Experimental Performance Modeling of MANET Interconnectivity

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Abstract

The proliferation of mobile wireless computing devices and the increasing usage of wireless networking have motivated substantial research in mobile ad hoc networks (MANETs). In addition, much has also been done to link autonomous MANETs to the Internet, and as MANETs become more prevalent, the need to interconnect multiple MANETs becomes increasingly important too. However, direct interconnection of MANETs has rarely been studied. In this paper, we report an experimental study on the performance of interconnected MANETs running two different routing protocols, viz., the Ad hoc On-Demand Distance Vector (AODV) and Optimized Link State Routing (OLSR) protocols, which represent the two major categories, and show that with the use of multiple gateways, it is possible to viably interconnect multiple networks running different MANET routing protocols.

1. Introduction

A Mobile Ad hoc Network (MANET) consists of mobile nodes coming together to form a network without the support of dedicated routers and base stations, and communicate with one another over multi-hop wireless links. Due to the dynamic nature of MANETs, traditional routing protocols designed for wired networks fare poorly in such environments. There are mainly three general categories of MANET routing protocols, namely, proactive, reactive and hybrid [1].

In proactive routing protocols, every node in the network maintains a route to every other node in the network at all times. Examples of proactive routing protocols include OLSR [2] and TBRPF (Topology Dissemination Based on Reverse-Path Forwarding). In reactive routing protocols, every node in the network maintains a route to another node only if it needs to transmit data packets to that node. AODV [3] and DSR (Dynamic Source Routing) are well known examples of such protocols. Hybrid routing protocols try to exploit the advantages of both categories. Generally, every node maintains a route to every other node in its locality at all times and a route to a node outside its locality only when it needs to send data packets to that node. Examples of hybrid routing protocol include ZRP (Zone Routing Protocol) and CBRP (Cluster-Based Routing Protocol).

Different MANETs exhibit different characteristics, such as node mobility, size of the network and traffic patterns [4]. Consequently, there is no single ad hoc routing protocol that will perform well under different network conditions. Therefore, it is not inconceivable for different networks to deploy different routing protocols based on the desired network requirements and policies. As MANETs become more prevalent, besides connecting them to wireless or fixed backbone networks like the Internet, the need to interconnect multiple MANETs becomes increasingly important too. However, interconnection of MANETs has rarely been studied.

In the Internet, different routing protocols, such as OSPF and BGP, can coexist because the Internet utilizes a hierarchical routing system [5]. Intra-autonomous system routing protocols, such as RIP and OSPF, are used to maintain routing tables for nodes in the same region while inter-autonomous system routing protocols, such as BGP, are used to maintain routing tables between different regions. However, this arrangement requires nodes in the same region to share a common network prefix and the routing tables in the Internet must always be up to date. When a node moves to another region, it either has to obtain another IP address or mobile IP has to be used.

In a MANET, nodes usually do not have to share a common network prefix. In proactive MANET routing protocols, the routing tables are complete and up to date as the nodes share routing information periodically. In reactive protocols, the routing tables are incomplete as a routing entry to a destination is only added and maintained when needed. The problem to address is how to manage and update the routing tables of nodes in reactive and proactive ad hoc networks so that they can communicate with one another without using mobile IP or any common network prefix.

In this paper, we report an experimental study on the performance of interconnected MANETs running two different routing protocols, viz., AODV and OLSR, which represent the two major categories. In the next section, we provide a brief description of the two protocols used in our study and the motivations behind the effort. In Sect 3, we provide an overview of related work. Next, we describe the mobile gateway architecture used in our study in Sect 4, and the mechanisms used for inter-network routing of packets in Sect 5. In Sect 6, we illustrate the operation of the system in some typical scenarios. Testbed setup and performance study results are presented in Sect 7 and we conclude in Sect 8.

2. Background and Motivation

The Internet Engineering Task Force (IETF) has identified four protocols as representative of the many that have been proposed, viz., reactive protocols AODV and DSR, and proactive protocols OLSR and TBRPF.

AODV makes use of destination sequence numbers to ensure loop freedom at all times, and designed to respond quickly to changing link conditions in MANETs. Route Request (RREQ), Route Reply (RREP) and Route Error (RERR) are the basic control messages used in AODV. The RREQ message is used by a node to initiate a route discovery to the destination. The destination node or a node with a route to the destination uses a RREP to reply to the source. RERR messages are used to invalidate routes that are unusable due to link breakages. HELLO messages are also used to provide connectivity information. These are RREP packets with their Time-To-Live (TTL) set to 1, and broadcast locally to all nodes within the vicinity of any particular node. A node uses HELLO messages only if it is part of an active route.

OLSR uses multipoint relays (MPRs) to reduce the transmission of control messages making it suitable for large MANETs where the network nod density is high. Multiple Interface Declaration (MID), HELLO, Topology Control (TC) and Host and Network Association (HNA) are the basic control messages used in OLSR. A MID message advertises any multiple interface of the node. HELLO messages are used for link sensing between neighbouring nodes. TC messages enable nodes to construct the routing table by knowing routes to all possible destinations in the network. HNA messages are used to provide OLSR nodes with external routing information from other non-OLSR networks.

Different protocols have been designed with different assumptions and to meet different requirements. Hence, each is expected to perform ideally in the target network scenario that it is designed for. As the scope of MANET deployment expands, it is likely that the communication between a pair of nodes span multiple network domains. Since mobile devices in general are memory constrained, it would also be impractical for mobile nodes to have many different routing protocols simultaneously loaded to handle data traffic carried by different routing protocols. Therefore, it would be more viable to deploy a gateway to interconnect nodes in different types of networks using different MANET routing protocols. In our study, AODV and OLSR are used to demonstrate the connectivity between two different ad hoc routing protocols. A typical interconnected network is shown in Figure 1.

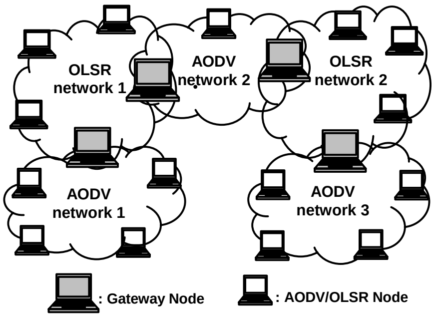

Figure 1. Multiple Interconnected Network Scenario

3. Related Work

While much research has initially focused on protocols and algorithms for autonomous MANETs, it soon became obvious that MANETs need to be connected to the Internet in order to be useful. The efforts in the IETF provide some good proposals for MANET-Internet connectivity. In [6], MANET nodes first need to obtain a globally routable address from an Internet gateway, after which it can communicate with other nodes in the Internet. Foreseeing that there will be a significant demand for globally routable addresses as well as other advanced features like security and quality of service, the proposal is based on IPv6. Another approach is to extend the existing IP routing protocols to cover MANETs[7][8]. Performance studies on key components like Internet gateway discovery, addressing and handover schemes have also been extensively studied [9][10]. There has been a few efforts to interconnect MANETs via some form wireless ad hoc infrastructure network, e.g. IS-MANET project [11] but they do not address the problem at the routing layer and thus our proposed scheme complements these efforts. To the best of our knowledge, the direct interconnection of MANETs, which is the focus of this paper, has not received much attention.

4. Mobile Gateway Architecture

To interconnect MANETs running different protocols, e.g. AODV and OLSR in this study, a mobile gateway (MGW) is needed. This MGW is loaded with both protocols and some changes to the protocols are needed to enable communication between multiple MGWs. However, pure AODV or OLSR nodes that do not act as gateways to other networks remain unchanged. Figure 2 illustrates the MGW architecture. As an optimization feature to improve the power efficiency of the MGW, the monitoring module listens for routing packets in the network and loads the OLSR module when there are surrounding OLSR nodes or unloads the OLSR module when there are no OLSR routing packets heard after a fixed time (set to a multiple of NEIGHB_HOLD_TIME), so that unnecessary control messages are not transmitted. The AODV module is always loaded since there are no additional routing messages incurred if there are no neighbouring AODV nodes.

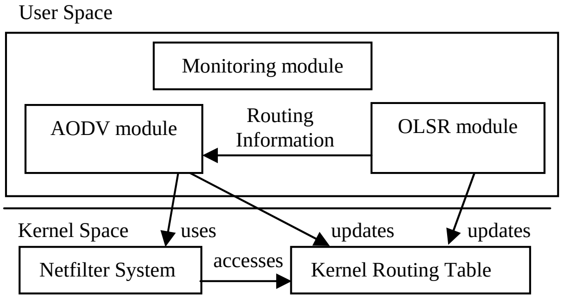

Figure 2. Mobile Gateway Architecture

5. Inter-network Routing Mechanisms

5.1 Processing of Routing Messages in AODV

When a MGW receives a RREQ, it first determines whether it has a path to the requested AODV node or whether it is the MGW for the OLSR node. If it has a path to the destination node, it will send a RREP to the sender. If the destination in the RREQ is a pure OLSR node, the MGW will have to keep track of the destination sequence number on behalf of the OLSR node, to ensure correct operation of the AODV protocol. If the MGW does not have a path to the destination, it will have to rebroadcast the RREQ to other AODV nodes and unicast the RREQ to other MGWs, enabling it to traverse OLSR networks. The discovery of other MGWs is achieved by broadcasting HNA messages into the OLSR network which is described in the next section.

When a MGW receives a RREP, it will create a forward route to the source of the RREP, and forward the RREP to the next hop of the reverse route. Similarly, the broadcasting of RERR messages will have to be modified. In AODV networks, RERR messages are unicast if there is only one predecessor or broadcast if there are more than one predecessor. However, if the node is a MGW, RERR messages will be unicast to every predecessor node that is a MGW.

5.2 Broadcasting of HNA Messages in OLSR

Under normal circumstances, an OLSR node that does not have a routing table entry for the destination of the data packet will simply drop the packet. However, the destination may be an AODV node, so the OLSR node will send the data packets to the nearest MGW. Then, the MGW will need to initiate route discovery on behalf of the OLSR node. In order to advertise the MGW’s connectivity to other AODV nodes as well as OLSR nodes which are separated by AODV networks, the MGW will broadcast HNA messages indicating that it is the default gateway for the OLSR nodes in the network. In the case of an OLSR node receiving HNA messages from multiple MGWs, the nearest MGW will be selected. These HNA messages also enable an MGW to discover other MGWs in the same OLSR network so that any RREQ can be unicast to these MGWs.

5.3 Processing of Data Packets

When the MGW receives a data packet, it will determine whether the packet is destined for an OLSR node, AODV node or MGW. This is done by searching the OLSR routing table as it has complete information about the OLSR network. For a data packet from an AODV node or another MGW, and the destination is not found, a RERR will be sent back to the sender. For a data packet received from an OLSR node, and the destination is not found, it will buffer the data packets and send a RREQ to initiate a route discovery process on behalf of the OLSR node. If no RREP is received after RREQ_RETRIES, then it will send an ICMP Destination Unreachable message back to the OLSR node.

5.4 Tunneling of Data Packets

Since an OLSR node has no route entry to other nodes (AODV nodes or OLSR nodes separated by AODV networks) other than the OLSR nodes in its own network, data packets have to be routed through a tunnel using IP encapsulation [14] between two MGWs. The original source address of the data packet will be replaced by the address of the source MGW while the destination address of the data packet will be replaced by the address of the destination MGW. When the data packet reaches the end of the tunnel, the original source and destination addresses of the data packet will be restored.

6. Gateway Operations

6.1 Single Gateway Operation

Figure 3 illustrates the route discovery process from an OLSR node to an AODV node interconnected by a single MGW. In this situation, the OLSR node will send all the data packets to the MGW which will initiate route discovery on behalf of the AODV nodes. After a route is discovered, the buffered data packets are forwarded.

Figure 4 illustrates the route discovery process from an AODV node to an OLSR node. In this situation, the MGW will send a RREP on behalf of OLSR nodes. After the AODV node receives the RREP from the MGW, it will send the data packets to the MGW which will then forward the data packets into the OLSR network.

6.2 Multiple Gateways Operation

Figure 5 illustrates the route discovery process from an AODV node to another AODV node in different AODV networks which are separated by an OLSR network. Two rounds of RREQs are needed to reach the destination as the first RREQ will only travel two hops while the second RREQ will travel four hops.

Figure 6 illustrates the route discovery process from an OLSR node to another OLSR node in different OLSR networks which are separated by an AODV network.

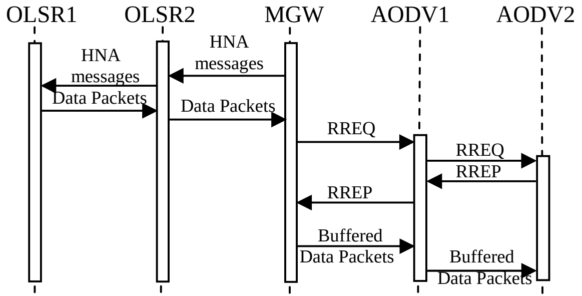

Figure 3. Route Discovery: OLSR1→AODV2

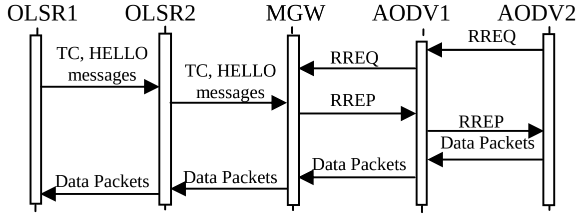

Figure 4. Route Discovery: AODV2→OLSR1

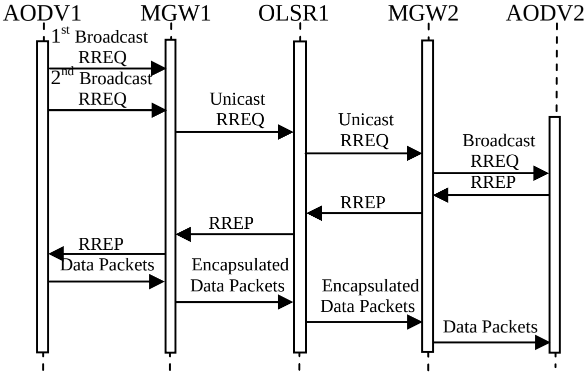

Figure 5. Route Discovery: AODV1→AODV2

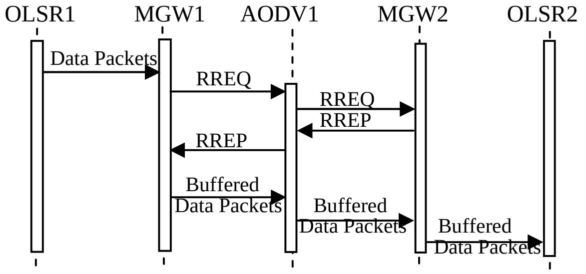

Figure 6. Route Discovery: OLSR1→OLSR2

7. TestBeds and Performance analysis

7.1 Testbed Setup

To test the implementation of the algorithm for multiple gateways operation, a testbed consisting of five mobile nodes are set up using AODV[12] and OLSR[13] as routing protocols. The different testbed configurations in are illustrated in Table 1. All the mobile nodes are equipped with Red Hat Linux 8.0/9.0 with kernels 2.4.16/2.4.20. The program 'iptables' is used to simulate the lack of connectivity between nodes to create a multiple-hop ad hoc network.

To test the ability to handle mobility of MGWs, the testbed shown in Figure 7 is used. In the tests, OLSR1 will resume communication with AODV1 even if either MGW moves out of the network. This increases the reliability of the network as either of the MGW can continue to provide connectivity even if one of the MGWs moves out of range.

Table 1. Various configurations of testbed setup

Testbed	NODE 1	NODE 2	NODE 3	NODE 4	NODE 5
Pure AODV	AODV1	AODV2	AODV3	AODV 4	AODV5
Pure OLSR	OLSR1	OLSR2	OLSR3	OLSR 4	OLSR5
Single MGW	AODV1	AODV2	MGW1	OLSR 1	OLSR2
Multiple MGWs 1	AODV1	MGW1	OLSR 1	MGW2	AODV2
Multiple MGWs 2	OLSR1	MGW1	AODV 1	MGW2	OLSR2

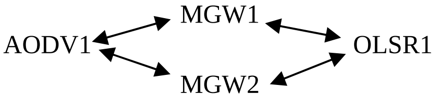

Figure 7. Testbed of 2 MGWs connecting AODV and OLSR networks

7.2 Performance Evaluation

Figure 8 shows the 1st packet Round Trip Time (RTT) delay for the 1st data packet to travel to the destination and back to the source for various node configurations with data packets originating from Node 1. This includes any delay due to route discovery process as well as ARP (Address Resolution Protocol) requests. For the pure AODV network, the route discovery times for the AODV network are not proportional to the number of hops as the AODV protocol uses expanding ring search for RREQ messages. The range for the first RREQ is two hops while for the second RREQ is four hops. This expanding ring search helps to reduce the number of RREQs if the destination node is near the source node but increases route discovery time if the destination node is many hops away from the source node. The first packet RTT delay for pure OLSR networks is insignificant as it is a link state routing protocol and the delays are mainly due to ARP requests. For the testbeds with MGWs interconnecting AODV and OLSR networks, the first packet RTT delay times are low if the MGW knows of routes to OLSR nodes but high if the MGW has to do route discovery.

Figure 9 illustrates the RTTs of PING packets from Node 1. These RTTs include transmission, processing and queuing delays. In most cases, the RTTs are proportional to the number of hops. From the tests conducted, some processing delays at the MGW resulted in about 20% increase in RTTs.

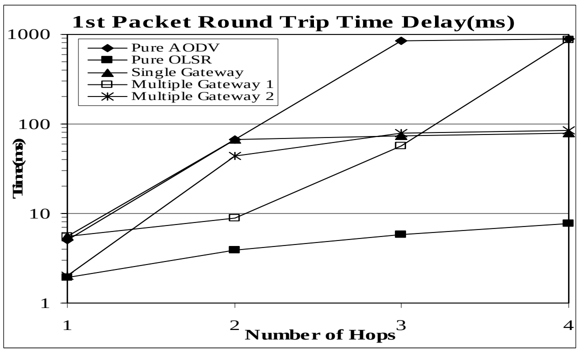

Figure 8. 1st Packet RTT Delays

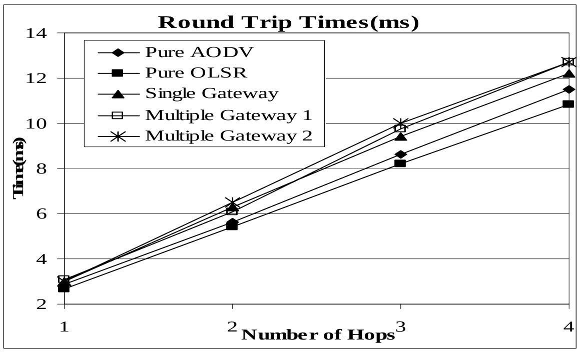

Figure 9. Round Trip Times

Figure 10 illustrates the data throughput using FTP. Default parameter values in the implementations of AODV and OLSR are used, and the higher throughput for the pure AODV network does not indicate that the performance of an AODV network is better than that of an OLSR network. For the various gateway configurations, the data throughput lies between the pure AODV and pure OLSR network, indicating that our gateway implementations do not negatively affect the performance of the network.

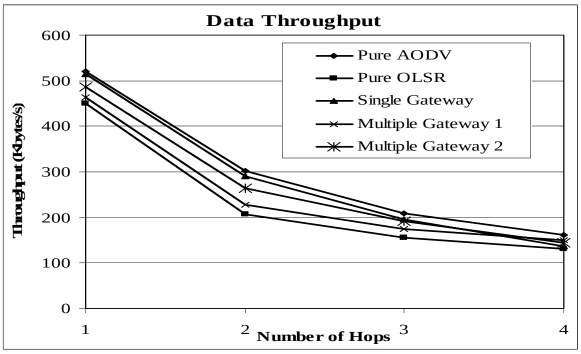

Figure 10. Data Throughput

8. Conclusion

This study has achieved the following objectives:

- Interconnectivity of AODV and OLSR protocols
- Compatible with current AODV[12] and OLSR[13] implementations on Linux
- Seamless roaming experience for the wireless nodes as the MGW to the node is discovered dynamically
- Automated configuration of routing protocols with dynamic loading/unloading of protocols by MGWs
- The MGW architecture can be utilized for mobile entities to provide dual protocol stack capability
- Extends the area of operations of ad hoc networks.

We aim to support all four ad hoc routing protocols (AODV, OLSR, TBRPF and DSR) selected by IETF as this will enable seamless roaming for end-users via automated detection/selection of the routing protocols.

The experiments have been carried out with a small number of nodes primarily for functional verifications, and the next step would be to conduct simulations to study the performance of the MGW in larger MANETs.

9. References

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