# Experimental Evaluation of Load Balancing for Mobile Internet Real-Time Communications*

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## Abstract

Mobile IP is the dominant Internet standard for the provision of Internet mobility support. However, Mobile IP does not provide any considerations for simultaneous use of multiple points of attachment. This feature is considered very important for Internet real-time communications. Filters for Mobile IP Bindings is a protocol extension of Mobile IP that allows mobile nodes to associate filters with simultaneous bindings for a single home IP address. Flows that match a filter are tunnelled to the point of attachment indicated by the binding. In that way load balancing is achieved. This paper experimentally evaluates load balancing of UDP flows in an experimental testbed. It is determined that during load balancing all flows demonstrated shorter interpacket delays, increased throughput and no packet loss.

## Key words

Filters, Mobile IP, Load Balancing, Real-Time, WLAN

## 1. Introduction

In the past years Internet services have penetrated in all aspects of modern life. This development has given place to a new trend in fixed networks, whereby data traffic has been overtaking voice traffic. Meanwhile, the widespread use of Internet applications has indicated the Internet Protocol (IP) as a potential carrier of audiovisual content. In this manner real-time audiovisual telecommunication services can be provided through data-communication services. It is expected that this tendency will expand into wireless networks.

Real-time audiovisual telecommunication services are required to follow strict time constraints to end-to-end packet delivery time. There have been several different approaches to this problem. The approach presented in this document assumes that through load balancing, a mobile node will be able to best utilise the resources available in a wireless overlay network for the delivery of real-time traffic.

The deployment of packet services in wide-area cellular networks accompanied by a rollout of standards for license free personal and local area communication networks are a strong indication that future mobile Internet communication systems will be built upon heterogeneous wireless overlay networks [1]. These will guarantee to mobile terminals ubiquitous access to a range of wireless Internet technologies. This prospect creates the need for a new breed of devices capable of hosting and operating more than one wireless technology interface simultaneously while introducing a protocol requirement for taking advantage of this property.

The Mobile Internet Protocol (IP) [2] is an extension of the basic Internet Protocol design. It inherits the integrating property of the Internet Protocol thus acting as the "glue" between the heterogeneous bearer technologies of a wireless overlay network [3].

Mobile IP enables mobile node roaming between IP networks without the need to interrupt active communications. As a mobile node moves, all of its incoming flows are redirected to its current location. However, this model of operation may not be adequate for mobile nodes capable of maintaining multiple points of attachment within a wireless overlay network. In that case, the mobile node may require utilising all of its available points of attachment to perform load balancing. This behaviour is not supported by Mobile IP.

Filters for Mobile IP Bindings [4], [5], [18] is a protocol extension of Mobile IP that enables mobile nodes to attach one or more filter definitions to Mobile IP signalling during registration. Flows that match a filter will be processed as defined by the control information of the filter. In this manner, it is possible for a mobile node to distribute flows among its available points of attachment and achieve load balancing. Filters for Mobile IP Bindings assumes that even though the mobile node maintains multiple points of attachment it only has a single home IP address. Should a mobile node maintain multiple home IP addresses (multi-homing) then Filters for Mobile IP Bindings would still be applicable separately for each home IP address.

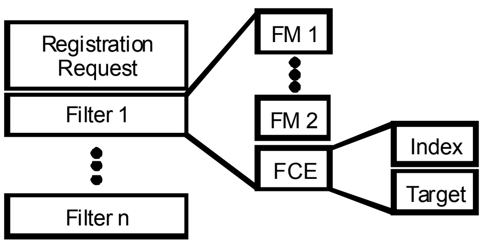


*Figure 1: Structure of a Filtering Request, FM=FilterModule, FCE=Filter Control Extension*

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The aim of this experimental evaluation is to demonstrate that with the help of Filters for Mobile IP Bindings it is possible to load balance incoming flows; a feature that is very important for real time communications. The latter are considered as User Datagram Protocol (UDP) flows that carry time sensitive content. Once this content is not received in time then it cannot be used. In this context, load balancing aims to provide mobile nodes with the capacity to choose which networks best match their requirements and enable them to use all of them simultaneously.

## 2. Internet Mobility Support

Currently, the dominant Internet standard for the provision of Internet mobility management services is the Mobile IP. It introduces two basic additional entities, namely the home agent and the mobile node. The first acts as a location register for the mobile node and is located in the mobile node's home network. A home network is an IP administrative domain (subnet) from which the mobile node acquires a permanent IP address. Similarly, a foreign network is any other network that is willing to temporarily allocate an (care-of) IP address to a mobile node. A mobile node that establishes link connectivity with a network and receives a care-of IP address from the corresponding IP administrative domain is said to have acquired a point of attachment to the network.

The mode of operation of Mobile IP resembles the post-office forwarding service. That is, every time that a mobile node acquires a new point of attachment, it is required to register its location (care-of IP address) with its home agent that maintains a registry of the mobile node's permanent and temporary care-of addresses, termed as a mobility binding. Following a successful registration, the home agent acts as a proxy for the mobile node and tunnels all incoming flows to the mobile node's most recently registered location.

Existing literature [6] has identified mobile node mobility as the main reason for changing a point of attachment. However, in wireless overlay networks it is not necessary for a mobile node to move in order to acquire or give up a point of attachment. A mobile node may best take advantage of this property by simultaneously utilising all of the available networks in order to balance the load of its incoming flows.

## 3. Load Balancing with Mobile IP

Home agents are unable to distinguish between individual flows and therefore redirect all intercepted traffic for a mobile node to the care-of address indicated by its binding. Consequently, as the binding is updated with every hand-off, the total of a mobile node's active flows are redirected to the most recently registered care-of address. Furthermore, if a mobile node requests for simultaneous bindings, it will receive at each registered care-of address a duplicate copy of every active flow [2]. However, a mobile node that maintains multiple points of attachment may wish to associate certain flows with specific points of attachment. This would enable the distribution of incoming flows across the available points of attachment in order to perform load balancing.

Due to the inability of standard Mobile IP to distinguish between individual flows and to handle them in a different way, it is not possible to perform load balancing. The following section introduces a protocol extension to Mobile IP that provides support for the required behaviour.

### 3.1. Filters for Mobile IP Mobility Bindings

Filters for Mobile IP Bindings [4], [5], [18] enables mobile nodes to associate one or more filters with mobility bindings during their establishment (registration, binding update). These mobility bindings will have to refer to the same home IP address. Should a mobile node maintain multiple home IP addresses (multi-homing) then Filters for Mobile IP Bindings will have to be used separately for each of those addresses. The advantage of this approach is twofold. The extension is applicable in environments were IP addresses are scarce (IPv4) while being complementary to multi-homing (IPv6).

Flows that match a filter will be processed as defined by the filter. In this manner, it is possible for a mobile node to distribute flows among its available points of attachment.

Filters for Mobile IP Bindings, requires that a mobile node includes in its registration requests or binding updates a list of filters (filtering request). In this manner, filtering agents (correspondent nodes, home or hierarchical agents [7]) become aware of the relationship between certain flows and specific bindings. A mobile node may consider different parameters such as network congestion status, communication QoS requirements, cost, user profile and others in order to determine filters. An investigation into these rules is considered an important research issue that eludes the scope of this investigation and is therefore not covered in this study.

Filters for Mobile IP Bindings defines nine different types of filter modules. In order not to violate layer independence, the selection of filter modules is based on flow description components made available by existing approaches to QoS support [14]. Mobile nodes can use a selection of such modules to form filters:

1. Behaviour Aggregate Filters Extension. Specifies to Filters data packets depending on the content of the DSCP field.
2. Protocol Extension. Specifies one or more protocols to be filtered.
3. Source Address Extension. Specifies one or more source addresses to be filtered.
4. Source Network Extension. Specifies one or more source networks to be filtered.
5. Source Port Extension. Specifies one or more source ports to be filtered.
6. Source Port Range Extension. Specifies one or more ranges of source ports to be filtered.
7. Destination Port Extension. Specifies one or more destination ports to be filtered.
8. Destination Port Range Extension. Specifies one or more ranges of destination ports to be filtered.
9. Free-Form Extension. It allows for the definition of complex Filters based on the value of an area anywhere within a packet. The mobile node is required to provide the packet offset, the qualifying value as well as a mask.

Filgure 1 illustrates the structure of a registration request with filters (Filtering Request). It can be seen that a filter consists of one or more Filter Modules and is terminated by a Filter Control Extension. A Filter Module may contain several predicates. There is an OR relationship between predicates of a Filter Module and an AND relationship between Filter Modules of the same Filter. Consequently, in order for a flow to match a Filter it is required to qualify for all of the Filter Modules contained in the Filter. The modular approach enables a mobile node to form powerful filters without the transmission of redundant information.

With the help of the Filter Control Extension, it is possible to associate a filter with an Index number and to define the Target of the filter. That is, the action to be undertaken when a flow matches a filter. Different Target values have been defined for the actions of rejecting (dropping) or forwarding a flow. The latter is used for the purposes of load balancing.

There are certain rules that need to be followed in order for a filter to be valid. For example, a filter that contains a Protocol Extension requesting filtering services for ICMP flows may not include any of the Port Extensions, as ICMP maintains no ports. Formed filters are relayed to filtering agents via normal registration requests/binding updates (filtering requests) that may contain more than one filter. Upon receiving a registration request, a filtering agent is required to apply the filter and issue a normal registration reply.

### 3.2. Protocol Overview

The model of operation of Filter for Mobile IP Bindings is illustrated in figure 2. It shows a mobile node that maintains multiple points of attachment in several visited domains, A and B. A visited domain may consist of several different IP administrative domains (subnetworks). Filters for Mobile IP Bindings does not provide any restriction as to how many points of attachment a mobile node may maintain within a visited domain as long as each point of attachment belongs to a different subnetwork. When a mobile node acquires a point of attachment in the home network then it is required to give up all other points of attachment. This limitation can be overcome by assuming that in future wireless overlay networks, mobile nodes will not have a home network, rather then only a home agent that will provide location registration services.

In figure 2, the mobile node has two separate points of attachment in the Mobile IP hierarchy of visited domain A. In addition, the mobile node maintains two incoming flows from Correspondent Node (CN) 1.

Incoming flows from CN1 are distributed between the available points of attachment at the home agent and tunnelled to different visited domains.

## 4. Related Work

There have been different approaches to the problem of simultaneous use of multiple points of attachment with Mobile IP. These can be classified into two major groups, namely those that assume that a mobile node may maintain multiple home addresses (multi-homing) and those that assume that a mobile node has only a single home address. In the first case the mobile node uses a different home address for different communications thus managing a better match between flows and points of attachment as well as load-balancing. It can be understood that a multi-homing solution is only possible in environments with ample of IP addresses to be allocated to mobile nodes, such as in IPv6 networks. However, considering the limited availability of addresses in IPv4 a multi-homing solution would not be feasible. In that case, flow distribution and load balancing is achieved with the help of filters. The major difference between such solutions lays on whether filters are of fixed structure or are constructed by smaller filter modules. That is, approach [15] assumes fixed filter types considering three criteria (home IP address, the senders IP address and port number) while Filters for Mobile IP Bindings defines nine different filter modules based on flow description components made available by existing approaches to QoS support [14]. Via the combination of individual modules more powerful filters can be built. In addition, a mobile node may utilise the most appropriate modules to best describe a flow while not transmitting any redundant information.

Another major difference between filtering approaches is based on their capacity to distribute a single flow between several points of attachment rather then just whole flows. That is, the individual packets of a single flow can be redirected either by their source or from a Filtering Agent to a different point of attachment, hence load balancing a single flow. A more detailed presentation of this functionality along with an investigation of its effect on real time and other communications is reserved as the subject of a future publication.

Comparing multi-homing with filtering flow distribution approaches, it is identified that multi-homing requires significantly more IP addresses for each mobile node. Filtering approaches can be used in conjunction with multi-homing, providing filtering services for each of the mobile node home addresses. Finally, with the help of filters it is possible to share a single flow between multiple points of attachment. Consequently, a combination of multi-homing and filtering approaches can adequately address the problem of simultaneous use of multiple points of attachment.

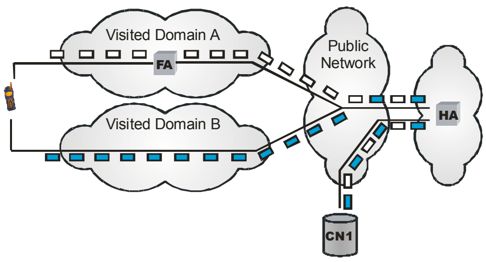


*Figure 2: Model of operation*

## 5. Experimental Setup

The aim of this experimental evaluation is to demonstrate that with the help of Filters for Mobile IP Bindings it is possible to load balance incoming flows; thus utilising resources in all available networks. This feature is considered as very important for Internet real-time communications with fixed resource requirements and end-to-end delay constraints.

In order to test the performance of load balancing the experimental testbed illustrated in figure 3 was constructed. It contains a home network from which the mobile node acquires a permanent IP address. The home network is host to a home agent that is mandatory for the support of Mobile IP. In addition, two other foreign networks are present that provide two points of attachment over two different IEEE 802.11b [9] wireless local area networks (WLAN). Each of the foreign networks includes a foreign agent that allocates a care-of address to the mobile node and acts as a tunnelling endpoint for all tunnelled traffic from the home agent. The mobile node is equipped with two IEEE 802.11b WLAN PCMCIA adapters that allow for simultaneous connection to both foreign networks.

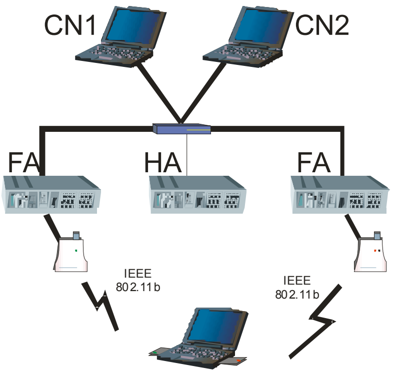


*Figure 3: Experimental testbed*

All agents and correspondent nodes are AMD Thunderbird PCs at 800 MHz. The mobile node is a Siemens Lifebook notebook with an Intel Pentium III at 750 MHz. Wirelined network connectivity has been provided through Fast Ethernet while for the wireless connectivity the IEEE 802.11b compliant Cisco Aironet Access Points and PCMCIA cards that operate at the unlicensed 2.4 GHz ISM band were used. The Access Points were configured to operate in non overlapping frequency-bands (at least 5 channels appart) in order to avoid interference.

All machines have been installed with the Linux Mandrake 8.2 distribution and the Linux Kernel 2.4.18. Mobile IP support was provided with the Sun Labs MIPv1.2 implementation [10] that was extended to provide support for Filters for Mobile IP Bindings [4].

The investigated scenario involves a mobile node that maintains two incoming flows from CN1 and CN2. Each of the flows is a 4Mbit UDP stream destined to the mobile node's permanent IP address. The offered load of both UDP flows amounts to a value greater than the achievable Layer-3 throughput of an IEEE 802.11b [16], [17] WLAN. Under such conditions it is possible to demonstrate the added value of load balancing with the help of Filters for Mobile IP Bindings. Apart from the main two flows no other background traffic was initiated. For the generation of the flows, the `iperf` traffic generator [11] was extended to provide information about the sequence numbers of UDP packets. In order to avoid packet fragmentation the maximum packet size was set to 1450 bytes. Finally, the `wonder shaper` [12] Linux script was utilised to increase the queuing priority of small packets originating from the mobile node. That way it was ensured that Mobile IP signalling would receive higher priority in each mobility agent encountered in its path to the home agent, in spite of any network congestion.

### 5.1. Experiment Description

In the beginning of the experiment, only one of the WLAN interfaces of the mobile node was active forcing both of the flows to be received at the mobile node over the same WLAN interface. At time point 10sec, the second WLAN interface was raised triggering the transmission of a registration request with filters to the home agent. Once the filter had been applied, one of the UDP flows was tunnelled to the newly acquired point of attachment and was hence received over the new WLAN interface. During the experiment, key attributes of the communication such as packet loss and throughput were measured. These are presented in the following section.

## 6. Experimental Results

All graphs to be presented in this section refer to the performance of two UDP flows. The one denoted as UDP Flow 1, is the UDP flow that remains on the same WLAN interface even after the appearance of an additional interface. UDP Flow 2 is denoted the one transferred to the new WLAN interface once it become available. The transfer is achieved with the help of filters transmitted during registration. In Mobile IP, a mobile node issues a new registration request only when it is performing a Mobile IP hand-off. This is initiated as a response to a change in its link-layer status, such as during link-layer hand-off. Throughout Mobile IP hand-offs a mobile node is unable to send or receive packets and is therefore said to suffer network service disruption [6]. However, in the investigated scenario the mobile node is not moving, nor does it perform a link-layer hand-off. As such, during the initiation of the registration request no service disruption is suffered and for this no packet loss can be accredited to it. As will be seen, the primary reason for packet loss in the investigated scenario is network congestion which is remedied by load balancing.

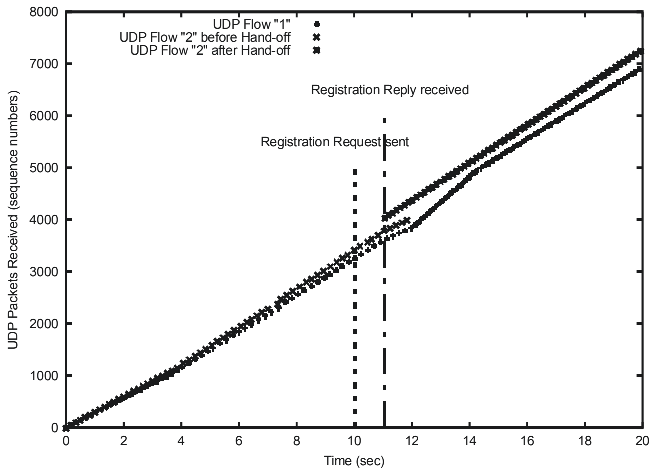


*Figure 4: UDP Flows progress*

Figure 4, illustrates the progress of the UDP flows. In the early seconds of the experiment both flows demonstrate a similar transmission rate. Approximately, at time 7sec both flows demonstrate a minor interruption. That is due to the transmission by the mobile node of a Mobile IP registration request intended to refresh a mobility binding. At time 10sec, the second WLAN interface is raised. This event is followed by the transmission of a registration request containing a single filter, requesting from the home agent to redirect UDP Flow 2 to the point of attachment provided by the second WLAN interface. The filter piggybacked by the registration request contained two filter module extensions along with a filter control extension. The filter modules identified key properties of the flow such as the protocol (=UDP) and destination port number (=6000) while the Target field of the Filter Control Extension would indicate to the home agent to forward via tunnelling matching flows to the point of attachment indicated by the registration request.

In figure 4, it can be seen that during the time period between the transmission of the registration request and the receipt of the corresponding registration reply, both flows manage to proceed normally. However, following the completion of the hand-off both flows demonstrate an anomaly in their transmission rate. UDP Flow 1 initially slows down and then accelerates to reach the offered load (4Mbps = 500KB/sec). UDP Flow 2 progresses for some time over both interfaces and then commences solely on the second WLAN interface. This is due to fact that prior to the registration, the network suffered significant congestion that caused UDP packets to be buffered in queues. This was made worse during the application of the filter at the home agent when large volumes of received UDP packets where buffered at the home agent. It is noted that this behaviour is caused by the Linux kernel and its queue management and has little to do with the Filters for Mobile IP Bindings protocol extension.

Following the completion of the registration buffered data was released onto the first WLAN interface while UDP Flow 2 resumed over the second WLAN interface. Once the buffered type was flushed, UDP Flow 1 accelerated to assume a transmission rate similar to that of UDP Flow 2.

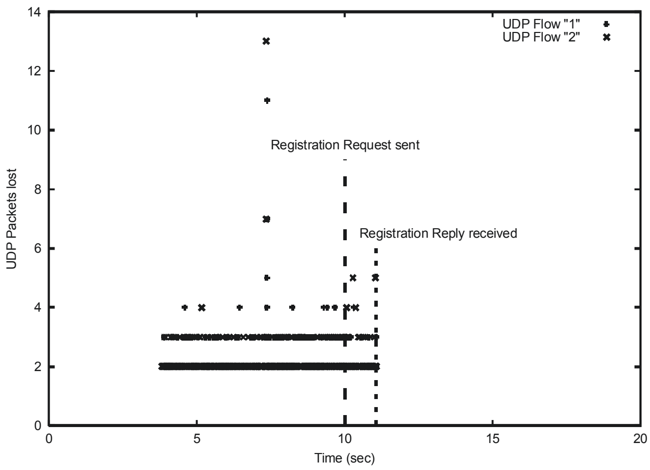


*Figure 5: UDP flows packet loss*

During the course of the UDP communications the packet sequence numbers of received data packets were monitored. After the completion of the communication it was possible to determine whether certain packets were received out of order or not at all. In figure 5, the packet loss of both UDP flows can be seen. A sequence of lost packets would signify a single loss event and is represented by a single entry. It is shown that in the early stages of the communication, no packet loss is present. This is due to the fact that all network queues were initially empty and reached maximum capacity at some point in the communication. From that point on, both communications demonstrated packet loss between 2 and 4 packets at a time. At time 7sec, extended packet loss was witnessed due to the transmission by the mobile node of a registration request. Due to the action of `wonder shaper`, incoming UDP packets were buffered for the processing of Mobile IP signalling and eventually dropped when the queue overflowed. A similar event but with smaller effect is witnessed during further registration request containing a filter declaration at time 10sec. During the application of the filter both flows suffer some packet loss. However, beyond the completion of the registration no packet loss was observed indicating that network congestion was relieved and each communication could proceed over its own WLAN segment.

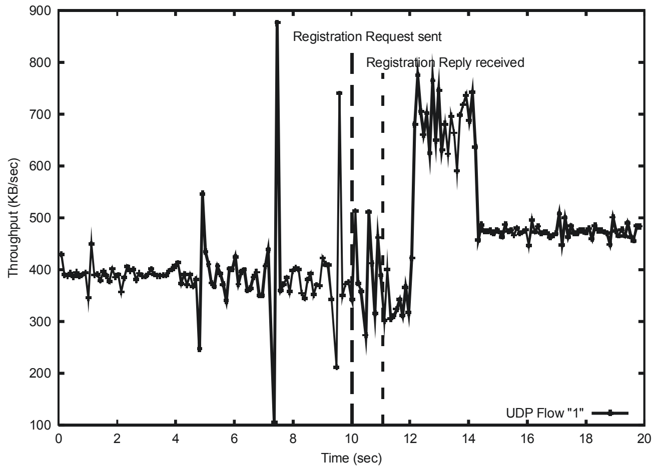


*Figure 6: UDP flow 1 throughput (100ms snapshot)*

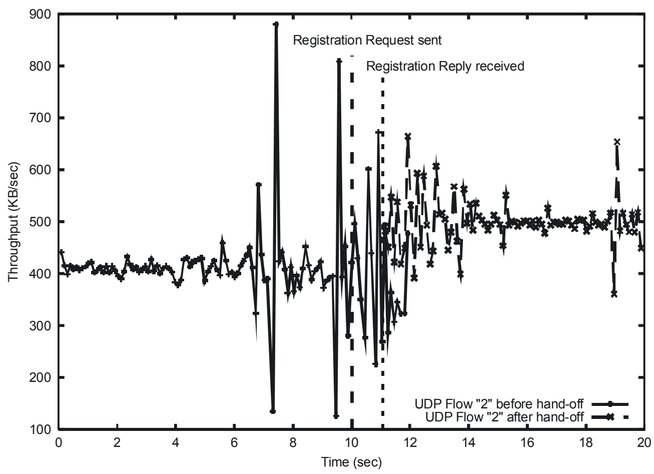


*Figure 7: UDP flow 2 throughput (100ms snapshot)*

A conclusion that can be derived from figure 4 is that both UDP flows tend to accelerate after the completion of the registration and their separation between two different WLAN interfaces. This fact is also made apparent in figure 6 that shows the throughput of UDP Flow 1. The throughput of the flow is defined as volume of data received at the mobile node during a time period of 100ms.

It can further be observed that prior to the registration the UDP flow demonstrates an unstable throughput whose values lay below those of the offered load (4Mbit=500KB/sec). Following the registration, the throughput rises rapidly as the buffered data is released only to drop to a stable value equivalent to the offered load. A similar behaviour can be observed in figure 7 for UDP Flow 2 with the primary difference that Flow 2 commences after the registration over both WLAN interfaces and therefore has two different throughput values for a significant time period.

It is understood that a mobile node capable of distributing active flows over multiple points of attachment is bound to manage a better performance than a mobile node forcing all flows over a single network path. The purpose of this study has not been to point out this fact rather than to introduce a protocol extension that will make this behaviour possible. Based on the assumption that future mobile Internet communication systems will be built upon heterogeneous wireless overlay networks a mobile node will be able to simultaneously acquire points of attachments in more then one network. Consequently, functionality similar to the one provided by Filters for Mobile IP Bindings will gain importance in order to take advantage of this property.

## 7. Future Work

In this study the performance of real-time UDP flows, during load-balancing, was determined. Future research issues include determining the performance of TCP communications when distributed across multiple points of attachment as well as when converging onto a single point of attachment. The primary difference between UDP and TCP experimental scenarios is that UDP has an almost constant bit rate and does not accelerate beyond the offered load during load-balancing. TCP on the other hand bases its flow control on a windowing mechanism that expands to make use of all the available bandwidth. As such, when load balancing is terminated and multiple TCP communications are forced to co-exist over the same network path then this might affect their performance.

## 8. Conclusions

This paper evaluates on an experimental testbed the performance of load balancing realised with the help of the Filters for Mobile IP Bindings protocol extension. The investigated scenario involved a mobile node receiving two real-time UDP communications from two different sources onto a single home IP address. Initially, the mobile node maintained a single WLAN interface forcing both UDP flows to be received over it. In that stage, extensive packet loss was observed along with high interpacket delays. During the experiment, an additional WLAN interface was made available. The mobile node reacted with an immediate registration, piggybacking filtering information. Subsequently one of the UDP flows was transferred to the second available WLAN interface. The load balancing of the flows relieved network congestion in the first WLAN network while eliminating all packet loss and increasing the throughput of both flows.

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