MPLS IMPLEMENTATION IN MOBILE AD-HOC NETWORKS (MANETs)

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ABSTRACT

This paper presents the idea of integrating the layer-II label-switching technique with the layer-III ad-hoc routing and to study the effect of MultiProtocol Label Switch (MPLS) mechanism on the performance of Mobile Ad-Hoc Networks (MANETs). This integration shows various effects on the QoS pramateres and in this paper, a number of these effects will be discussed through various anlyses and simulations.

Keywords: MPLS, MANETs, QoS, AODV, OLSR, ZRP.

1 INTRODUCTION

MPLS was introduced in late 90s to support Quality of Service (QoS) and Traffic Engineering (TE) for optical networks. The IETF (Internet Engineering Task Force) specifications for MPLS [1] and the requirements for support of Differentiated Services-aware MPLS Traffic Engineering (TE) [2] propose solutions for special treatment of data on the Internet backbone. The IPv6 Mobility [3] also discusses the mobility issue with IP version 6. These three, mark the starting point in the understanding of the MPLS and Mobile-IP Ad-Hoc Network (MANET) integration. In this article, the integration of MPLS with three MANET protocols will be discussed. Figure 1 (*a* and *b*) show variety of MANET protocols, based on their categories.

2 MOTIVATION

MPLS was initially designed for high speed optical backbone using super fast optical switches. This required fast processing power. Utilizing MPLS in a wireless context, from one hand provides extraordinary improvement in a faster processing of layer-II headers, which improves the end-to-end delay figures, however requires an extensive downgrade of infrastructure to meet wireless limitations (limited battery and processing power of wireless nodes). Other benefits from this integration are: improvement of QoS parameters (round-trip delays, packet loss/drop ratios, etc), fault tolerant paths [4], and structural management services. The motivation of this paper is to study the effect of integrating MPLS with Flat On-Demand (Reactive), Flat Table-Driven (Proactive), and Flat Hybrid Routing Protocols. For this, we selected Ad hoc On-Demand Distance Vector (AODV) [5], Optimized Link State Routing (OLSR) [6], and Zone Routing Protocol (ZRP) [7]. Table 1 shows the basic comparison characteristics between these three flat routing protocols.

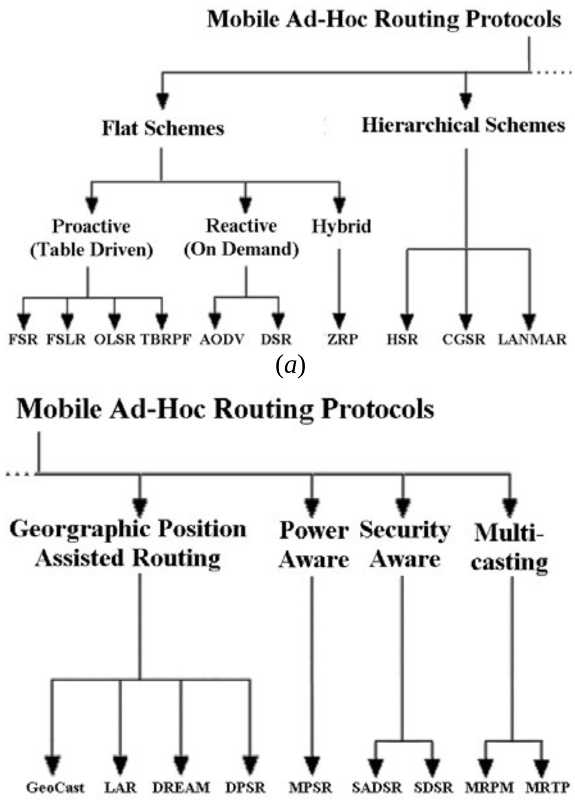

Figure 1: Different categories of MANET protocols

	Proactive	Reactive	Hybrid
Topology dissemination	Periodical	On-demand	Both
Network organization	Flat / Hierarchical	Flat	Hierarchical
Route latency	Always available	Available when needed	Both
Mobility handling	Periodical updates	Route maintenance	Both
Communication overhead	High	Low	Medium

Table 1: Characteristic summary between proactive, reactive, and hybrid routing protocols

3 MULTIPROTOCOL LABEL SWITCHING

3.1 Introduction

MPLS is a packet forwarding protocol that is capable of layer III to Layer II mapping. The essence of this protocol is to assign packet flows to Label Switched Paths (LSPs). Packets are classified and at the *ingress* router (edge router at the MPLS domain) or the Label Edge Router (LER), based on Forwarding Equivalence Classes (FECs) [8, 9].

In MPLS, traffic is aggregated into FEC groups. FECs are assigned to specific LSP and Traffic-Engineering (TE) can be implemented to assign high-priority FECs onto high-quality LSPs and lower-priority FECs onto lower-quality LSPs.

MPLS is therefore capable of connection-oriented QoS treatment. FECs summarize essential information about the packet, such as:

- Destination
- Precedence
- Virtual Private Network (VPN) Membership
- Layer III information (QoS specifications, selected interfaces, etc)

Labels are assigned at the *ingress* after normal layer III headers are stripped-off. At the MPLS domain's ending edge (*egress*), normal layer III information is attached back to the packets. Figure 2 shows a typical MPLS Domain with its edge routers.

MPLS benefits both from c*ircuit-switched* network attributes, similar to ATM, which can provide m*inimum bandwidth guaranteed*, and from p*acket-switched* network attribute, offering connectionless flexibilities, such as in IP. From functional point of view, the other reason for migrating to MPLS is the fact that MPLS works at the layer II and can integrate wide variety of protocols on to the data link layer. Therefore, MPLS acts as a network layer independent protocol. It is, therefore highly reliability, it supports variety of QoS criteria, and Traffic Engineering (TE).

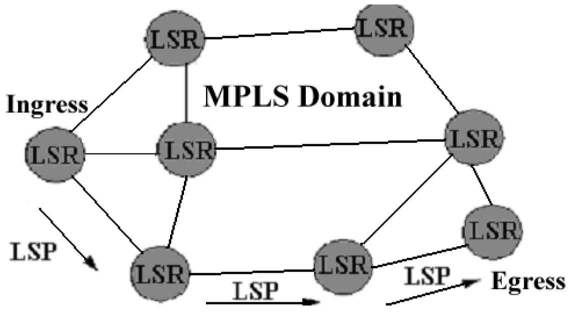

Figure 2: A typical MPLS domain with edge routers

Traffic Engineering (TE) is the assignment of particular treatment to groups of traffic with similar identifier as opposed to single-flow treatment for IP-based traffic.

3.2 Advantages of Mobile-IP using MPLS

The integration of MPLS with Mobile-IP has improved numerous mechanism efficiencies, such as:

Fast Switching: Normally under IP, the packet header is examined at every node, which increases end-to-end delay. This issue has been dealt with in MPLS by assigning layer II labels and switching is performed based on the label information.

Small State Maintenance: MPLS-DiffServ [10, 11] requires LSRs to maintain signalling flow and small state maintenance in the core. This way, the forwarding decisions are based on the MPLS shim header, therefore the Per Hop Behaviour (PHB) needs to be inferred through the assignment of three experimental bits (Exp) in the MPLS header to carry DiffServ information in MPLS (Figure 3).

Label (20 bits)	Exp (3 bits)	S (1 bit)	TTL (8 bits)

Figure 3: MPLS Header

Highly Reliable: Reliability is the most critical issue at the edge of MPLS domain, where FECs are assigned. In the core, MPLS-enabled routers are often deployed in pairs to create redundant paths. Hardware redundancy is another important aspect of the reliability issue, which is vendor dependent.

Highly Scalability: FECs have local meaning between two LSRs, therefore MPLS systems are highly scalable. For the purpose of QoS and TE, flows are aggregated into traffic trunks (collection of individual flows that share forwarding decisions along the same path and the same class of service) [1]. By routing at the granularity of traffic trunks, scalability is achieved.

Connection-Oriented QoS: A connectionless network, such as an IP-based network, can not provide firm QoS. MPLS-based networks, however, imposes a connection-oriented framework on an IP-based traffic by assigning particular treatment to particular traffic. This way, guaranteed QoS could be implemented and high priority traffic could be assigned to high quality FECs. These parameters are:

- **Guaranteed Minimum Bandwidth**
- **Guaranteed Maximum Delay**
- **Guaranteed Maximum Jitter (for voice)**
- **Precedence for specific data, and etc.**

3.3 Disadvantages of Mobile-IP using MPLS

MPLS was primarily designed for fixed optical networks mostly supporting fiber-optic links. MPLS offers advantages compared to other technologies (as discussed in details in section 3.2) and in the recent years, the application of MPLS in mobile technologies has gained popularity [8, 9]. Besides numerous advantages of MPLS and ad hoc networks integration, the few drawbacks of such integration are summarized as follow:

Limited Processing Power: MPLS mechanism requires high scale of processing power, which is not an issue in fixed networks. However this is a major issue in mobile networks, where each node has a limited battery power and a small portion of this power could be dedicated to the processing units. There is a trade-off between processing power and the battery life-time, which is set to maximize the battery-life with minimum acceptable processing power for energy saving modes.

Complexities in Handoff and handover: Handoff and handover mechanisms in MPLS-domains require the deployment of hierarchical structures to support smooth handoffs. This increases the complexity of the infrastructure and requires nodes to support multipath routing, which is only supported in a number of ad hoc routing protocols.

Potential Bottlenecks: If the mobile-node moves from one MPLS-domain to another and the domains are not back-to-back located, this requires multiple conversion processes of layer III (IP) to layer II (MPLS Header) and back to layer III at the ingress/egress interfaces. This could become a potential bottleneck, increase mobility constraints and introduce additional unnecessary overhead, undermining the whole purpose of the mobile-IP-MPLS integration. Therefore to prevent such degradation, MPLS-domains have to be connected back-to-back to other MPLS-domains using MPLS-ready gateways and no IP-based domains should be located between MPLS-domains for maximal efficiency.

Label Challenges: The assignment of unique labels in a distributed environment could become a challenge when hierarchical model is used. To ease this issue, labels should be issued on an global sense. Since MPLS is highly scalable, it manages such assignments globally to prevent duplicate label assignments in nested environments with high reliability.

Multihome Support: Multihome is when a node has more than interfaces involved in the scheme. MPLS supports multihome connectivity.

3.4 LSP Setup and Release Mechanisms

LSP setup and release mechanisms are discussed as follow [12]:

LSP Setup Mechanism: Assume that a connection is to be established from the LSR *A* to LSR *Z* with a specific bandwidth requirement of *BW*. Assume there is a shortest path between LSR *A* and LSR *Z* passing through the LSRs between *A* and *Z*, which satisfies the bandwidth requirement *BW* of the connection. An LSP is explicitly established from *A* to *Z* passing through the nodes of {LSR *A*, …, LSR *Z*}. This LSP is uniquely identified in the MPLS domain by an LSP identifier LSP***i***. LSP***i*** setup follows the basic CR-LDP (Lable Distribution Protocol) setup procedure. Additionally, information related to the LSP requirements for local recovery is stored in the LSRs along the LSP. Traces of the explicit route record {LSR *A*, …, LSR *Z*} along with the constraint parameter *BW* and LSP identifier LSP***i*** are stored in each LSR on LSP***i***.

LSP Release Mechanism: In the case that handoff and handover occur or path rerouting is necessary, CR-LDP calculates a new path, which triggers the setup of a new LSP, switches the load from the old LSP to the new LSP and releases the old LSP. In the case of multi path load balancing, for hierarchical architecture support, it recalculates the load distribution weights and redistributes the traffic according to these weights. After having a successful rebalance, the LSR of the source, floods the rebalance updates to all ingress LSRs. Then the rebalance process repeats itself, until either there is no link exceeding the rebalance threshold or no rebalance increases the network performance. To guarantee the system’s proper functionality, the waiting times have to be set to the maximum message exchange time between two LSRs.

4 MPLS AND AD-HOC ON-DEMAND DISTANCE VECTOR (AODV)

As noticed in Figure 1, AODV is an on-demand flat routing ad hoc protocols. It offers the followings:

- Quick adaptation to dynamic link changes
- Low processing and memory overhead
- Low network utilization
- Supports unicast routing
- Supports destination sequence numbers to ensure loop free routing

4.1 AODV Mechanism

In AODV, only nodes located on the active path, participate in route detection, which are responsible for maintaining routing information. Broadcasting is done on-demand. When a node requires a communication with another node, a Route Request (RREQ) Message (Figure 4) is generated and sent.

Type (0–7)	J	R	G	Reserved (10–23)	Hop Count (23–31)
Flood ID (32 bits)					
Destination Sequence Number (32 bits)					
Source Sequence Number (32 bits)					
Destination IP Address (128 bits)					
Source IP Address (128 bits)					

Figure 4: Route Request (RREQ) Frame Format

The first row fields are:
J: Join flag, which is reserved for multicast
R: Repair flag, which is reserved for multicast
G: Gratuitous RREP flag, for unicast nodes

In reply to RREQ message that each node receives, it sends a Route Reply (RREP) message back to the source node the generated the RREQ message in the first place. Figure 5 shows the RREP message format.

Type (0–7)	R	A	Reserved (9–16)	Prefix Size (16–23)	Hop Count (23–31)
Destination Sequence Number (32 bits)					
Destination IP Address (128 bits)					
Source IP Address (128 bits)					

Figure 5: Route Reply (RREP) Frame Format

The first row fields are:
R: Repair flag used for multicast
A: Acknowledgment

For reliability mechanism built into the MPLS scheme, it is important that AODV is equipped with multihomed connectivity capability. To support multihomed-enabled nodes, upon receiving several RREP messages from neighbouring nodes, the source node will choose two interfaces (Figure 6), which lead to two separate paths from source to the destination with the following conditions:

1. The two routes are maximally disjoint
2. They can fairly divide the traffic (fair load balance)

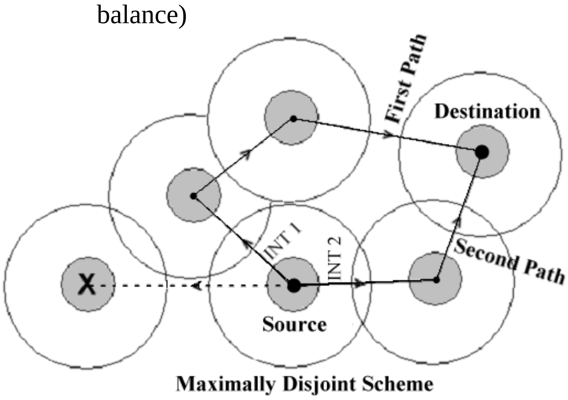

Figure 6: Multipath Routing Scheme in AODV

The source node then saves the two paths in a local cache, later used by MPLS to construct two different LSPs.

Each LSP-FEC pair is generated using the following information:

- Destination IP Address
- Destination Sequence Number
- Specific interface
- Specific Path to the destination

4.2 Multipath AODV (AOMDV)

The Ad hoc On-demand Multipath Distance Vector (AOMDV) or simply Multipath AODV [13] is a variation of AODV in which multipath routing is supported. As mentioned, multipath routing is essential when redundancy, load sharing, and load balancing are required. This is to ensure there are maximal disjoint paths selected for more efficient multipath routing, in which the protocol computes multiple loop-free and link-disjoint paths. Reference [13] cites the performance comparison between AOMDV with AODV with NS-II simulation software. It shows that AOMDV is able to achieve a huge improvement (more than two times) for the end-to-end delay. This sharply reduces (more than 20%) the routing overheads. The structures of routing table entries for AODV and AOMDV are shown in Figures 7 and 8.

Destination
Sequence number
Hop-count
Next-hop
Life-time

Figure 7: Routing Table Structure of AODV

Destination
Sequence Number
Advertised Hop-Count
Route-List: *{(nexthop$_1$, hopcount$_1$), (nexthop$_2$, hopcount$_2$), ...}*
Life-Time

Figure 8: Routing Table Structure of AOMDV

4.3 MPLS-AODV Testbed

The integration of MPLS with AODV is tested using OPNET and the results are compared against the results in reference [12], where a new AODV-based multipath routing protocol is proposed. This model uses a new method to find a pair of link-disjoint paths, which do not have any common link between the source and the destination. This gives the maximum redundancy in terms of reliability and Packet Delivery Ratio (PDR). For the simulation, we tried the same simulation setup, as in reference [12], where:

- Each node has been assigned a radio range of 250 m
- The channel traffic capacity of 2 Mbps
- MAC layer protocol is 802.11b

- The mobility model uses randomly distributed nodes in the field of 2200 m x 6000 m area
- Nodes have speeds from 0 to 20 m/s with no pause.
- Nodes are variable between 30 to 100

The simulation results are computed for two QoS parameters:

- Average Delay (sec) versus Variable Node Speed
- Average Delay (sec) versus Number of Nodes

The simulation results are shown in Figures 9 and 10 in which they show major improvement between MPLS-AODV, traditional AODV, and the proposed Multipath AODV in reference [12]. The average delay is reduced from 1.05 *Sec* for traditional AODV down to 0.4 *Sec* for the Multipath AODV and to 0.28 *Sec* for MPLS-AODV.

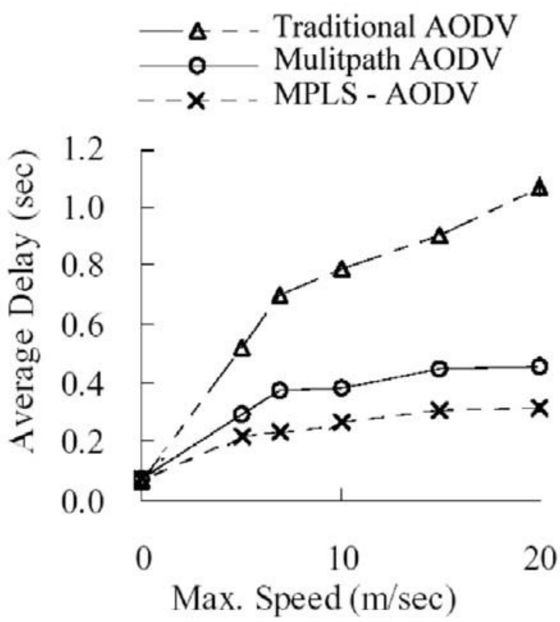

Figure 9: Delay/Variable Node Mobility in AODV

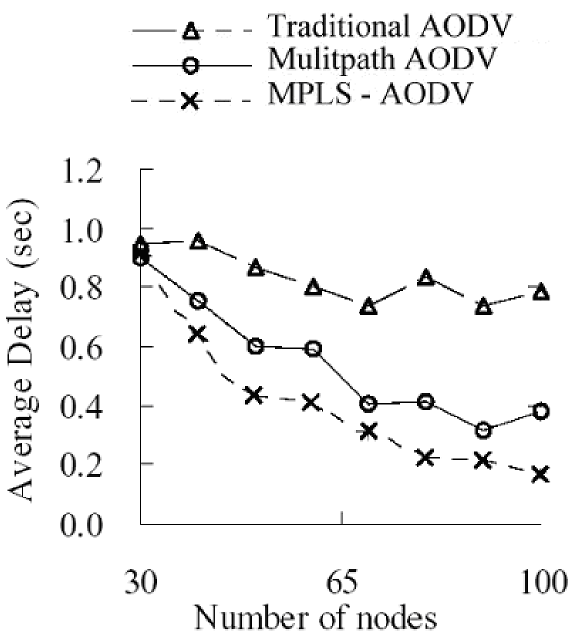

Figure 10: Delay/Variable Node Density in AODV

4.3.1 Observations

Figure 9 suggests that when mobility increases, the performance of the traditional AODV deteriorates. However the performance delays introduced because of mobility for the MPLS-AODV is kept low, due to the fact that MPLS nodes have inherent coping capabilities against movements of nodes.

Figure 10 shows the average delay for the three flavors against the number of nodes. When the number of nodes decreases to 30, all three protocols have the same results as for the delay. When the nodes grow in number, the MPLS-AODV scheme outperforms the other two schemes.

5 OLSR-MPLS INTEGRATION

The Optimized Link State Routing Protocol is an optimization of the classical link state algorithm tailored to meet mobile-IP wireless LANs' requirements. It follows the following functionalities:

- Inherits the stability of link-state protocol
- Performs Selective Flooding
- Performs Periodic Link-State Routing Information Exchange
- Deploys MultiPoint Replays (MPRs) for optimization
- Information is generated only by an MPR

- Reduces flooding through using only multipoint relay nodes to send information throughout the network
- Reduces the number of control packets by reducing duplicate transmissions

The key concept is the fact that MPRs forward broadcast messages during the flooding process. Selective flooding is an important part of this proactive link-state algorithm. OLSR minimizes the overhead from flooding of control traffic through using only selected nodes, MPRs, for retransmitting control messages. To achieve shortest path routes, OLSR requires flooding of partial link state.

The core functioning of OLSR is made up from the following components:

- Packet Format and Forwarding
- Link-State updates Transmission
- Neighbour Detection
- MPR Selection and Signalling Schemes
- Topology Control Message Diffusion
- Route Calculation and Recalculation

Each MPR in the OLSR scheme has a dual in the MPLS mapping, which is an LSR with an assigned FEC.

5.1 Packet Format

Figures 11.a and 11.b show the OLSR's Packet and Hello frame formats. For the MPLS-OLSR integration, the following information forms the necessary information to generate specific FEC:

- Packet Sequence Number
- Message Sequence Number
- Neighbor Interface Address

0	7	15	31
Packet Length		Packet Sequence Number	
Message Type	V-Time	Message Size	
Originator Address			
Time-to-Live	Hop-Count	Message Sequence Number	
Message			

(a)

0	7	15	23	31
Reserved		H-Time	Willingness	
Link Code	Reserved	Link Message Size		
Neighbor Interface Address				
Neighbor Interface Address				
⋮		⋮		⋮

(b)

Figure 11: OLSR Packet Format (a) and Hello Format (b)

Selected fields in OLSR frames are defined as follows:

Message type: An integer stating the type of message. Message types from 0 to 127 are reserved and from 128 to 255 are marked "private" for customization of the protocol.

V-Time: This field indicates the validity time for the information contained.

Time-To-Live (TTL): The maximum number of hops by which this message can be forwarded before it is discarded. It is often set to 32 or 64. This is used to prevent infinitive looping of packets, which are not received by their destinations.

Hop Count: The number of times the message has been sent and received.

Message Sequence Number: This number incremented by one each time a new OLSR packet is sent by this node.

Link-Code: This field contains both information about the type of the neighbor and the link to the neighbor.

5.2 MPLS-OLSR Testbed

The integration of OLSR and MPLS is tested using OPNET and the results are compared against the traditional OLSR performance. The parameter under test is the average delay versus maximum speed and number of nodes, with the same network testing conditions as in MPLS-AODV testbed, where:

- Each node has been assigned a radio range of 250 m
- The channel traffic capacity of 2 Mbps
- MAC layer protocol is 802.11b
- The mobility model uses randomly distributed nodes in the field of 2200 m x 6000 m area
- Nodes have speeds from 0 to 20 m/s with no pause.
- Nodes are variable between 30 to 100

The simulation results are shown in Figures 13 and 14.

5.2.1 Observations

Figure 12 shows that the delays in both traditional OLSR and MPLS-OLSR schemes act somehow linearly when nodes start from zero mobility up to around 5 *m/Sec*. The delay of MPLS-OLSR reaches stability afterwards, however the traditional OLSR keeps increasing the delay. Figure 14 shows sharp decrease of delay in MPLS-OLSR scheme when the number of nodes increases from 30 to 100.

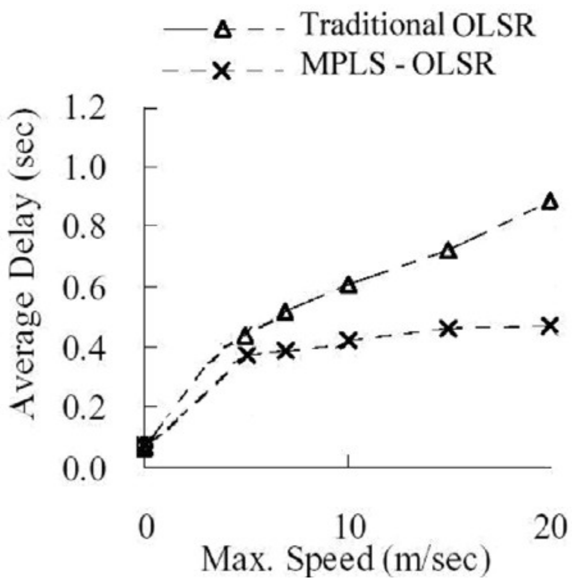

Figure 12: Delay/Variable Node Mobility in OLSR

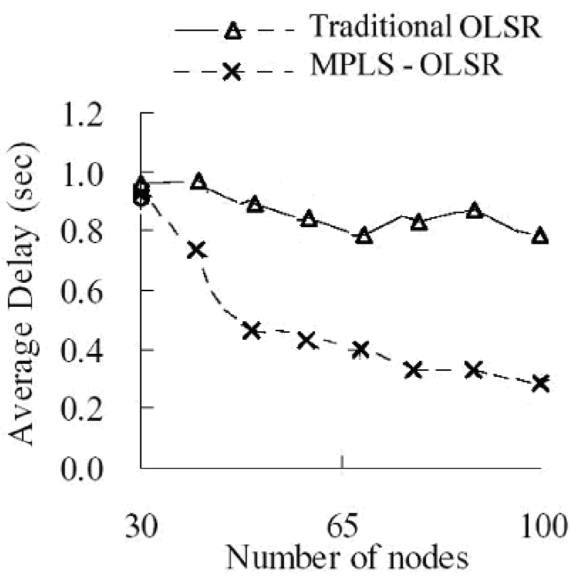

Figure 13: Delay/Variable Node Density in OLSR

6 ZRP-MPLS INTEGRATION

The hybrid Zone Routing Protocol (ZRP) [7] is able to adapt to a wide variety of network scenarios by adjusting the range of the nodes to maintain routing zones proactively. ZRP divides the network into overlapping routing zones, where independent protocols are run inside and between the zones. ZRP utilizes two mechanisms: *intra-zone protocol (IARP)* and *inter-zone protocol (IERP).*

The intra-zone protocol (IARP) is a proactive protocol that works inside the zone and learns all the possible routes, proactively. The inter-zone protocol (IERP) is a reactive mechanism. By sending RREQ messages to all border nodes, a source node finds a destination node, which is not located within the same zone. This continues until the destination is found. ZRP is therefore a dual mechanized protocol with both reactive and proactive agents.

In ZRP, it is preferred to have large routing zones with many slowly moving nodes inside each zone. However if we have fast moving nodes, it is preferred to have smaller routing zones. In best case scenario, when ZRP is properly configured, it can perform nearly as good as a pure proactive protocol or reactive protocol, depending on the network conditions and topologies. The reactive section, as mentioned, is based on a multicast-based mechanism to propagate route queries throughout the network, rather than reactively relying on neighbour-broadcast flooding. Therefore ZRP performs at best in networks where no reliable neighbour is broadcasting or inefficient. From this description, it becomes evident; MPLS might not be a good choice for ZRP integration. In any case, as a general rule, ZRP is well performs relatively well with multi-technology routing fabrics and networks with high load transmissions.

6.1 ZRP Architecture

ZRP architecture is based on three types of nodes (Figure 14) and based on the following functional entities (Figure 15):

- **NDM:** Neighbour Discovery/Maintenance Protocol, in which each node is required to send a HELLO message once in a while to be known to its neighbors
- **IARP:** IntrAzone Routing Protocol
- **IERP:** IntErzone Routing Protocol
- **BRP:** Bordercast Resolution Protocol is a multicast route query provided by the IARP
- **ICMP:** Internet Control Message Protocol
- **IP:** Internet Protocol

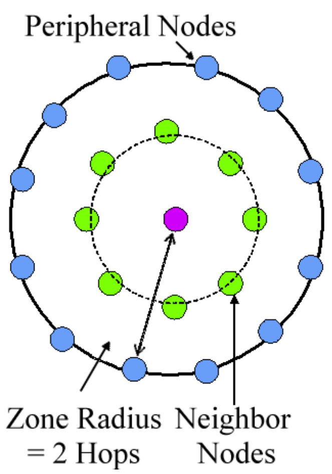

Figure 14: Three types of Nodes in ZRP

For more information about the terminologies mentioned in the ZRP architecture, please refer to the reference [14].

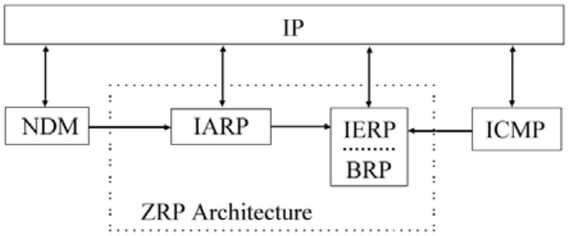

Figure 15: ZRP Architecture

6.2 Packet Format

Since ZRP incorporates several algorithms (NDM, IARP, IERP, BPE, and ICMP), there is no single frame structure, therefore the following is ZRP's summary:

- It offers fast convergence and it is comprised of a very flexible algorithm.
- ZRP is a MAC-based protocol because it uses NDM to find its neighbors.
- ZRP provides multiple loop free routes. This increases robustness and performance.
- It uses a flat routing scheme instead of a hierarchical scheme; therefore it reduces the organization overhead.
- The protocol has a built in fast optimal route searcher, which reduces the chances of congestion and this can minimize route acquisition time
- Based on NDM outcomes and a selection of optimal routes, and the following other information, an FEC-LSP pair can be constructed for the MPLS-ZRP mapping:
    - Link Destination Address
    - Link State ID
    - Zone Radius
    - Metric Type and Value

6.3 MPLS-ZRP Testbed

The same network settings and parameters are used to construct the simulation testbed for MPLS-ZRP system and the simulation outcomes are depicted in Figures 16 and 17.

6.3.1 Observation

Figures 16 an 17 show an average of 20% reduction in delay times comparing the performance of traditional ZRP with MPLS-ZRP. This reduction happens for mobility of 10 *m/Sec* or higher and average number of nodes of 35 or higher.

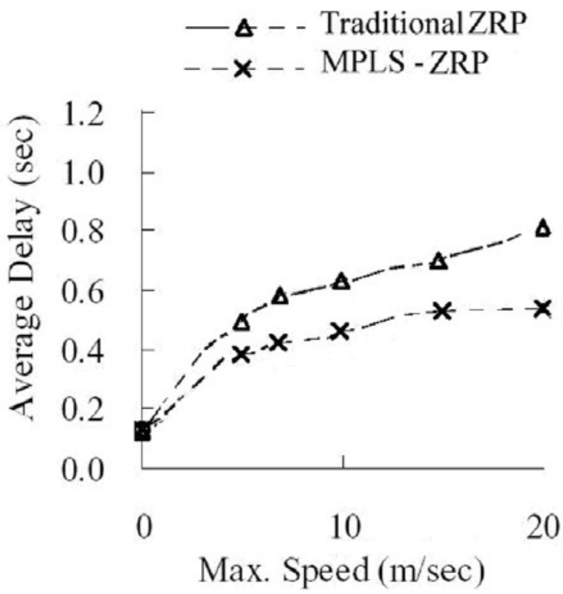

Figure 16: Delay/Variable Node Mobility in ZRP

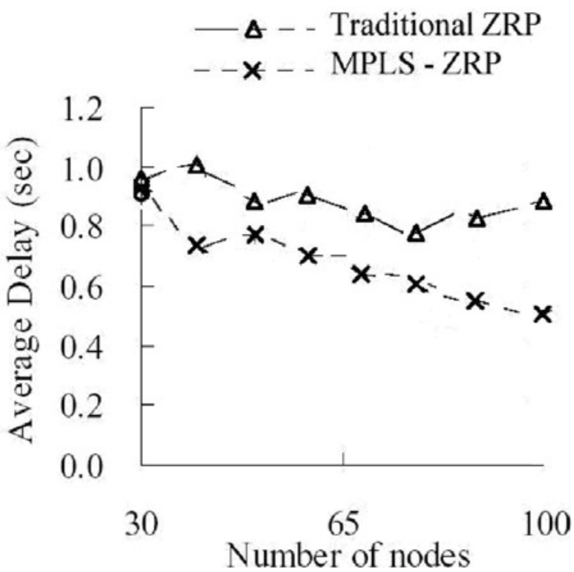

Figure 17: Delay/Variable Node Density in ZRP

7 CONCLUSION

In this paper, the integration of MPLS with AODV, OLSR, and ZRP were studied and the performances of the traditional protocols and their integrations with MPLS were simulated in terms of average delay versus mobility speed and the nodes density.

Figures 18 and 19 show the relative delays in the mentioned three routing protocols. AODV shows the best performance compared to OLSR and ZRP. This is because AODV is capable of multipath routing, which is well suited for integrating with MPLS.

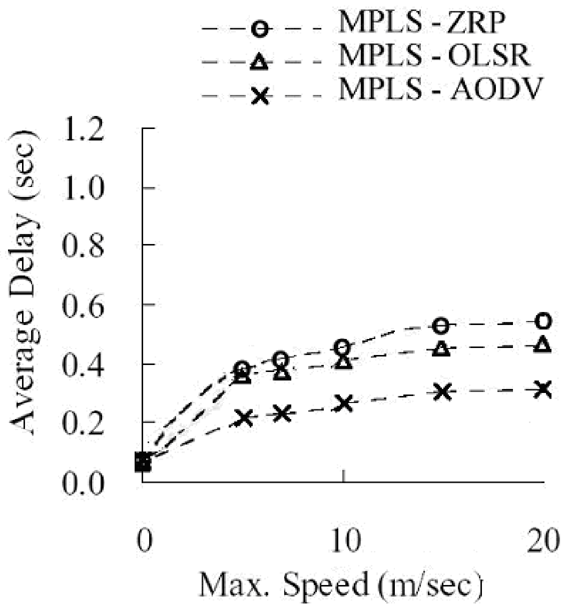

Figure 18: Relative Delay/Variable Node Mobility in ZRP, OLSR, and AODV with MPLS Integration

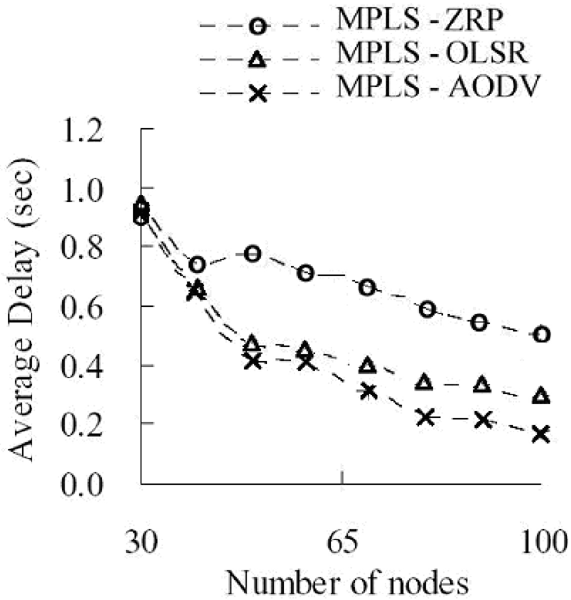

Figure 19: Delay/Variable Node Mobility in ZRP, OLSR, and AODV with MPLS Integration

From the other hand, ZRP shows worst performance because it is not well matched with a reliable protocol, such as MPLS.

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