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IP-Layer Soft Handoff Implementation in ILNP

Ditchaphong Phoomikiattisak
School of Computer Science
University of St Andrews, UK
dp32@st-andrews.ac.uk

Saleem N. Bhatti
School of Computer Science
University of St Andrews, UK
saleem@st-andrews.ac.uk

ABSTRACT

We present the first results of an implementation of IP-layer soft handoff, based on the Identifier Locator Network Protocol (ILNP). In our testbed experiments, we show minimal gratuitous packet loss in vertical handoff scenarios (WiFi-3G). Unlike the IETF Mobile IP proposals, the ILNP uses a purely end-to-end architecture, and does not require proxies, middleboxes or tunnelling to support mobility. Our testbed is based on an in-kernel implementation using a modified Linux IP stack.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*; C.2.2 [**Computer-Communication Networks**]: Network Protocols

Keywords

Mobility Management; Vertical Handoff; Identifier-Locator Separation; Linux Kernel

1. INTRODUCTION

Seamless mobility is increasingly desired today. Lower level network technologies, such as 3G/4G networks or wireless LAN (WLAN or WiFi) networks already enable mobility support, by allowing mobility within the same underlying technology, *horizontal handoff*. However, effective solutions to enable seamless *vertical handoff* across different wireless technologies are still developing. In this paper, the term *handoff* always means a *vertical handoff*.

The problem of mobility in an IP network can be described with the help of Table 1. As shown in the second column, an IP address is used to bind state in the transport layer, but is assigned to a specific physical interface – it acts as an *identifier* at the transport and physical layer. However, the IP address is also used at the network layer for routing – it acts as a *locator*. As a locator could change when a node moves to a new IP network, changing an IP address would alter the end-to-end transport layer state. However, an identifier should remain stable during handoff. This semantic overloading of the IP address requires special treatment enable mobility in IP today. This use of IP addresses also impacts many other IP operations such as multihoming, failover, concurrent sessions via multiple interfaces, and roaming [11].

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Table 1: Use of names in IP and ILNP.

Protocol layer	IPv4 and IPv6	ILNP (ILNPv6)
Application	FQDN, IP address	FQDN or app.-specific
Transport	IP address	Node Identifier (*NID*)
Network	IP address	Locator (*L64*)
(interface)	IP address	dynamic binding

1.1 Naming in ILNP

The third column of Table 1 shows the use of names in ILNPv6 (the *Identifier-Locator Network Protocol (ILNP)* [2, 3, 5] implemented as a superset of IPv6 [4, 6–8]). ILNPv6 uses *distinct namespaces* with *dynamic bindings* to implement mobility. Application level protocols can use their own namespace, but default to using fully-qualified domain names (FQDNs), consistent with an Internet Architecture Board (IAB) Recommendation from 1996 [10]. Transport-layer protocols should use only a *Node Identifier (NID)*, which has no topological significance. The *NID* always represents a (logical, virtual or physical) *node* rather than a specific interface on a node. Another topologically-significant namespace called the *Locator (L64)*, is used at the network layer for routing and forwarding. In addition (not visible in Table 1), there are one-to-many dynamic bindings between *NID* and *L64* values, as well as a separate dynamic bindings between physical interfaces and *L64* values. So, mobility in ILNP is simply implemented by changing these dynamic bindings between *NID* and *L64* values, and between *L64* values and interfaces. When the node is mobile, the *L64* values can change without impacting end-to-end state invariance, as the *NID* value does not change once a session is in progress. Mobile nodes can have multiple *NID* and *L64* values and use multiple interfaces simultaneously, by adjusting dynamic bindings between them as required. From an engineering viewpoint, an *NID* value can be derived in the same way as IPv6 host-ID, and the *L64* value is an IPv6 routing prefix [16].

1.2 Structure of this paper

Our contributions in this paper is the first presentation of a performance evaluation of a prototype implementation of the ILNPv6 mobility in the Linux kernel. After overview of some related work in Section 2, we briefly describe an implementation of our ILNPv6 prototype in Section 3. We then present our evaluation and results in Section 4, followed by a conclusion in Section 5.

2. RELATED WORK

To the best of our knowledge, there is no other end-to-end (host-to-host) IP-layer soft handoff mechanism available at the time of writing. Our previous overlay-emulation results show the potential for good performance from ILNP [26]. However, we present a summary of some related work, focussing on those solutions that have been reviewed by the IETF or the IRTF. A more comprehensive list of IP mobility solutions can be found in [30].

2.1 Network-based Mobility Solutions

This type of solution uses new network entities, e.g. proxies or middleboxes, to help manage mobility. Sometimes tunnelling is also used for communication between those proxies, increasing packet overhead and potentially impacting the MTU size that is available to the application.

Use of Middleboxes. This could become a single point of failure and performance bottlenecks, and also poses an attractive target for for a malicious user to perturb the operation of the mobility mechanism. End-to-end integrity for the transport layer connections is lost, and so other functions, such as IPsec, may not be possible without further modifications.

- IETF Mobile IPv4 (MIPv4) [24] use a Home Agent (HA) and Foreign Agent (FA) to map between a Home Address (an identifier for the node) and Care-of-Address (locator for the node), while Mobile IPv6 (MIPv6) [25] require only a HA. MIPv4 and MIPv6 have the problem of high packet loss during handoff because they use the *hard handoff* model, and handoff delay is high.

- Hierarchical Mobile IPv6 (HMIPv6) [29] uses a proxy called a Mobility Anchor Point (MAP) to manage local mobility in addition to an HA to reduce handoff delay.

- Proxy Mobile IPv6 (PMIPv6) [15] use Mobile Access Gateway (MAG) and Local Mobility Anchor (LMA) for mobility management hiding the mobility process from mobile nodes.

- Locator Identifier Separation Protocol (LISP) [14] and its extension for mobility support, LISP mobile node (LISP-MN) [28], use a *mapping system* to map IP addresses into different schemas: Endpoint Identifier (EID) and Routing Locator (RLOC).

Use of Tunnelling. This impacts per-packet performance, and could create sub-optimal routing. The additional packet overhead will also reduce the MTU seen by the application. There will be extra signalling needed to manage the tunnels.

- MIPv4 use tunnelling between HA and FA, while MIPv6 eliminates tunnelling by *Route Optimisation* using a *Binding Update*.

- Fast Handover for Mobile IPv6 (FMIPv6) [18] use tunnelling between the Previous Access Router (PAR) and the New Access Router (NAR) to forward packets arriving at the previous location to minimise gratuitous packet loss during handoff [17].

- PMIPv6 use tunnelling between MAG and LMA.

- LISP, including LISP-MN, use tunnelling to encapsulate packets between LISP routing nodes.

2.2 Host-based Mobility Solutions

The mobility management of this type of solution is handled by end hosts, without requiring additional middleboxes. So, the end-system protocol stack requires updates.

- Level 3 Multihoming Shim Protocol for IPv6 (SHIM6) [23] separates identifier and locator from a single IP address by introducing a new 'shim' layer between the network and the transport layer. Mobility using SHIM6 has a problem of high handoff latency [13]; optimisation is in-progress [20]. Mobility support for a multihomed mobile node is also possible [1].

- Host Identity Protocol (HIP) [19, 22] uses public and private key pairs to manage identifier and locator of a mobile host. An optional, additional middlebox, a rendezvous server (RVS), is recommended to be deployed for better performance of session initiation.

3. ILNPV6 PROTOTYPE IN LINUX

We have implemented a prototype of ILNPv6 (ILNP as a superset of IPv6) in Linux kernel v3.9.0. *L64* and *NID* values are encoded into the IPv6 address space – see Figure 1 [6]. The top 64 bits, *L64* , have the same syntax and semantics as a routing prefix in IPv6. Its value is obtained from a normal IPv6 Router Advertisement (RA). The lower 64 bits, *NID* , has the same syntax as the IPv6 Interface Identifier, but different semantics i.e. it represents a whole node, not a specific interface of the node, and is not used for routing in the core network. For convenience, our implementation uses an *NID* value derived from the MAC address of the first active interface. To improve security and privacy, the *NID* values could be randomly generated similar to a privacy extensions for IPv6 addresses [21].

```
IPv6 (RFC3587 and RFC4291):
 |             64 bits            |          64 bits              |
 +--------------------------------+-------------------------------+
 |     Unicast Routing Prefix     |     Interface Identifier      |
 +--------------------------------+-------------------------------+

ILNPv6 (RFC6741):
 |             64 bits            |         64 bits               |
 +--------------------------------+-------------------------------+
 |            Locator (L64)       |     Node Identifier (NID)     |
 +--------------------------------+-------------------------------+
```

Figure 1: Encoding of NID and L64 values into the IPv6 address bits. An ILNPv6 L64 value has the same syntax and semantics as an IPv6 routing prefix. An ILNPv6 NID value has the same *syntax* as an IPv6 Interface Identifier, but different *semantics* as it represents the *node* not an *interface*.

The Linux system library (*eglibc* for handling names from */etc/hosts*) and kernel code were modified to enable mobility support. We summarise the changes below.

3.1 Name resolution

Rendezvous concerns how correspondent nodes initiate connections to a mobile host. ILNP can use DNS [5, 8] just like IPv6 and MIPv6. However, our focus here is to study the handoff performance, so we ignore DNS and use a modified version of */etc/hosts* for mapping names to initial *NID* and *L64* values.

The list of ILNPv6 hosts along with their *NID* and *L64* value is presented in the */etc/hosts* file with a new syntax: `L64|preference,NID hostname`

The *getaddrinfo()* networking API is modified to interpret this new entry in the file. When *getaddrinfo()* detects a "," in an address field, it extracts an Identifier, Locator and preference value (ignored for now) and passes them to the kernel via the *Netlink Socket* to store in an Identifier-Locator Vector (I-LV) cache. Then, an ILNPv6 'address', which looks similar to a traditional IPv6 address, is built from those NID and L64 value and is returned to the caller. This allows the current socket() API to be re-used. Hence, well-behaved legacy applications (those that use the socket descriptor only, and do not use address bits for application state) should work with ILNPv6 just like they would with IPv6. By checking the I-LV cache, the kernel can identify if the provided *sockaddr* structure contains an IPv6 address or ILNPv6 address. Internally, a new 'is_ilnp' flag is used in the socket data structure (*struct sock*) so that the kernel can distinguish ILNPv6 sockets from IPv6 sockets.

3.2 ILNPv6 packets

For each incoming and outgoing packet, the kernel must be able to detect if it is an ordinary IPv6 packet or an ILNPv6 packet. For outgoing packets, the destination IP address is checked against the I-LV cache. If the address is found in the cache, the destination is an ILNP node. The sender then adds a nonce value [7] and, for convenience in our prototype implementation only, sets the flowlabel in the IPv6 header to 0x0800. For each incoming packet, the flowlabel is checked. If the flag is set to 0x0800, then this is an ILNP packet, and additional operations for ILNPv6 are performed including validation of the *NID* and *L64* of the sender, checking the nonce value, and updating information in the *ILNP Communication Cache (ILCC)* which is, effectively, a table of ILNP sessions.

3.3 ILNP Communication Cache (ILCC)

The ILCC stores information of all active ILNPv6 communication sessions of the mobile host. It is implemented in the kernel as a combination of a hash table and linked list. Important members of each ILCC element are shown in Table 2. Each element contains remote and local *L64* values implemented as a linked list of *struct l64_info*, which has important members shown in Table 3. The nonce value represent a unique communication session. In this initial evaluation, we use the *bidirectional* nonce value – both communication ends use the same nonce value. The sender would use the nonce value presented in the ILCC or generate a new one, if the value is not set (i.e. a new session is initiated). For a new session, the receiver would obtain the nonce value from the nonce option in the first received packet. For each session, there is only one 'active' local *L64* and one 'active' remote *L64* at the same time. The 'active' local/remote *L64* is changed when handoff, see Section 3.4 for more details.

Table 2: Important members of an ILCC entry.

Name	Type	Description
Remote *L64*	struct l64_info	List of remote *L64*
Remote *NID*	64-bit int	Value of remote *NID*
Remote Nonce	32-bit int	Remote nonce of this session
Local *L64*	struct l64_info	List of local *L64*
Local *NID*	64-bit int	Value of local *NID*
Local Nonce	32-bit int	Local nonce of this session
Session Timer	struct timer_list	Timer to clear nonce values after session timeout

Table 3: Important members of struct l64_info.

Name	Type	Description
L64 value	64-bit int	Value of *L64*
flag	32-bit int	status of this *L64* (active, valid, aged, or expired)
lifetime	32-bit int	Duration that this *L64* stay valid
Timer	struct timer_list	Timer to set flag to 'expired' for stale *L64*

3.4 Handoff Management

In ILNP, handoff is implemented by manipulating the dynamic bindings between *NID* and *L64* values. A mobile host detects a location change when receiving a new prefix i.e. it moves to a new network and picks up a new prefix from the IPv6 RA sent by a new access router. Once a new prefix is received, a new ILNPv6 address is configured. For ILNPv6, the new address is built from a new prefix (*L64*) and the *NID* , not the interface identifier like ordinary IPv6 addresses. The mobile node would then notify a change of *L64* value using *Locator Update (LU)* message [4] to all active correspondent nodes listed in the ILCC.

There are two types of handoff in ILNP: hard handoff and soft handoff. For hard handoff, the mobile host always uses only *one L64* value at a time. Soft handoff allows the mobile host to use more than one *L64* values (e.g. an 'active' one and a 'valid' one), which means that a mobile host can belong to two IP networks simultaneously.

In Figure 2, once the mobile host, X, obtains a new *L64* value ($L2_X$), it updates the current 'active' local *L64* value in ILCC and could (i) set the flag of previously active *L64* ($L1_X$) to 'aged' – *hard handoff*; or (ii) maintain bindings with both $L1_X$ and $L2_X$ when it stays in an overlap region between the two networks (e.g. through radio-cell coverage) i.e. the flag of the previously active *L64* ($L1_X$) is changed to 'valid' – *soft handoff*. With hard handoff packet loss could occur because the correspondent node, Y, still using the old *L64* value, where the packets sent to the 'aged' destination *L64* value. With soft handoff, the packet loss during handoff is minimised, and may be close to zero because the previous *L64* value is still 'valid' for the mobile node, as long as it stays in the overlap area. For Y, once a LU is received, the 'active' destination *L64* would be updated to the new value and the LU-ACK would be sent back to the sender.

3.5 Modification of UDP

We use a UDP application for evaluation, hence the protocol needs to be modified to support ILNPv6. Unlike TCP, UDP is a *connectionless* protocol – there is no session binding. Therefore, the only modification we make is to ensure that the source address and the destination address that will

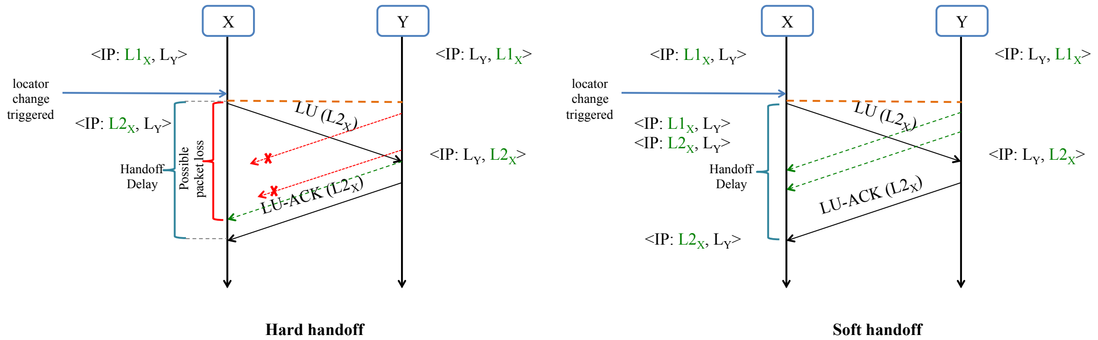


Figure 2: A comparison of hard handoff and soft handoff. Once a mobile node X enters a new network, it receives a new L64 value:$L2_X$. In hard handoff (left), X simply switch to use the new L64 ($L2_X$) and stops using the old one ($L1_X$). Packet loss (red/dotted arrows) could occur until the correspondent node Y learns the updated L64 value, from the Locator Update (LU) sent by X, subsequent packets will be accepted (green/dashed arrows). In soft handoff (right), X uses both $L1_X$ and $L2_X$ simultaneously until it receives the LU-ACK sent by Y, minimising packet loss during the handoff.

be used for building an IP header are up-to-date (i.e. stale values after a location change are not used). The kernel always selects the current 'active' *L64* value from the ILCC to derive the source/destination IPv6 address instead of using the values provided from user space (passed to the socket() call after using getaddrinfo()), which may now be stale.

4. EVALUATION

We examine the handoff performance comparing hard handoff and soft handoff, by considering: (i) the impact on UDP application flows; and (ii) the handoff mechanism based on the LU/LU-ACK exchange.

4.1 Experiment Configuration

Our testbed is configured as in Figure 3. All connections are *wired* Ethernet 1Gbps connections: we emulate WiFi network and 3G network behaviour in terms of loss and delay by using *netem*[1], a popular Linux network emulation tool. Table 4 summarises the characteristic of the WiFi network and the 3G network, and Figure 4 presents the cumulative frequency distribution of the one-way delay. These profiles were obtained from real *ping* measurements of our local office WiFi network and a 3G network from an Apple iPhone 5, over a 40 minute period for each network.

Table 4: Network characteristics of WiFi and 3G.

Connection	Packet Loss [%]	One-way Delay [ms]			
		mean	stdev	95%	99%
WiFi	0.26	33	26	76	180
3G	10.10	112	50	140	276

The routers, R1 and R2, are unmodified Linux machines running *radvd*[2] to announce prefixes for the site networks L_1, L_2 and L_3. To allow the mobile host to pick up new prefixes quickly once it enters a new network, we configure radvd to generate RAs every 1s-2s.

We used a simple UDP/IPv6 application to generate two kinds of traffic between H1 and H2: Voice over IP (VoIP) flows and streamed video flows. The VoIP flows are generated based on characteristics of Skype traffics [9, 12], using a packet size of 300 bytes to generate a 64kbps flow. We use 1 Kbyte packets to generate 250 kbps video (ViIP) flows, as an emulation of mobile YouTube traffic [27]. For both flows, an acknowledgement is sent for each packet, so, the sender can evaluate loss.

We emulated a mobile node moving between WiFi to/from 3G while each of the two flow types was in progress. Handoff

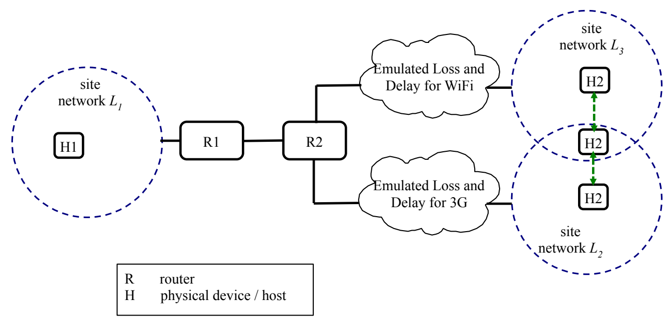


Figure 3: The topology for the experiment. The hosts H1 and H2 reside in different networks, with Locator values of L_1 and L_2, respectively. The green / dashed arrows identify movements of H2 between site networks generating a handoff.

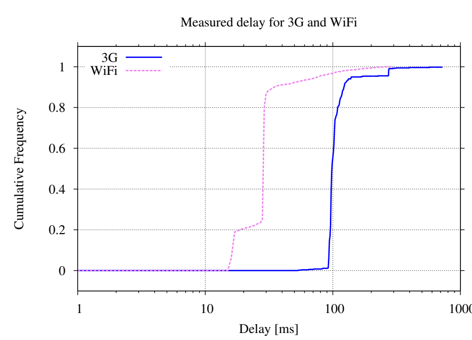


Figure 4: The cumulative frequency distribution of one-way delay of WiFi network and 3G network.

[1]http://www.linuxfoundation.org/collaborate/workgroups/networking/netem/
[2]http://http://www.litech.org/radvd/

was emulated by turning interfaces on and off between the emulated WiFi network and the emulated 3G network. The handoff is triggered when a new interface of H2 comes up and receives a new L64 from an IPv6 RA. The handoff is completed by an LU/LU-ACK handshake as: (i) H2 updates new *L64* value to H1 by sending a LU messages, (ii) H1 responds with an LU-ACK to H2. If H1 did not receive the LU-ACK within in 1 second, the LU was retransmitted. The retransmissions stop after 5 attempts. The handoffs were made every 9 seconds, with 5 seconds in the overlap area (i.e. both interfaces of H2 were on).

Each flow was 75 seconds long. We performed 10 repetitions for each of the scenarios above using hard handoff and soft handoff.

4.2 Results

Packet delay is the application level packet delay. This is the time taken to deliver a packet to another end host. The values are measured using half of the round-trip time (RTT/2) of each acknowledged packet, as the path was symmetric. The closer this is to the natural value, the better. (Figure 5a.)

Handoff delay is the time taken for a mobile host to completely switch to use a new *L64* , i.e. the duration of the LU/LU-ACK handshake. The closer this value is to the RTT, the better. (Figure 5b.)

Overhead is the number of LU / LU-ACK handshakes that are required in order to complete a handoff process. The closer the number is to 1, the better. (Figure 5c.)

Gratuitous packet loss is the application level packet loss additional to the natural network loss, i.e. loss caused by the handoff mechanism. The values are the differences of overall loss (calculated from the number of sent packets and the number of acknowledged packets) and natural loss (see below). The closer this is to zero, the better. (Figure 5d.)

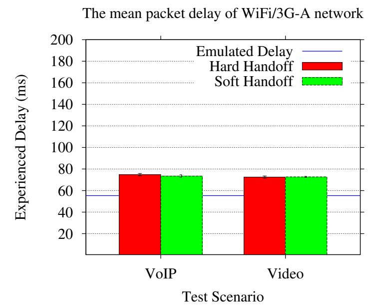
The main finding is that, for our experimental configuration, soft handoff minimises gratuitous loss (Figure 5d), while having similar performance to hard handoff in terms of packet delay (Figure 5a), handoff delay (Figure 5c), and signalling overhead (Figure 5c).

Figure 5d shows that gratuitous packet loss was minimised, and was almost zero. Hard handoff incurred gratuitous packet loss, as expected from our discussion in Section 3.4 and Figure 2, as some packets were transmitted with the incorrect L64 value while the LU/U-ACK handshake was incomplete. As the mobile host started in the WiFi network and handed-off every 9 seconds, it spent 36 seconds (48%) in the 3G network and 39 seconds (52%) in the WiFi network. Hence, the 'natural' loss is calculated from the Eqn. (1), use $Loss_{WiFi} = 10.10$ and $Loss_{3G} = 0.26$ (from Table 4), giving a value of 4.98%.

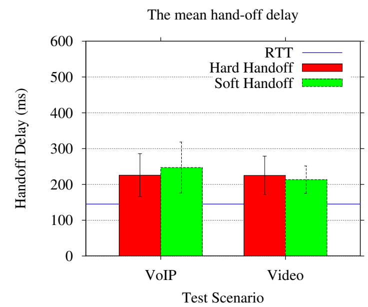
$$Loss = (52Loss_{WiFi}/100) + (48Loss_{3G})/100) \qquad (1)$$

The measured delay, for both hard handoff and soft handoff, is slightly higher than the emulated values in every case by (∼20ms) (see Figure 5a) due to the cumulative processing delays in the end systems and netem. The 'natural' delay can also be calculated from Eqn. (1): by replacing $Loss_{WiFi}$ with $Delay_{WiFi}$ (33ms) and $Loss_{3G}$ with $Delay_{3G}$ (112ms), the natural delay is 70.92ms.

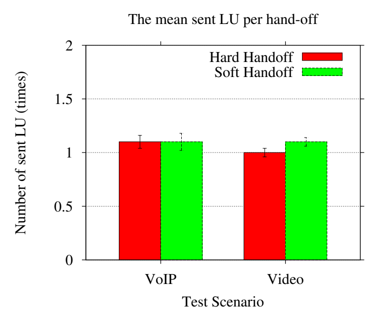
The minimum value of the mean handoff delay (Figure 5b) would be the RTT – 66ms when handing off to WiFi (4 times) and 224ms when handing off to 3G (4 times). So,



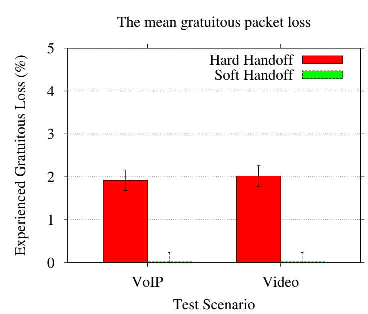
(a) Packet delay.



(b) Handoff delay.



(c) Overhead.



(d) Gratuitous packet loss (Overall loss – Natural loss).

Figure 5: Performance of hard and soft handoff. Error bars at 95% confidence from 10 runs. Horizontal/bue lines are 'natural' values (see Section 4.2).

the mean RTT for the duration of the flow is 145ms. The observed handoff delays are higher than RTT because of some LU/LU-ACK loss which meant handoffs may have had more than one attempt to complete (see the larger error bars). However, the mean value is still low (less than 2

RTT), and we can see that the mean number of LUs sent (i.e. handovers attempted) is low (Figure 5c).

5. CONCLUSION

Our in-kernel Linux implementation of ILNPv6 shows that soft handoff with ILNP minimises gratutous packet loss during handoff, while maintining similar performance to hard handoff in terms of handoff delay, application level packet delay and signalling overhead. We believe that ILNPv6, with soft handoff, could work well in a range of wireless network scenarios including WiFi networks and 3G networks (see our previous work [26]).

The ILNP mobility model is purely end-to-end, not requiring middlesboxes, proxies or tunnelling, and has low overhead. Not requiring middleboxes or proxies also obviates performance bottlenecks, single points of failure and targets for attack by malicious users.

For the future, we plan to complete the ILNPv6 prototype and test against various existing mobility solutions, including Mobile IPv6 and, in a range of scenarios and including with the use of real applications.

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