the same direction as *z* from *y*.

Condition 1: $(RT_{temp}[y, t]=-1) \wedge (ST_{temp}[z, t]=-1)$

This condition shows that *y* does not receive in *t*, and *z* does not send in slot *t* by any antennas.

Condition 2. $(H_y[y, w]=1) \wedge (RT_{temp}[w, t]=-1) \wedge (A_y^w \wedge A_y^z \neq \Phi)$

This condition implies that neighbor *w* of *y* don't receive in slot *t*, from *y* where neighbor *w* is in the same angular direction as *z*.

Condition 3: $(H_y[z, w]=1) \wedge (ST_{temp}[w, t]=-1) \wedge (A_z^w \wedge A_z^y \neq \Phi)$

This condition expresses that neighbor *w* of *z* don't send in slot *t*, from *z* where neighbor *w* is in the same direction as *y*.

When finishing the above loop, the new QREQ will be rebroadcasted and the status of selected slots will be changed from free to allocate if the NH_{temp} is not null. When the QREQ is forwarded from the source node *S*, it can be regarded as a special case of intermediate nodes. The above steps are performed by replacing *y* with *S*, and PATH and NH are null.

When the destination node D_i ($D_i \in$ *Destination_Set*) receives the first QREQ, a path p_1 has been formed. The path bandwidth is the minimum number of available slots of links in PATH. In other words, the path bandwidth is the number of slots in l_{narrow} (i.e., b_i=| l_{narrow}|). l_{narrow} is the bandwidth of narrowest link. The destination node D_i sends a QREP(S, D_i, id, b_i, *PATH*). The intermediate nodes along PATH will reserve b_i slots.

When the source node *S* receives all QREPs from the destination nodes in *Destination_Set*, it computes the available bandwidth and the delay of a multicast tree. If the following conditions are satisfied, the source node *S* finds a QoS multicast tree. Delay (l_i) expresses the hop-count of the *i*th route.

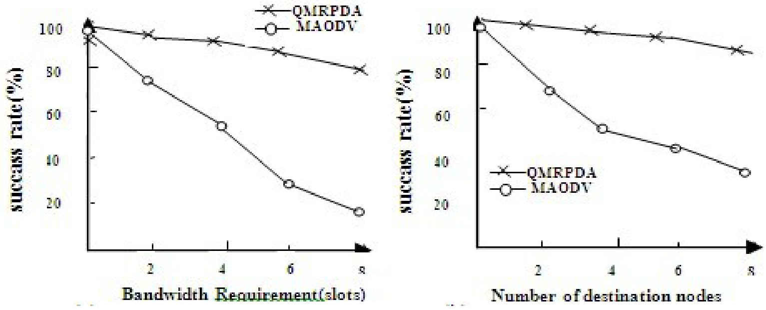
$$\text{Min } \{b_i\} \geq b \tag{6}$$

$$\text{Max } \{ \sum_{l_i \in PATHs} delay(l_i) \} \leq D \tag{7}$$

5. Simulation

In this section, a simulation study is performed using ns 2 to evaluate the performance of our protocol. Suppose 25 nodes randomly placed in 1000m × 1000m area. Every connection request is generated with a randomly chosen source-destination pair. The number of date slots in a frame is 32. Suppose that the transmission range of wireless nodes is 250 meters and the interference range is 500 meters.

Fig 4 shows call success rate under different network enviroment for our QoS multicast routing protocol with directional antennas and MAODV. Our protocol is labeled as QMRPDA. Assume that the delay bound is set to 3 hops. The number of antennas is four. When the number of destination nodes is very small or bandwidth requirement is very low, MAODV will almost have the same success rate with our QoS multicast routing protocol. However, as the number of destination nodes or bandwidth requirement increase, our QMRPDA will gradually ourperform MAODV. In Fig. 4(a), assume the number of destination nodes is 5. When the bandwidth requirement increases, the call success rate of QMRPDA will range from 98.2% to 78.5%. MAODV will be blocked. In Fig. 4(b), when the number of destination nodes increases, interference between links will increase. QMRPDA alleviates the interference between links by using four directional antennas.

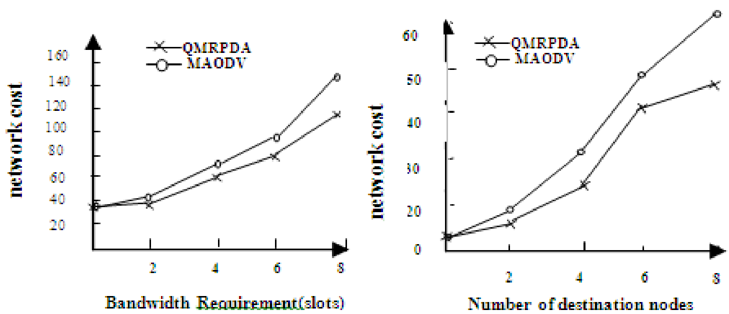


(a) (b)

Fig 4. Call success rate under different network enviroment

Fig.5 shows network cost under different network enviroment for our QoS multicast routing protocol with directional antennas and MAODV. When the number of destination nodes is very small or bandwidth requirement is very low, MAODV will almost have the same network cost with our QoS multicast routing protocol with four antennas. In Fig. 5(a), assume the number of destination nodes is 5. When the bandwidth requirement increases, the network cost of MAODV will be blocked. In Fig. 5(b), assume the bandwidth requirement is 2 slots. However, as the number of destination nodes increases, interference between links will increase, and avalible bandwidth on links will drop. Though MAODV selects a multicast tree with small network cost, but these paths may not meet the bandwidth requirement, thus MAODV has the higher network cost than QMRPDA.

Fig.6 shows the percentage of successfully received data packages under different antenna enviroment for our QoS multicast routing protocol. The percentage of successfully received data packages ranges from 45.25% to 19.26% in the one antenna case. The highest percentage is obtained in the four antennas case which ranges from 88.56% to 76.36%. It is increasingly easier for the network to acquire data packages as the number of antennas increases.



(a) (b)

Fig 5. Network cost under different network environment

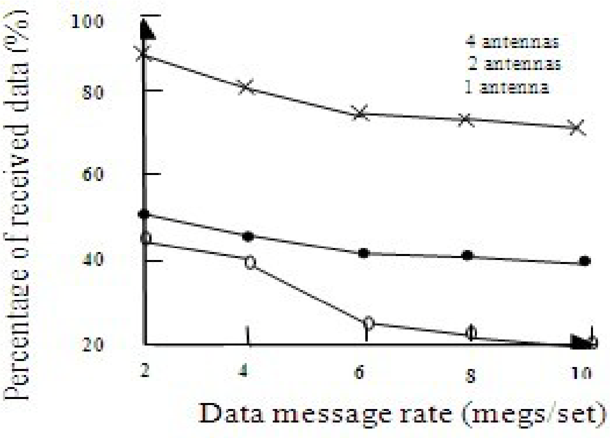


Fig 6. Percentage of successfully received data packages

6. Conclusion

In this paper, we propose a QoS multicast routing protocol in mobile ad hoc networks using directional antennas. The source tries to discover a multicast tree that is capable of providing the desired QoS requirement. The slot allocation and reservation procedure use the local topology information. The protocol takes advantage of the significant increase in spatial reuse provided by the directional antenna environment. The simulation results clearly show that compared with MAODV, our approach can obtain better performance in terms of success rate and network cost.

Acknowledgment

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. B20091904).

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