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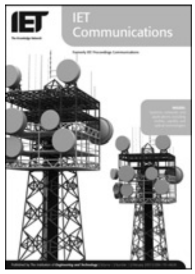

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Flooding-limited for multi-constrained quality-of-service routing protocol in mobile *ad hoc* networks

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Abstract: Multi-constrained quality-of-service (QoS) routing is used to find routes in a network to satisfy multiple independent QoS constraints. This problem is considered to be NP-complete, and most existing QoS routing algorithms are based on maintaining a global network state at every node. A multi-constrained, flooding-limited, QoS routing method to deal with limited available resources and minimum computation in a dynamic environment is proposed. The solution is based on decomposition of a routing area and a restriction in the exchange of routing information. It reduces the size of the control messages, restricts the amount of routing information, minimises the overhead from the flooding of control traffic and decreases the complexity of path selection. It is also proved that the flooding-limited-path heuristic can achieve very high performance by maintaining entries in each node, which indicates that the performance of the limited-path heuristic is not sensitive to the number of constraints. Simulation results show that this protocol provides better performance than other protocols, especially with regards to end-to-end delay, throughput and packet loss.

1 Introduction

The internet has already become indispensable for human life. There are two kinds of media transmission for the internet: wireless and wired. Many limitations exist in wireless networks, and hence many wired services are difficult to implement in wireless networks, especially when quality of service (QoS) is needed for real-time applications (such as video and voice).

The QoS requirement of a point-to-point connection is typically specified as a set of constraints, which can be concave metrics (e.g. bandwidth, batter energy), additive metrics [e.g. cost, delay, delay variation (jitter)] and multiplicative metrics (i.e. packet loss rate, propagation delay). For example, the bandwidth constraint requires that each link along the path support a certain bandwidth. It can be defined as the minimum of the residual bandwidth of all links on the path, or the bottleneck bandwidth. The delay constraint requires that the aggregate delay of all links along the path be less than the delay requirement. Multi-constrained QoS routing finds a path that satisfies multiple independent path constraints. One example is delay-cost-constrained routing, that is finding a route in the network with a bounded end-to-end delay and bounded end-to-end cost. Multi-constrained QoS routing problems have been proven to be NP-complete [1] and cannot be solved by a simple and efficient algorithm. Although many heuristics algorithms [2, 3] have been proposed to reduce computation, and some distributed QoS routing schemes that work with imprecise state information were recently proposed [4], the computational complexity and the premise that every node has up-to-date information for a global network state, make these algorithms impractical and unattractive.

The MANET is composed of a set of mobile hosts with wireless transceivers. It does not rely on any infrastructure or centralised management. Wireless mobile hosts communicate with each other through multiple-hop wireless paths. The data transmission of a mobile host is limited by the transmission range, and therefore it needs the assistance of intermediate mobile hosts. Many papers [5–15] have discussed MANET routing protocols. The Internet Engineering Task Force has a workgroup that focuses on problems arising from MANET; it encourages research in this area. Basically, MANETs classify the routing protocol into two categories. The first is a proactive routing protocol and the other is a reactive routing protocol. Proactive routing protocols need to exchange packets between mobile hosts frequently and update their routing databases continuously. Each mobile host must maintain the network status in real time. This overloads mobile hosts, makes the network crowded and requires lots of memory space. The advantage is that each mobile host has correct and up-to-date data. So, when we need a path, we can find it directly in the memory and establish links quickly. Examples of routing protocols are CGSR [16], DSDV [17], OLSR [18, 19] etc. The main topic of these protocols is 'How to reduce the frequency of broadcast and at the same time maintain the correct information of the routing table'. On the other hand, the reactive routing protocol searches for a path to the destination only when it is needed. The advantage is that routing tables in the memory are not updated continuously. These routing protocols do not need more memory space to record network information. However, the disadvantage is that they cannot establish connections in real time. The common routing protocols are AODV [20, 21], DSR [9, 22], TORA [23] etc. Thus, the main topic of these protocols is 'How to save time while searching the routing paths and prevent delays in maintenance.' The routing protocol we proposed is 'reactive'. Its operation is like the dynamic source routing (DSR) protocol.

To guarantee QoS routing, we have to consider the end-to-end delay, the path bandwidth and the battery energy of mobile hosts. Therefore the multi-constrained parameters considered should include delay time, bandwidth and power consumption. We propose an on-demand routing algorithm, named flooding limited for multi-constrained QoS routing protocol (FLMQRP). This novel protocol addresses how to find a feasible path to satisfy QoS conditions (i.e. bandwidth, end-to-end delay and power consumption). FLMQRP uses a flooding-limited mechanism to broadcast QoS route request (FLMQRP_QRREQ) packets to find a suitable routing path. The destination will reply with the QoS route reply (FLMQRP_QRREP) packet to form a reverse path back to the source. Whenever a wireless link connection breaks, the route maintenance procedure will be initiated for route recovery. We adopt a detection mechanism called 'acting against the QoS mechanism' [24], which can trigger the route recovery immediately. The destination node will send an unsolicited FLMQRP_QRREP packet back to the source node to repair the path. The flooding-limited approach addresses QoS functionality to deal with limited available resources in a dynamic environment. We add the QoS flow requirements to our proposal. The solution is based on decomposition of a routing area and restriction on the exchange of routing information. It reduces the size of the control messages, restricts the amount of routing information, minimises the overhead from the flooding of control traffic and decreases the complexity of path selection.

The remainder of this paper is organised as follows: Section 2 introduces other related protocols. Section 3 presents our routing algorithm, from searching for a route to maintenance of the route. Section 4 describes assumptions for simulation, our simulation environment and the simulation results. Finally, the last section draws conclusions and suggests future work.

2 Related works

Mobile hosts in the MANET can communicate with each other directly without base stations. Because of limitations in the transmission range, if two mobile hosts want to transfer packets to each other, they may rely on intermediate mobile hosts to provide transfer assistance. These mobile hosts are called 'routers'. Therefore the method of finding a path between nodes is called a 'routing protocol'. In the following, we briefly introduce a few MANET routing protocols.

2.1 AODV and DSR routing protocol

AODV [20, 21] and DSR [17, 9] routing protocols are the two most widely studied on-demand approaches for finding routes. An on-demand route is one that is established only when it is required by a source node for transmitting packets. It allows the network to be completely self-organising and self-configuring, without the need for any existing network infrastructure or administration. In AODV, the source node and the intermediate node store the next-hop information corresponding to each flow for packet transmission. In an on-demand routing protocol, that source node floods a route request packet (AODV_RREQ) to its neighbours and then to the neighbour's neighbours, until the desired destination node receives this AODV_RREQ packet. It may obtain multiple routes to different destinations from a single AODV_RREQ packet. When all intermediate nodes have valid routes to the destination, the destination node is allowed to send a route reply packet (AODV_RREP) back to the source node. It establishes a reverse path at the same time and discards the other AODV_RREQ packets later. The source node uses this path as the packet transfer path. The major difference between AODV and other on-demand routing protocols is that it uses a destination sequence number to determine an up-to-date path to the destination. The disadvantage of this protocol is that multiple AODV_RREP packets in response to a single AODV_RREQ packet can lead to heavy control overhead and the periodic beaconing can lead to unnecessary bandwidth consumption.

The DSR is a simple and efficient routing protocol designed specifically for use in multi-hop wireless *ad hoc* networks. When the source node has packets to be sent to the destination node, it initiates a DSR_RREQ packet. The DSR_RREQ is flooded throughout the network. Each node, upon receiving a DSR_RREQ packet, rebroadcasts the packet to its neighbour if the node is not the destination node, provided the packet's time to live (TTL) count has not exceeded. A destination node, after receiving the first DSR_RREQ packet, replies to the source node through the reverse path the DSR_RREQ packet had traversed. The protocol is composed of the two mechanisms of 'route discovery' and 'route maintenance', which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the *ad hoc* network. The major difference between AODV and DSR stems from the fact that DSR uses source routing, in which a packet carries the complete path to be traversed. The disadvantage of this protocol is that route maintenance does not locally repair a broken link and the routing overhead is directly proportional to the path length.

2.2 Flood-and-prune QoS routing

Song and collaborators' research [25] proposes a distributed QoS routing scheme to support multi-constrained traffic. This scheme is based on the flooding-based concept and has a built-in quick-pruning mechanism. The established connections are guaranteed and all QoS metrics specified [i.e. bandwidth, end-to-end delay and delay variation (jitter)]. The proposed algorithm allows multiple QoS checks at every node, depending on the cooperative scheduling algorithm in operation at the nodes. The QoS constraint at each node is mainly used to check that enough resources are there to guarantee multiple QoS constraints. The bandwidth constraint is defined as

$$R_l^* + B_i^* \leq C_l^*$$

where B_i^* is the minimum bandwidth guaranteed for connection i; R_l^* the bandwidth reserved for QoS connection requests for the link l; and C_l^* the total link capacity.

For the delay constraint, the authors compared the end-to-end delay bound requirement of the request with the accumulated delay up to that node. The maximum packet length L_i of that session and the request packet contain the end-to-end delay bound requirement D_i of the session. Thus, the delay constraint is defined as

$$d_i^* + (L_i^*/B_i^* + L_{\max}^*/C_l^* + P_l^*) \leq D_i^*$$

where d_i^* is the accumulated delay up to that node; P_l^* is the propagation delay over link l and $L_{\max}^*$ is the network maximum transmission unit.

Delay jitter constraint, similar to the delay constraint, compares the end-to-end delay-jitter bound requirement J_i^* of the session i with the accumulated delay jitter up to that node j_i^*

$$j_i^* + L_i^*/B_i^* \leq J_i^*$$

The above descriptions reveal that this algorithm can support multiple QoS constraints, as many as the application requires. The algorithm uses a 'quick-pruning' technique to release immediately any resources reserved in excess, makes the destination send immediate confirmation upon receipt of the first request packet of a connection, and sends a prune-forward packet to release the resource quickly on any path that is not on the QoS route. The advantage of flood-and-prune QoS routing is that there is no need for information distribution and complex route computations. The drawback is that it is not very efficient, especially when there are mobile nodes or link failures.

3 FLMQRP mechanism

When a mobile host wants to communicate with another host on the MANETs, the communication would need to satisfy QoS (e.g. minimum requested bandwidth, maximum allowable delay etc.) routing requests if it were real time. Hence, we propose a routing protocol to satisfy the QoS requests. We also add power constraints to make our protocol more robust and reliable. The FLMQRP mechanism can be divided into two parts: one, route establishment; the other, route maintenance. The route establishment contains the procedures for route discovery and data transmission. As shown in Fig. 1, a source node S attempts to send data to the destination node D. First, the source node S initiates the QoS route discovery procedure. Once destination node D is found, the source starts the data transmission. Whenever any wireless link in the communication path breaks, the protocol initiates the procedure for route recovery. Details are explained later.

3.1 Multi-constrained QoS routing

Assume that a network is represented as a weighted graph $G = (V, E)$, where V denotes the set of vertices as nodes, and E denotes the set of edges as communication links connecting the nodes. $|V|$ and $|E|$ denote the number of

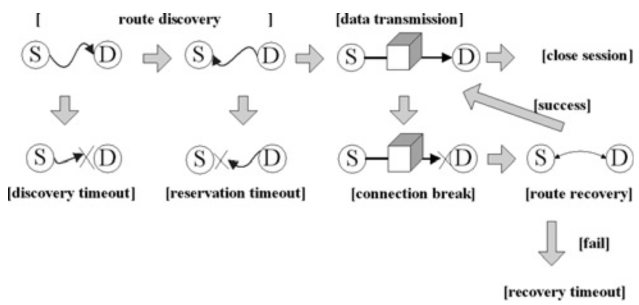

Figure 1 *Flowchart of FLMQRP*

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