Fast IP Handoff Support for VoIP and Multimedia Applications in 802.11 WLANs

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Abstract

Wireless LANs (WLANs) have edged into numerous mobile and wireless users' daily experience worldwide as a mainstream connectivity solution for a broad range of applications. Even though WLANs offer very high channel bandwidth, they show long network-layer handoff latency. This is a restraining factor for mobile clients using interactive multimedia applications such as voice over IP (VoIP) or video streaming. This paper presents an 802.11-dependent fast IP handoff method which quickly restores IP connectivity for mobile clients running next generation WLAN applications such as Voice over WLANs (VoWLAN). This method outperforms other existing proposed IP mobility solutions in 802.11 WLANs as verified from real performance testing, while introduces insignificant compulsory additions to the existing 802.11 wireless LAN framework.

1. Introduction

The IEEE 802.11 technology is one of the most prevailing wireless communication options today. A critical and most discussed issue in the area of wireless communications is the handoff latency problem caused during roaming of the 802.11 wireless clients. The 802.11 clients need also be *mobile* as well as being wireless. Next generation applications like VoIP running on wireless networks, pose an emerging need to both provide users with the ability to remain IP connected and to quickly restore (preserve) their ongoing sessions during any kind of movements (handoffs) inside WLANs. The network reconnection latency during intra-subnet handoff is solved by the existing IEEE 802.11f Inter-Access Point protocol (IAPP); however, no existing IEEE standard addresses the IP handoff issue. As a result of that, users suffer from great IP recovery periods during inter-subnet movements (excessive latency and jitter, degraded voice quality). There is an emerging need to optimize the time required to complete the inter-network BSS transitions of wireless clients. The key issues involved in a client's subnet movement include the roaming latency, the proper and fast adjustment of IP state information at the 802.11 Access Points (APs), the preservation of a client's ongoing sessions, and the ability to continue to be IP-connected regardless of its physical position.

In this paper we propose a method, named IP-IAPP, for the provision of fast IP handoffs in wireless LANs. This method, which forms an extension to the 802.11f IAPP, offers the 802.11 mobile clients constant IP connectivity everywhere, even when associated to an AP of a foreign network (FN). After a subnet handoff, L3 connectivity is restored almost simultaneously to the link-layer connectivity. IP-IAPP leads to extremely small IP-reconnection delays and very low packet loss, without burdening the wireless clients. The total service interruption delay, during which a client cannot receive IP packets, is minimized to the link-layer handoff latency plus one TCP/IP round-trip time. Therefore, even the most demanding real-time IP sessions suffer insignificant disruption. The IP-IAPP approach is focused and heavily based on the IEEE 802.11 technology, and works on the existing 802.11 infrastructures without any modifications or additional devices. It considers APs with advanced routing functionality. The access points are acting as mobility agents for the clients, and are responsible for the IP mobility management.The total IP handoff process is transparent to the wireless clients. The proposed mechanism is not based on forecasts of imminent link-layer handoffs. It only makes use of and slightly extends the existing 802.11f IAPP protocol for communication between the home and foreign agent.

Unlike Mobile IP (MIP) [1], the widely used solution for host mobility, and its optimization variants, IP-IAPP is fully applicable to the IEEE

802.11 infrastructures, and shows better performance over most mobility approaches. Several techniques have been proposed to optimize the MIP performance by improving either MIP handoff latency ([10], [11]) or optimizing MIP routing [4]. The significant Mobile IP handoff delay (the Movement Detection process alone may range up to 3 seconds [8]) affects the service quality especially of multimedia applications. Most of the MIP optimization techniques (Table 1) are L2 independent and based on forecasts of impeding link-layer handoffs ([2], [3], [6], [7]). Unfortunately, in the 802.11 case, by no means can the 802.11 clients or the APs predict an imminent handoff. Moreover, most of them work only for *soft* handoffs, where a client is able to communicate with *both* the old and the new AP. Some of them also assume *backward* handoffs. Link layer handoff in IEEE 802.11 infrastructure-mode WLANs is both *hard* and *forward*. In *hard* handoffs a wireless station cannot communicate with more than one access point during handover, while in *soft* handoffs it is able to communicate with *both* the old and the new AP. A handoff is called *forward* if the station communicates only with its new AP during the handoff (not with the old one). These characteristics introduce limitations to most of the related IP mobility proposals in terms of applicability and effectiveness on 802.11 wireless networks, as they are expedient only to *soft* and *backward* handoffs.

Table 1. Summarized comparison of relevant IP mobility solutions

Method	Mobile IP Compliant	Based on L2 triggers	Mode	Handoff Latency
DFA	No	Yes	Soft	~10ms
Neighbor Casting	Modified MIP	Yes	Soft	NA
Pre/Post Registration	Modified MIP	Yes	Soft	NA
LCS	Modified MIP	Yes	Soft	>1sec
ECS	Modified MIP	Yes	Soft	>500ms
FHCS	Modified MIP	Yes	Soft	<500ms
Probing & Replaying	Yes	No	Hard	<100ms
IP-IAPP	No (IAPP compliant)	No	Hard	<50ms

2. The IP-IAPP approach

2.1. Operation Basics

The IP-IAPP mechanism is built on top of IEEE 802.11f IAPP. Two new handoff procedures are added to the existing IAPP protocol operation, which handle the IP movements of the clients and offer L3 roaming capabilities. In order for the APs to participate in the proposed L3 roaming protocol, they must support the IP-IAPP core mechanism. This mechanism acts upon link-layer handoffs, and performs a specific IP configuration procedure to support a client's network handoff. It considers APs which serve as mobility agents; the APs are responsible for management and provision of IP mobility support to their associated clients. The MNs preserve their initial home IP address everywhere, regardless of their physical location.

Every MN is assigned with a Home Agent (HA) inside its home network (HN). The HA handles mobility of its associated clients, and supports routing of their data even when the clients have roamed to different subnets. The HA is incorporated in the 802.11 AP entity and is also referred to as the Home AP (HAP) of the MN. The HA is the AP to which a station is last associated inside the HN. Every AP acting as a HAP preserves a list of its registered clients, with the necessary IP mobility related information. When a client moves to a different IP segment, it is assigned with a foreign agent (FA): the client reassociates with an AP which resides on the foreign network (FN). This AP becomes the FA of the MN. The FA is the entity which provides advanced routing services to every associated foreign MN; it is responsible for offering IP connectivity to clients coming from different subnets. The FA is also incorporated in the 802.11 AP entity and is referred to as the Foreign AP (FAP) of the 802.11 MN. Every AP serving as a FAP preserves a list, "Visitor List", of its associated MNs who have roamed from foreign subnets.

Upon receipt of a L2 trigger by the reassociating (foreign) mobile node, the new AP (FAP) carries out the IP-IAPP *movement detection* phase. In case it figures a network handover during reassociation, it initiates the *IP-IAPP mobility management procedure* instead of the standard 802.11f IAPP. The two involved APs (the FAP and the HAP) carry out a fast notify/response transaction comprising of two TCP/IP IP-IAPP packets (802.11f formatted), and setup a specific framework necessary for routing MN traffic. After successful completion of the IP-IAPP mechanism, the client enjoys IP-connectivity for as long as it remains inside the FN. At its foreign location, the MN is identified via the foreign AP IP address; this is the Foreign Agent Care of Address (FACOA). The IP-IAPP, exchanged between the involved parties in case of a L3 handover, follow the 802.11f packet format, and are extended to carry the mobility specific information concerning the IP-state of the wireless station. The four new packets and their usage are listed below:

- ***Roam-Request*** [TCP/IP, FAP→HAP]: Causes registration of the FACOA to the HAP, and triggers HAP-FAP advanced routing setup. Follows the IAPP *MOVE-notify* packet format, extended with IP-related context.

- ***Roam-Response*** [TCP/IP, HAP→FAP]: Response to a *Roam-request* packet; informs the FAP about completion of HAP actions (advanced routing setup). Similar to the IAPP *MOVE-response* packet format.

- ***RouteUpdate-Request*** [TCP/IP, HAP→PAP]: Informs the Previous FAP (PAP) for a new movement and causes the removal of stale routing entries at the PAP in cases of intra/inter-foreign network movements.

- ***RouteUpdate-Response*** TCP/IP,PAP→HAP]: Response to a *RouteUpdate-request* packet, indicating completion of PAP actions (removal of advanced routing setup).

The overall IP mobility management procedure is transparent to the client itself, as it does not participate in any of the IP-IAPP protocol traffic transactions.

2.2. Movement detection and location update mechanism

More specifically, a new Information Element (IE) is added to the 802.11 (Re)Association.Request and Response messages for IP-IAPP purposes. The *movement detection* phase is accomplished via certain MN IP specific information which is acquired from the IP-IAPP IE of the 802.11 Reassociation frames. The MNs are only responsible for filling in this IE with information previously retrieved from the last (Re)Association.Response message; it does not need to perform any decision making upon filling up the IP-IAPP IE. The IP movement detection is every time carried out simultaneously to the L2 reassociation. Therefore, IP-IAPP has zero-delay movement detection phase. The new AP, upon receipt of the Reassociation.Request frame, examines the IP-IAPP IE to identify the current handover case:

(a) If the MN has just performed an intra-network movement, then this involves only a L2 handover (standard IAPP protocol is then initiated by the new AP).

(b) If the MN has just performed an inter-network movement between the Home and a Foreign Network, this is called a *Network HandOver* (NHO): movement from HA to a FA.

(c) If the MN has performed a movement between two FAs of the same (or different) Foreign Network(s), this is a *Foreign NHO* (FNHO).

The NHO and FNHO procedures of the IP-IAPP mechanism which handle the cases of L3 handover are described in the following:

2.2.1. The "NHO" procedure. In this case, the MN reassociates to a New AP (NAP) in a foreign network, while previously associated to its HAP (inside HN). Upon receipt of a Reassociate.Request indicating a NHO handover, the NAP communicates with the HAP, and they establish an advanced routing setup to provide IP-connectivity to the MN at its foreign location. The protocol sequence involved in an inter-network handover (NHO) is shown in Fig. 1.

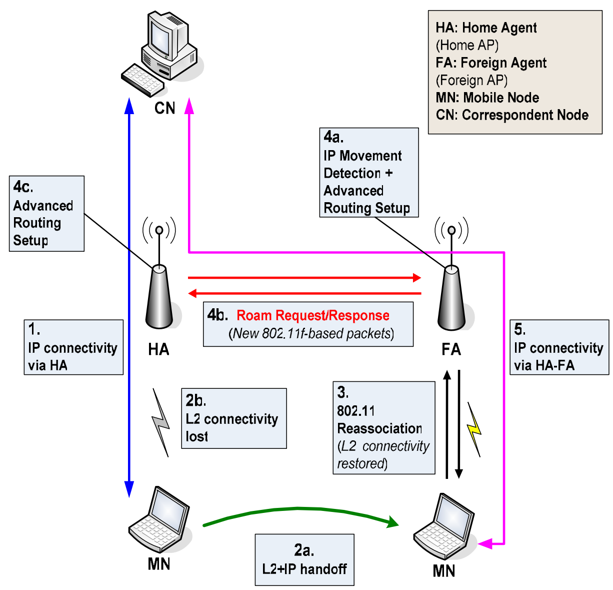

Figure 1. The IP-IAPP *NHO* procedure

The FAP first identifies the handover type. In the event of a NHO, it inserts a mapping for the MN and its HAP to the "Visitors List". It quickly informs the HA of the MN about this event via transmission of a Roam-Request message with a type of NHO. The FAP is responsible for capturing all IP traffic destined to the MN, and for forwarding all IP traffic originating at the MN to its Home Agent through the established IP-IP tunnel. The HA, upon receipt of a Roam-Request message, updates its MN association list to indicate that the specific MN is currently "away" from HN. It also maps the MN IP address to the FAP IP address (FACOA). The HAP intercepts all IP traffic which arrives in the Home Network and is destined to the MN IP address, and then routes these packets towards the MN current FACOA. After completion of the IP-IAPP inter-AP communication, the mobile client regains IP connectivity via the IP-IP tunneling routing methods. While connected to the FA, the MN is able to transmit/receive packets using its original IP address. As soon as the client restores network connectivity, there is an intermediate TCP adjustment period until its sessions are fully restored (update of ARP tables, etc). Using advanced routing techniques, the IP-IAPP mobility entity of the AP takes the necessary actions for the client to quickly obtain the TCP specific information of its previous sessions. This reduces packet loss during the handover.

2.2.2. The "FNHO" procedure. The MN reassociates to a new foreign AP, while previously associated to another foreign AP. Upon reassociation, the new foreign AP identifies a FNHO handover. The protocol procedure consists of the same phases as in the inter-network movement, with an addition of a communication between the HA and the previous foreign agent. Both APs delete the previous routing setup concerning this MN.

The FAP inserts a mapping for the MN and its HAP to its "Visitor List", as in the NHO case. It quickly informs the MN HA of this event via transmission of a Roam-Request message with a type of FNHO. This type of Roam-Request also carries information about the previous FAP. The new foreign agent immediately sets up an IP-IP tunnel towards the HA IP address, and performs the same advanced network setup as in the case of a NHO. The HA, upon receipt of a Roam-Request message indicating a FNHO, updates its MN association list: it maps the MN IP address to the new FAP IP address, and characterizes the previous FAP as "TEMP". As for the advanced routing, it firstly creates an IP-IP tunnel towards the new FAP, and adds the same routing entries as in the case of a NHO, however the new rules refer to the new FAP IP address. As soon as the setup for the new MN location is successfully established, it sends a RouteUpdate-Request to the previous FA, and disables all routing entries which referred to that tunnel. In the case of a FNHO, any IP datagrams intercepted by the HAP, after the new registration, are delivered to the MN new location (FACOA). It is possible that some packet may escape through the existing tunnel towards the previous FA, until the HA routing setup is appropriately updated. The previous tunnel is disabled and deleted within a few milliseconds, and all the packets are properly routed via the new active tunnel between the HA and the new FA. After completion of the FNHO IP-IAPP procedure, the routing of MN IP traffic is handled the same way as in the NHO case. Again, the total IP service interruption is short enough to successfully restore the ongoing sessions during a FNHO.

4. Performance measurements

The testbed used in the performance tests of the proposed IP handoff method is shown in Fig. 2. The mobile client's 802.11b driver has been slightly modified to provide transport of the necessary network-related information during handoffs. The *Chariot* Console [9], was used to measure the handoff performance under real-time and multimedia traffic. In all tests, the laptop performed subnet roaming while having an active IP session towards the correspondent IP host. The measurements were taken for movements from the HA to the FA (NHO) and vise versa. We also examined the scenario for client movements between two FAs (FNHO): the client was attached to the AP-2 and roamed to another AP (not its HA) of a different foreign subnet.

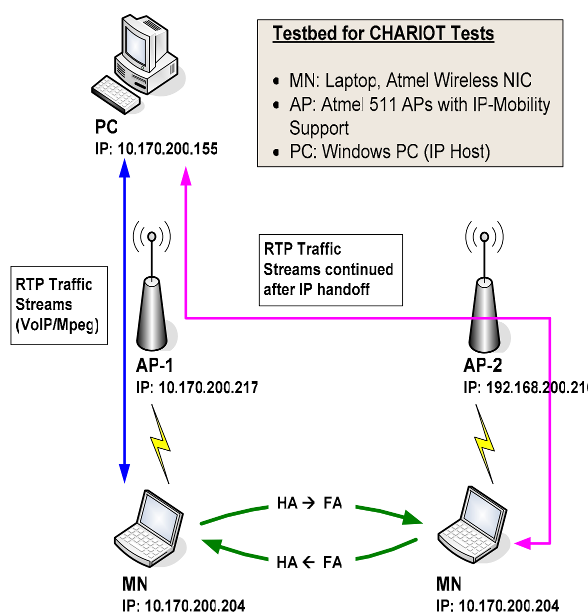

Figure 2. Testbed for Chariot Tests

In the first test, the client was running a VoIP session towards the PC (RTP Stream, Chariot *G.711u* script). The client roams from HA to FA at around 17th second of the Chariot test, and from FA back to HA at around the 24th sec. What can be observed from Fig. 3 are the very small one-way delay and a very small packet loss. The overall throughput suffered a degradation of only ≈ 9%. To determine the quality of VoIP under packet loss, the most common metric is the Mean Opinion Score (MOS) [5], which evaluates the effect of bursty loss on VoIP perceived quality (the Overall Voice Quality). In a MOS test, the listeners rate audio clips by a score from 5 to 1, with 5 meaning Excellent, 4 Good, 3 Fair, 2 Poor, and 1 Bad. The MOS estimate of the first Chariot test shows that the call was not interrupted; It only suffered substantial quality degradation with a low peak at MOS=1, and quickly restored its initial quality (MOS=4).

In the second test using again a VoIP session, the client roams from an FA to a new FA approximately at the 16th second, and from the new FA back to the HA at around the 37th sec. As can be seen from Fig. 4, all results are increased by a small factor. During the movement towards the new FA, the session throughput suffered a degradation of about 19%. This is due to the fact that the HA must first disable all previous IP settings for forwarding packets to the previous FA. This poses a small additional delay to the overall IP reconnection period. Again the IP handoff delay is small enough to efficiently preserve the VoIP session, as also verified by the MOS estimate. Data loss could be further decreased via the use of an advanced buffering mechanism at the involved APs.

5. Conclusions and future work

As verified by the real experimental results, the IP-IAPP method significantly contributes in shortening the total IP handoff latency during subnet movements. The demanding real time and multimedia applications suffered insignificant quality degradation and were quickly restored. With IP-IAPP, the mobile hosts utilizing VoIP and other multimedia applications are freely moving between neighboring subnets, without experiencing any service interruption and without even realizing the IP handoff. Next tests will be focused on measurements using advanced buffering mechanism on the APs. Another future consideration is to study ways to extend the current IAPP-based RADIUS protocol usage to support fast and secure transfer of station’s context (such as QoS parameters, IPsec, etc.), as well as to support roaming-specific services in 802.11 WLANs. Finally, examination of efficient ways to integrate the contribution of IP-IAPP usages in the emerging IEEE 802.11r standard will be the predominant subject of our future work.

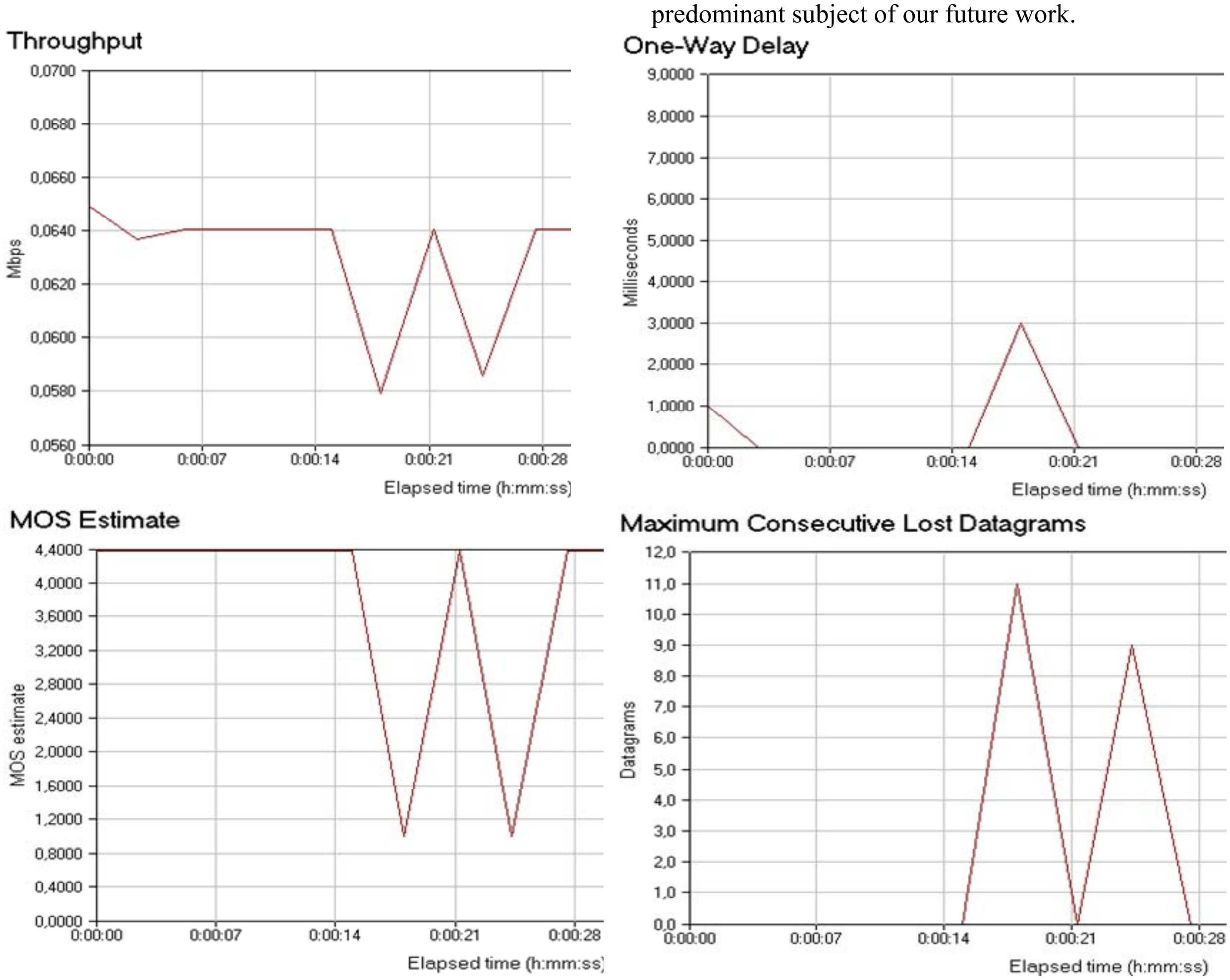

Figure 3. Test 1: VoIP session (RTP Stream) – Movements between HA-FA

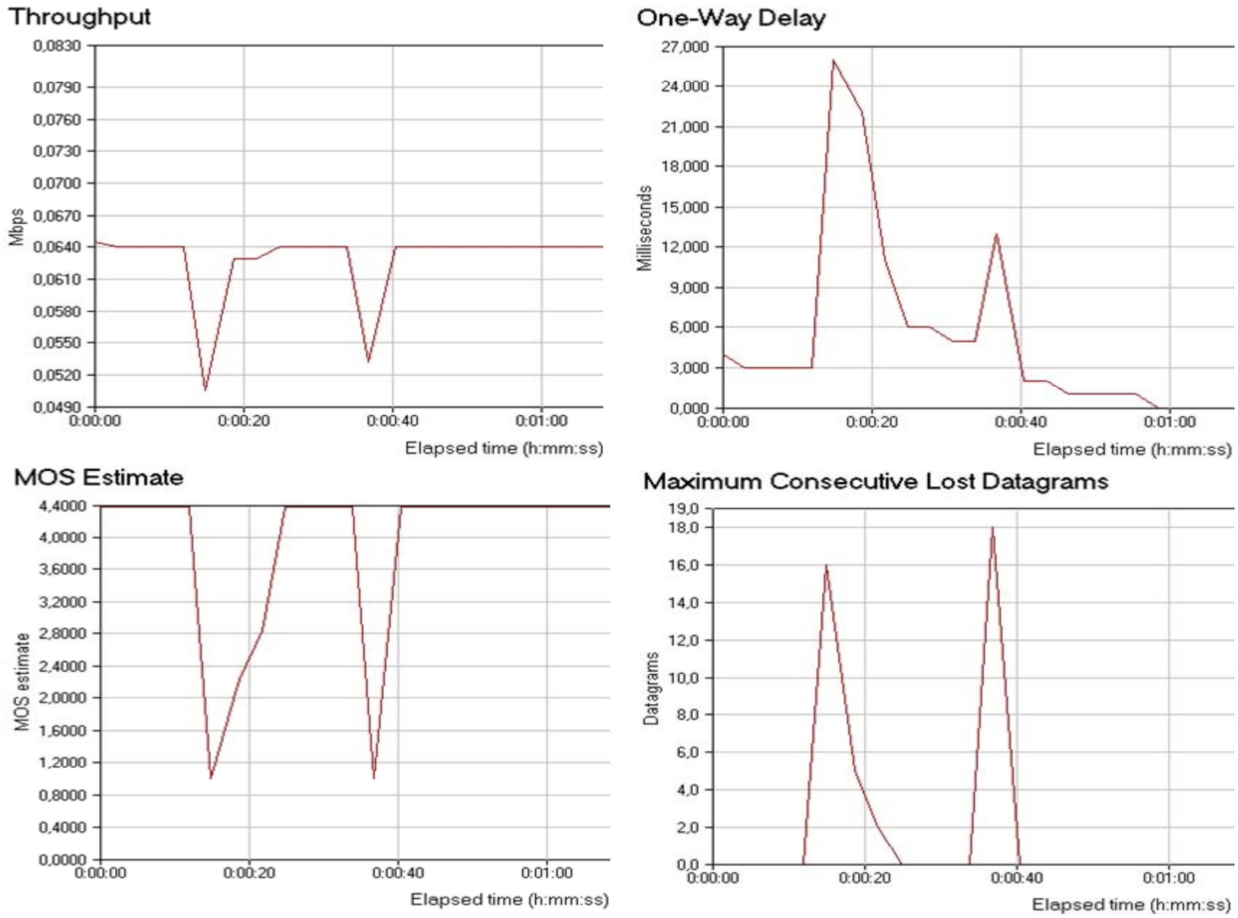

Figure 4. Test 2: VoIP Session (RTP Stream) – Movements between two FAs

6. References

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