On-Demand Multicast Routing Protocol with Multipoint Relay (ODMRP-MPR) in Mobile Ad-Hoc Network

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***Abstract*—ODMRP protocol is an on-demand multicast routing protocol in mobile ad-hoc network. This paper presents the On-Demand Multicast Routing Protocol with Multipoint Relay(ODMRP-MPR) which bases on ODMRP. ODMRP-MPR inducts multipoint relay technique to reduce the control overhead, obtain high scalability and effectively solve the unidirectional link problem of wireless communication. At the same time, ODMRP-MPR reserves the key merits of ODMRP such as high throughput and energy efficiency in conditions with frequently changing topology. We evaluate ODMRP-MPR performance with ODMRP for ad hoc networks via extensive and detailed simulation.**

Keywords—multicast; ad-hoc network; ODMRP; MPR

I. INTRODUCTION

With the development of network technologies and new applications, multicast has become a significant networking service. In mobile ad-hoc networks, multicast communication also holds an important position. Such applications as disaster discovery, search and rescue, and automated battlefields are typical examples of where ad-hoc networks are deployed.

A mobile ad-hoc network is a group of wireless mobile nodes which self-organize into a network in order to communicate. Such networks can operate without fixed infrastructure or configuration. Because the nodes are dynamically linked in free ways, the most prominent feature of ad-hoc networks is frequently changing and undetermined topology of the network besides their nature of broadcast. What's more, the limited energy, low bandwidth and unreliable communication are vital factors affecting the performance. So routing protocols for wired network with little modification and adaptation don't suit ad-hoc networks. There are many new concepts and novel ideas emerged for the new requirement.

Due to their inherent broadcast capability, wireless ad-hoc networks are well suited for multicast. Multicast routing is always built on top of unicast routing infrastructure in wireline network, but in wireless ad-hoc networks it's not the case. Many multicast routing protocols independent of unicast are even more efficient. There are some typical multicast protocols of mobile ad-hoc networks such as MAODV (Multicast Ad hoc On-Demand Distance Vector Routing), ADMRP (Adaptive Demand-Driven Multicast Routing in Multi-Hop Wireless Ad Hoc Networks), AMRIS (Ad hoc Multicast Routing protocol utilizing Increasing id-numberS), AMRoute (Ad-hoc Multicast Routing Protocol), ODMRP(On-Demand Multicast Routing Protocol)[3], FGMP(Forwarding Group Multicast Protocol) and CAMP(The Core-Assisted Mesh Protocol).

ODMRP protocol is a simple on-demand multicast routing protocol with high performance among these protocols(See [4], [5]). Inspired by OLSR[2] protocol, we utilized the Multipoint Relay(MPR) technique[9] into ODMRP, trying to reduce the control overhead and resolve the unidirectional link problem.

The remainder of the paper is organized as follows. Section 2 illustrates the protocol in detail. Qualitative analysis and comparison to ODMRP are presented in Section 3. Section 4 describes the simulation model and methodology followed by simulation results and analysis. Concluding remarks are made in Section 5.

II. ODMRP-MPR PROTOCOL

ODMPR-MPR is a mesh based on-demand multicast protocol. It is suitable for dynamic topology with mobile nodes, uses multipoint relay technique to achieve low control overhead and adapts to scenarios with unidirectional links.

A. MPR Technique and Selection Algorithm

The MPR technique is to efficiently fulfill the flooding function in wireless networks. It is a technique to reduce the number of redundant re-transmission while diffusing a flooding packet throughout the entire network.

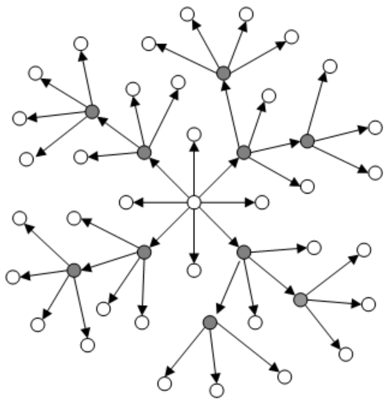

Figure 1 Flooding Example via MPR

Each node N in the network selects some neighbors as its Multipoint Relays(or MPRs). Only these neighbors will retransmit the flooding packets broadcasted by node N. We define those nodes as N's 2-hop neighbors whose distance to N is 2 hops. The MPR selection algorithm should guarantee that the flooding packets from N can be received by all its 2-hop neighbors after re-broadcasting of N's MPRs. We call this flooding mechanism using MPR technique MPR-flooding (or the verb. MPR-flood).

It shows us a good example of the mechanism of MPR-flooding in Figure 1.

Each node periodically sends Hello messages that comprise a list of neighbors from whom it can receive packets. When a node N receives a neighbor's Hello message whose neighbor list includes itself, node N adds the neighbor to its neighbor set and set a Hearable flag for the neighbor(Such a neighbor is called a bidirectional neighbor). Meanwhile, node N gets its 2-hop neighbor set from the collection of Hello messages.

There is a complex heuristic MPR selection algorithm presented in [2], which can almost find a minimal MPRs set of a node. According to the needs of ODMRP-MPR, we propose a simple algorithm that prefers selecting the up-to-date neighbors as MPRs and keeps redundancy in the MPRs set.

Take node x as an example. The algorithm is described as follows:

1) Start with an empty multipoint relay set M(x).
2) Sort all bidirectional neighbors of node x by the time when x received their last Hello Messages. The latest one takes the first position of the sequence. Assume the sequence is S(x) = {N1, N2, … , Nk} and the 2-hop neighbor set is Q(x).
3) Select the first element Ni (i ∈ {1, 2, … , k}) from S(x). If there is any element of Q(x) in the neighbor list of Ni, add Ni to M(x) and delete these elements from Q(x). Then remove Ni from S(x).
4) If S(x) is empty or Q(x) is empty, end the calculation and M(x) is what we want. Otherwise go back to 2) and continue.

Node x' MPRs set is also included in the Hello message. So each neighbor in the neighbor list knows whether it is *MPR-Neighbor* of x(if it's in x' MPRs set) or *NMPR-Neighbor* of x (if it isn't in x' MPRs set). Other nodes which are not in x' neighbor list, may receive x' Hello message. They don't set any flag, but actually they will re-broadcast flooding packets from x, as x' MPRs do.

B. Multicast Route and Mesh Creation

ODMRP-MPR protocol creates a mesh to delivery data in the ad hoc network. Multicast routes and group membership are updated by the sources "on demand". As shown in Figure 2, each source S will periodically MPR-floods Join Query message to the entire network. In the Join Query message, we use a Query_Seq field for duplicate detection and a Hop_Count field denoting transmitting distance. Especially there is a Flood_Freq (>=1) parameter in ODMRP-MPR. Source S floods a Join Query message each time after it MPR-floods Flood_Freq common Join Query messages.

When a node N receives a Join Query of source S from upstream neighbor F, it chooses whether to refresh its unicast route table and retransmit the message. The algorithm selects the newest and shortest dual link as its unicast route according to the value of Query_Seq and Hop_Count fields in the message and whether F is N's bidirectional neighbor. If N is **not** F's NMPR-Neighbor (including MPR-Neighbors and nodes out of F's neighbor list) and the Join Query message is not duplicated, N retransmits the message.

When a group member R receives a Join Query, it adds S to its Sender List. R periodically broadcasts the Join Reply message, which contents entries of network addresses of each multicast source and the nexthop neighbor to the source. When a neighbor receives a Join Reply, it checks if the nexthop address of one of the entries matches its own address. If it does, the neighbor realizes that it is on the path to the source and thus is the part of forwarding group. It then sets the FG_Flag (Forwarding Group Flag) for the group and broadcast its own Join Reply built upon matched entries. The Join Reply message is thus propagated by forwarding group members until it reaches the multicast sources via a shortest path. This process constructs (or updates) the multicast routes from sources to receivers and builds a mesh of nodes, the "forwarding group".

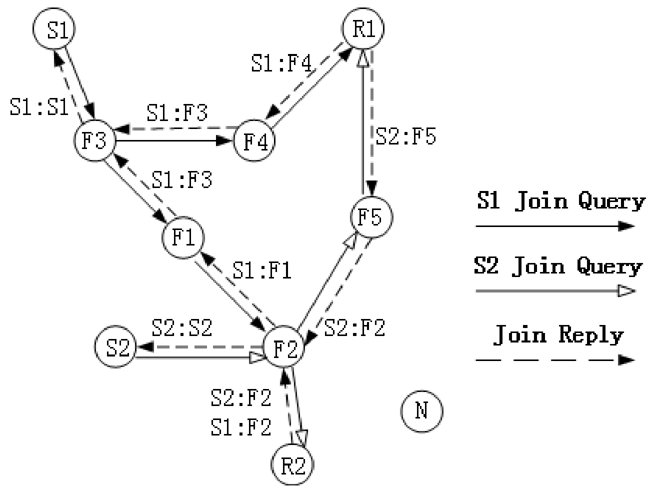

Figure 2 Mesh Creation of ODMRP-MPR

The reliable transmission of Join Reply plays an important role in establishing and refreshing multicast routes and forwarding groups. In ODMRP-MPR, we use a passive acknowledgement scheme used in [10] to improve the reliability. The rebroadcast of the expected nexthops is a passive acknowledgement. When a node needn't rebuild and transmit the Join Reply, it will reply Ack message (We call this action Ack.) actively. This active acknowledgement process may take place when a multicast source receives a Join Reply for itself. In addition, a forwarding group member may Ack actively. Each forwarding group member records the latest time when it received a Join Reply for each source S. If a new Join Reply for S comes in a short interval, it won't rebuild and retransmit the Join Reply but Ack back actively. This process is called the *Suppression of Join Reply*. A node may hope to receive several Acks(passive or active) from different neighbors. If a node fails to receive Acks from all expected neighbors in a certain period, it will rebroadcast unacknowledged part of the Join Reply no more than 3 times.

All the forwarding group members and the links between them make of a mesh. The essential feature of mesh is that the nodes don't care the upstream from which the data come, and they rebroadcast the none-duplicate data. Any pair of nodes of a mesh has a link between them if they can communicate directly. Thus mesh has more links than tree and enhances the robustness of multicast, which is suitable for ad-hoc network with abundant and frequent link breaks.

C. Soft State

In ODMRP-MPR, no explicit control packets need to be sent to join or leave the group. If a multicast source wants to leave, it simply stops to send JOIN QUERY messages. So after some time, the source won't appear in any JOIN REPLY as a source. If a receiver wants to leave a particular multicast group, it stops sending JOIN REPLY messages for the group. Then nodes in the forwarding group are denoted to none-forwarding nodes if not refreshed (no JOIN REPLY received) before they timeout.

III. QUALITATIVE ANALYSIS OF ODMRP-MPR

ODMR-MPR inherits from OMDRP[3] and keeps its most merits. ODMR-MPR builds and maintains a mesh for each multicast group. Providing multiple paths by the formation of mesh configuration makes the protocol robust to mobility. The protocol doesn't yield excessive channel overhead in highly mobile networks because no control packets are triggered by link break. ODMRP-MPR also applies demand-driven multicast route construction and takes soft approach in membership maintenance. These inherited key properties are:

1) Simple and low storage overhead
2) Usage of up-to-date shortest routes
3) Simple and reliable construction of routes and forwarding groups
4) Maintenance and utilization of mesh, robustness to host mobility

ODMRP-MPR uses MPR technique and the Suppression of JOIN REPLY to reduce control overhead, improve scalability and resolve unidirectional link problem. There are four main differences between the two protocols:

1) When there are a lot of multicast sources in the network, flooding of JOIN QUERY brings a mass of overhead. ODMRP-MPR uses MPR-flooding to reduce flooding overhead of JOIN QUERY, which is significant in large networks.

2) ODMRP-MPR avoids unidirectional links in forwarding paths when nodes transmit JOIN REPLY, while ODMRP takes no action to deal with it.

3) In ODMRP-MPR, forwarding group members reduce the overhead of JOIN REPLY by Suppression of JOIN REPLY. Otherwise the redundant transmission of JOIN REPLY takes place when lots of receivers reply to a same source or nodes retransmit JOIN REPLY because of the miss of acknowledge. ODMRP only mentioned such kind of consideration.

4) Both ODMRP and ODMRP-MPR have the capability of unicast and can work together with other unicast protocols. Most unicast protocols use HELLO messages which can be utilized by ODMRP-MPR. Particularly, ODMRP-MPR can get all it needs from HELLO messages of OLSR[2] and thus reduces more control overhead.

We give detail analysis on some points in the following paragraphs.

A. Overhead of ODMRP-MPR

In ODMRP-MPR, each node periodically broadcasts HELLO messages, which are additional overhead to ODMRP. Just thinking of the channel overhead, periodically broadcasted HELLO messages of each node can be thought as flooding of HELLO from one flooding source.

Suppose there are N multicast sources of all groups in the network and the length of JOIN QUERY is L1. Assume the average length of HELLO messages is L2, so each message equals to L2/L1 JOIN QUERY. Assume MPR-flooding overhead of JOIN QUERY is C(C<1) times of common flooding overhead. The overall overhead of HELLO and JOIN QUERY is lower than that in ODMRP if the following inequation is true:

$$N*C + (L2/L1) < N$$

or:

$$N > L2 / (L1* (1 – C))$$

L1 is a constant, while L2 and C are determined by the density of the network. Given a network, the benefit from MPR-flooding is more and more marked as the number N increases. If L2/L1 << N in extreme, the overhead is about C times of that in ODMRP. So ODMRP-MPR performs better in condition of large scale multicast groups and networks.

B. The redundancy of JOIN QUERY

The purpose of MPR-flooding is to reduce the overhead of JOIN QUERY. Because of the unreliability of wireless communication especially in environment with high host mobility or heavy load, we need redundant JOIN QUERY to help construct and maintain the mesh reliably.

First, the MPR selection algorithm selects more neighbors than the minimal required, and it prefers the up-to-date neighbors suiting for mobile environment.

Second, multicast sources send special JOIN QUERY messages with a FORCE_FLOODING flag every FLOOD_FREQ times. This kind of JOIN QUERY is commonly flooded into the network. After elaborately selection of the value of FLOOD_FREQ, the protocol can perform well with low overhead.

C. Resolution of Unidirectional Link Problem

With neighbor information, nodes know their bidirectional neighbors and unidirectional neighbors. So they can avoid selection of unidirectional links to reply JOIN REPLY and delivery multicast data. A simple example is given below.

In Figure 3 and Figure 4, the lines with two arrows mean bidirectional links while the line with an arrow between F2 and R means a unidirectional link (R can receive packet broadcasted by F2, while F2 can't receive from R). If R selects F2 as the upstream from S, then the creation of mesh will fail (See Figure 3).

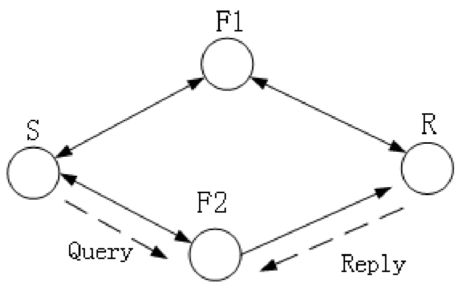

Figure 3 Unidirectional links in ODMRP

In ODMRP-MPR(See Figure 4), F2 broadcasts HELLO messages not including R in the neighbor list, so R gets to know it's a one-way link from F2 to R. R then selects F1 as its upstream node from source S and thus avoids the trouble caused by the unidirectional link.

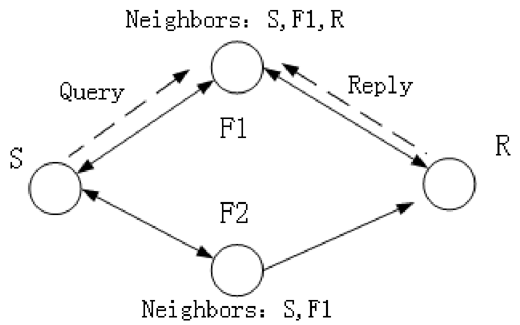

Figure 4 Unidirectional links in ODMRP-MPR

While the detection of unidirectional links is not much exact and timely because of the interval of HELLO or lost of HELLO messages, nodes just prefer bidirectional links and maybe select detected unidirectional links as an alternative if no bidirectional links available. It deserves mention that the detected bidirectional links are more likely to be stable and reliable links than other links, for the successful communications of HELLO messages are good demonstrations.

IV. PERFORMANCE EVALUATION

A. *Simulation Environment and Methodology*

The simulations of ODMRP-MPR and ODMRP are both implemented in ns2.1b9[8]. Our simulation models a network of 50 mobile hosts placed randomly within a 1200m×1200m area. Radio propagation range is 250 meters in scenarios without unidirectional links and carrier sense range is 550 meters. The channel capacity is 2 Mbit/sec. There is a little temporal partition of the network. Each simulation executes for 400 seconds of simulation time. Multiple runs with different random seed number are conducted for each scenario and collected data is averaged over those runs.

We use the two ray ground propagation model in our experiments and the MAC layer is IEEE 802.11 Distributed Coordination Function(DCF)[6] implemented in ns2.1b9.

The implementation of ODMRP-MPR inherits from the father class of ODMRP and all the same parameters in the two protocols are given the same value.

The multicast data streams are CBR streams with jitters. The size of data packet is 512 bytes. The multicast sources are selected from all 50 nodes randomly and most of them act as receivers at the same time. Receivers join one multicast group at the beginning of the simulation and never leave the group during the simulation. The simulation scenarios are created by the Setdest tool of ns2.1b9. Nodes randomly select a destination and move with a predefined average speed.

We have used the following metrics in comparing protocol performance. Some of these metrics were suggested by the IETF working group for routing/multicasting protocol evaluation[1].

- ✧ **Packet delivery ratio**: The ratio of the number of data packets delivered to the destinations versus the number of data packets supposed to be received. This number presents the effectiveness of a protocol.
- ✧ **Number of data packets transmitted per data packet delivered**: This number reflects the efficiency of the forwarding groups.
- ✧ **Control Overhead**: We compare overhead of all kind of control messages including JOIN QUERY, JOIN REPLY (including ACK), HELLO and the total overhead of all control messages.
- ✧ **Number of control and data packets transmitted per data packet delivered**: This measure shows the efficiency in terms of channel access. It is an important metric because most link layer protocols of mobile ad-hoc network are typically contention-based.

B. *Simulation Result*

We tried to emulate as many scenarios as possible to investigate the protocol performance under different network situations. We've varied the following four items: mobility speed, number of multicast senders, multicast group size and network traffic load, and we test the performance in scenarios with lots of unidirectional links. While the two protocols both perform similarly and well in scenarios that vary in mobility speed, multicast group size or network traffic load, we only mention them here and put the emphasis on other items.

C. *Number of Senders*

1) *Scenarios*

We varied the number of multicast members to investigate the scalability of the protocol. In the experiment, the multicast group size is 20. Average mobility speed of nodes is slow(1m/s) and maximum speed is 2m/s. The traffic load is relatively light(10 pkt/sec). The number of sources ranges in the set {1, 2, 5, 10, 20}.

2) Results and Analysis

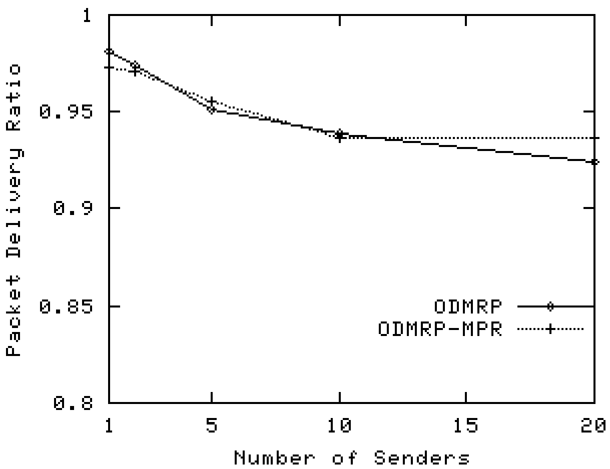

Figure 5 Packet delivery ratio as a function of number of senders

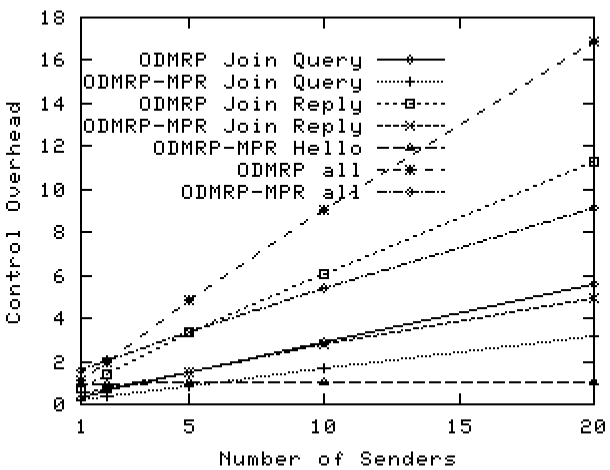

Figure 6 control overhead as a function of number of senders

Packet delivery ratios as a function of the number of multicast senders are shown in Figure 5. As the number of sources increases, the overheads of JOIN QUERY and JOIN REPLY increase, which cause degradation as more packets are lost by collision, congestion and channel contention. While redundant mesh links help to improve the performance, the packet delivery ratios of ODMRP-MPR and ODMRP only slightly fall. Owning to additional HELLO overhead, ODMRP-MPR performs a litter worse when there are few sources. As the number of sources increases, ODMRP-MPR shows advantage because of great reduction of JOIN QUERY and JOIN REPLY overheads.

Figure 6 shows the control overhead. The JOIN QUERY and JOIN REPLY (including the ACK overhead for JOIN REPLY) overheads of both protocols have a linear relation to the number of sources. The overhead of HELLO, which is only affected by the network topology, is nearly constant. And ODMRP-MPR has much less overhead of all control messages when there are many sources in the network, which owes to the MPR-flooding and Suppression of JOIN REPLY. This figure well presents that ODMRP-MPR has better scalability.

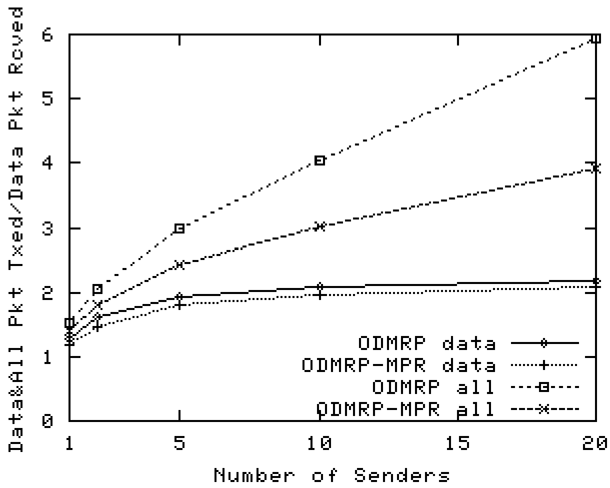

Figure 7 Number of data/all packets transmitted per data packet delivered

Figure 7 shows the number of data/all packets transmitted per data packet delivered. The number of all packets transmitted per data packet of ODMRP-MPR is relatively small and denotes that it is more efficient than ODMRP.

D. Unidirectional links

1) Scenarios

In this experiment, we use a 1000m×1000m area to obtain higher density of nodes in the network so as to avoid much network partition. The average mobile speed of nodes is 1m/s and maximum speed is 2m/s. We changed the transmission power of nodes, so the propagation ranges of node range in the set {150m, 175m, 200m, 225m, 250m, 275m, 300m, 325m, 350m}. While fixing the number of senders at one, the multicast group size was varied from one to twenty.

2) Results and Analysis

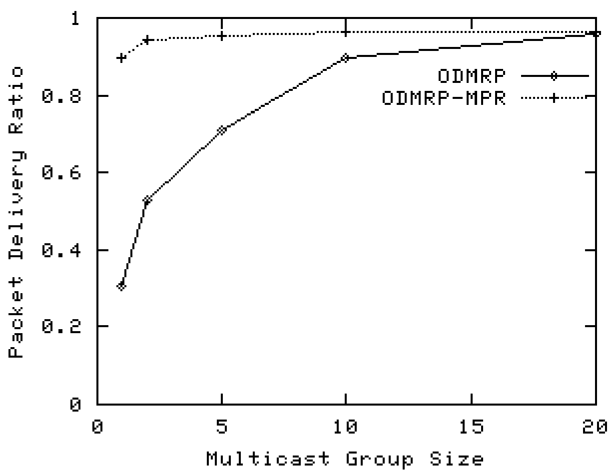

Figure 8 Packet delivery ratio as a function of group size

From the results in Figure 8,we can see that ODMRP-MPR resolves the unidirectional link problem well. When there are few receivers, ODMRP is severely degraded, and the packet delivery ratio drops much more than ODMRP-MPR. As the multicast group size increases, redundant links of mesh take effect and help to delivery data. So ODMRP also performs as well as ODMRP-MPR when there are twenty receivers in the network.

V. Conclusion

We have presented ODMRP-MPR for mobile ad-hoc network and shown its features in comparing to ODMRP. ODMRP-MPR inherits most key properties of ODMRP, performs better with high scalability and deals well with unidirectional link problem. Besides, ODMRP-MPR may cooperate seamlessly with some unicast protocols such as OLSR, which will be our related work.

Acknowledgment

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