Integrated Services (IntServ) [1] and Differentiated Services (DiffServ) [2]. IntServ uses the RSVP protocol [3] to carry the QoS parameters from the sender to the receiver to make resource reservations along the path. IntServ/RSVP provides for a rich end-to-end QoS solution, by way of end-to-end signalling, state-maintenance (for each RSVP-flow and reservation), and admission control at each network element. DiffServ on the other hand, does not have any end-to-end signalling mechanism and works on a service level agreement between the provider and the user. All packets from a user are marked to specify the service level and are treated accordingly. Multiple flows in DiffServ model are mapped to a single service level and state information about every flow need not be maintained along the path.

IntServ-based model on per-flow resource reservation is not particularly suitable for MANETs because of the frequently changing topology and limited resources in MANETs, resulting in more signalling overhead and unaffordable storage and computing process for mobile nodes. DiffServ-based is a lightweight model using a relative-priority scheme to soften the hard requirements of hard QoS models like IntServ. The service differentiation is based on per-hop behaviours (PHBs) [4], so no flow states need to be maintained within the core of the network. Thus the model could be a potential QoS model in MANETs.

The current existing solutions for QoS provisioning in MANETs are mainly based on the IntServ or DiffServ model. AQOR [5] uses a reservation-oriented method to decide admission control and allocate bandwidth for each flow. INSIGNIA [6] employs an in-band signalling protocol rather than out-of-band signalling protocol as RSVP to decrease reservation overhead. FQMM [7] is designed to provide QoS in ad hoc networks by mixing the IntServ and DiffServ mechanisms. High priority applications are provided by IntServ per-flow QoS guarantee, while lower priority applications are provided with per-class differentiation based on DiffServ. SWAN [8] is based on reservation-less approach. By avoiding signalling, it simplifies the whole architecture and provides a differentiation between real-time and best effort in spite of not being able to guarantee the QoS needs of each flow for the whole session due to frequently changing topology and limited wireless bandwidth restriction.

Multipath routing allows the establishment of multiple paths between a single source and single destination node during a single route discovery. Some multipath routing protocols [9,10,11] in MANETs have been proposed to provide load balancing, fault-tolerance and higher aggregate bandwidth as well as eliminate route discovery latency after a link break by making use of the availability of multiple route paths. However, these multipath routing protocols lack QoS support in the process of transmission of data packets.

In this paper, we present a novel node-disjoint Multipath QoS Routing protocol for supporting DiffServ (MQRD), which makes DiffServ readily over a multipath routing protocol, Node-Disjoint Multipath Routing (NDMR) [9], for QoS provisioning in MANETs.

The remainder of this paper is organized as follows. In section 2, an overview of NDMR is presented. Section 3 gives a simple overview about DiffServ. Section 4 presents MQRD QoS model for MANETs. In section 5 a simulation model based on OPNET is proposed. Performance evaluation and comparison of NDMR and MQRD are presented in Section 6 and concluding remarks are made in Section 7.

2. NDMR

Ad hoc On-Demand Distance Vector (AODV) [12] and Dynamic Source Routing (DSR)

entry. If the number of hops is larger than the shortest number of hops, the node drops the RREQ packet. Otherwise (less than or equal to), the node appends its own address to the route path list of the RREQ packet and broadcasts the RREQ packet to its neighbouring nodes. If the compared result is less than zero, the old shortest number of hops in reverse route table entry should be updated by the new shortest number of hops.

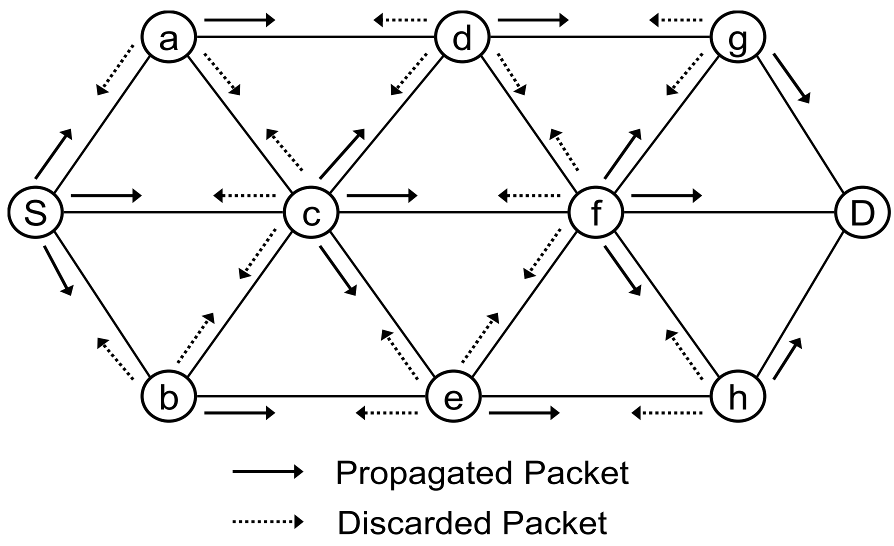

Figure 2. Route Request Process with Low Overhead

Figure 2 illustrates the route request process with low routing overhead in the entire network. Source S broadcasts a route request packet. Each intermediate node uses the approach with low routing overhead to propagate and discard packets. Therefore, only seven packets (S-c-f-D, S-a-d-g-D, S-b-e-h-D, S-c-d-g-D, S-c-e-h-D, S-c-f-g-D, S-c-f-h-D) can reach the destination D. However, not all of paths packets that arrive in destination are node-disjoint. In next section we discuss how to choose node-disjoint paths.

2.3. Select Node-Disjoint Paths

In NDMR, the destination is responsible for selecting and recording multiple node-disjoint route paths. In Figure 2, its three node-disjoint route paths are: S-a-d-g-D, S-c-f-D, S-b-e-h-D. When receiving the first RREQ packet (the shortest route path: S-c-f-D), the destination records the list of node IDs for the entire route path in its reverse route table and sends a RREP that includes the route path towards the source along the reverse route. When the destination receives a duplicate RREQ, it will compare the whole route path in the RREQ to all of the existing node-disjoint route paths in its route table entry. If there is not a common node (except source and destination) between the route path from the current received RREQ and any node-disjoint route path recorded in the destination's reverse route table entry, the route path of the current RREQ (such as S-a-d-g-D or S-b-e-h-D) satisfies the requirement of node-disjointness and is recorded in the reverse route table of the destination. Otherwise, the route path (such as paths: S-c-d-g-D, S-c-e-h-D, S-c-f-g-D, S-c-f-h-D) and the current received RREQ are discarded.

4. MQRD

Although NDMR provides node-disjoint multipath routing with low route overhead in MANETs, it is only a best-effort routing approach, which is not enough to support QoS. DiffServ is an approach for a more scalable way to achieve QoS in an IP network. It could be a potential QoS model in MANETs because it acts on aggregated flows and minimises the need for signalling. However, one of the biggest drawbacks of DiffServ comes from the fact that the QoS provisioning happens separate from the routing process. MQRD combines the advantages of NDMR and DiffServ and makes it suitable for the environment of MANETs with QoS support.

4.1. Integration of NDMR and DiffServ

Both of NDMR and Diffserv operate at the network layer, so it is easy to work naturally together. Although NDMR was designed without taking QoS into consideration, it and DiffServ could be complementary techniques that can be implemented in MANETs to support an end-to-end QoS solution. When used together, DiffServ provides the standardized QoS mechanisms and NDMR provides node-disjoint multipath routing techniques increasing the network resource optimization and decreasing routing overhead. In MANETs, the source node classifies data packets and then marks them with the corresponding DSCP. The intermediate mobile nodes use PHB to determine the scheduling treatment and drop probability for each packet.

4.2. QoS and Resource Management of MQRD

Effective QoS mechanism can be used to provide better service to certain flows in the environments of limited wireless bandwidth. In MQRD this is done by either raising the priority of a flow or limiting the priority of another flow. In order to support service differentiation, scheduling and queue management are thought to be two important aspects of resource management. The former is done by the scheduler which decides the opportunities of flows for link access and the latter holds the valid packets when necessary drops some packets from the buffer in case of network congestion.

4.2.1. Priority Scheduling

In MANETs, when a mobile node is receiving traffic faster than it can transmit, the node may buffer the extra traffic until bandwidth is available. Using a queuing algorithm to sort the traffic has been deployed to handle an overflow of arriving traffic in wired networks. In MQRD, priority queuing is used to build a priority scheduler. The priority scheduler includes two queues: a high-priority queue and a low-priority queue. The high-priority queue must be emptied before packets are emptied from low-priority queues.

Although DiffServ has a lot of classes defined, the most essential use of DiffServ is to provide support for the two most common applications:

(A) Voice, Video traffic.

(B) Best effort data.

Let us denote the two classes as A and B. Class A applications require generally low loss, low latency, low jitter and assured bandwidth service, so packets of class A are classified as Expedited Forward (EF) traffic. Class B is classified as Best Effort (BE) traffic which offers a

analyze the proposed node-disjoint Multipath QoS Routing protocol for supporting DiffServ (MQRD) and compare performances with NDMR, which does not take QoS into account.

5.1. Mobility and Traffic model

The random waypoint model [19] is used to model mobility. Each node starts its journey from a random location to a random destination with a random velocity of 0-20 m/s. Once the destination is reached, another random destination is targeted after a pause. Field configuration of 1000m x 1000m field with 50 nodes is used and each node uses the IEEE 802.11[20] with a 250m transmission radius. The pause time is kept constant at 30seconds for all our simulation experiments. Traffic sources with 512 byte data packets are CBR (constant bit rate). The source-destination pairs are spread randomly over the network and the number of sources is varied to change the offered load in the network.

In order to investigate the usage of network ability, the number of EF (Expedited forwarding) sources with 80kbit/s (20pkt/s) bandwidth requirement is varied from 5 to 20 in intervals of 5. 20 other nodes are randomly chosen to send background BE (Best Effort) traffic with 2pkt/s. Simulations are run for 800 simulated seconds.

5.2. Performance Metrics

The following metrics are used in varying scenarios to evaluate the two protocols:

- *Packet delivery ratio:* The ratio of the data packets delivered to the destinations to those generated by the CBR sources.
- *Average delay of data packets:* This includes all possible delays from the moment the packet is generated to the moment it is received by the destination node.

6. SIMULATION RESULTS

Comparing Figure 5 and Figure 6, we can find that the packet delivery ratio of MQRD has better performance than that of NDMR with the increase in the number of EF sources. In order to show clearly and compare simulation results of different type of packets, packet delivery ratios of EF packets, BE packets and ALL packets (combination of EF and BE packets) are depicted respectively in the two figures. Figure 6 shows that EF packets have higher delivery ratio than BE packets because priority scheduler is used in MQRD. When the number of EF sources increases, NDMR drops a larger fraction of the packets than that of MQRD. The reason is that there exists more congestion in mobile node buffers when the number of EF sources increases.

From Figure 7 we can see that EF packets and BE packets in NDMR have little difference in End-to-End average delay. The reason is that there is no priority policy to deal with the incoming EF and BE packets in mobile nodes. Figure 8 shows that EF packets of MQRD has a much lower average delay than BE packets because priority scheduler in MQRD makes EF packets be forwarded more quickly. With the increase in the number of EF sources average delay of BE packets in MQRD increases more quickly than that of EF packets. The reason is that an increase in the number of EF sources leads to higher network load traffic. Because of the limitation of a constrained wireless bandwidth, BE packets that will be sent or forwarded have to stay in buffers and wait for a longer time to get a radio channel available than EF packets in order to avoid traffic congestions.

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