Hybrid Routing with Periodic Updates (HRPU) in Wireless Mesh Networks

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***Abstract*— This paper proposes HRPU, a hybrid routing algorithm for wireless mesh networks. In HRPU, the mesh portal periodically broadcasts a mesh update message, which allows all nodes to have a route towards the mesh portal stored semi-permanently in their routing table. Whenever a node has data to be sent to backbone network, it sends the data without any route establishment delay using the route to the mesh portal. Numerical results show the higher throughput and lower overhead of proposed HRPU. In HRPU the mesh portals and mesh points adapt some critical parameters to further improve performance.**

***Index Terms*— Wireless Mesh Networks, Routing, Hybrid routing, Proactive component, Mesh Updates**

I. Introduction

Mesh networking is emerging as a potentially useful technology for wide area deployments of IEEE 802.11. IEEE 802.11 working group has created a task group 'TGs' [1] for standardization of mesh networks. Mesh networks aim to achieve interconnection between the access points wirelessly to form an extended service set (ESS). A mesh network would thus form a multi-hop wireless distribution system and it also plays an important role from the ad-hoc perspective, e.g. to extend current ad-hoc solutions with mesh mechanisms and to integrate infrastructure mode and IBSS mode. Mesh networks include automatic topology learning and dynamic path configuration. The transfer of packets from STA to backbone would be handled by the routing algorithm used in mesh network.

Routing in mobile ad hoc networks (MANET's) has received significant attention in recent years (see for e.g., [4] and related references). Directly applying routing techniques from ad hoc networks in mesh networks would result in inferior performance as the peculiarities of mesh networks are not utilized. In typical mesh networks, a large percentage of traffic is directed towards the backbone and thus all the source nodes require a route to the mesh portal for data delivery beyond the mesh. Reactive algorithms [5, 7] would generate multiple requests towards mesh portal thus increasing the traffic and overhead near mesh portal. Moreover with large network size, the time to acquire the route towards the mesh portal would be significant and thus the overall delay would increase. On the other hand in proactive algorithms each mesh point sends periodic updates of its entire routing table, which results in a large overhead.

This paper proposes hybrid routing with periodic updates (HRPU), a novel routing algorithm for wireless mesh networks. In HRPU, the mesh portal periodically broadcasts an update about itself which allows each of the mesh points to establish a route towards the mesh portal. This flooding of information from the mesh portal eliminates the necessity for nodes to transmit a route request whenever there is data to send to the mesh portal and thus eliminates the delay in route establishment. The proposed algorithm also has a tunable parameter that allows a graceful tradeoff between routing overhead and network throughput. The low complexity implementation of HRPU allows it to readily scale to large scale networks. Numerical results show the superior performance of HRPU in both low mobility and high mobility scenarios.

The remainder of this paper is organized as follows. Section II provides the background for mesh networks and current routing schemes. Section III describes the proposed HRPU protocol in detail. Section IV discusses the simulation setup and provides the numerical results and analysis of the numerical results. Finally, Section V provides brief concluding remarks.

II. Background And Related Work

A. Fundamental difference between mesh and ad hoc networks

Mesh and ad hoc networks are conceptually similar with an 802.11 device relaying the traffic for other 802.11 compliant devices and creating a multi hop wireless networks. Though conceptually similar, wireless mesh networks have distinct characteristics that differentiate them from ad hoc networks [11, 12]. Ad hoc networks are created with stations in range to enable direct communication without the support of any infrastructure while mesh networks are created with a combination of stations and access points connecting each other wirelessly with an aim of creating a wireless distribution system. Each node in a mesh network that helps in routing the data packets is termed as a Mesh point. Both access points and stations can be categorized as mesh points if they support forwarding of data. Thus, with mesh networks, an access point

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can communicate with another access point wirelessly, which is not possible in the current standard. Moreover, ad hoc networks are stand alone local networks [1][2] that are created in real-time as desired, *e.g.*, at meetings and conferences. Ad hoc networks do not require connectivity to the backbone. However in an 802.11 mesh network, the wireless distribution system created by wireless mesh points would have either one or more wired connections to backbone. The mesh point connected to the backbone is called a mesh portal analogous to the portal (access point) defined in current 802.11 standard [2].

In ad hoc networks, for the nodes which are not in direct communication range, data packets are carried from source to the destination, via the intermediate nodes with help of routing algorithm implemented on all of the nodes. IETF's MANET [4] [9] group currently designs and proposes the schemes for routing over ad hoc networks. The routing is implemented at layer 3, conceptually similar to traditional wired network routing [13]. However for mesh networks, the routing has to be implemented at layer 2, since each access point is essentially a MAC layer device and cannot decipher the contents of the packet including IP address information. In current 802.11 standard [2, 3], the access point just strips off the 802.11 header and forwards the packet to the default router for delivery. However in a mesh network, mesh points need to make a decision on whether to forward the packet to the mesh portal for delivery to destinations outside the mesh network or whether to route the packet internally. Hence, routing algorithms for mesh network operate at layer 2.

The routing algorithms for mesh networks may borrow concepts from MANET routing algorithms and the entire message structure would scale to layer 2 frames. Routing tables would contain the MAC addresses instead of IP addresses unlike the current routing algorithms [4]. Moreover certain messages like Address Resolution Protocol [16] messages may be eliminated in Layer 2 routing algorithm. For instance in Layer 3, for obtaining the address of the destination, the node first looks up the routing table for the destination and finds the next hop IP address. Then the node sends an ARP request to get the MAC address for the destination and then once it has the MAC address it sends the frame to the next hop which follows the same procedure again. However in mesh networks, the routing has to be handled at layer 2 and hence the routing tables would have the MAC address of the next hop thus eliminating the need to send the ARP message in a pure layer 2 algorithm. Thus, layer 2 routing algorithms would change with respect to way certain messages like ARP are transmitted but the core approach of the routing and message structures remain the same as layer 3 protocols.

B. MANET and ad hoc routing

The IETF – MANET [8] group mainly concentrates on two types of routing protocols viz. proactive and reactive [4]. The protocol classification is done based upon the time of route availability to the source node when a node has any data packet to send. In proactive routing algorithms, the source node has the knowledge of the route before it has any data packet to send. Routes to the destination nodes are semi-permanently maintained in the routing table by exchanging routing tables between neighboring nodes periodically. On the other hand in reactive routing algorithms, routes are established 'on-demand' *i.e.*, when the source node has any data to send, it initiates a route discovery procedure and once the node has acquired the desired routing information from the route discovery procedure, the node forwards the data on the route obtained. Destination sequence distance vector (DSDV) [6] is one of the commonly used proactive routing algorithms while dynamic source routing (DSR) [6] or ad hoc on demand distance vector (AODV) [4][5] is preferred when there is a requirement for an on demand routing scheme. In any reactive routing algorithm, when a node has data to send to a destination which is not within its direct contact, it broadcasts a route request to its neighbors which in turn rebroadcasts the route request to their subsequent neighbors. Every time a node broadcasts a route request message, a reverse entry is created in the node's routing table for the source which has initiated the route request. When the destination receives the route request, it unicast a route reply back on to the reverse route created on the way. If a source node receives multiple route replies, it selects the route with best performance (e.g., minimum hop count). In the event of a link breakage, the node that detects the link breakage sends an error message back to the source thus forcing all the intermediate nodes to invalidate the route and making the source node send a new route request if the source node has additional data to send.

The intermediate nodes maintain the route for a finite amount of time after which the route is purged. If the source (or the intermediate node) has to transmit another data packet to the same destination then it initiates the RREQ again and gets back the reply and the same process is repeated. In any reactive protocol the main disadvantage is that the packet cannot be sent until the source node has a valid route to the destination. Thus, in large networks, there is considerable delay in establishing the route.

Both proactive and reactive protocols have their own set of advantages and disadvantages characterized by varying overhead and route acquisition latency. In practical networks, it is often required that a trade off be achieved between the two. Such tradeoff is achieved by hybrid protocols like zone routing protocol [10] which uses both proactive as well as reactive components to achieve the routing objectives.

The proposed HRPU protocol integrates a proactive component in the reactive routing scheme for use in mesh networks. Specifically, HRPU ensures that a route entry towards the mesh portal always exists at all nodes. Consequently, stations can transmit the data immediately without incurring any route acquisition delay. Thus we proactively maintain the route towards the mesh portal while for the nodes within the mesh network, reactive routing algorithm is used. Traditional hybrid routing protocols proactively maintain routes to all nodes within an 'n'-hop neighborhood while using a reactive algorithm for destination elsewhere in the network. In contrast, with HRPU proactive component is achieved by the periodic transmission of "MESH UPDATE" message. The following section describes the proposed HRPU protocol in detail.

III. HRPU ALGORITHM

Hybrid routing with periodic updates (HRPU) in wireless mesh networks as the name suggests is a combination of proactively and reactively routes establishment. As mentioned in section I, in current mesh networks a large percentage of traffic (typically about 85% or higher) is directed towards mesh portal. For large networks a purely reactive routing algorithm would result in a large delay in establishing the routes, whereas a completely proactive algorithm would require high overhead in maintaining the routes. The proposed protocol reduces the delay and overhead by adding a proactive component in a reactive protocol.

In HRPU, each of the mesh portals periodically broadcast a "MESH UPDATE" message throughout the mesh network. This "MESH UPDATE" message is similar to the Route Reply message of a reactive protocol like AODV. Upon receiving the "MESH UPDATE" message, each of the mesh points creates a forward entry in their routing table towards the mesh portal. If the mesh point already has an entry for the mesh portal, then it compares the new route and updates the routing table if the newer route is *better or newer* than the previous one. In this paper, we use hop count as the metric of interest. However, more complex metrics are applicable as well. Thus, the new route is updated if it has newer information as determined by a higher sequence number or if the sequence number is the same as the existing entry but the new route is shorter.

If the route towards the mesh portal is created or updated, the mesh point re-broadcasts the "MESH UPDATE" message. Otherwise, the received "MESH UPDATE" message is discarded. Thus on successful broadcast of the MESH UPDATE message into the mesh network, each of the mesh points would have the correct route towards the mesh portal. The route is semi-permanently maintained into the routing table and updated as necessary upon reception of another MESH UPDATE message. In HRPU, the routes are not associated with any expiry timer and hence are characterized as being semi-permanently maintained.

The periodic nature of the "MESH UPDATE" message ensures that the route towards the mesh portal stays current. Since the route towards the mesh portal is always present in the routing table at each mesh point, any data towards the mesh portal would be sent immediately without incurring additional delay in establishing the route.

The frequency of broadcasting the MESH UPDATE is a tunable parameter and can be adapted based upon the implementation scenario and network requirements. A smaller mesh update interval would generate higher overhead as compared to higher interval for mesh updates. On the other hand, a larger update interval could result in frequent link outages in high mobility scenarios. Numerical results in section IV capture the trade off between performance and overhead for various mesh update intervals.

In networks with high node mobility, link breakages occur frequently. Thus on link breakage, the route towards the mesh portal might become invalid for a particular mesh point.

Reactive protocols typically transmit a Route Error message back to the source node on detecting a link breakage. In HRPU depending upon the network requirement, the mesh point may choose to either send a Route Error message back to source or initiate a route repair by sending a Route Request itself for the mesh portal. When the mesh point sends a Route error message, then the route towards the mesh portal is invalidated for all nodes on the way between the source node and the node that has detected the link breakage. All the packets for the mesh portal are buffered and would be sent when the node gets the route towards the mesh portal in the next Mesh Update message.

This approach of waiting till the next Mesh Update message is a conservative approach and is used when reducing the routing overhead is the primary concern. For scenarios where throughput is the primary concern, the node that detects the link breakage would itself buffer the packet and send the route request for the mesh portal and obtain the route towards the portal with the default reactive algorithm approach. This approach of sending route request on link breakage increases the routing overhead of the network, but ensures lower delay as the packets are not buffered till the arrival of next Mesh Update interval.

HRPU routing algorithm works exactly as the existing reactive protocols [5, 8] when the destination of the data packet lies within the mesh network, thus providing a reactive component for the proposed protocol. The proactiveness/reactiveness of the routes is judged by the way the routes are established and maintained, *i.e.,* a priori or on-demand. In HRPU, proactiveness is given by the semi-permanent maintenance of routes, whereas reactiveness comes when the data is to be transmitted within the network

A. Intelligent Mesh Portal & Mesh Points

By observing the data that is passing through the mesh portal, the mesh portal is able to gather traffic statistics on the number of nodes sending data to the portal and the rate at which packets are received. These traffic statistics are used by the portal to adaptively determine the frequency of transmitting "MESH UPDATE" messages and in special cases, whether to discontinue transmission of "MESH UPDATE" messages. The mesh portal compares the distribution of traffic between intra-mesh traffic and traffic to/from outside the mesh network with certain set thresholds, and it adjusts the interval of the mesh update message transmission. For instance, if most of the traffic is intra node communications, then broadcasting "MESH UPDATE" messages would result in significant overhead for marginal gains; in such cases, the mesh portal can decide to not transmit any "MESH UPDATE" messages.

The threshold for determining when to transmit the "MESH UPDATE" message depends on network topology, dynamics and traffic; qualitative performance comparison of the proposed method with AODV protocol are given in Section IV for various ratios and can be used to determine the threshold. It is typically expected that the traffic towards the mesh portal would be above 85% percent of the overall traffic. Depending on the scenario where the mesh network is deployed, this distribution may differ. Thus if the mesh network is deployed for more of intra-network communication, most of the traffic would be destined to nodes within the mesh network. In that case employing the MESH UPDATE message broadcast would generate a greater overhead, even greater than pure reactive protocols.

In order to eliminate the excessive overhead generated when the traffic is only within the mesh network, we propose the implementation of an intelligent mesh portal. The mesh portal would dynamically decide based on certain thresholds at what frequency it should send the mesh update, based upon the traffic distribution towards the mesh portal. If the intra-node level of communication is higher, then the mesh portal may also choose to stop transmitting the Mesh Update message by setting the threshold value very large. In scenarios with lower mobility, the frequency of link break is small and thus it is not required to send the mesh update at smaller intervals. The mesh portal may decide to send mesh update messages at larger intervals thus reducing the overhead in the network. This adaptation is justified by the results in Section V. In networks with high mobility, there would be frequent link breakages and is necessary to send the mesh updates at faster intervals. Thus the intelligent mesh networks would be able to adapt to changing network parameters while maintaining low overhead and high packet delivery ratio.

Packet delivery ratio suffers in high mobility scenarios due to frequent link breaks. As discussed in Section III, the node that detects the link breakage would buffer the packet and send the route request and then send the data on receiving the route reply. This approach of sending route request would generate extra overhead because, sometimes, the node would get the mesh update within short time of detecting a link breakage. To avoid generating excess overhead in the event of the link breakage by sending the route request to the mesh portal, the mesh points can buffer the data packet and send the route request only if the time to next mesh update is greater than some threshold. (*e.g.,* half of the interval of the next mesh update message). The heuristic for the error avoidance is depicted in the form of a flowchart shown in Figure 1. For illustration, we set the threshold as half of the MESH UPDATE interval. Thus whenever the node detects a link break it checks if the time for next mesh update message (TMFRNXTMUP) is greater than the threshold and if it is, the node sends the route request; else the node buffers the packet and waits for the next scheduled "MESH UPDATE" message to get the route towards the mesh portal. This adaptation offers the flexibility to tradeoff the delay and overhead in establishing the route towards mesh portal. A higher threshold also results in a lower packet delivery ratio since nodes buffer packets longer before transmitting the packets.

B. Analysis of HRPU

The idea of combining two types of routing has been explored before. However, the novelty of HRPU is the mechanism to effectively combine proactive and reactive routing schemes for better performance in mesh networks, since in previous proposals nodes maintained routes to all nodes that are at most n-hops away. One advantage of HRPU is the usage of intelligent mesh portal and mesh point to avoid extra overhead introduced by link breakage. Another advantage is the tunable broadcast period based on traffic statistics.

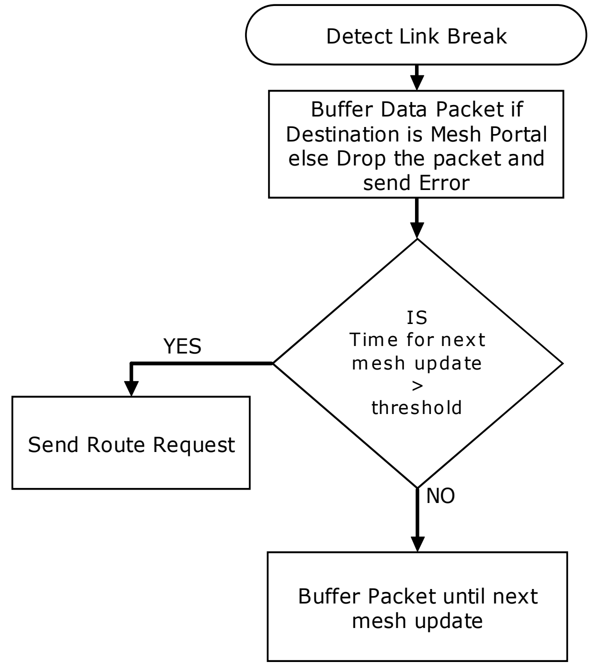

Figure 1. Heuristic for Error handling at each node.

IV. SIMULATION SETUP

Implementation of HRPU was done in Network Simulator 2 [9] and compiled in Fedora Core 4 Linux environment. As noted before, AODV is used as the reactive part of the proposed protocol. HRPU was implemented on top of AODV by adding the functionality of a Mesh Update message. The commonly adapted model of simulation [8] was used to compare the performance of HRPU and pure AODV.

We consider a network with 50 nodes randomly distributed over a 1500x300 meters area. One of the nodes is designated as the mesh portal, which periodically broadcasts the Mesh Update message. Node mobility is characterized in terms of 'pause times'. The simulation does not consider scenarios with multiple mesh portals. Each node at the start of simulation would remain stationary for 'pause time' amount of time, then select a new location in the 1500x300 meters space, and move to that location with a constant speed randomly chosen between 1 and 20 m/hr. It has to be noted that the target of this analysis and simulation is for networks without vehicular mobility and in which mesh points do not move at high speed.

After reaching the destination, the node again remains stationary for "pause time" amount of time and repeats the procedure. The total simulation time is set to 900 seconds and 15 different scenarios were generated for each of the following pause times: 0, 30 60 120 300 600 and 900 seconds. Clearly, a pause time of 900 seconds implies no node mobility over the period of simulation while a pause time of 0 seconds implies that each node is constantly in motion.

The traffic model was set to constant bit rate traffic with rate of 4Kbps. A total of 20 nodes act as source nodes. Each source node begins node transmission randomly between 0 to 180 seconds of the simulation time and continues to transmit till the end of the simulation. The probability of packet losses in transmission is set to 1% for each link and is independent of losses on other links.

A. Performance Metrics

The performance of the routing protocol is characterized by the following three typically used metrics: packet delivery ratio, routing overhead and delay. Simulations are performed for three different frequencies of Mesh Updates: 5, 10 and 20 seconds.

Figure 2 shows the packet delivery ratio in mesh networks using HRPU routing protocol and pure AODV protocol. As is clear from the figure the packet delivery ratio using HRPU is the same for all "MESH UPDATE" intervals in static scenarios and is higher than in AODV. This increase in packet delivery ratio is due to the semi-permanent routing entry towards the mesh portal in HRPU. Further, in static scenarios, the frequency of link breakage is small and thus the penalty due to link breakages is small. In high mobility scenarios, the packet delivery ratio depends critically on the mesh update interval. For mesh update interval of 5 seconds the packet delivery ratio is highest, due to the fact that, with mobile scenarios, the frequency of link breakages is more. With higher frequency of mesh update messages, the routes are updated very often and the new route towards the mesh portal is obtained quickly. Moreover with the intelligent mesh portal, the time difference between the arrival of next mesh update and the threshold decreases and hence the nodes only send the route request infrequently and waits for the next mesh update message.

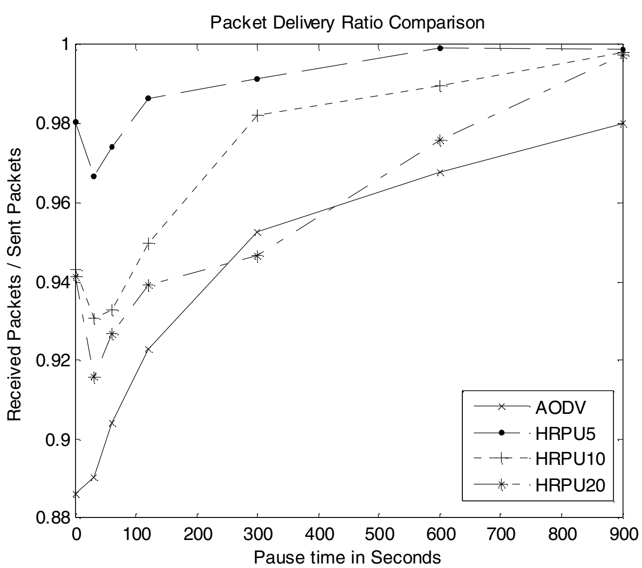

Figure 2. Figure 1: Packet Delivery Ratio Comparison between HRPU and AODV for different mesh update intervals.

Figure 3 shows the routing overhead in mesh networks using both HRPU and pure AODV protocol. It is clear from the figure that the routing overhead incurred with HRPU protocol is lower than that of AODV. The main reason for the lower overhead is that in HRPU the routes to the mesh portal are semi-permanent with no expiration timer, thus the nodes do not need to re-broadcast the route request after every route expiration period. However, with the intelligent mesh points the nodes sends route request on detection on link breakage if the time of arrival of next mesh update is greater than the threshold.

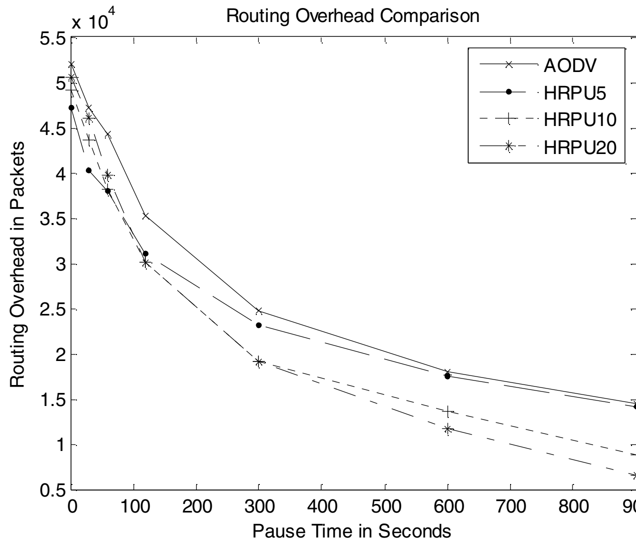

Figure 3. Routing Overhead Comparison for HRPU and AODV for different mesh update intervals

Most link breakages occur in scenarios with high mobility and thus the routing overhead though less than pure AODV is comparatively higher as seen with the pause times of 0, 30 and 60. As the mobility in the network decreases, link breakages become infrequent and so does the frequency of sending Route request. Thus the overhead is mainly a function of number of mesh updates in static and low mobility scenarios. For completely static scenarios (*i.e.,* with 900 sec pause time), the routing overhead depends solely upon the frequency of mesh updates. Moreover, from Figure 2 it is clear that the packet delivery ratio for static scenarios is approximately equal for all the mesh update intervals. Thus depending upon the requirement, the tradeoff can be achieved for low routing overhead and marginally higher packet delivery ratio. The intelligent mesh portal, with an ability to detect mobility can dynamically vary the frequency of mesh updates and control the routing overhead and packet delivery ratio. With higher intervals for mesh update messages, the routing overhead incurred would be higher in static scenarios but in mobile scenarios, sending the mesh update intervals frequently would increase the packet delivery ratio of the network as shown in figure 2.

The end-to-end delay for the packets using HRPU and AODV in mesh networks is shown in Figure 4. With the HRPU algorithm, the end-to-end delay for the packet is considerably reduced for all the static scenarios and the scenarios with low mobility. This reduction of delay is due the fact that, with the semi-permanent routes towards the mesh portal, the data packet is sent immediately in HRPU. In pure AODV, the data packet is first buffered, then the route request is sent and subsequently the data packet is transmitted when the node gets the route reply. In scenarios with high mobility, the end-to-end delay is a function of mesh update interval. With higher interval for mesh updates, the delay is comparable to AODV, since the mesh points would send the route request in the event of link breakages which are frequent in high mobility scenarios. With high intervals for mesh updates however, the fresh routes are maintained very frequently thus allowing the nodes to have newer and better routes if there is a link breakage. In high mobility scenarios, with high intervals for mesh updates, the threshold for transmitting route request is quite low and consequently the delay increases.

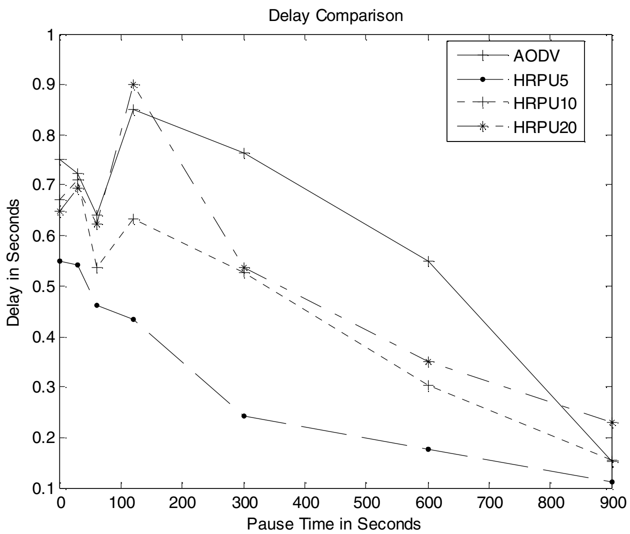

Figure 4. Delay comparison between HRPU and AODV for varying mesh update intervals

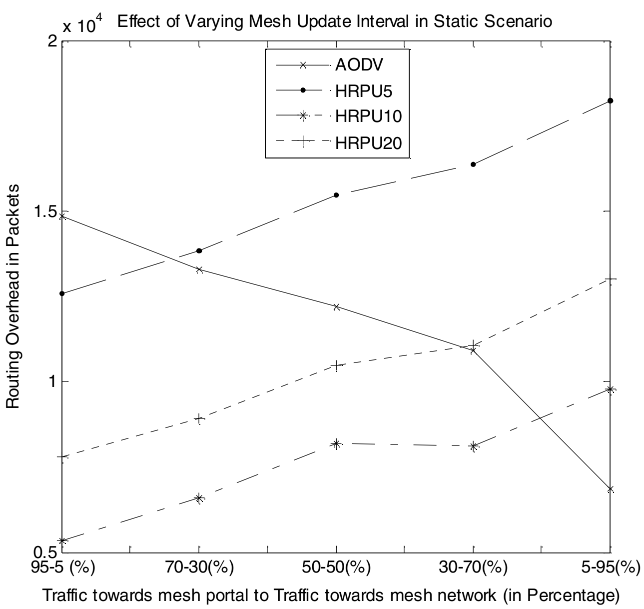

Figure 5. Need for Intelligent mesh portals

As discussed in Section I, in mesh networks, it is expected that most of the traffic would be destined towards the mesh portal. However depending on where the mesh networks are implemented the distribution of traffic can vary to a large extent. Thus the mesh portal should be able to dynamically adapt to changing situations and traffic patterns to provide optimum network parameters. Figure 5 shows the routing overhead of AODV and HRPU for static scenarios with varying traffic patterns. Clearly when the traffic is predominantly intra mesh communications, the overhead generated by the HRPU increases and eventually exceeds the overhead generated by AODV. The crossover point beyond which HRPU generates more routing overhead than AODV depends on the frequency of mesh updates. As discussed in Section III, by observing the data that is passing through the mesh portal to the backbone, the mesh portal is able to gather statistics on the number of nodes sending data to the portal and also the rate at which packets are received. Based on these results the mesh portal can dynamically change the frequency of the mesh update thus allowing the reactive protocol to take over from the hybrid protocol when the intra mesh traffic increases.

V. CONCLUSIONS

This paper proposes HRPU a hybrid routing algorithm for wireless mesh networks. In HRPU, the mesh portal broadcasts periodically a mesh update message which populates the route towards the mesh portal in the routing table for each of the mesh points. HRPU also allows the use of intelligent mesh portals and mesh points to further improve the performance of mesh network.

Current work is focused on incorporating a QoS constraint within the HRPU framework. Also, at incorporating handling of scenarios where a mesh point cannot receive MESH UPDATE messages. Simulation for mobility scenarios where mesh points move at higher speed will also be considered. Future work should consider networks with multiple mesh portals.

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