Heterogeneous Routing Protocol Coordinator for Mobile Ad Hoc Networks*

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Abstract. Lots of routing protocols have been proposed in the literatures to overcome several challenges in ad hoc networks. The fundamental point we consider in this paper is that most of such protocols are generally based on the assumption that mobile nodes are functionally equivalent to each other in computing power and memory space. Moreover, all of the mobile nodes are required to use a common routing protocol to communicate with each other. However, such assumptions do not reflect the real world, even further the future oriented ubiquitous world. The ubiquitous paradigm requires networking technologies to support the heterogeneity including various capabilities to compute, amounts of storage, radio interfaces, patterns of mobility and others. In real scenario, for instance, some nodes may not want to relay packets for others owing to their power constraints. Also there might be nodes employing different routing protocols in a single communication zone. To cover some of these cases, this paper proposes a simple but efficient approach called HRPC (Heterogeneous Routing Protocol Coordinator) that works well in our previously proposed MANET architecture. HRPC is not a stand-alone routing protocol but a coordinating module for support bridging functionality between heterogeneous routing protocols in MANET. This paper also gives HRPC implementation and its demonstration results, where DYMO and OLSR routing protocols are used as an exemplified scenario to evaluate the operability of HRPC.

1 Introduction

Mobile ad hoc networking is currently regarded as one of the most promising solutions to support the future oriented ubiquitous paradigm from the aspect of construction time and cost efficiency. However, there are several challenges to practically deploy it into the real field. Most challenges (e.g. scalability, load balancing, reliability etc.) are related to the difficulty in routing because MANET is self-organized without any support of a centralized coordinator or pre-installed

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infrastructure [1]. Therefore, routing schemes used in conventional wired network can not work well in ad hoc networks.

Routing in packet networks generally consists of the route discovery phase and maintenance phase. The main difference between wired and wireless network appears in the latter rather than the former. In wired network, on one hand, the processing of route maintenance is activated once a link is broken. The link breakage is generally caused by the fault of router along the path or serious buffer overflows owing to the congestion at an intermediate router. On the other hand, the maintenance processing in wireless networks, especially in multi-hop based mobile wireless network, is very frequently and randomly activated. In this kind of networks, not to mention the faults as in wired network, link can be broken in several reasons, for instance changes in topology caused by the node mobility, switching to power saving mode (i.e. sleep mode or turn off the power) at any intermediate node on the path. Therefore it is a challenge to find and maintain a stable route in MANET, further, it becomes more difficult to solve as the scale of network increases [2].

To overcome (at least reduce) those shortcomings, lots of routing protocols have been proposed in the literatures [3]. In particular, many research results have shown that clustering approach is a good solution to enhance the scalability of MANET [4], [5], [6]. Moreover, in order to maximize the gains of clustering, most studies (e.g. [7], [8] and [9]) typically used a hybrid routing protocol based on the hierarchical network architecture. In such schemes, researchers have commonly assumed that mobile nodes are homogeneous and all of nodes in the same communication domain use a common routing protocol. However, such assumptions may not be adaptable to the real scenario. As time goes by, mobile devices are going to be heterogeneous in several aspects such as computing power, amount of memory, video/audio capabilities, operating system, communication interfaces and others. In addition, each of them prefers to install a single or at most two dominant routing protocols according to their capabilities of computing and memorizing.

Despite the trends of great generality, there is a common requirement that is the increasing desire to communicate with each other for sharing information without any restriction such as time and place, the kind of device system, the type of wireless technology, and so on. It might be a trivial scenario that a powerful laptop needs to communicate with a small device equipped with very low computing power and limited storage. More badly, the small device is not equipped with the routing protocol that the laptop uses. Up to our best knowledge, no previous work can solve this scenario. In this sense, this paper is intended to find a solution that allows mobile nodes to communicate with each other even though they are equipped with heterogeneous routing protocols in a single communication domain.

The organization of this paper is as follows. Section 2 presents network models, where nodes are required to be equipped with two different routing protocols. In section 3, we give the problem statements that might be occurred in the network models described in section 2. Afterwards, we give the proposed HRPC and its operation in section 4. Section 5 presents the HRPC implementation and its experimental test results. Finally, section 5 concludes this paper.

2 Network Model

The proposed HRPC can be deployed into a cluster-based MANET, where a cluster head node is equipped with the HRPC module. In this section, we first describe the cluster based MANET and then give an advanced model of the architecture called u-Zone based MANET.

2.1 Cluster-Based MANET

The communication in MANET only relies on mutual and cooperative routing functionalities of ordinary nodes without any specific relaying devices. Moreover, network topology can be unpredictably changed over time due to the mobility of nodes. These make a flat ad hoc network difficult to be deployed into a large scale network. Cluster-based MANET architecture is regarded as an alternative solution to the scalability problem. The result of [10] has shown that clustering reduces the routing overhead by a factor of $O(1/M)$, where M is the cluster size.

In such architecture, the mobile nodes are logically partitioned into a set of clusters and a cluster head node is elected for each cluster by predefined algorithm. The cluster head node binds ordinary nodes in his cluster to perform routing procedures that include management of cluster members, routing information distribution, and communication management. The limitation is the cluster head election overhead because all nodes must exchange information to elect a cluster head in addition to the routing procedure itself. Furthermore a cluster head should be reelected whenever the network topology of a cluster is changed. In some scenarios, it results in very high overhead owing to the frequent changes in topology. To reduce the overheads presented in cluster-based MANET, Zone-based Hierarchical Link State Routing Protocol (ZHLS) was proposed, where the network is divided into non-overlapping zones and there is no zone head [9]. However, ZHLS requires that all nodes are equipped with GPS like system.

2.2 Semi-infrastructured MANET

All of cluster-based schemes have a common limitation from the practical usage point of view. They assumed that all nodes are functionally equivalent as well as they are kindly willing to become a head node. In real life, however, most nodes do not want to become a header node because they may not want to spend their power to forward/relay packets of other nodes. On the contrary, in many cases, they become a selfish node resulting in breakage of a route. The u-Zone based MANET that we have introduced in [13] is a solution to the problem.

As shown in Fig. 1, we borrowed the concept of cluster based routing protocols. That is, MANET is divided into a set of u-Zones and a u-Zone Master (u-ZM) is assigned for each of the u-Zones. The u-ZM is not an ordinary node (i.e. neither a source nor a sink node) but a super node having high computing power and robust electrical power. For example, a service provider (e.g. a committee of workshop or manager of event) can install u-ZMs within the expected communication space. A u-ZM assists its member nodes in most of routing functionalities such as gathering and/or relaying routing information so that the proposed architecture can reduce lots of overburden of ordinary nodes and the amount of control packets necessary to maintain both route and cluster.

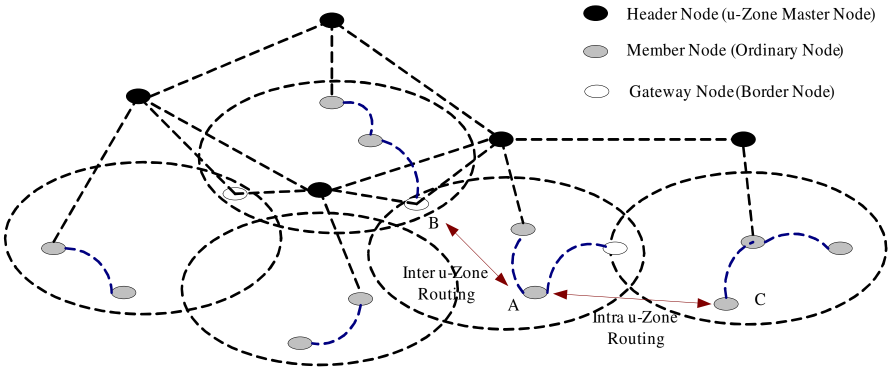


Fig. 1. Network model

The u-ZM is different from a fixed network device such as AP or BS in other wireless networks. The u-ZM is an assistant device to reduce routing overheads of mobile nodes as does a cluster head in cluster-based approaches. But, the AP or BS is the main device; therefore, failure of such a device results in breakdown of the network. Besides, in AP/BS based network, all data must go through the AP/BS even though a receiver is placed within the transmission coverage of a source. In the proposed network, however, if a source has routing information to the receiver then he can send data directly. Hence the proposed architecture is regarded as a semi-infrastructured MANET.

Two or more u-Zones are connected with each other by direct wireless links between u-ZMs. Such a wireless back bone (WBB) offers reliable communication and reduction in hop counts from a source to a particular destination. The decreased number of hops is desirable since larger hop counts results in worse performance in wireless communication. Moreover, it offers spatial reuse resulting in enhanced performance of overall network by assigning different radio channel or frequency to WBB from one used for links within a zone. If the WBB is not used, traffic may concentrate on just a few nodes resulting in a long end-to-end delay due to congestion at the nodes and a high energy consumption of the nodes.

2.3 Routing Protocol

MANET routing protocols are generally divided into three categories; proactive, reactive, and hybrid routing protocols. In proactive routing protocols, the routes are immediately available because all nodes contain routing table showing direction to all possible destinations. Therefore, lots of control packets are necessary to keep track of up-to-date network topology. To eliminate the overheads, reactive routing protocols have been proposed. Unlike proactive schemes, a route is discovered when a source has packets to send in an on-demand way. Such routing protocols also introduce lots of control packets, especially route request query packets that are to be flooded throughout the network.

In cluster-based MANET, researchers typically employed a hybrid approach into their routing protocols such as HARP [7], ZRP [8] and ZHLS [9]. Hybrid routing approach exploits the advantages of both proactive routing protocol and reactive routing protocol. They utilized a proactive approach within a zone (see route from A to B in Fig.1) and a reactive approach beyond the zone (see route from A to C in Fig.1). That is, hybrid routing methodology consists of two levels: intra zone routing and inter zone routing according to the destination's location corresponding to the source (i.e. within the same zone or beyond the Zone). In this paper, we also employ the hybrid routing approach. DYMO and OLSR are used as a reactive and proactive routing protocol respectively.

In DYMO routing protocol, a source sends RREQ message toward the destination node to discover a route [11]. Once the RREQ message arrives at the destination node, it responds RREP message back to the source node over the discovered path by unicasting. During such a route discovery process, intermediate nodes (i.e. nodes that relay the RREQ and RREP message) update its routing table based on the routing information that is present in those two messages for each direction.

Optimized Link-State Routing protocol (OLSR) obtains routing information for all nodes by periodically exchanging control packets [12]. The primary advantage of the proactive approach is that delay required to setup a connection is lower than that of a reactive approach. On the other hand, proactive routing approach introduces more control overheads because it must broadcast control packets to all nodes in the network periodically. Multipoint relays (MPR) has been presented to alleviate the control overheads by propagating the topology information via only selected nodes. Additionally, complexity and lack of mobility support are regarded as disadvantages of OLSR.

3 Problem Statement

This section describes a set of problems that are possibly occurred in MANET. In hybrid routing approach as described in section 2, a proactive routing protocol is used within a zone and a reactive routing protocol is used to discover a route to the destination which is placed at different zone from the source. Despite the efficiency of such a hybrid approach, it is of no use in the case, where a node can not execute both two routing protocols at the same time owing to the limitation of its capability (e.g. low CPU and small space of memory). A node employing a reactive routing protocol only, for instance, can not figure out the network topology composed of a set of nodes running a proactive routing protocol (i.e.

within a zone). We divide such problem set into two parts; intra-zone and inter-zone problem.

3.1 Intra-zone Routing Problem

Fig. 2 shows three cases that any existing routing algorithm can not support, where two different routing protocols (i.e. proactive and reactive routing protocol) are supposed to be used.

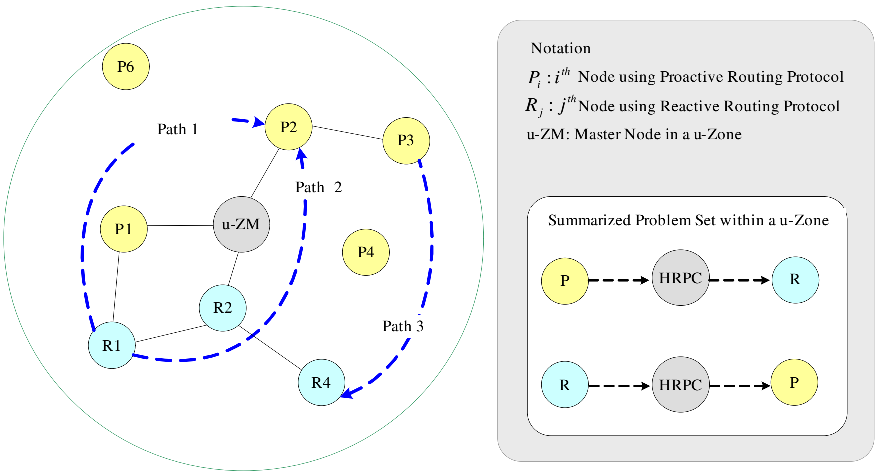


Fig. 2. Intra-zone HRPC processing

We note here that the *Path 1* of Fig. 2 can not be solved even though HRPC is properly installed. But any other scheme proposed so far also can not solve the problem. The last two problems (i.e. *Path 2* and *Path 3*) that can be solved by HRPC are simplified into two cases as follows (we show the cases in the box at the right hand side of Fig. 2).

- A *proactive node* needs to communicate with a *reactive node* within a zone.
- A *reactive node* needs to communicate with a *proactive node* within a zone.

3.2 Inter-zone Routing Problem

In the proposed MANET architecture (see subsection 2.2), WBB is used to enhance the reliability and performance. Hence, the set of intermediate u-ZMs (i.e. $\{u - ZM_k\}$) are simply regarded as a virtual link form the ingress u-ZM to the egress u-ZM as shown in Fig. 3. For example, an intermediate uZM that receives a control packet addressed to the destination retransmits the packet on the link connected to the next-hop u-ZM of the WBB. Similarly to the intra-zone problem, there are two cases possibly occurred in the MENET as follows.

- A *proactive node* needs to communicate with a *reactive node* beyond a zone.
- A *reactive node* needs to communicate with a *proactive node* beyond a zone.

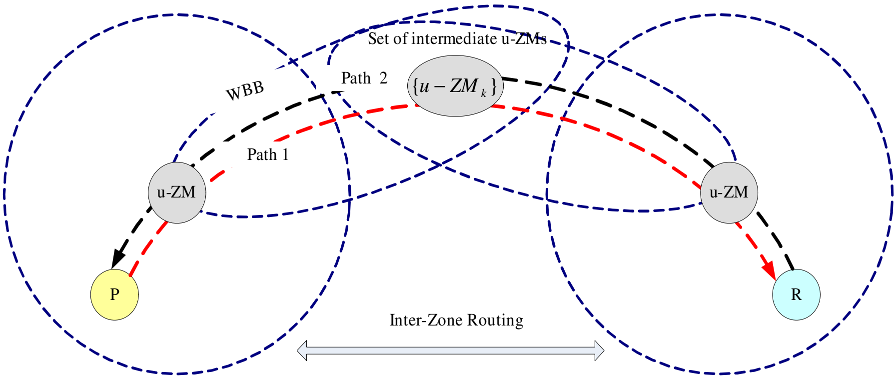


Fig. 3. Inter-zone HRPC processing

4 Proposed Scheme

4.1 Heterogeneous Routing Protocol Coordinator

HRPC is not a stand-alone routing protocol but a coordinator module running on u-ZM (or cluster head node) for support bridging functionality between heterogeneous routing protocols in MANET. The flow diagram illustrated in Fig. 4 shows how HRPC works, where OLSR and DYMO are used for a proactive and reactive routing protocol respectively.

Once a packet arrives at HRPC of u-ZM, HRPC first checks whether it is a control packet (see the left side of Fig. 4) or not (see the right side of Fig. 4). If the packet is identified as a control message then HRPC distinguish which routing protocol can use the packet. Afterwards the control packet is handled by the specification of the distinguished routing protocol (i.e. either DYMO or OLSR). In the next subsection, we discuss the HRPC operations in detail.

4.2 HRPC Processing

As described in section 3, two cases are enough to show the funtional operability of HRPC.

- Reactive node (DYMO) $\longrightarrow$ u-ZM (HRPC) $\longrightarrow$ Proactive node (OLSR)

When the DYMO module of u-ZM receives a route request message (RREQ), it first looks up the destination in its routing table (RT_{DYMO} shown in Fig. 6). If it can finds an available path (i.e. next hop toward the destination), it generates a route reply (RREP) to send it back to the RREQ requestor. Otherwise, it queries to the HRPC module to look up the destination in RT_{HRPC} table which is coupled with RT_{OLSR} table (both routing tables are also illustrated in Fig. 6). If the destination node using OLSR is resided in the same zone with the route requestor, OLSR module of u-ZM definitely knows the routing information owing

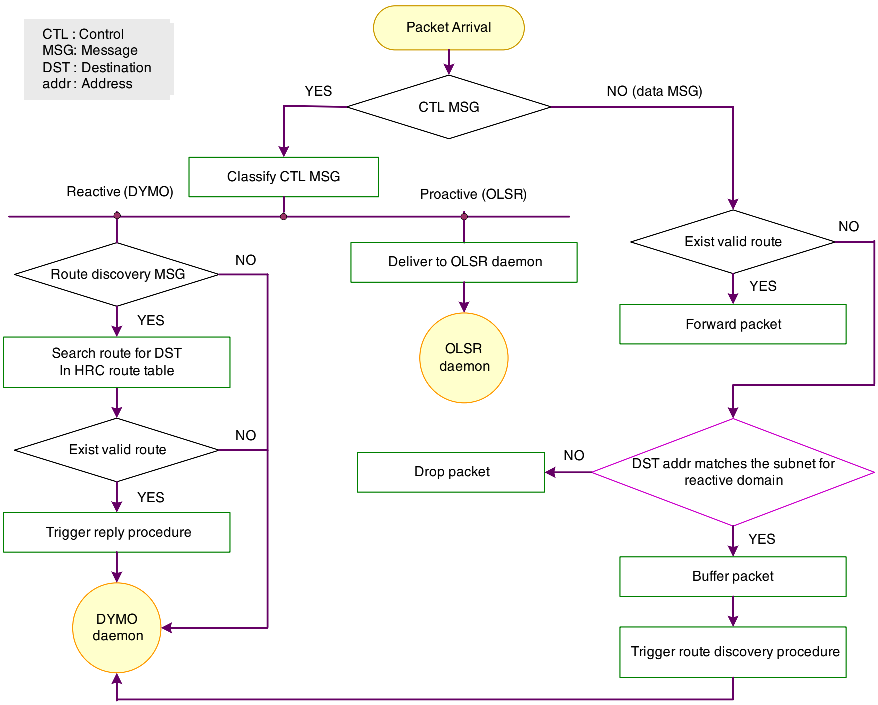
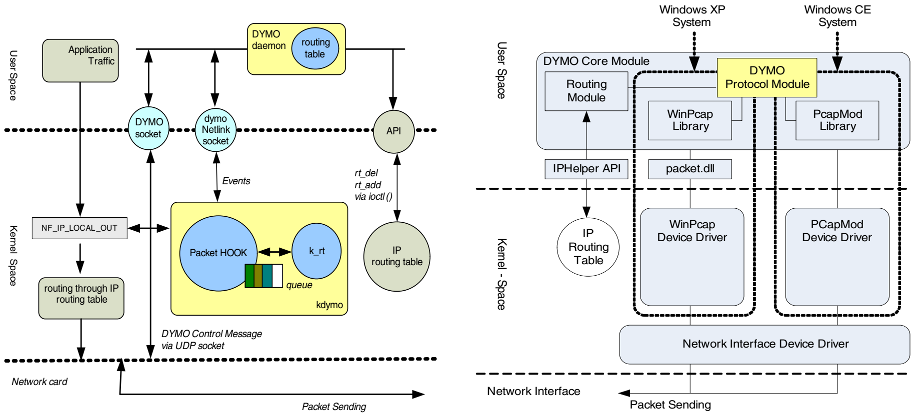


Fig. 4. HRPC processing flow

to the table driven manner of OLSR routing protocol. Hence, the u-ZM can send a route reply (RREP) back to the requestor. If there is no information, the u-ZM broadcasts the RREQ to his zone to find the destination that must be use DYMO as a routing protocol. Also the RREQ is forwarded to the next hop u-ZM to discover the destination beyond the zone. The final u-ZM which includes the destination node as a member node in its zone can generate RREP in the same way to the case of intra-zone.

- Proactive node (OLSR) ⟶ u-ZM (HRPC) ⟶ Reactive node (DYMO)

In order to enable OLSR nodes to discover a DYMO node, HRPC utilizes "*Host and Network Association (HNA)*" message of OLSR which is defined for providing OLSR MANET with connectivity to external network. Once a node receives a HNA message, it is able to create a routing entry for its routing table by using the network address and netmask conveyed in the HNA message thereafter the originator of HNA message operates as a gateway for the external network. In our scheme, u-ZM is the originator of the HNA message. In case there is no routing information in the RT_{OLSR} of u-ZM, then HRPC activates DYMO module to start a route discovery process. After getting RREP from the destination node, the u-ZM updates its routing table which is synchronized



(a) Linux system (b) MS Windows system

Fig. 5. DYMO implementation for heterogeneous operating system

with RT_{OLSR}. Now, the u-ZM is able to inform OLSR nodes of the routing information by looking up the DYMO node in RT_{HRPC}.

5 HRPC Implementation and Demonstration

This section first describes the implementation of HRPC and then shows experimental results. To demonstrate the HRPC, we have ported a freely available implementation of OLSR [14] and implemented our own version of DYMO as a proactive and a reactive routing protocol respectively. The selected OLSR daemon is well structured and can be applied into various platforms (e.g. GNU/Linux, Windows, FreeBSD, etc). The OLSR daemon is completely compatible with RFC 3626 and supports both IPv4 and IPv6.

The DYMO implementation was based on the specification of the earlier version of Internet-Drafts [11] posted at MANET working group in IETF. In particular, to support heterogeneous mobile nodes, the DYMO have been implemented not only on the Linux system but also on the Windows based systems (Windows XP for a laptop and Windows CE for a PDA) as shown in Fig. 5.

5.1 HRPC Implementation

The HRPC module resides in the kernel space of Linux operating system as a daemon process. Three different ways are possible to implement it into kernel; Snooping, kernel modification and Netfilter framework. Advantages and disadvantages of each of such three methodologies were described in [15]. We decided to use Netfilter which is a raw framework consisting of a set of hooks inside the Linux kernel. The hooks are generally regarded as specified points along a handling flow of packets (there are 5 hooks for IPv4). A protocol (or a developer)

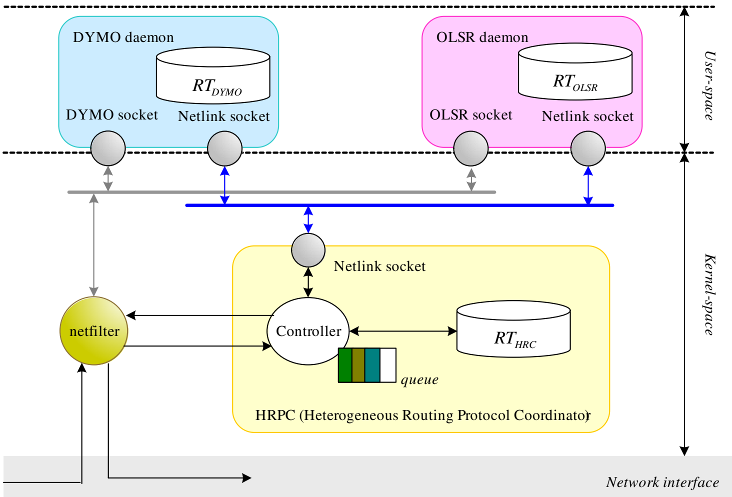


Fig. 6. HRPC module diagram

is allowed to define its own functionalities and then attach them to each of such points. Fig. 6 illustrates the simplified module architecture of HRPC.

HRPC holds its own routing table (see RT_{HRPC} in Fig. 6) and collects topological information from both OLSR and DYMO routing tables (see also RT_{OLSR} and RT_{DYMO} respectively in Fig. 6). Hence, the maintenance of RT_{HRPC}, for example addition and deletion of routing table entries, are tightly coupled with both routing protocols. Like most routing protocol implementations (e.g. AODV-UU [16], AODV-UCSB [17]), both RT_{OLSR} and RT_{DYMO} are placed at the user space so that we have utilized the Netlink socket to enable inter-communication between kernel and user space. Netlink socket is commonly used IPC (Inter-Process Communication) facilities and follows the functionalities of standard socket APIs. In addition to the Netlink socket, each of both routing protocols creates their own socket to send/receive control messages.

5.2 Test Environment

We have evaluated the operations of HRPC module using the network topology as shown in Fig. 7.

The testbed was comprised of three laptops equipped with IEEE 802.11b wireless chipset. All laptops were Linux system and their communication state was set to ad hoc mode. Each of three nodes employed one or more routing protocols as follows.

– Node employing DYMO as a reactive routing protocol
– Node employing OLSR as a proactive routing protocol
– u-Zone Master node employing HRPC, DYMO and OLSR protocols

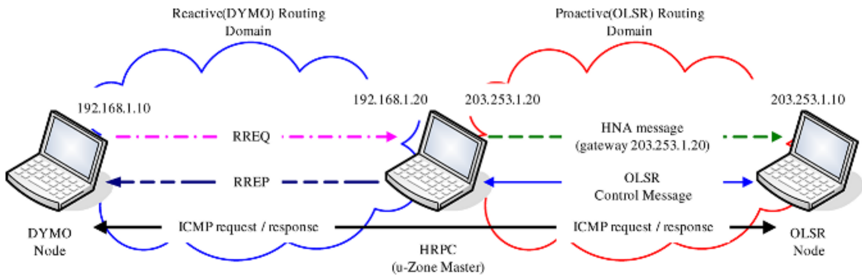


Fig. 7. Testbed for HRPC demonstration

5.3 Test Results

We show the results of the following two cases. In the first case, OLSR node wants to send "ping packets (ICMP Echo packets)" to DYMO node via an intermediate u-ZM. In the second case, the way to evaluate HRPC is same to the first case but the packets are delivered in a reverse way. In both cases, u-ZM informs that it is the gateway by means of OLSR HNA message as the first step.

- case 1: OLSR node ⟶ HRPC (u-ZM) ⟶ DYMO node

Fig. 8 and Fig. 9 show the results of the first case. We have utilized a network protocol analyzer called Ethereal [18] to monitor the packets over time from the source to the destination. Fig. 8 is a snapshot of the monitoring outputs of Ethereal running at the source, where both the ping request and the reply

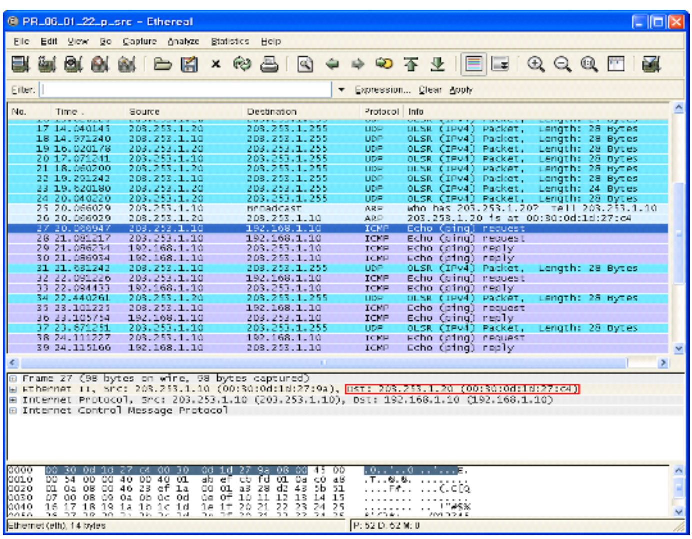


Fig. 8. Test result for case 1 (snapshot at proactive source node)

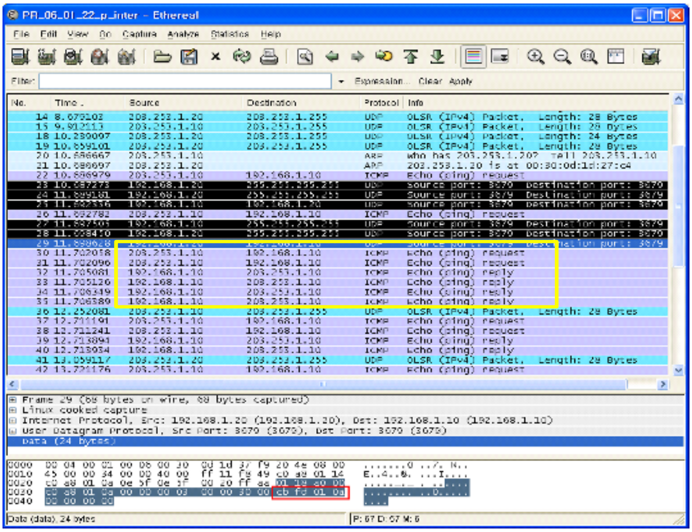


Fig. 9. Test result for case 1 (snapshot at u-ZM)

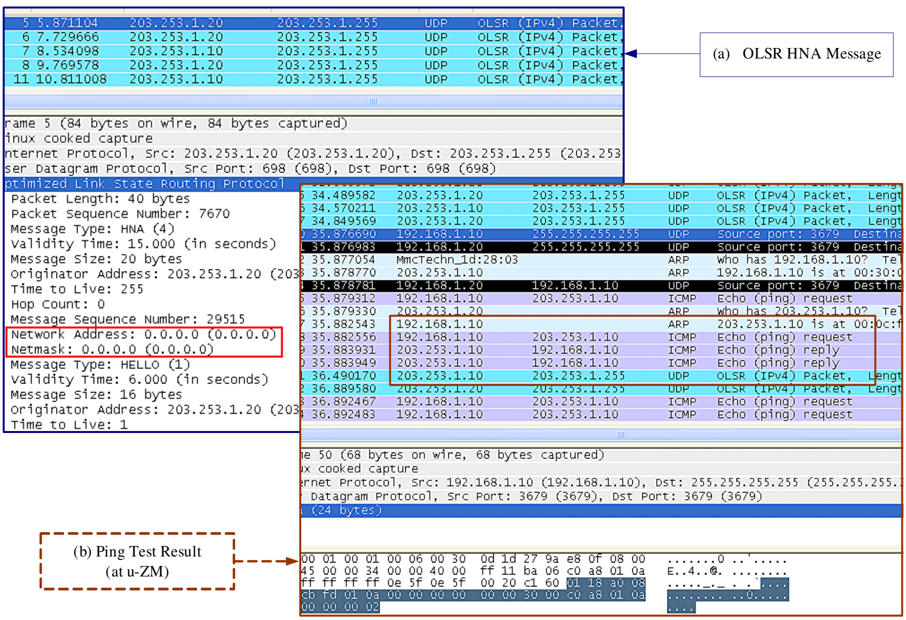


Fig. 10. Ping test from reactive node to proactive node

packets are shown. Like Fig. 8, Fig. 9 also shows the deliveries of echo packets but the figure was taken at the u-ZM.

OLSR sends ICMP echo request packet to u-ZM then the u-ZM hooks the packet to determine the next processing by means of Netfilter. Afterwards, the u-ZM aware that the destination is not an OLSR node so that it activates a route discovery process (i.e. broadcasting a RREQ packet). The DYMO node sends RREP to u-ZM as a response of the RREQ. Now, the u-ZM is capable of sending the ICMP packets queued in its buffer.

- case 2: DYMO node $\longrightarrow$ HRPC (u-ZM) $\longrightarrow$ OLSR node

As described above, the way to demonstrate the second case are similar to the first case. The test result is shown in Fig. 10.

6 Conclusion

In ubiquitous networks, various types of communication devices are to be interconnected beyond the limitation of time and place. We believe that mobile ad hoc networking is one of the most promising technologies playing an increasingly important role in the upcoming ubiquitous networks. But such a technology still introduces several challenges from the viewpoint of practicality. Among those, the primary focus of the paper was on the heterogeneity of nodes. More specifically, the paper has presented an efficient approach to allow mobile nodes to communicate each other regardless of the type of routing protocols. We have shown in this paper that the proposed HRPC running on u-ZM works well in the u-Zone based MANET.

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