EFFICIENT OVERLAY MULTICAST ROUTING FOR HYBRID NETWORKS

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ABSTRACT

Multicast can be done on link layer, IP layer, and application layer respectively. The application level overlay multicast is easier to deploy as compared to non overlay multicast but at the cost of efficiency. However, the utilization of these approaches is limited by current Internet architecture. Overlay and non overlay integrated solution have not yet been proposed for hybrid networks. In this paper, we propose a novel protocol named Efficient Overlay Multicast Routing (EOMR), in which multilayer multicast methods are integrated and the conversion among these methods is performed dynamically. Moreover, a Multicast Address and Port Translation (MAPT) protocol is used to achieve low-level overlay forwarding in intermediate systems, while the application-level multicast can only be implemented in end systems. The EOMR described here is mainly oriented to the hybrid network, a superset of pure MANET. The performance of EOMR with MAPT is evaluated by comparing it with other multicast protocols proposed for mobile ad hoc networks.

Keywords – Mobile Ad-hoc Networks, Overlay, Multicasting, Routing.

1. INTRODUCTION

Overlay networks are generally used to embed network services that cannot be deployed in the lower layers (e.g., network layer). Such overlay networks can implement application-specific routing strategies, for instance, construction of distribution trees (multicast overlays) to optimize link usage. Multicast services are provided either as basic network services or as application-layer services. Multicast implementation at higher layers often provides more sophisticated features, and can provide multicast services, where no network layer support is available. Overlay multicast networks offer an intermediate option, potentially, combining the flexibility and advanced features of application layer multicast with enhanced efficiency of network layer multicast. Overlay multicast networks play an important role in the Internet. Indeed, since Internet Service Providers have been slow to enable IP multicast in their networks, Internet multicast is only widely available as an overlay service.

Multicasting is done on link, network, and application layer respectively [6] [8] [9]. The application-level overlay multicast is easier to deploy at the cost of efficiency as compared to non-overlay multicast [1]. So far the research on multicasting is done in three directions. Firstly, overlay multicasting which overcomes the issues related to deployment, reliability, and scalability of IP layer multicasting [1] [2]. Secondly, new policies such as mesh topology and on-demand routing have been introduced into ad-hoc multicast protocol [3]. Thirdly and lastly, link level hardware multicast has been enriched such as WLAN [4], WMAN [5], and GSM/WCDMA.

However, the rising multicast technologies still have some limitations. For Example, the overlay multicast cannot visit link level multicast services to control the duplicate transmission of the same packets as done in IP multicast, the ad-hoc multicast protocols are designed for MANETs and do not perform well in infrastructure-based wireless networks or wired networks, and. physical subnets limit the cover range of hardware multicast.

All the routing protocols for wireless ad-hoc networks like, AODV [9], and WRP (Wireless Routing Protocol) [11]), we know so far, work for a particular type of a network and does not allow tooverride the functionalities of the network layer to enhance performance [9]. Overlays are scalable, easily deployable, and offer o accommodate flexible routing strategies but lacks control on physical link as well as resource utilization and hence are inefficient. On the other hand, non-overlay networks are secure, use resources efficiently but exhibit complex routing issues and increased delays. This paper presents an efficient overlay multicast routing protocol for hybrid networks. The protocol combines strengths of overlay and non-overlay multicast protocols into one scheme. The protocol is compared with well known protocols including ODMRP [29], and MAODV [30]. The simulation results show that the proposed scheme achieve similar performance with relatively low protocol overhead. The rest of the paper is organized as follows. In Section II, we briefly review related work. Section III illustrates our proposed solution in detail. Finally, we conclude our work in Section IV.

2. Related work

The overlays are constructed in three different ways: mesh [13] [14] [19] [20] [21], tree [8] [15] [16] [18] [26], or hybrid [22]. The mesh strategy provides multiple paths between a pair of nodes. In the tree case, a single path is established between any pair of nodes. Overlay meshes provide the underlays that allow message forwarding mechanisms between members or nodes of the overlay. Essentially, these meshes provide managed tunnels among nodes across the underlying IP network. Various strategies are considered in establishment of these meshes including use of graphical shapes that deploy well known geometric routing principles as well as information about the underlying network or Internet.

Subnet Multicast (SM) [18] connects the IEEE 802 subnets that support MAC layer multicast by an IP unicast based overlay tree. The IP multicast has been neglected in subnet multicast scheme for its deployment issue. A number of overlay multicast protocols such as HMTP [16] and Yoid [26] apply themselves to interconnect IP multicast networks. They commonly choose a representative node or proxy for each network, and then build overlay links to connect all the proxies. In intranet, data delivery is done by IP multicast routing, while the inter network data delivery is achieved by overlay multicast protocols.

In general, the solutions mentioned above under perform for hybrid networks. Firstly, the overlay and non-overlay multicast protocols concerned are independent of one another; at least two multicast protocols as well as a conversion module are required in each representative node. Not only the deployment issue of traditional IP multicast remaining in the networks, but also an overlay multicast protocol should be deployed in some pre-selected nodes. So the flexibility of pure overlay multicast is eliminated. Secondly, these solutions assume the borders of the subnets or the networks are fixed. The splitting and merging of non-overlay multicast domains are not taken into consideration. Lastly, management and configuration are needed for protocol interaction; however, these mechanisms are not valid in self-organizing networks.

Keeping in view the node mobility and frequently changing topology, ad hoc multicast protocols are preferred. But to the best of our knowledge, existing protocols can only be classified into IP multicast and overlay multicast [24] [25] [27] [28]. No overlay and non-overlay integrated solutions have yet been proposed.

3. Efficient Overlay Multicast Routing

Efficient Overlay Multicast Routing (EOMR) is proposed to integrate and balance the flexibility of overlay multicast and the efficiency of non-overlay multicast. The basic idea is to give priority to the low level multicast methods, but if the lower multicast method is not accessible, delivery method at higher level will be employed as an alternate mechanism.

The hybrid network environment is considered. The network refers to the actual wired cum wireless access network environment which includes multiple underlying subnet techniques. An example of such network is shown in figure (1).

The main characteristics of hybrid network include:

- Multiple subnets overlap in the same space, nodes have corresponding network interfaces to access all or a part of these subnets concurrently.
- The network structure of each subnet can be ad-hoc or infrastructure-based, and the network topology may be static or change unpredictably.
- Each subnet may be operated by a different organization which can use its own unicast routing algorithms inside.
- Some subnets may support multiple-access and hardware multicast, i.e., Ethernet and IEEE 802.11 Wireless LAN, others may support point-to-point connections only, i.e., Frame Relay and ADSL.

Routing protocols are needed for hybrid networks because of their subnets interconnection feature. But unlike traditional Internet, all the nodes in a hybrid network may be personal devices such as laptops, PDAs, or smart phones; it is difficult to distinguish hosts from intermediate systems. According to the limited capability of such nodes, it is better to deploy only one type of multicast protocol for all the subnets. However, as discussed above, none of current multicast routing protocols fully satisfy requirements for such complicated environments.

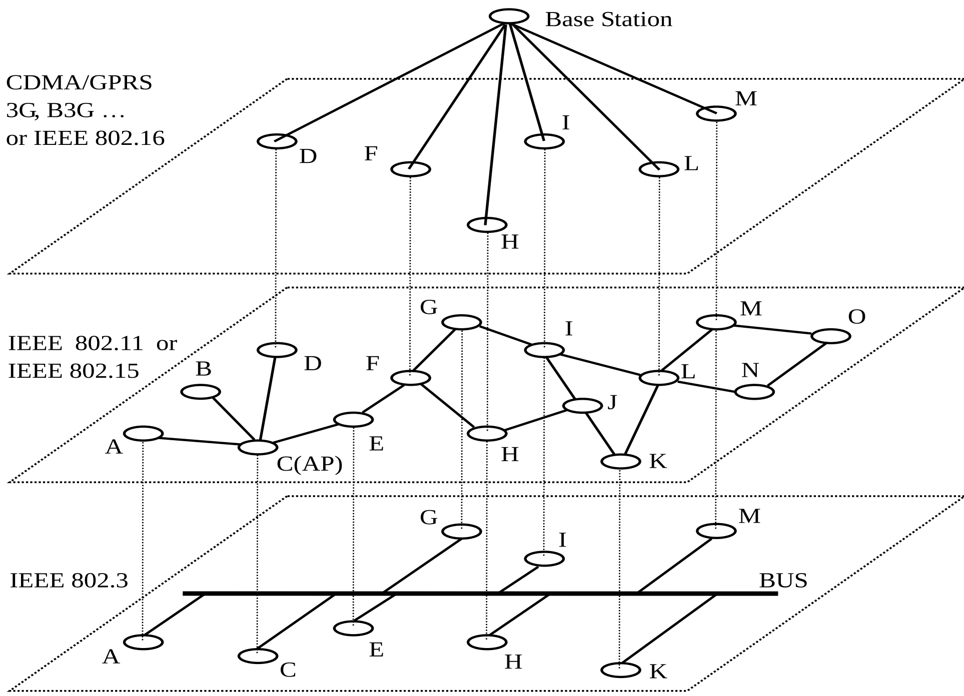

Figure 1. A case for hybrid access networks

3.1 EOMR Design

The multicast topology construction of EOMR protocol is based on the Efficient Overlay Topology (EOT) model.

3.1.1 The definition of EOT model

In EOT model, the entire network is denoted as N = (V, E) Where V is set of nodes and E is the set of physical links. G is a set of multicast groups. For each group $g \in G$, $V_g \subseteq V$ denotes the set of member nodes that have joined the group g, and we also assume that $E_g \subseteq E$ is the set of links connecting the nodes in V_g. All nodes in V support IP protocol and each of them has a universal unique identifier (ID). The node's ID can be one of the unicast IP addresses that were assigned to the node.
The whole network is divided into three regions:

A. Physical Multicast Region (PMR):

$V_p \subseteq V_g$ is a subset of nodes, if for $(\forall v_i)(\forall v_j)$ $(v_i \in V_p \wedge v_j \in V_p)$, the multicast data delivery between v_i and v_j can be achieved only by physical media and link layer protocol, then (V_p, E_p) is a Physical Multicast Region (PMR), where $E_p \subseteq E$ is the set of links connecting the nodes in V_p.

B. Network Multicast Region (NMR):

$V_n \subseteq V_g$ is a set of nodes, if for $(\forall v_s)(\forall v_d)$ $(v_s \in V_n \wedge v_d \in V_n)$, at least one path $(v_s, \eta_0, \ldots, \eta_k, v_d)$ exists, and $\eta_i \in V_n$ holds true for $\forall \eta_i$ (i=0, …, k) in the path, protocols not higher than network layer are needed for the multicast data delivery among the nodes in V_n, then (V_n, E_n) is a Network Multicast Region (NMR), where $E_n \subseteq E$ is the set of links connecting the nodes in V_n.

C. Overlay Multicast Region (OMR)

$V_o \subseteq V_g$ is a subset of nodes, if $(\exists v_s)$ $(\exists v_d)$ $(v_s \in V_o \wedge v_d \in V_o)$, making every path between v_s and v_d consists at least one relative overlay path of V_g, then (V_o, E_o) is an Overlay Multicast Region (OMR), where $E_o \subseteq E$ is the set of links connecting the nodes in Vo. Specially, the physical links composing overlay links are also included in E_o. Generally, $OMR_g = (V_o, E_o) = (V_g, E_g)$, namely, OMR_g is equal to the EOT based multicast logic topology of the group g.

D. Relative Overlay Link

Given a node set V', if there exists a path $p(v_i, \ldots, v_j, \eta_0, \ldots, \eta_k, v_m, \ldots, v_n)$, where $v_j \in V'$, $v_m \in V'$, but $\eta_h \notin V'$ for $\forall \eta_h$ (h=0, …, k), then the path $p'(v_j, \eta_0, \ldots, \eta_k, v_m)$ is a relative Overlay Link of V'.

PMR and NMR each have a Designated Node (DN). The DN of PMR is abbreviated as PDN and the DN of NMR is abbreviated as NDN.

3.1.2 The EOT based representation of hybrid networks

Let $PMR_g = (V_p, E_p)$ be a relative PMR of the group g, then the nodes in V_p must belong to the same physical subnet in which link layer multicast is supported. To forward multicast data packets, the sender just needs to encapsulate each multicast packet into one or more multicast frame which has a destination multicast address or identifier corresponding to g. The data delivery process is managed by the link layer protocol and it is transparent to the multicast routing protocol.
In Fig.2; A, C, E, and H have Ethernet adapter and belong to the same collision domain. Since IEEE 802.3 supports MAC layer multicast, so the four nodes and cables connecting them form PMR. For switched Ethernet, if hardware multicast is supported by VLAN, IGMP, GARP/ GMRP or snooping etc then nodes from different collision domain can also be included in PMR.

In a wireless subnet, nodes sharing a common broadcast domain can form a PMR. This is shown in figure 3(a). Generally, PMR construction can not be adapted to multi-hop wireless subnet as the one shown in figure 3(b), except that the link layer protocol supports frame forwarding.

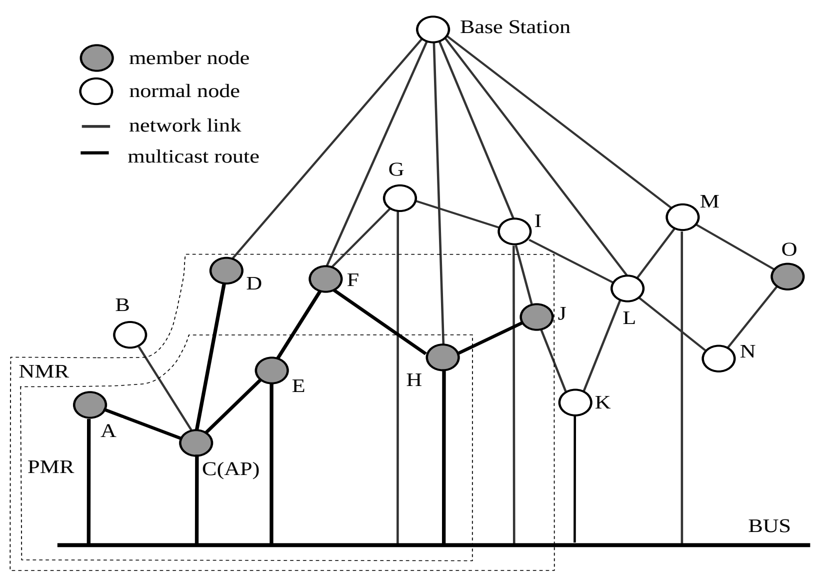

Figure 2. EOT representation of the hybrid network in figure 1.

NMR_g represents a region in which the members of group "g" can communicate by IP layer multicast. The concept of NMR includes group relativity, so it is not identical to IP multicast. NMR is different from PMR in several aspects.

Firstly, besides physical links, the basic construction unit of NMR is node, whereas the minimal unit of PMR is network interface of node. So, nodes having multiple interfaces may belong to more than one PMR but at any given time it can be a part of only one NMR. Secondly, any two nodes in a PMR can also build multicast communication up to IP layer, so a PMR must be a part of a NMR, but the nodes in a NMR may not have access to link layer multicast.

A typical OMR may include multiple NMR and the overlay links connecting the NMRs. The multicast data forwarding must be achieved with the aid of unicast routing protocols. In figure 2, the whole network except node B and link (B, C) is a single OMR related to the group. The node O has no group-mates in its neighbors, so it can be considered as the minimal unit of PMR and NMR.

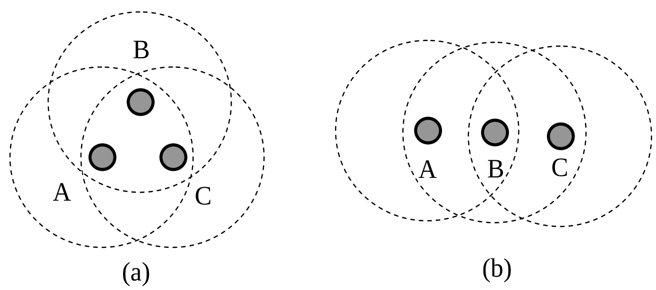

Figure 3. The PMR construction influenced by radio range

Every PMR and NMR would elect a DN respectively. Extremely, when a PMR and a NMR are equivalent in nodes and links, there should have a PDN and a NDN in the same region. The only function of PDN is to be the identifier of NMR, the ID of PDN is the ID of PMR. Besides contributing identifier, another use of NDN is to exchange messages and user data with other NDNs as the delegate of NMR.

3.1.3 Nodes Join and Leave

An explicit join mechanism is used in this protocol. Before joining a multicast group g, the node needs to get the group list by some means. To join a multicast group, each node has to send a request to any member node of the group. The new node's membership will be confirmed only after receiving the positive reply from the member node. After receiving the reply, new node can get group information and start sending HELLO messages to the group members. If there exist some nodes in the group then PMR and NMR relation is built. Otherwise, the node will initialize new PMR, NMR group and declare itself the PDN and the NDN.

Normally, before leaving, member node will notify its peer before it quits, in this way other members can adjust half overlay topology upon receiving notification. If a node quits abnormally, then there will be no other way to know about the node except timer expiration.

3.1.4 Message of EOMR

There are four types of messages in EOMR namely, HELLO, REQUEST, REPLY, and NOTIFY. The HELLO message is used to construct and maintain the EOT structure. The HELLO message consists of a) Group ID; b) Sender's ID; c) Sender's type (e.g. PDN, NDN or normal member); d) Priorities for the sender and for the interfaces of the sender; e) The PDN information for a non-PDN sender; f) The NDN information for a non-NDN sender; g) The OMR peers information for a NDN sender; h) Source sequence number.

1) Creation of group

Every time a multicast group is created, it will be allocated a unique ID. Our protocol does not limit the creation of ID, if an IP multicast address is not used by other protocols, then it can directly serve as the group ID for EOMR. For single-interface node, the node's ID is equal to the interface's IP address, but for multiple interface nodes, the two values may be different, so both of them are included in the node's information. To avoid the duplicate and outdated messages, a sequence number for each HELLO packet is generated.

2) Selection of Designated Node

A priority mechanism is involved for the election of PDN and NDN. The elected DN should meet the demands both for stability and efficiency to the best of its ability, so multiple parameters are introduced into the calculation of priorities. These parameters can be classified into two categories:

I) *Fixed parameters* show the data process and communication ability of a node. It includes the total bandwidth, overall process speed, and memory size. These parameters can be acquired at the initialization phase and they will not change in the lifetime of EOMR instance.

II) *Dynamic parameters* include δjoin and δDN, where δjoin is the time difference between current time and the join time, and δDN is the time difference between the current time and the time when the node became a DN. If the node is not a DN, then δDN is zero.

3.1.5 The Management of PMR

At joining, every node that joined a multicast group will create a new PMR per interface and will consider itself as the PDN of the PMR. HELLO messages will be exchanged if other members are present; then the node having higher PMR priority will be chosen as the PDN otherwise it will consider itself as a PDN. If the PMR priorities are equal; the node having higher node ID will be chosen as PDN. Every node will maintain its PMR neighbor's list and will set a timer for each node. This timer is reset on receiving HELLO packet from neighbors, and if the timer expires, the node is regarded as invalid and is deleted from PMR neighbor list. If the PDN expires, a new election procedure is invoked.

3.1.6 The Management of NMR

The NMR will be initialized in the same manner as PMR. When other members of NMR are found; the merge procedure of NMR and the election of NDN is triggered. The two typical situations that can trigger the NMR merge are shown in Figure 4.

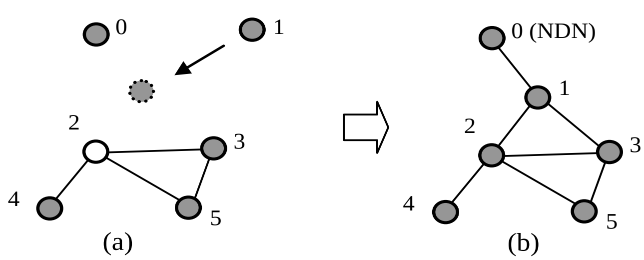

Figure 4. Merge of NMRs triggered by the change of network topology

In figure 4(a), member node No.1 moves closer to other nodes, and non-member node No.2 joins the group; the status change of these two nodes lead the whole network to become a single NMR as shown in figure 4(b). Generally, when member node A received a HELLO packet from another member B, and the appointed NDNs of these two nodes are different, then node A would choose the one that has higher NMR priority as its NDN. If the NMR priorities are equal, the one having a lower node ID will be chosen. This policy is just contrary to the corresponding method in PDN election for the purpose of load balancing. After election process, if node A's NDN is other than its original one, node A will send NOTIFY message to its NMR neighbors immediately. Other members will do NDN election in the same way after receiving the notification. At last, the consentaneous NDN information will be spread to all the NMR parts that are merged together, and all the involved members would choose the same node as their NDN.

Normally, NDN only connects a part of the members in the same NMR. This is different from PDN, which is always connected to all the PMR mates. The NMR members that are not adjacent to the NDN can only get the NDN information indirectly for intermediate members. So it is not enough for the non-NDN members to merely know about the NDN's ID and priorities. First, if a member has detected that one of its NMR neighbors is no longer valid, the member may lost contact with its NDN too. The member needs extra information to make certain if the contact exists or not. Second, if the neighbors send NDN information to current node; the current node needs to judge that which one can be trusted. An example is shown in figure 4(b). The node 2 can get NDN information from its four neighbors, obviously, the information from node 1 is totally correct while the NDN information from the node 4 should be ignored. To solve these problems, EOMR employs a *Path Vector* (PV) algorithm to maintain the connectivity of NMR. The basic operations in this algorithm are: NMR neighbors exchange the strict paths to their NDN. Each path includes all the identifiers of the nodes between current node and the NDN, its format is (ID of NDN's neighbor, ID of current node's neighbor). After a node received PV list from one of its NMR neighbors, the node would use the following operations to choose and to keep one of the shortest path from the list.

Procedure *PV_Update*(T_i, T_j, N_i)
Input: T_i is the path vector table of current member i. T_j is the path vector table received by member i from a neighbor member j. N_i is the NMR neighbor list kept by member i.
Output: Updated T_i.
(1) Initialization: P'←null path; Delete all the paths which include j from $T_{i;}$
(2) **for** P←each path in T_j **do**
(3)   **if** i is included in P **then continue**;
(4)   **if** P includes any element of N_i **then**
(5)   P←the sub-path of original P from the beginning to the first place where the node ID is also included in N_i;
(6)   **if** P exists in T_i **then continue**;
(7)   **if** P' is not null **and** length(P') ≤ length(P) **then continue**;
(8)   Delete P' from T_i; Save P to T_i; P' ←P.

Figure 5. Operations taken by a member i on receiving a path vector table T_j.

Procedure *PV_Reset*(x, T_j, N_i)
Input: x is the latest NDN ID of current member i. T_j is the path vector table received by member i from a neighbor member j. N_i is the NMR neighbor list kept by member i.
Output: T_i, the path vector table of member i.
(1) Initialization: T_i ←null path vector table (denote as '{}');
(2) **if** x is equal to i **then return**;
(3) **if** $x \in N_i$ **then return**;
(4) **if** T_j is null **then**
(5)   P←(j); save P to T_i; **return**;
(6) PV_Update (T_i, T_j, N_i).

Figure 6. Operations taken by a member i after its NDN changed.

Using the example in Figure 4(b) again, a relative stable status of the NMR is listed as following:
0:{} 1:{} 2:{(1)} 3:{(1)} 4:{(1, 2)} 5:{(1, 2), (1, 3)}

For node 4, the only path to NDN passes through node 2. For node 3, its path to NDN gets across node 1, which is the neighbor of node 2. For both the situations, the node 2 would not accept the NDN information offered by node 3 and 4.
Corresponding to the merge of NMR, another basic operation related is NMR fragmentation. In case such as link break and member leaving, a NMR may divide into several parts. The members near the break point would be conscious of the disconnected communication. Consider nodes A and B are two adjacent non-NDN members and node B has been failed. After node A noticed that it can not get messages from node B any more, the node would delete all the paths which contain node B's identifier from its PV table first, and then check if it is a neighbor of NDN and if the PV table is empty next. If node A is not a neighbor of NDN and the PV table is empty, the original NMR must have been divided, moreo-

ver, node A and the NDN are in different parts of the network. Consequently, node A would declare itself as a NDN and notify the failure of node B to the members within the same NMR region. Other members would deal in the same way after receiving the NOTIFY message. The merge of NMRs and the election of NDN would be activated in each NMR region. On the other hand, if node A connects to the NDN or the PV table is not empty, the situation is that node A still has connection with the NDN, then node A just need to delete the node B from the NMR peer list. A special case is that the NDN fails, in this situation all the neighbors of the NDN would declare themselves as new NDNs, and new NDN election procedure would be triggered.

3.1.7 The Management of OMR

The overlay topology is a completed graph in each OMR, in which all the NDNs of NMR are the vertices and all the links connecting these NDNs are edges. For each OMR to be fully connected we employ following strategies. 1) The OMR peer will exchange complete NDN list for connectivity. 2) If some nodes get isolated due to link breakage, a multi-hop HELLO message should immediately be sent to them after link recovery. 3) Non NDN node would also maintain the global NDN information that is maintained by their NDNs. 4) if the NDN has been re-elected in an NMR while the original NDN is alive, the original NDN would have to handover OMR peer list to the new elected NDN. 5) If a member node does not receive any message from its peer for a long period of time, the node should quit and try to join the group again. 6) If a multi-hop Hello message is sent to a non-NDN member, the member should notify the sender the proper NDN information through Reply message.

To improve performance, EOMR does not use UDP or IP tunnel as the overlay data forwarding approach, although the tunnel approaches also work. A novel Multicast Address and Port Translation (MAPT) is introduced into OMR level data forwarding. Every NDN would maintain a MAPT table. The structure of this table is shown in TABLE I.

Generally, when one NDN node A needs to forward a data packet to another NDN node B, node A would check its MAPT table for the entry that matches the ID of node B, the destination address and the UDP or TCP port of the multicast packet. If the entry is found, node A would replace the packet's original destination address and port by the Translated Address and Port, and then forward the packet through unicast routing. Otherwise, if no matched entry exists, node A would cache the packet and send a translation request to node B. The data packet's destination address (Group ID) and port is included in the request message. After the request is received, node B would assign an idle port for both (Group ID, Service Port), record the mapping result in local MAPT table and then send it back to node A. When node A received the reply message, it would also record the mapping result, and then translate and forward the cached data packet. When the data packets arrive at node B, node B would also check its local MAPT table by using data packet's destination port and will retrieve the original multicast data packet's destination address and port.

TABLE I: THE STRUCTURE OF MAPT TABLE

Field Name	Description
Node ID	The ID of the node in which the Multicast Address and Port mapping is kept.
Group ID	The ID of the multicast group. This is usually a multicast IP address.
Service Port	The transport layer port number that identifies a multicast service.
Translated Address	The address used to replace the original destination address (Group ID) in a multicast data flow. This address may equal to the Node ID or not.
Translated Port	The transport layer port assigned to the duple (Group ID, Service Port) by the mapping node.

3.1.8 Data Forwarding

Based on the EOT structure maintained locally, the members of a certain group can choose the most efficient way from hardware multicast, IP layer multicast and overlay multicast to forward data packets. In PMR, the data forwarding process is transparent to EOMR. EOMR instance just need to handover multicast data to the link layer protocol via certain method or intermediate module. In NMR, the IP layer network topology constructed by EOMR is a mesh structure. Because all the nodes contained in a NMR are members of the same group, so EOMR can use Reverse Path Forwarding (RPF), a broadcast algorithm for in-group data forwarding. As described before, a PMR must be a subset of a NMR, if it needs to convert from link layer multicast to IP layer multicast, member at PMR border can get IP multicast packet easily from multicast frame, and forward it as IP layer logic has defined. NDNs are in charge of the data forwarding among

NMRs. Assume a data source is in one NMR, the NDN of the NMR would translate the multicast data packets into unicast data packets by MAPT, and then forward them to other NDNs through overlay links. When a NDN receives MAPT translated data packets, the NDN would recover the original multicast data packet and then forward it in the local NMR. A typical data forwarding procedure is shown in figure 7.

In Figure 7, the physical links in PMRs are not drawn because the physical topologies in every PMRs are all completed graph, namely, there has links between every two members in a PMR. The node 5 has two network interfaces, each of the two interfaces connects to a link layer multicast supported subnet. So PMR 1 and PMR2 get an intersection at this node.
Two important things need to be clarified here. Firstly, according to the definition, non-member nodes have no understanding of the half overlay topology of a multicast group. So if the source node 1 is not a member of the group, it needs to commission a member node to forward data packets. Secondly, duplicated packets are not totally eliminated, because mesh structure is used in NMR. To avoid forwarding of duplicated packets, source sequence number is added to each data packet. As a result, a member may receive same packets from different link, but it will not forward the same packet twice. If the sequence number of a packet is discarded when the packet get cross NMR borders, a new sequence number would be added by the NDN of destination NMR.

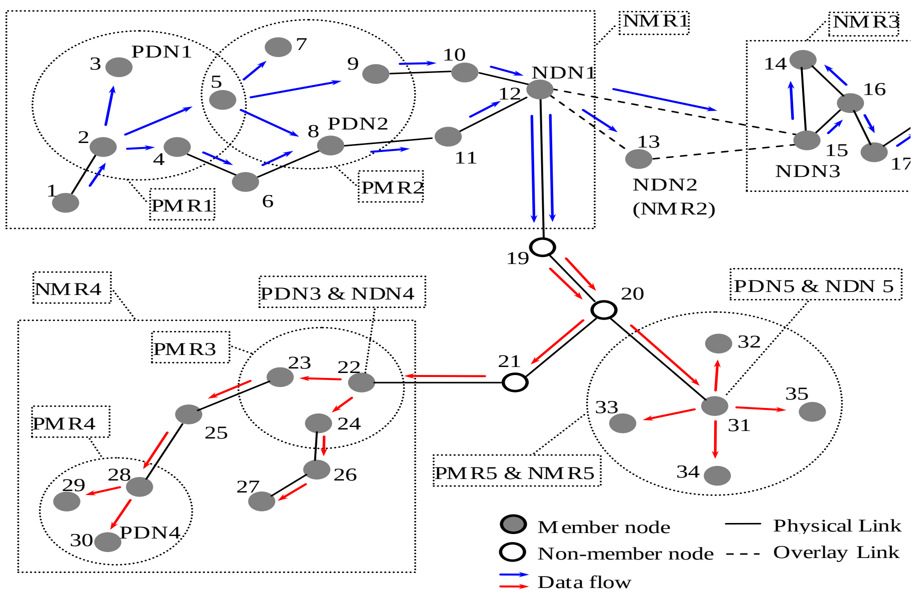

Figure 7. Illustration of data forwarding in a typical EOT scenario.

4. SIMULATION RESULTS

For evaluating the performance of EOMR, a comparative study among EOMR, ODMRP [29], and MAODV [30] is performed in NS-2 environment. ODMRP and MAODV are both IP multicast routing protocols for MANETs, where ODMRP is regarded as one of the best [30,31] ad hoc multicast routing protocols, whereas MAODV is the multicast extension for AODV [9], which performs well for ad hoc networks. As we have chosen AODV as the unicast protocol that supports overlay link construction and inter-NMR data forwarding, it is very meaningful to compare EOMR with MAODV.
According to the suggestions of IETF MANET working group [32], following metrics are used to compare performance of different protocols.

- ***Packet Delivery Ratio:*** The ratio of the number of non-reduplicated data packets actually received by the application layer to the number of non-reduplicated data packets supposed to be received.
- ***Packet Transmission Ratio:*** The ratio of the number of data packets transmitted to the number of non-reduplicated data packets actually received.

- ***Control Overhead Ratio:*** This is computed as the ratio of total number of control bytes transmitted to the total number of non-reduplicated data bytes actually received by the receivers. It is important that not only the bytes of control packets, but also the bytes of data packet headers are included in the number of control bytes transmitted.
- ***Channel Access Efficiency:*** This ratio of the number of control and data packets transmitted to the number of non-reduplicated data packets actually received.

As MAODV and ODMRP do not take hardware multicast into account, the link layer multicast invoking EOMR is not considered for the fairness of the evaluation, that is, only IP layer and overlay level performance is compared. In addition, the overhead of AODV is also included when calculating the control overhead of EOMR.

The general parameters used in the simulation include: up to 50 unsynchronized nodes are placed randomly within a 1000 m × 1000 m flat area, The IEEE 802.11 MAC is used. The maximum radio propagation range is 250 m and channel capacity is 11 Mbps. Constant bit rate (CBR) is chosen as the communication model. Each source transmits packet at the rate of 2pkt/sec and the packet size is 512 bytes. Each simulation runs for 600 simulation seconds. The members join the group in the first 50 seconds on permanent basis for the rest of the simulation run. In total, 60 different scenarios are simulated and averaged values of these scenarios are presented.

a) *Mobility Speed*

Each node moved at a pre-defined speed and the direction of each node is selected randomly. The node speed is varied from 0 m/sec to 20 m/sec. A total of 25 nodes are simulated where 5 of them act as data sources. Figure 8 illustrates the packet delivery ratio of the protocols for varying mobility speed. Being a hybrid protocol, EOMR outperforms pure IP based multicast protocols even in highly dynamic situations. The performance of EOMR is very similar to that of MAODV; depicting the effect of unicast routing policy. For EOMR protocol, when the nodes lose PMR or NMR connections with other peers, they would try to repair the connections by unicast based overlay forwarding. The more the physical topology changes, the more frequently unicast routing is used. Though the trends are similar, EOMR clearly outperforms MAODV. This is because EOMR is a mesh-based protocol in NMR level, and that MAODV is a tree-based protocol. The redundant routes provided in mesh topologies enable EOMR to be robust to node mobility.

As shown in figure 9, 10, and 11, the trends of the three metrics are similar to each other. The overhead and channel access efficiency of EOMR is higher than MAODV, but lower than ODMRP. On the other hand, MAODV has lower packet delivery and transmission ration than EOMR. Thus, for delivery and transmission ratio, EOMR has comparable results as that of ODMPR but with overhead comparable to MAODV. Integration degree is a crucial factor for the performance difference between MAODV and EOMR. The multicast operations are tightly integrated with unicast abilities in MAODV, however, as a unicast independent multicast protocol, EOMR has no such tight integration with AODV. To keep the protocol independency, we did not optimize the interaction between EOMR and AODV.

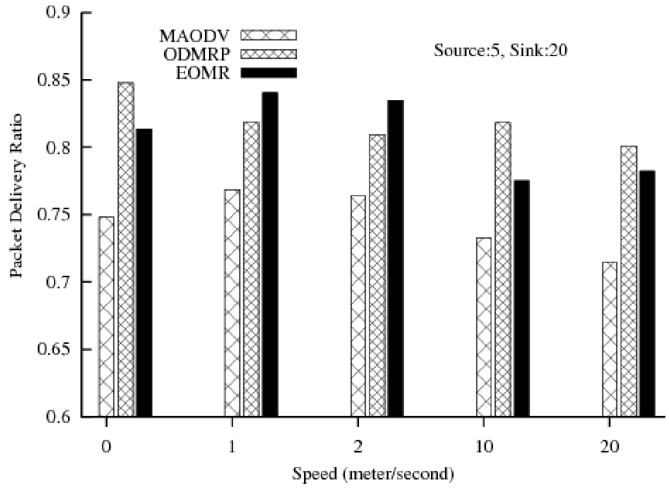

Figure 8. Mobility Speed Vs Packet Delivery Ratio

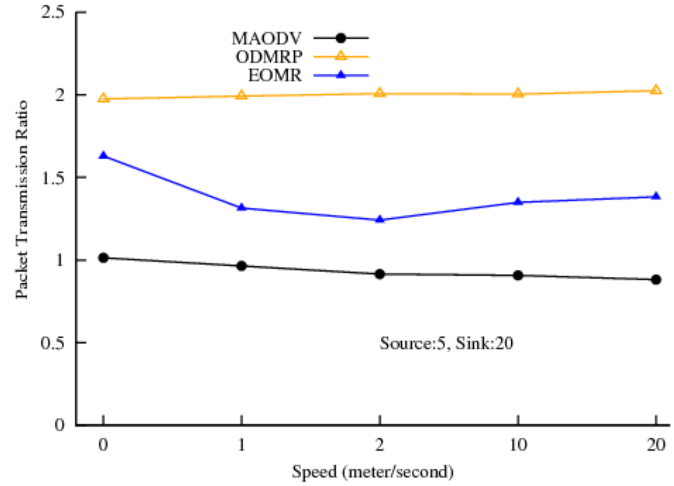

Figure 9. Speed Vs Packet Transmission Ratio

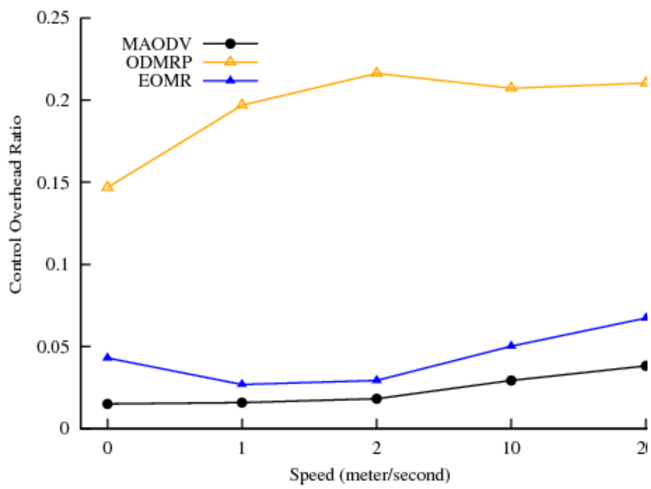

Figure 10. Speed Vs Control Overhead Ratio

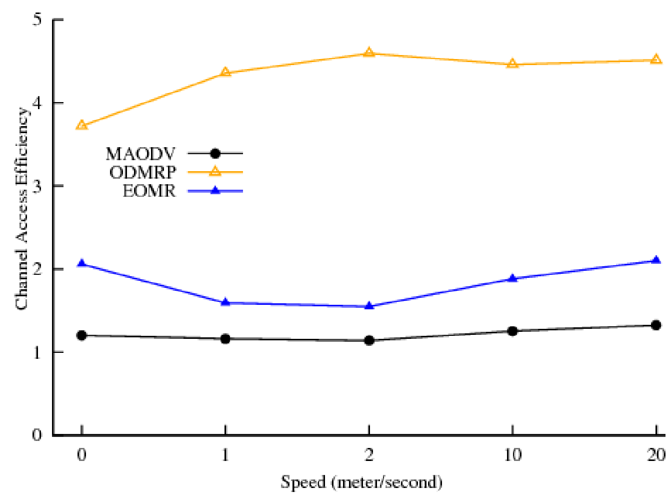

Figure 11. Speed Vs Channel Access Efficiency

Considering that ODMRP also has unicast routing capability, we can deduce that the unicast routing efficiency of ODMRP is not as good as AODV.

b) *Number of Senders*

For this simulation scenario, the group size was kept as 20 members, node mobility speed was kept 1m/s, and the number of data sources was varied from 1 to 20.

Figure 12 depicts packet delivery ratio variation with respect to the number of senders. With increased number of data sources, the performance of all the protocols degrades sharply. It is evident from the figure that for higher number of senders, EOMR is outperforming both the protocols.

This shows that link capability has become the most important factor that affects delivery ratio. Because packet generating rate was kept constant, so with the increase of data sources, more packets were discarded because of the limited channel capability. From the control overhead ratio shown in figure 13, we can find out that the protocol overhead of ODMRP and EOMR increased with the growing number of sources, the overhead increase of ODMRP is very sharp, whereas the overhead of MAODV decreased with the increasing number of senders. This difference finally influenced the performance of packet delivery ratio.

In addition, the tree-based structure of MAODV showed its superiority over mesh-based structure. The tree structure completely avoided the duplicate packet transmission. Although this feature can not ease the overcrowding, but the negative impact was relatively lower.

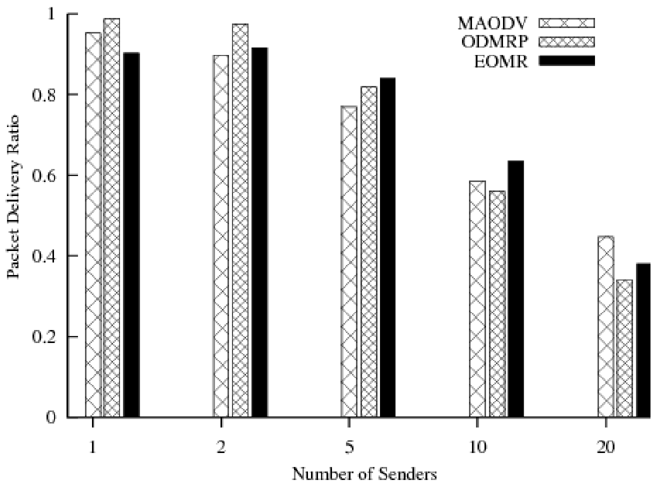

Figure 12. Number of Senders Vs Packet Delivery Ratio

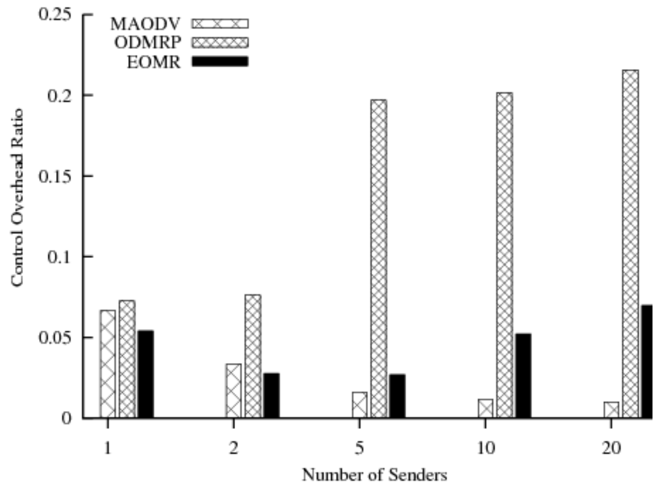

Figure 13. Number of senders Vs Control Overhead Ratio

c) *Multicast Group Size*

The number of members was varied in this part of experiment to investigate the influence of group size on routing performance. While fixing the number of senders at 5, mobility speed at 1m/s, the multicast group size was varied from 5 to 40 members.

As shown in figure 14, when the group size increased, EOMR outperformed the other protocols interns of packet delivery ratio. This result can be attributed to network density. In a limited space, the greater is the size of group members, the larger scale NMR can be formed, and accordingly, more multicast forwarding is done by non-overlay methods. This is helpful to improve the success probability and efficiency of packet delivery. The reason why the packet delivery ratio of EOMR is higher than that of ODMRP is because the NMR level forwarding algorithm used by EOMR is similar to flooding algorithm, and the performance of flooding is better than ODMRP in most cases.

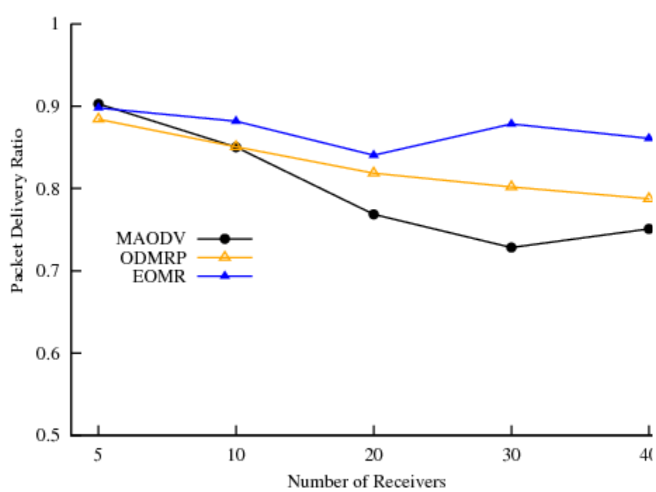

Figure 14. Number of Receivers Vs Packet Delivery Ratio

5. Conclusion

This paper analyzes the characteristics of hybrid networks, and presents an EOT model to meet the rigorous requirements for multicast routing in hybrid networks. Detailed routing strategies of half overlay multicast routing are also described in this paper. A hybrid routing strategy, EOMR, is presented that covers various features both of overlay and non-overlay multicast approaches in a single integration. The features include: 1) No need for the multicast routing protocol to be deployed continuously or completely in the internet, as a result, multicast data can be forwarded through multicast disabled uncontrollable network areas; 2) No need for the underlying unicast methods, multicast routing functions can work correctly both at hosts and network nodes; 3) Nodes participating in multicast are only sensitive to the groups that they have joined; this greatly reduce resource consumption in each node and also prevent bottlenecks; 4) The response time is reduced compared to pure overlay multicasting for changes in physical topology because efficient overlay multicasting can directly monitor link status in PMR and NMR areas; 5) Link layer and IP layer delivery approaches are used prior to the unicast based approach whereas using this proposed technique the link level duplicated packets are reduced more effectively as compared to pure overlay protocols.

Simulation studies show that the overhead of EOMR is relatively low while maintaining comparative forwarding performance to pure IP multicast protocols.

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