A Shoelace-Based QoS Routing Protocol for Mobile Ad Hoc Networks Using Directional Antenna

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***Abstract*— This paper proposes a new QoS routing protocol for mobile ad hoc network (MANET) using directional antenna. The scheme offers a bandwidth-based routing protocol for QoS support in MANET using the concept of multi-path. Our MAC sub-layer adopts the CDMA-over-TDMA channel model. The QoS on-demand routing protocol determines the end-to-end bandwidth calculation and bandwidth allocation from a source node to a destination node. The paths are combined with multiple cross links, called as shoelace, when the network bandwidth is strictly limited. Due to the directional antenna property, these cross links can simultaneously transmit data without any data interference. This investigation develops a shoelace-based QoS on-demand routing protocol by identifying shoelaces in MANET to more easily construct a QoS route which satisfied the bandwidth requirement. Finally, simulation results demonstrate the better performance in our proposed routing protocol.**

I. Introduction

A mobile ad hoc network is a group of wireless nodes that dynamically formed a network without the use of any existing network infrastructure. Nodes cooperate to forward packets with each other so that a node can communicate with another node by multi-hop. In a MANET, host mobility can cause frequently unpredictable topology changes, thus the design of a QoS routing protocol is more complicated than traditional networks. Some works has recently intensively studied QoS issues in MANETs [1][2]. These QoS routing protocols use the omnidirectional antennas to transmit the data. If nodes use omnidirectional antennas to transmit, the node generates unnecessary interference to other nodes thereby reduces the network capacity.

Recently, there are some existing MANET routing protocols with directional antennas [5][6]. With directional transmission both transmission range and spatial reuse can be substantially enhanced by having nodes concentrate transmitted energy only towards their destination's direction, thereby achieving higher success rate. The use of directional antenna in the context of MANETs can largely reduce the radio interference, thereby improving the utilization of wireless medium and consequently the network performance. However, these routing protocols [5][6] for MANETs with directional antenna don't provide the QoS function. Saha *et al*. [7] proposed a scheme for supporting priority-based QoS in MANETs by classifying the traffic flows in the network into different priority classes. The paper has adopted a control-theoretic approach to adaptively control the low-priority flows so as to maintain the high priority flow-rates at their desired level. Then, they modified the scheme to show the overall improvement in throughput using directional antenna. Ueda *et al*. [8] used the notion of zone-disjoint routes to avoid the contention between high and low priority routes by reserving high priority zone of communication. The primary objective is to devise a priority based routing scheme, which will protect the high priority flows from the contention caused by the low priority flows. Above-mentioned researches [7][8] use uni-path scheme. If the network environment is strictly limited, the QoS routing path will fail.

This paper provides a dynamic routing path, which is depended on network environment. The main features of our shoelace-based routing protocol are summarized as follows: (1) the shoelace-based routing protocol produces cross link which can simultaneously transmit data without any data interference; (2) our routing protocol employs the concept of multi-path to achieve QoS requirement when the network bandwidth is strictly limited; (3) the shoelace-based protocol offers a higher success rate to achieve the QoS requirement. This paper assumes that nodes are capable of determining the directional at which a neighbor is located by using one of the techniques proposed in [3]. In particular, our proposed scheme can be directly applied to most existing routing protocols.

The rest of this paper is organized as follows. Section II describes the system model and basic idea. Our proposed shoelace-based QoS routing protocol is presented in Section III. The simulation results are examined in Section IV. Finally, Section V concludes this paper.

II. System model and basic idea

This paper mainly introduces a special multi-path structure from the source to the destination which satisfies the bandwidth requirement. The multi-path inherits the advantage of a high success rate of searching for a QoS route and the robust and reliable mechanisms. The network model assumptions are as follows. The MAC sub-layer in our model is implemented by using the CDMA-over-TDMA channel model [4]. There are many advantages in CDMA-over-TDMA channel model, such as multiple sessions can share a common TDMA time slot via CDMA, and overcome a hidden-terminal problem. The bandwidth requirement is realized by reserving time slots on links. Under such a model, the use of a time slot on a link is only dependent on the status of its neighboring links.

Fig. 1 illustrates that an area around the node is covered by M sectors [3]. We assume that the sectors are not overlapping. We number the sectors from 1 to M starting from the sector that

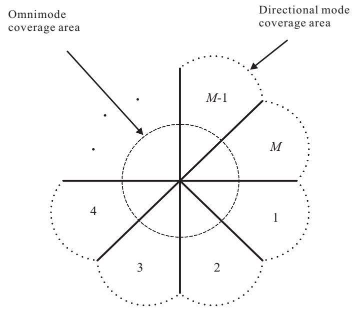

Fig. 1. A node with M sectors

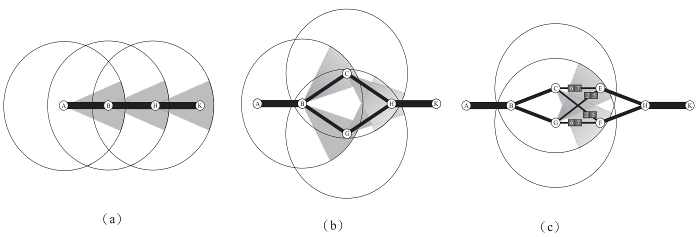

Fig. 2. Examples of different QoS situations

is located just right of the 3 o'clock position. Using directional antenna will bring about many benefits, for example, spatial reuse, enhancing transmission range, and saving power. This paper employs these benefits to achieve QoS routing protocol.

Definition : Shoelace path: Consider a pair of neighbor nodes *B* and *H*; a QoS path is requested between nodes *B* to *H* which satisfies a bandwidth requirement B_r. Fig. 2(a) shows that it only provides a uni-path routing, when the network bandwidth is sufficient. In the Fig. 2(b), if the actual network bandwidth $B_{\overline{BH}}$ between nodes *B* and *H* is less B_r ($B_{\overline{BH}} < B_r$), the node B finds more sub-paths between *B* and *H* and the total bandwidth of sub-paths is equal to B_r. Fig. 2(c) displays the concept of shoelace path. When the network bandwidth is strictly limited, we uses the shoelace-based routing protocol. Give a group of one-hop neighboring node, $\begin{bmatrix} h_1 & k_1 \\ h_2 & k_2 \\ \vdots & \vdots \\ h_m & k_n \end{bmatrix}$, where m, $n > 1$. By using directional antenna, the link $\overline{h_i k_{j+1}}$ and $\overline{h_{i+1} k_j}$, where $i = 1, \ ..., m$ and $j = 1, \ ..., n$, from a cross link and can use the same time slot to transmit data without interfering with each other. The total bandwidth of all links between nodes h_i and k_j is equal to B_r. The more cross links compose the shoelace path. For example, the total actual bandwidth $B_{\overline{BC}}$ and $B_{\overline{BG}}$ is equal to the bandwidth B_r, but the bandwidth of next hop is insufficient ($B_{\overline{CH}}$ + $B_{\overline{GH}} <$ B_r). This situation results the routing procedure fail. But the shoelace-based routing protocol can reduce this situation, our routing protocol can find more nodes to satisfy the bandwidth requirement. Because this paper uses directional antenna, the cross links do not interfere with each other and transmit packet simultaneously. In addition, the proposed employed fewer nodes and then found more paths to achieve a QoS path.

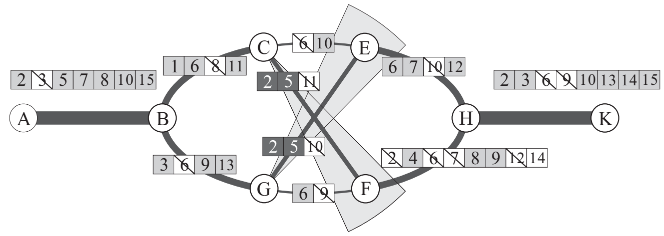

Fig. 3. Identifying of shoelace and link reserved time slots

III. Shoelace-based QoS routing protocol

A. Phase I: Time slots reservation

In MANET, each node periodically broadcasts the hello message, where the message lifetime is two-hop. Because the message lifetime is two-hop, each node acquires two-hop neighboring information. The time slots reservation procedure is performing after collecting the link-state information for all nodes in the MANET. Let $\begin{bmatrix} & h_1 & k_1 & \\ & h_2 & k_2 & \\ \alpha & \vdots & \vdots & \beta \\ & h_m & k_n & \end{bmatrix}$ denote a shoelace-based sub-path between α and β. Further, each node decides the reserved time slots with its neighbors. Since the MAC layer adopts CDMA-over-TDMA model, the time slots reservation of routing path has the following rules.

R1. Time slots reserved on all links $\overline{\alpha h_i}$ must be differed, where $1 < i < m$.

R2. Time slots reserved on all links $\overline{k_j \beta}$ must be differed, where $1 < i < n$.

R3. Time slots reserved on link $\overline{\alpha h_i}$ and $\overline{h_i k_j}$ must be differed, where $1 < i < m$, $1 < j < n$.

R4. Time slots reserved on link $\overline{h_i k_j}$ and $\overline{k_j \beta}$ must be differed, where $1 < i < m$, $1 < j < n$.

R5. Time slots reserved on link $\overline{h_i k_j}$ and $\overline{h_{i'} k_{j'}}$ must be differed, where $i = i'$ or $j = j'$.

To calculate reserved time slots between two nodes, some symbol is defined as follows.

- $F[i]$: a set of free time slots of node *i*.
- $SF[i, j]$: a set of share free time slots of nodes *i* and *j*. $SF[i, j] = F[i] \cap F[j]$.
- $RSF[i, j]$: a set of reserved share free time slots of nodes *i* and *j*.
- $ASF[i, j]$: a set of available share free time slots of nodes *i* and *j*. $ASF[i, j] = SF[i, j] - RSF[x, i] - RSF[y, j]$ where *x* is node *i* other neighbors and *y* is node *j* other neighbors.

Fig. 3 illustrates the calculating result. $SF[F, H]=\{2, 4, 6, 7, 8, 9, 12, 14\}$, $ASF[F, H]=SF[F, H] - RSF[C, F] - RSF[G, F] - RSF[E, H] - RSF[H, K]=\{2, 4, 6, 7, 8, 9, 12, 14\} - \{2, 5\}-\{6\}-\{6, 7, 12\} - \{2, 3, 10, 13, 14, 15\}=\{4, 8, 9\}$, $RSF[F, H]=\{4, 8, 9\}$. After calculating, the cross links $\overline{CF}$ and $\overline{GE}$ transmit data using the same time slots $\{2, 5\}$ without interfering each other. In this paper, the bandwidth in time slotted network is represented by amount of free time slots. Therefore the actual bandwidth is $|RSF|$. Afterward, this paper uses $|RSF|$ to denote bandwidth.

B. Phase II: Shoelace path discovery

Each node employs beacon to find neighbors' location and neighbors' free time slot using directional antenna and calculates the reserved time slot of link. The source node initiates a QoS route to a destination and broadcasts the SL_REQ packet. When the destination receives the SL_REQ packet, the destination sends a route reply to source node. A SL_REQ packet is denoted as SL_REQ (*S*, *D*, *NH*, TH_NEI, *NL* , *RSF*, B_r, *B*), where each field of the packet is defined as follows: *S*: the source address; *D*: the destination address; *NH*: the node which the neighbor of the source and received a SL_REQ packet. *TH_NEI*: the common neighbors of the next hop. *NL*: a list of nodes, which denotes the through nodes from source to current traversed node; *RSF*: a list of reserved time slot. This field records reserved time slot between current node and next hop node; B_r: the bandwidth requirement from source to destination. *B*: the total bandwidth from current current node to its neighbors. Based on the network environment, the network topology has various form. There are three cases in this paper.

Case I: when the network bandwidth is sufficient, the each node detects that the bandwidth between itself and its neighbors is satisfied. The routing path appears uni-path result.

Case II: when the network bandwidth is insufficient, the uni-path is unsuitable. The node finds more sub-paths such as the total bandwidth is equal to B_r. The multi-path result is used. The procedure is described as follows:

Step 1: give a path [n_1 n_2 n_3 n_4], the $B_{\overline{n_1 n_2}}$ is equal to B_r and the $B_{\overline{n_2 n_3}}$ is less then B_r. If the $B_{\overline{n_2 n_3}}$ is less than B_r, the node n_2 finds other nodes n'_i, where *i* = 1, 2 , ..., *p*, such as the total bandwidth on $\begin{bmatrix} & n'_1 \\ n_2 & \vdots \\ & n'_p \end{bmatrix}$ is equal to B_r and calculates the RSF[n_2, n_3], RSF[n_2, n'_1], RSF[n_2, n'_2], ..., and RSF[n_2, n'_p]. Then node n_2 record the sector ID which n_2 uses to connect with nodes n'_i and n_3, updates the SL_REQ (*S*, *D*, $n'_i(n_3)$, n_4, $\{[n_1\ n_2]\}$, *RSF*[n_2, n'_i], B_r, *B*) and sends routing packet to notify nodes n_3 and n'_i the reserved share free time slots and two hop neighboring n_4 information.

Step 2: when node n_3 and n'_i received the routing packet from node n_2 , they respectively calculate *RSF* with their common neighbor. Then the node n_3 and n'_i updating the SL_REQ packet and forward the routing packet to the next hop. The nodes n_3 and n'_i record the sector ID which they use to connect next hop and receive from preceding hop.

Step 3: node n_4 received routing packet from n_3 and n'_i and the bandwidth on $\begin{bmatrix} n_3 & \\ n'_1 & \\ \vdots & n4 \\ \vdots & \\ n'_p & \end{bmatrix}$ is equal to B_r.

Case III: under preceding multi-path network topology, sometimes some parts of bandwidth are insufficient due to the network bandwidth is strictly insufficient. The shoelace-path is used and the procedure is described as follows. Let $\begin{bmatrix} & & h_1 & & \\ n_1 & n_2 & \vdots & n_5 & n_6 \\ & & h_p & & \end{bmatrix}$, where $p \geq 2$ denote multi-path. The front and post of multi-path bandwidth are not satisfied bandwidth requirements. But there are more bandwidth on one or more link. Now let there be more bandwidth on link $\overline{n_2 h_1}$. The operation is described as follow.

Step 1: the node n_2 finds other node h'_i, where *i* = 1, 2, . . . , *x*, *x* ≥1, such as the total bandwidth on $\begin{bmatrix} & h'_1 \\ & \vdots \\ & h'_x \\ n_2 & h_1 \\ & \vdots \\ & h_p \end{bmatrix}$ is equal to B_r and calculates *RSF*[n_2, h'_1], *RSF*[n_2, h'_2], . . . , *RSF*[n_2, h'_x]. Afterward, the node n_2 the updates SL_REQ and sends routing packet to notify h'_i the reserved share free time slots and two hop neighbor information and records the sector ID which node n_2 uses to connect with node h'_i.

Step 2: when the node h'_i received the packet from node n_2, the node h'_i calculates the *RSF*[h'_i, n_5]. The node h_1 find other node k_i, where *i* = 1, 2, . . . , *q*, $q \geq 1$ such as the bandwidth on $\begin{bmatrix} & k_1 \\ h_1 & \vdots \\ & k_q \end{bmatrix}$ is equal to on [n_2 h_1] and calculates *RSF*[h_1, k_i]. The nodes h_1 and h'_i update the SL_REQ and forward the routing packet to next hop and record the sector ID which nodes h_1 and h'_i use to connect with next hop and receive from preceding hop.

Step 3: when the nodes n_5 and k_i received the routing packet from nodes h'_i and h_1, the nodes n_5 and k_i calculate *RSF*[n_5, n_6] and *RSF*[k_i, n_6], respectively. The node n_5 and k_i update the SL_REQ and forward the routing packet to next hop and record the sector ID which nodes n_5 and k_i uses to connect with next hop and receive from preceding hop.

Step 4: the node n_6 received the routing packet form nodes n_5 and k_i and the total bandwidth is equal to B_r. The shoelace path is constructed.

C. Phase III: Shoelace path maintenance

Each node can move at random leading to the link break. The maintenance procedure is started to maintain the bandwidth requirement. If the shoelace-path fails resulting in the total bandwidth is less than B_r, then the preceding hop nodes of the fails or moving node try to search other node to replace the failing or moving node.

IV. Simulation results

This section evaluates our shoelace-based QoS routing protocol, Saha *et al.*'s scheme, and Ueda *et al.*'s scheme. All these protocols are implemented using the NCTUns 3.0 simulator. The system parameters are given below. The simulation is run in a 1000x1000 m^2 area. The mobility speed is from 10 to 50 km/h. The number of time slots is set to be 16. The numbers

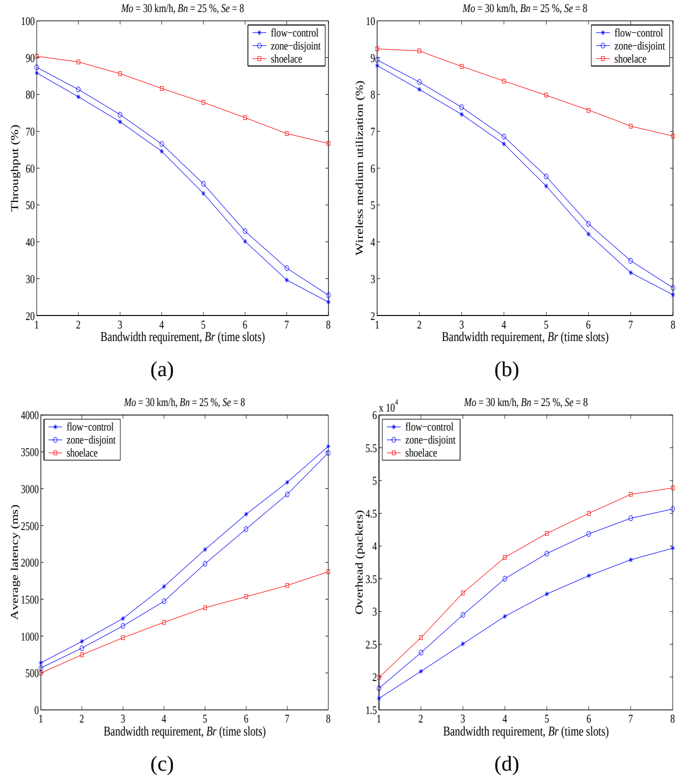

Fig. 4. Performance comparisons

of sector is 8 and the transmission range is 100 meters. The bandwidth requirement is 1 to 8 time slots. The data rate is 2 Mb/s.

A. Throughput

The number of received data packets for all destination hosts divided by the total number of data packets sent from the source host. The simulation result shown in Fig.4(a) illustrates the throughput. The shoelace-based scheme has a better throughput than other schemes. This is because the zone-disjoint scheme and flow-control scheme only guarantee the QoS requirement of high priority flow. The entirety throughput of network is lower due to other priority flows are not satisfied the QoS requirement.

B. Wireless medium utilization

The number of received data packets for all destination hosts divided by the simulation area. The simulation result shown in Fig. 4(b) illustrates the wireless medium utilization. When the bandwidth requirement is increasingly, the shoelace-based protocol is obvious better than others. This is because the cross links of the shoelace scheme can simultaneously transmit data on a space without any data interference.

C. Average latency

The interval from the time the transmission is initiated to the time the last host finishes its received. The simulation result shown in Fig. 4(c) illustrates the average overhead. The shoelace-based scheme has better average latency than other schemes, even if the bandwidth requirement is high. This is because when the bandwidth requirement is high, the low priority flows of zone-disjoint scheme and flow-control scheme easier block flow and reduce flow rate, respectively. Then the low priority flows have high average latency resulting in the network latency is higher.

D. Control overhead

The total numbers of control packets. The simulation result of zone-disjoint, flow-control, and shoelace-based protocols is shown in Fig. 4(d) to reflect the control overhead. Our approach aims to obtain a more reliable QoS routing result by sacrificing the extra overhead cost. Our scheme increasing extra control packets to offer the better results of throughput, wireless medium utilization, and average latency.

V. Conclusion

This paper presents a new QoS routing protocol, namely shoelace-based QoS routing protocol for MANET using directional antenna, where the MAC sub-layer adapts the CDMA-over-TDMA channel model. These cross links can simultaneously transmit data without any data interference. Our scheme provides a dynamic routing path, which is depended on network environment. The shoelace-based routing is a uni-path if the network bandwidth sufficient and a multi-path if the network bandwidth insufficient. The performance results reflect that the shoelace-based scheme presents better performance when the network bandwidth is strictly insufficient. Our shoelace-based scheme improves the success rate, throughput, and average latency.

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