A Performance Comparison of Multipath Multicast Routing Protocols for MANET

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Summary
Mobile ad hoc networks (MANETs) are characterized by dynamic topology, limited channel bandwidth and limited power at the nodes. Because of these characteristics, paths connecting to the source nodes with destinations may very unstable and go down at any time, making communication over ad hoc networks difficult. Multicasting is intended for group-oriented computing. Multicast generally needs a tree construction that connects all the members of the multicast group as well as the nodes where data packets are duplicate. In this paper, we compared the multicast multipath routing protocols. The MAODV (Multicast Ad hoc On-demand Distance Vector) routing protocol shows a smooth performance in light load ad hoc networks. However, as degraded quickly. Multipath routing allows building and use of multiple paths for routing between source and destination pair. It exploits the resource redundancy and diversity in the underlying network to provide benefits such as fault tolerance, load balancing, bandwidth aggregation, and improvement in QoS metrics such as delay. Multiple Path - MAODV (MP-AODV) distributes traffic through two node-disjoint routes to improve network efficiency and balances the network loads. Multiple Tree- MAODV (MT-MAODV) routing protocol consists mainly of constructing two disjoint trees. Only when the two links are broken, the source nodes restart to find new routes. So it decreases the number of routing discovery and reduces routing overhead. The MT-MAODV and MP-MAODV preferably ensure the network performance in heavy load ad hoc networks.
Key words:
Multicast, multipath, VCR, mobile adhoc network

1. Introduction

MANETs[14] are infrastructure-less wireless networks where nodes are capable of moving. They are formed dynamically by a collection of arbitrarily located wireless mobile nodes without much set up time or cost and without the use of existing network infrastructure or centralized administration. Generally, some or all nodes of a MANET function as routers and communication between two hosts is done by multi-hop routing through the nodes of the network. Devices such as laptops, PDAs, mobile phones, pocket PC with wireless connectivity are commonly used.

Multicasting [8-13] is intended for group-oriented computing. There are more and more applications where one-to-many dissemination is necessary. The multicast service is critical in applications characterized by the close collaboration of teams (e.g. rescue patrol, battalion, scientists, VCR etc) with requirements for audio and video conferencing and sharing of text and images. The use of multicasting within a network has many benefits. Multicasting reduces the communication costs for applications that send the same data to multiple recipients. Instead of sending via multiple unicast, multicasting minimizes the link bandwidth consumption, sender and router processing, and delivery delay. Maintaining group membership information and building optimal multicast trees is challenging even in wired networks. Routing is needed to find a path between source and destination, and to forward the packets appropriately.

Multipath routing is a technique that exploits the underlying physical network resources by utilizing source to multiple m paths. It is used for a number of purposes, including bandwidth aggregation, minimizing end-to-end delay, increasing fault-tolerance, enhancing reliability, load balancing and so on. The idea of using multiple paths has existed for some time and it has been explored in different areas of networking.

The focus of our work is to analyze the MAODV [1] based multicast multipath routing protocol using VCR application. Our implementation compares the performance of the MP-MAODV [2] and MT-MAODV [3]. Both protocols extend the MAODV protocol. The performances of group learning module of VCR are analyzed using MP-MAODV and MT-MAODV routing protocols for parameter of network load.

MP-MAODV [2] is a multipath routing protocol extension based on MAODV [1]. In this extension

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MAODV is based on three aspects: multipath selection and establishment, multipath route maintenance and load distribution for distributing traffic among node-disjoint paths. They add two control messages and one backup routing table for the MP-MAODV, and extend it from three aspects: multipath selection and establishment, multipath routing maintenance and load distribution. The flag S with value 1 is added to control message MACT-S and RREP-S for selecting and establishing disjoint paths.

MT-MAODV [3] routing protocol consists mainly of constructing two disjoint trees. In order to accomplish this, each node can have one of five statuses: multicast group member, ON GROUP; forwarding node of the two trees: ON TREE 0; forwarding node of tree-one: ON TREE 1; forwarding node of tree-two: ON TREE 2; not tree member: NOT ON TREE.

The organization of the paper is as follows: The detail of multipath routing background is discussed in section 2. Next we have introduced the base protocol and MAODV based multicast multipath routing protocols in section 3. In section 4, performance comparison results of the base protocol and the above two routing protocols are discussed. Finally, conclusion of this paper is presented in section 5.

2. Multipath Routing in Ad Hoc Networks

Mobile ad hoc networks are characterized by a dynamic topology, limited channel bandwidth and limited power at the nodes. Because of these characteristics, paths connecting source nodes with destinations may be very unstable and go down at any time, making communication over ad hoc networks difficult. On the other hand, since all nodes in an ad hoc network can be connected dynamically in an arbitrary manner, it is usually possible to establish more than one path between a source and a destination. When this property of ad hoc networks is used in the routing process, we are in need of multipath routing.

In most cases, the ability of creating multiple routes from a source to a destination is used to provide a backup route[4]. When the primary route fails to deliver the packets in some way, the backup is used. This provides a better fault tolerance in the sense of faster and efficient recovery from route failures. Multiple paths can also provide load balancing and route failure protection by distributing traffic among a set of disjoint paths.

Paths can be disjoint in two ways: (a) link-disjoint and (b) node-disjoint. Node-disjoint paths do not in common, except the source and destination, hence the do not have any links in common. Link-disjoint paths, in contrast, do not have any links in common. They may, however, have one or more common nodes as shown in Fig. 1. In order to use multiple paths simultaneously they need to be as independent as possible. So not only do they

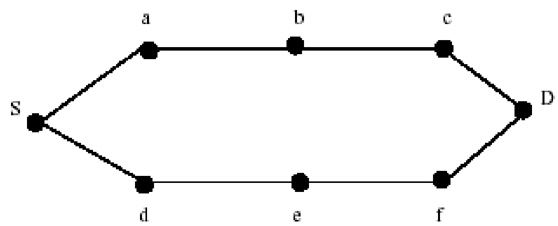

Fig. 1a. Two node-disjoint paths from source *S* to destination *D*

need to be disjoint, also route coupling[15] must be taken into account, because routes can interfere with each other. Route coupling takes place when a path crosses the radio coverage area of another path. There is a protocol that uses this property of radio broadcast to create

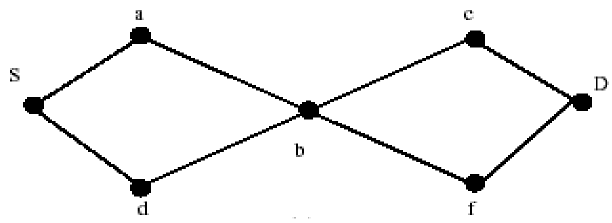

Fig. 1b. Two link-disjoint paths from source *S* to destination *D*. Note that they are not node-disjoint, since they share node *b*

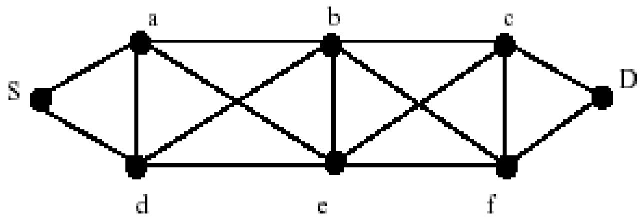

Fig. 1c. The two node-disjoint paths from Fig. 1a, when they are in each other's radio coverage

backup-routes [5], but in the case of multiple-path data transport route coupling is unwanted. Routes may be link- or even node-disjoint but still interfere with each other due to route coupling. Consider the node-disjoint routes of Fig. 1a again. In the situation of Fig. 1c, for example when node *a* sends data to node b (both route 1), node *d* on the other route cannot transmit data to *e* on route 2, since the nodes (and thus routes) are in each other's radio coverage area and interfere with each other. Since none of the routing protocols take the route coupling into account, we will ignore it in the sequel. Disjointness will be the only measure used for path independence.

2.1 Requirements for Multipath Routing in Ad Hoc Networks

When a routing protocol is needed for the purpose of using data transport in mobile ad hoc networks, certain properties are required. The described requirements are listed below:

- The routing protocol must provide multiple paths to destinations.
- The routing protocol must provide loop-free paths to destinations.
- The routing protocol must provide node-disjoint paths to destinations, because (in this case) this is the strongest measure of path independence.
- The multiple paths need to be used simultaneously for data transport, the data packets are need to arrive more or less simultaneously at the destination, so the multiple paths must not be backup routes, used only when the first route fails.

The above mentioned properties are requirements, protocols however may also have a number of properties, which are not required but give them certain advantage over other protocols:

- Routes need to be completely known at the source, and verify the disjointness of the path.
- For each route the QoS metrics must be known:
  - Bandwidth,
  - Delay
  - Cost.

3. Multicast Routing protocols for MANET

3.1 Multicast Ad hoc On-demand Distance Vector protocol (MAODV):

MAODV[5] is a multicast extension of AODV. In MAODV, all members of a multicast group are formed into a tree (which includes non-member nodes required for the connection of the tree) and the root of the tree is the group leader. Multicast data packets are propagated among the tree. The core of the MAODV protocol is about how to form the tree, repair the tree when a link is broken and how to merge two previously disconnected trees into a new tree. There are four types of packets in MAODV: Route Request (RREQ), Route Reply (RREP), Multicast Activation (MACT) and Group Hello (GRPH). RREQ and RREP are also packets in AODV. A node broadcasts a RREQ, when it is a member node and wants to join the tree, or it is a non-member node and has a data packet targeted to the group.

When, a node in the tree receives a RREQ and it response with a RREP using unicast. Since RREQ is broadcast, there may be multiple RREP's received by the originating node. The originating node should select one RREP that has the shortest distance to the tree and unicast a MACT along the path to set up a new branch to the tree.

GRPH is the group hello packet, it is periodically broadcasted by group leader to let the nodes in the tree to update its distance to the group leader.

3.2 Multiple Path - Multicast Ad hoc On-demand Vector (MP-MAODV):

MP-MAODV[2] is a multipath routing protocol extension based on MAODV [1]. In this extension MAODV is based on three aspects: multipath selection and establishment, multipath route maintenance and load distribution for distributing traffic among node-disjoint paths. They add two control messages and one backup routing table for the MP-MAODV, and extend it from three aspects: multipath selection and establishment, multipath routing maintenance and load distribution. The flag S with value 1 is added to control message MACT-S and RREP-S for selecting and establishing disjoint paths.

3.2.1 Multipath Selection and Establishment

In MAODV, when a node broadcasts a RREQ message, it is often likely to receive more than one response message since any node in the multicast tree can respond to the message. If the source node receives one or more RREP messages in this time, it queries the multicast table and check if the route is activated to confirm which one is the first arrival. The source node unicasts a MACT to the node which RREP is the first arrival for activating the route and sends packets through the path due to the first path has the shortest latency. The intermediate nodes, which received MACT, activate the related entry in multicast table, and then forward the MACT to next hop until one group member receives MACT. If the RREP received by the source node is not the first arrival, the source node replies MACT-S to the next hop. The intermediate nodes, which received MACT-S, query the multicast table and check if the route is activated. If the route is activated, the intermediate nodes discard this MACT-S, if not , it will add an entry to the backup route table to establish reverse route in backup route table and send MACT-S to the next hop until this MACT-S forward to a group member. The multicast group node received the MACT-S then unicasts a RREP-S to the source node.
The intermediate node that received MACT-S adds an entry to the backup route table to establish forwarding route and then forwards it to the source node. So this mechanism can guarantee two node disjoint paths and avoids loops.

Source node is likely to receive one or more RREP-S messages during this time, but it selects the route with largest sequence number and smallest hops by checking the RREP-S messages as the second path, and adds an entry to the backup route table. Maintaining more than two backup paths cannot evidently improve route performance. So we select only two paths in order to reduce resource consumption and improve calculation efficiency. If the source node does not receive a RREP-S message before timeout, it uses the single path to send the data packets.

3.2.2 Load Distribution

Once the source node activates the first path, it sends all packets through the path in order to reduce latency caused by route discovery. When two paths has been selected, the source node starts to send packets through two paths in turn, that is, send a packet through the first path, then send the next packet through the second path. This simple method can balance the network load and relieve the network congestion.

3.2.3 Multipath Route Maintenance

The wireless link is easy to break because of nodes mobility or other reasons. When a node doesn't receive any message from the adjacent node or can't send any packet to the next hop, it thinks the link is broken. If the broken node on the tree, it will be treated according to the MAODV. If not, the upstream node unicasts a route error message (RERR) to the source node which notifies the source node that link is broken. When the intermediate nodes in this path receive RERR, they delete the entry in the route table, and continue to forwarding RERR until the source node receives RERR message. When the source node receives the RERR, it deletes the related entry in the route table, searches backup route table and checks whether both paths are invalid. If the two paths are broken at the same time, the source node broadcasts RREQ to initiate a new route discovery.

3.3 Multiple Tree Multicast Ad Hoc On-Demand Distance Vector (MT-MAODV)

MT-MAODV [3] routing protocol consists mainly of constructing two disjoint trees in MAODV routing protocol. The following steps are used to develop the routing protocol.

Step 1: A node begins by request. If this node's status is ON TREE 0 then it needs to change it to ON GROUP and thus needs not to send the RREQ-J because it is already member of both trees. A field in the RREQ-J request, named tree is chosen to represent which tree the node wants to join: one, two or zero if it wants to join both trees. If the node either has no information about the group leader (GL) in the group leader table or it is not its first trial to send a RREQ-J request, then if it is ON TREE 1, it should broadcast RREQ-J with value two in the tree field, if it is ON TREE 2, it should broadcast RREQ-J with value one in the tree field, otherwise if it is NOT ON TREE, it should broadcast RREQ-J with value zero in the tree field. If the node has information about the group leader in the group leader table or it is its first trial to send a RREQ-J request, then if it is ON TREE 1, it should unicast a RREQ-J with value two in the tree field to the group leader, or if it is ON TREE 2, it should unicast RREQ-J with value one in the tree field to the group leader, otherwise if it is NOT ON TREE, it should unicast RREQ-J with value one in the tree field to the group leader and then wait for RREP TIMEOUT which is 30 ms and then unicast RREQ-J with value two in the tree field to the group leader.

Step 2: If the node is intermediate node means, it should do two things: if the node is the successor of the node sending the join request, then it should save its ID in the first hop field, suppose if it is not, then it should forward only one RREQ-J.

Step 3: The multicast members should reply to the RREQ-J request. Priority is given first to construct two disjoint trees and then if no different route exists, then priority is given to the tree connectivity rather than disjointness.

Step 4: Forward the RREQ-J.

Step 5: Store the best RREQ-J request received.

Step 6: Activate the multicast tree using MACT. This step is done as in the MAODV routing protocol, if no reply is received, the node can resend its request or become the GL for the multicast group if the maximum number of retries is achieved.

4. Results and Discussion

The above mentioned protocols are implemented to form a Virtual Class Room (VCR) [5]. A VCR is one that can be immediately established, and whose members can be dynamically added or removed; the group structure of the members can be reorganized dynamically. Fig. 2 illustrates such an idea. The ad hoc classroom can support urgent and timely learning activities, thus improving learning effectiveness. For example [6], a teacher may establish a virtual classroom from his residence, students located around can take the opportunity to form an ad hoc group to improve the teaching learning process at any time using IEEE802.11g WLAN. VCR based on ad hoc network has been constructed [6] as shown in Fig. 2 The network has been formed with 30 PDA nodes. Each node in the network is assigned with static IP address. The software components used for development are Microsoft Visual Studio C#.Net 2005, Windows Mobile 5.0 Pocket PC SDK, Microsoft ActiveSync Version 4.2 and Microsoft.Net Compact Framework 2005 and XML technology. The XML technology was used for providing description and representation of data and control packets.

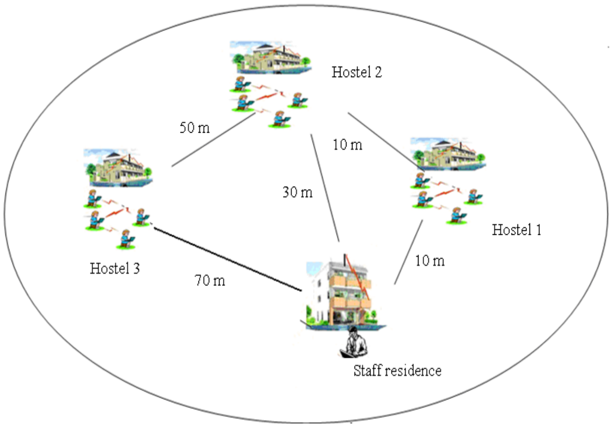

Fig. 2: A scenario of VCR using MANET

The application allows the user to initiate a query session with the peer or to lesson handling. The lesson file can include multimedia data like image, audio and video. Whenever a student (who is source of the communication session) wants to discuss any topic with other students or with a teacher (who is the destination of the communication session), they can initiate a query session by selecting the destinations from the member list displayed. To support transfer any type of file, UUEncode (Unix to Unix Encode) is used to convert the binary contents into plain ASCII characters, which can be transmitted over the network. At the destination side UUDecode is used to get back the original contents of the file.

The performances of MAODV, MP-MAODV and MT- MAODV multicast routing protocols are analyzed using group learning module of VCR. Evaluation parameter for this implementation is network load. The parameter values are calculated from the log file maintained at each PDA node. The log file contains the sequence of actions performed and the necessary tables maintained by each routing protocols.

We have computed the average delivery latency, which reflects data average deliver time from source node to destination node. Next analysis is packet delivery ratio, which reflects the efficiency of the routing protocol. Another evaluation is throughput; it reflects the data processing capability of networks. These three criterions are generally used for evaluating the ad hoc routing protocols.

Table 1. Experimental Environment

Number of members (students and teacher)	29+1
Number of teacher (sender)	1
Number of students	29
Packet size	512 bytes
Speed	1 m/ sec
CBR	10,20,30,40 and 50 data packets/ sec
Area	500×500 m
Node placement	Random
Experiment duration	900 sec

In VCR Environment, we have tested the network load as a parameter; the packet flow has increased from sending out 10 data packets per-second to 50 packets per-second. The ratio of packet sending raises in source nodes, the network load is increasing. Fig. 3 depicts the average end-to-end delay of MAODV, MP- MAODV and MT-MAODV for different network load. The average delivery latency of MT- MAODV is lower than MP- MAODV and MAODV. When the source node sends out 10 packets per second, the average end-to-end latency of MT-MAODV is about 5 percent lower than MAODV protocol and 2 percent lower than MP-MAODV. Suppose the source node sends out 20 packets per second, the average end to delay is somewhat similar to previous load. When the source node sends out 50 packets per second, the average end-to-end latency of MT-MAODV is about 3 percent lower than MAODV protocol and 1 percent lower than MP-MAODV. In MT-MAODV, the trees are link disjoint, thus it is very rare that both trees break at the same time also MP-MAODV adopts multipath routing transmission, the source node will initiate a new route discovery process only when the both of paths is broken. So it reduces the network latency caused by frequently route discovery. The source node sends the packets to two nodes disjoint path, which can provide a better network load balance, and it reduce the delay caused by the more number of packet competition for a channel at the same time.

Fig. 4 shows the packet delivery ratio of MAODV, MP- MAODV and MT- MAODV for different network load. When, we increase the network load, all the MAODV and the MP-MAODV and MT-MAODV's packet delivery ratio have decreased. However, the MAODV decreased more quickly compare to MP-MAODV and MT-MAODV. Suppose the source node sends out 50 data packets per second, the packet delivery ratio of MT-MAODV is 9.7 percent higher than MAODV, also 2 percent higher than MP-MAODV.

Because of the impact of network load, the three protocol's packet losing rate is increased, too. But, the multipath or multiple tree transmission improved the network congestion and reduced the packet loss rate compared to the MAODV.

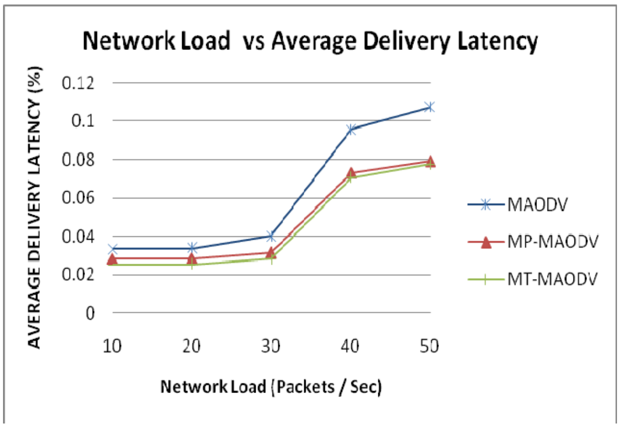

Fig. 3 Network load Vs Average End-to-End Delay

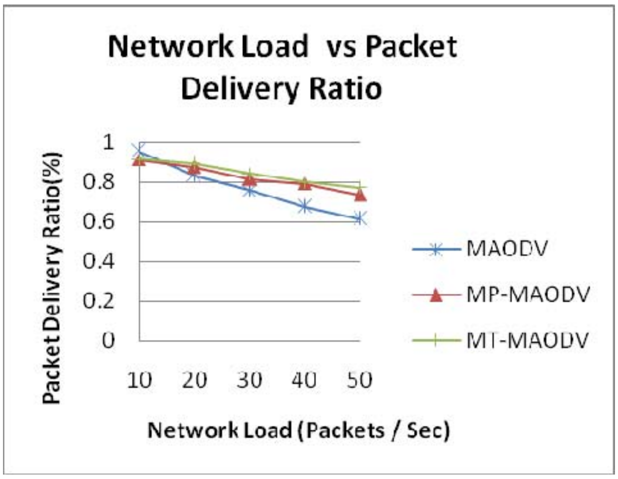

Fig. 4 Network load Vs Packet Delivery Ratio

The throughput of MT-MAODV is higher than MP-MAODV and MAODV, as shown in Fig. 5. When the source node sends out 50 data packets per second, the throughput of MT-MAODV is about 114 KB/s higher than MAODV similarly, the throughput of MP-MAODV is about 80 KB/s higher than MAODV.

5. Conclusion

In this analysis, we have presented a performance comparison of MT-MAODV, MP-MAODV, and MAODV using VCR with different implementation scenarios. Our results shows, when network load increased, MT-MAODV and MP-MAODV preferably ensure the network performance and improve protocol's robustness. In all these, performance enhancements were observed and promising results pointed to the better

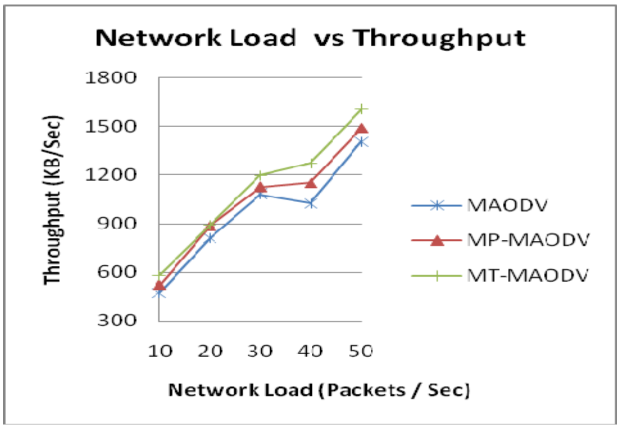

Fig. 5 Network load Vs Throughput

deployment of the schemes when multipath or multiple tree routing is used. So MT-MAODV and MP-MAODV has better performance than MAODV in relatively high load networks.

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