A Proximity-Aware Transparent Handoff Mobility Scheme for VoIP Communication over Infrastructure Mesh Networks

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Abstract — **Mobility Management plays a key role in Voice-over-IP (VoIP) communications over Wireless Mesh Networks (WMN) as clients should maintain adequate levels of Quality of Service (QoS) as they move across the network. This paper presents PATH, a Proximity-Aware Transparent Handoff mobility scheme for real time voice communications over wireless mesh networks. Our study focuses on Medium Access Control (MAC) layer procedures and relies on gratuitous ARP unicasting in order to provide fast-handoffs. An experimental evaluation has been conducted and its results are shown in this paper.**

***Index Terms* – Wireless Mesh Networks; Quality of Service; Mobility Management; Voice over IP.**

INTRODUCTION

WIRELESS mesh networks (WMNs) are nowadays used for a wide range of applications [1]. One of its most challenging applications and the topic of our interest is Voice-over-IP (VoIP) over wireless mesh networks.

Traditionally, VoIP has been considered as a stationary communication technology; however, as 802.11 networks have gained popularity over the past years, VoIP has also made a transition towards mobility.

While mobility represents an important feature in 802.11 networks, mobile VoIP clients (from this point referred to as “mobile clients”) should maintain adequate levels of Quality of Service as they move across the network. Ideally, such set of transitions, also known as “handoffs”, should be fast enough to be transparent to the mobile clients.

Our research has focused on the development of a mobility scheme that would provide seamless connectivity for mobile clients. Therefore, we have studied the strengths and weaknesses of other schemes by conducting experimental tests under similar environments in order to provide a fair comparison [2].

We have found that sending gratuitous ARPs to mobile clients constitutes one the most effective methods to provide fast handoffs within wireless mesh networks.

This paper presents a Proximity-Aware, Transparent Handoff (PATH) mobility scheme that uses MAC layer procedures in order to provide such a fast mobility for mobile VoIP clients over wireless mesh networks.

The bases of our mobility model can me summarized as follows:

1) All client devices are configured to use a well-known IP address as their default gateway, referred to as “virtual default gateway”. IP addressing is set to static in order to avoid excessive delays caused by DHCP provisioning, as suggested in [3].

2) Mesh nodes are configured to use one interface to communicate with the mobile clients and one interface for communicating with other mesh nodes. All interfaces are configured in ad hoc mode in order to avoid the overhead created by the client’s network discovery routines. For our experimental tests, we used OLSR to perform routing duties; more details are described in section 3.

3) Mesh nodes permanently and independently monitor their link quality with mobile clients. As soon as the link quality with a client reaches a fixed threshold, a gratuitous ARP unicast message is sent to it, updating its virtual default gateway address and thus switching its connectivity to the new mesh node.

4) Our approach is independent from the routing protocol used by the mesh network. Any routing protocol may be implemented along with PATH.

II. RELATED WORK

There are currently many solutions to mobility issues experimented in 802.11 networks [4], [5], [6], [7], [8] as well as studies related to VoIP and real time communications over wireless networks [9], [10]. In this section, we examine the two most relevant schemes considered in our research.

A. SMesh

SMesh by Amir et al. [7] is a wireless mesh network that provides seamless mobility to clients. Mesh routers are configured to use one wireless interface to communicate with the clients.

By implementing a DHCP server on each router, SMesh has full control over the network’s IP addressing. A hash function is performed on each client’s MAC address to get a unique network address. An IP lease time of 90 seconds is used to force regular DHCP request broadcasts. These requests are used to both detect the presence of clients and to determine which router has the best link to a client.

If multiple mesh routers believe they have the best connectivity to a mobile client, and until they synchronize on which should be the one to handle that client, data packets from the Internet gateway (or another source within the mesh network) to the client are duplicated by the system in the client's vicinity. While the presence of duplicated packets can minimize packet loss, it could flood the communication with a high overhead.

On the other hand, as suggested in [3], DHCP-based IP addressing schemes may incur in latencies of up to 5 seconds in highly mobile wireless mesh networking.

B. LCMIM

Light-weight Client Mobility in Infrastructure Mesh networks (LCMIM [8]) consists of two main components: the control over the client's handoff and the routing through the infrastructure mesh network.

In LCMIM, all mesh routers regularly broadcast gARP packets. This will update the client's ARP cache and thus switch its connectivity.

LCMIM implements a custom version of the AODV protocol. Each mesh router maintains a list of the clients that are connected to it. If a client does not send any traffic during a fixed period of time, it is removed from the client list. In order to deal with silent clients, each time a mesh router receives a RREQ, and it does not find the destination address in its client list, the mesh router will send an ICMP ping message to the destination. This will cause the client to respond and eventually be located in the mesh network. However, this procedure is only done when a client is being located and it's not in the client list.

While this approach presents both a light-weight set of protocols and a low source of overhead, the continuous broadcasting of gratuitous ARP messages will inevitably generate not only connectivity oscillation in large wireless mesh network implementations with a large number of clients, but will also cause randomness in terms of capacity and latency, as clients could switch their connectivity between different routers in a certain period of time.

III. A PROXIMITY- AWARE TRANSPARENT HANDOFF MOBILITY SCHEME FOR VOIP INFRASTRUCTURE MESH NETWORKS

This section presents a set of procedures and assumptions that have been taken into consideration for developing our new mobility scheme designed to support VoIP, communication over wireless mesh networks.

In PATH, each mesh router in the network defines two wireless interfaces. The first is used for communicating with the clients. This interface is set with one single IP address for each mesh router.

All clients are configured with this IP address as its virtual default gateway. The second interface is used for backhaul communication and routing duties.

In our experiments, we used the OLSR routing protocol [11]. as it is easy to integrate with any operating system (such as OpenWRT) without changing the format of the IP header [12].

As of the addressing scheme, each client's IP is set to static in order to reduce possible latencies caused by the DHCP requests as suggested in [3]. Each client's IP is defined under the same subnet of mesh routers' default gateway IP address.

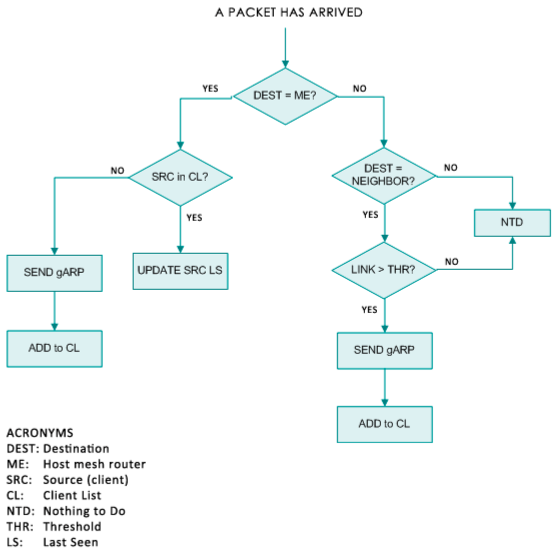

Figure 1. Flowchart for the Client Monitoring algorithm in PATH.

A. Client Monitoring

In PATH, each mesh router continuously monitors their link quality with the clients by setting its wireless interface in monitor mode. When a mesh router detects the presence of a new client and determines that its link quality has reached a certain (pre-defined) threshold, the mesh router will send a *gratuitous-ARP* (gARP) unicast message to the client, instructing it to connect to each other at route its outbound traffic (forward direction) to the new mesh router. At this point, the router adds the client to a list known as client list.

Each mesh router also keeps a list of the vicinity routers. By doing this, they are capable of determining when a client is sending traffic to vicinity routers and moving closer to it. However, a client is not added to the clients group nor advertised with a gARP unicast message if its link quality hasn't reached the required threshold.

To determine whether a client has sent a packet to the mesh router or to a neighbor, each mesh router performs a check of the receiver MAC address (whom the packet is being sent to). A flowchart of the algorithm of the client monitoring procedure is depicted in Figure 1.

B. Inactivity Check

In order to deal with inactive clients, PATH continuously keeps track of the last time that each client communicated with its associated mesh router. When a client has not sent any traffic for a period of time (known as "inactivity period"), the mesh router sends an ICMP ping message to that client. This task is done in parallel with the client monitoring. At this point, we identify three different scenarios that might occur:

a) The client is still within the coverage area of the router, but it is been idle for a long period of time. The client will respond and the mesh will hear it and update the client list with the last time that client was seen.

b) The client has silently moved to the coverage area of another mesh router, i.e., the client has moved but it is been idle for a long period of time. The ping request will go through the mesh network and reach the client. Eventually, the client will respond to the ICMP request and the response will travel at least one hop to the old mesh router that originated the request. The new mesh router will hear the mesh router reply sent by the client and thus, a gARP message will be sent to switch its connectivity. The old mesh router will not hear the ICMP response directly from the client as in (a) and the client will be removed from the old mesh's client list.

c) The client has moved from the coverage area of another mesh router while sending traffic. This will cause the new router to send a gARP message to switch the client's connectivity immediately. On the other hand, the old mesh router is expecting a direct response from the mesh client, but as in (b), it will not hear the response directly from the client, but from the neighbor mesh router that sends the response on behalf of the client. The old mesh router will then remove the client from its client list.

It should be noted that both the client monitoring and the inactivity check procedures are executed in parallel and that both cooperate with each other: the client monitoring will find new clients, add them to the client list and update the list with the last time that each client has been seen.

On the other hand, the inactivity check will poll clients to check connectivity, remove those clients that have been inactive for a long time so that the client monitoring process could eventually attend them again if they return.

C. Routing

A key advantage of our approach is that it is independent from the routing scheme used by the mesh network: it does not require any particular routing protocol to work, as opposed to SMesh and LCMIM.

To evaluate PATH, we used OLSR for routing although we expect to test our approach with other routing protocols as a future work.

Most of the overhead created by mesh networks comes essentially from the type of routing protocol being used. For instance, reactive protocols might incur in less overhead [13], although for highly mobile mesh networks, route discovery could affect the perceived delay during handoffs [14].

On the other hand, proactive protocols might incur in more overhead, but they will get updated information about available routes at any time [13]. This is expected to minimize delays experimented during a handoff. However, testing is needed to make a final verdict.

IV. EVALUATION

To evaluate our model, we implemented a small wireless mesh network that consisted of a client, three mesh routers and one stationary client. For each test, a mobile client interchanged data with a stationary PC as it moved across the mesh network following an 80 mts path during a 70 seconds walk. Our tests were conducted with a constant background noise of -90 dBm using the 802.11 channel 11.

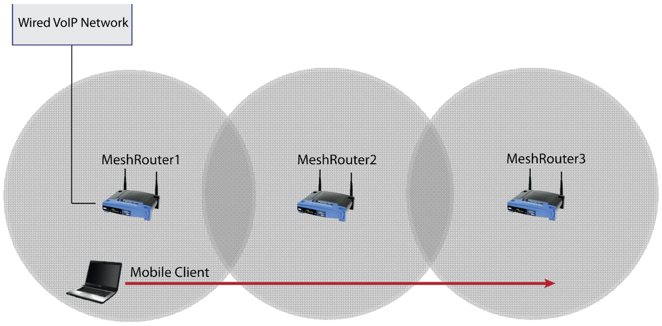

Figure 2. Network topology for each test. Path is shown as a red line. Path length: 80 mts.

We implemented the PATH mobility scheme on three Linksys WRT54GL routers installed with OpenWRT [15]. A polling interval of 5 seconds was used to check client inactivity. We used an inactivity period of 7 seconds and a gARP threshold of -65 dBm. Figure 2 shows the configuration for the three mesh routers used in our tests: MeshRouter1, MeshRouter2 and MeshRouter3. Figure 2 also indicates the path followed by the Mobile Client.

Following a similar logic to a previous research work on WMSs mobility schemes [1], we evaluate the network with three different types of tests that are presented as follows:

a) *VoIP Calls:* We deployed a small VoIP wired network that consisted of a PC running Asterisk [16] and a PC using a SIP softphone. The wired VoIP network was connected to the mesh network via its mesh gateway. The mobile client ran another SIP softphone. On this scenario, the stationary client (the PC) made calls to the mobile client while the client moved through the wireless mesh network. By using Wireshark [17], we were able to capture incoming packets to both the moving and the stationary clients and calculate delay. We plotted the average delay an jitter perceived by both the mobile and the stationary clients.

b) We also calculated handoff delays at the forward (mobile client to mesh routers) and the reversed (mesh routers to mobile client) direction. To calculate handoff delays at the forward direction, we checked the time that took the destination MAC address of the outgoing RTP packets to change after a gARP message was received by the client. In the case of the reversed direction, we checked the time that took the source MAC address of the incoming RTP packets to change after a gARP message was received by the client.

d) *Throughput (UDP):* we used iPerf [18] on both clients to determine the maximum throughput by sending an 10 Mbps data rate UDP stream from the mobile client to the stationary client.

V. NUMERICAL RESULTS AND ANALYSIS

A. VoIP Calls

Figure 3 depicts the average delay perceived by both the moving (red line) and the stationary (blue line) clients. Results show that the average delay perceived by both clients is around 20 ms, which is under the 150 ms limit recommended by the ITU [19].

Figure 4 depicts the average delay perceived by both the moving (red line) and the stationary (blue line) clients. Results show an average perceived jitter of less than 10 ms, which is below the 20 ms jitter recommended by the ITU [19].

Figure 5 and Figure 6 plot the delay perceived by the stationary and the moving client, respectively. The dots represent the packets received by the clients. As seen in Figures 5 and 6, packets arrive within 150 ms of delay. The peaks observable in the Figures do not correspond with handoffs, but due to natural variation in the wireless channel.

Figure 7 depicts the average delay perceived by the stationary client during one of our tests (delay of the packets arriving to the stationary client). Traffic sent from the mobile client to MeshRouter1, MeshRouter2 and MeshRouter3 (as result of the mobile client's association with each mesh router) is shown with different line colors: red, blue and green respectively. In addition, black crosses show the moment at which gARP messages were sent to the mobile client to switch its connectivity.

Figure 8 depicts the average delay perceived by the mobile client during one of our tests (delay of the packets arriving to the mobile client). Traffic sent from MeshRouter1, MeshRouter2 and MeshRouter3 to the mobile client is shown in different line colors: red, blue and green respectively. Black crosses show the moment at which gARP messages were sent to the mobile client to switch its connectivity.

Figures 7 and 8 show that handoffs did not affect significantly the average delay perceived by both the stationary and the mobile clients as result of switching the mobile client's connectivity during our test.

Table I shows the best, worst and average case for the delay perceived by the client during each handoff at the forward direction (from the mobile client to the mesh routers).

Results show that handoff delays in our tests were extremely low as they were very close to the 20 ms time interval between each RTP packet sent during a VoIP call. In other words, the mobile client performed fast handoffs as result of fast ARP cache updates produced by the gARP messages.

Table II shows the best, worst and average case for the delay perceived by the mobile client during each handoff at the reversed direction (from the mesh routers to the mobile client).

Results show that these delays were acceptable as they are under the 150 ms delay recommended by the ITU. Although not as low as handoffs at the forward direction, they are still acceptable for VoIP communications.

It should be noted that our approach provides a fast handoff model for a mobile client's forward direction only.

The handoff at the reversed direction is handled by the OLSR routing protocol. Results in Table II show that OLSR provides acceptable handoff delays for the reversed direction. Handoffs at the reversed direction will be the topic of a future work.

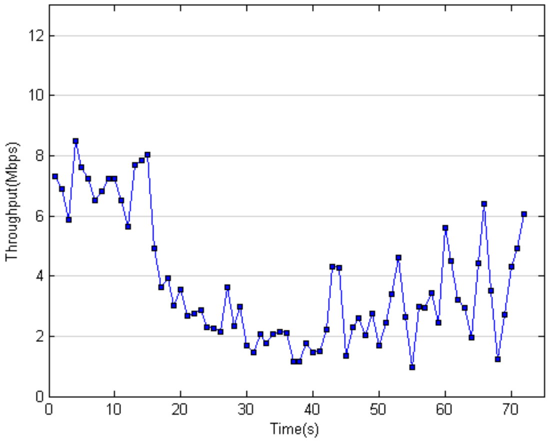

Figure 9. UDP Throughput test.

B. Packet Loss

In the packet loss tests, the mobile client sent UDP packets to the stationary client as it roamed through the mesh network. Out of 7,171 packets sent, only 4 were lost, none of them were lost during a handoff. This represents a 0.05% of packet loss. The ITU recommends a maximum packet loss rate of 1%. Therefore, the results show that our approach presents acceptable levels of Quality of Service in terms of packet loss.

C. Throughput Tests

Figure 9 depicts the maximum UDP Throughput that the stationary client perceived while the mobile client moved through the mesh network.

As shown in the Figure, throughput decreases around second 10 due to a handoff from MeshRouter1 to MeshRouter2. The throughput becomes more unstable after a handoff that occurred at 55 seconds. This instability corresponds to natural variation in the wireless channel.

VI. CONCLUSION

This paper presented PATH, a Proximity-Aware Transparent Handoff mobility scheme for providing seamless handoffs to VoIP clients in wireless mesh networks. In PATH, mesh routers continuously monitor their link quality with unmodified mobile clients. As soon as the link quality with a mobile client reaches a certain threshold, the mesh router sends a gARP message to the mobile client, switching its connectivity and thus redirecting its outbound traffic to that mesh router.

This paper demonstrated that in a practical deployment, PATH achieves adequate levels of Quality of Service in terms of delay, jitter, packet loss and throughput. Mobile clients that roamed through a test wireless mesh network using PATH experienced very low handoff latencies.

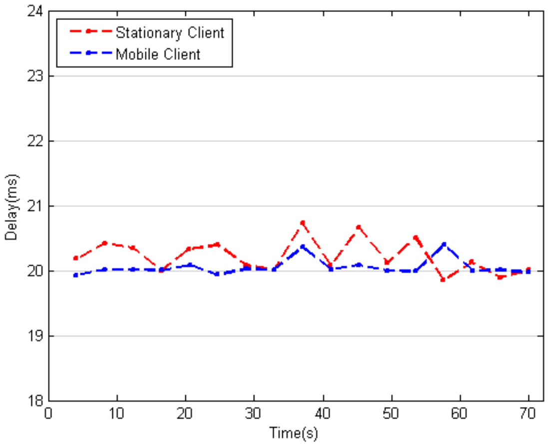

Figure 3. Average delay perceived by the stationary client (red line) and the mobile client (blue line).

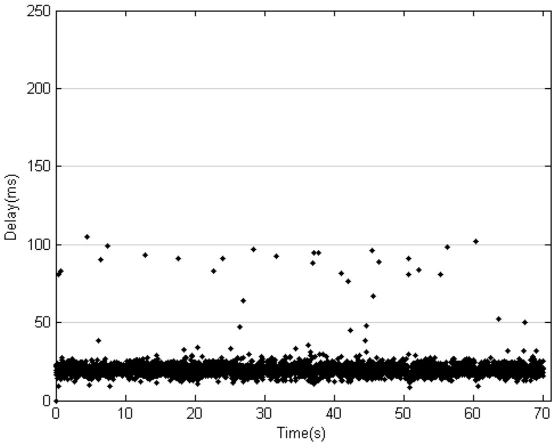

Figure 4. Delay perceived by the stationary client.

TABLE I. HANDOFF DELAY. FORWARD DIRECTION.

Case	**Handoff delay (in ms)**	
	From MR1 to MR2 [a]	***From MR2 to MR3*** [b]
Best	19.20	9.84
Worst	29.30	28.20
Average	24.88	16.12

a. Handoff from MeshRouter1 to MeshRouter2
b. Handoff from MeshRouter2 to MeshRouter3

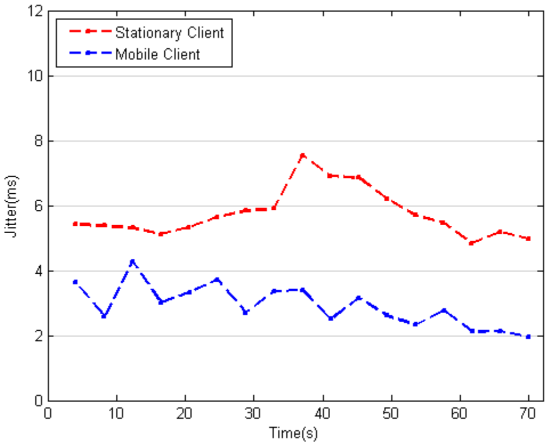

Figure 5. Average jitter perceived by the stationary client (red line) and the mobile client (blue line).

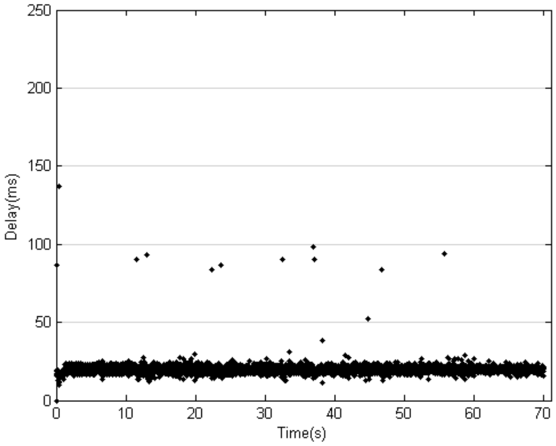

Figure 6. Delay perceived by the moving client.

TABLE II. HANDOFF DELAY. REVERSED DIRECTION.

Case	**Handoff delay (in ms)**	
	From MR1 to MR2 [a]	***From MR2 to MR3*** [b]
Best	39.32	42.49
Worst	72.68	61.10
Average	55.05	51.61

a. Handoff from MeshRouter1 to MeshRouter2
b. Handoff from MeshRouter2 to MeshRouter3

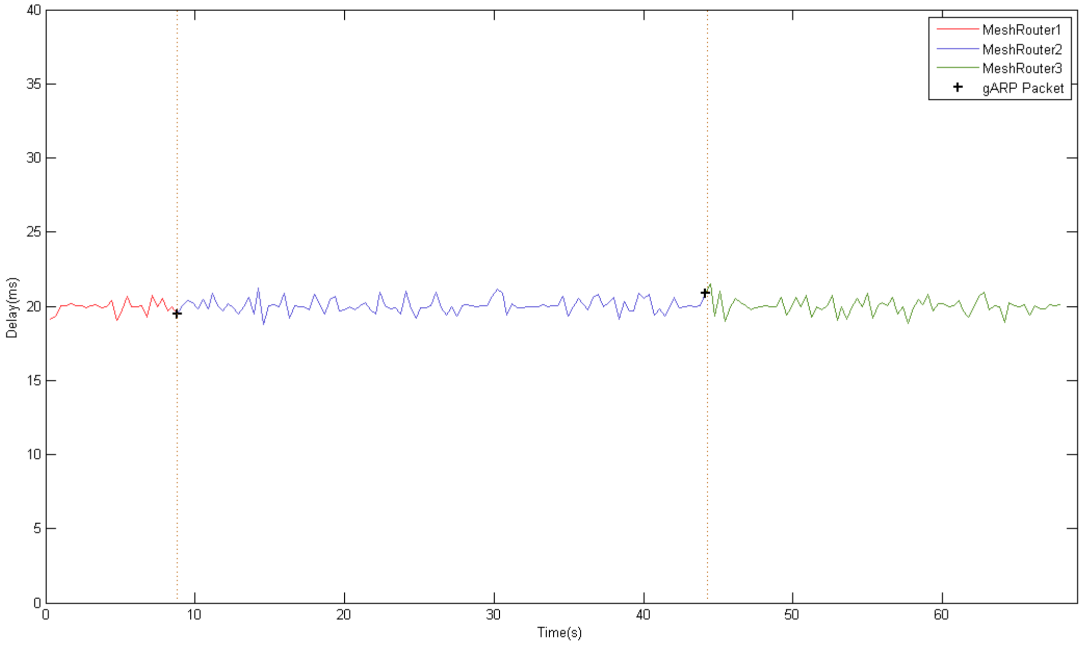

Figure 7. Delay perceived by the stationary client during one of our tests. Traffic sent from the mobile client to each mesh router is shown in different line colors. gARP messages sent to the client are shown as black crosses.

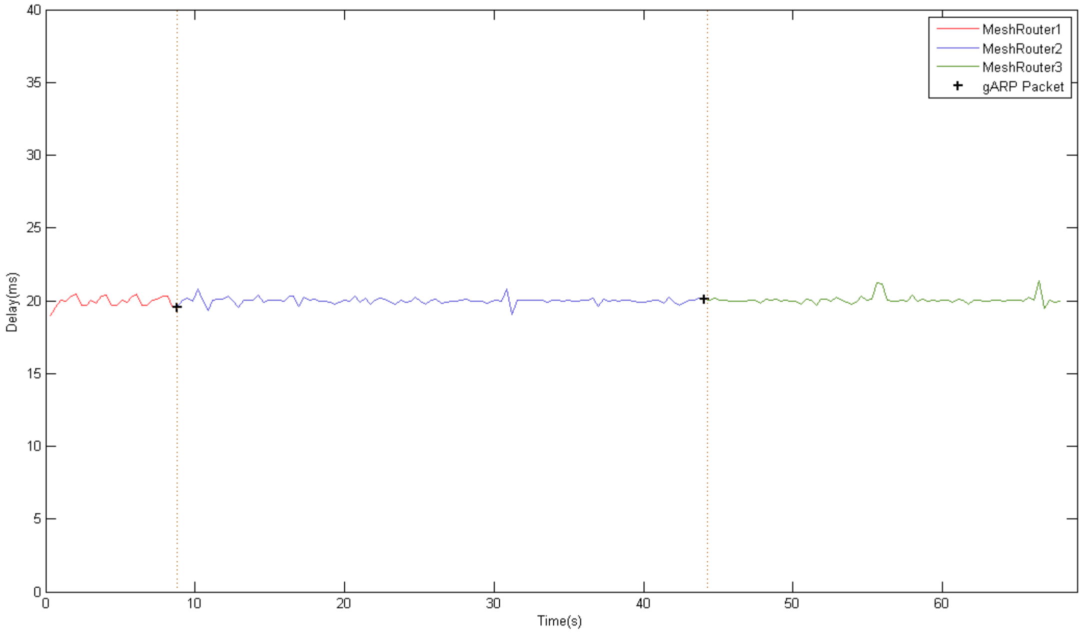

Figure 8. Delay perceived by the moving client during one of our tests. Traffic sent from the mobile client to each mesh router is shown in different line colors. gARP messages sent to the client are shown as black crosses.

Our evaluation also determined that it is feasible to implement PATH using OLSR for routing as it provides acceptable levels of QoS to mobile clients during handoffs.

As a future work, we will look forward into testing PATH with other routing protocols in order to find the routing scheme that yields the best QoS levels with our model.

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