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Media Independent Handover Transport Using Cross-Layer Optimized Stream Control Transmission Protocol

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Abstract The Media Independent Handover (MIH) architecture finalized by the IEEE 802.21 working group facilitates handovers between heterogeneous networks. The signaling messages exchanged between the network entities, namely Mobile Nodes (MNs) and Points of Service (PoSs) must be delivered in a timely and reliable manner. In this document, we analyze the current proposed solutions to transport MIH messages and review their limitations. We also propose an efficient solution using the Stream Control Transmission Protocol (SCTP). The solution uses SCTP's multihoming and multistreaming capabilities and is optimized by using the MIH services. We analyze the performance of the proposed solution for various packet loss conditions and loads.

Keywords Media Independent Handover, Cross-layer, SCTP, Multihoming

1 Introduction

Nowadays, laptops and phones are able to simultaneously connect to different types of access networks. The emergence of WiMAX, also known as IEEE 802.16, and the future capabilities of fourth generation (4G) networks such as Ultra Mobile Broadband (UMB) or Long Term Evolution (LTE) promise to offer users with more bandwidth and coverage. Users are expecting providers to offer permanent connection while roaming between networks. For example, a Voice over IP user might want its call to be uninterrupted when he is moving from his home to his office. In order to provide such continuous service, an operator might switch technologies according to the location of the user, and adapt the flow data rate to fit the network performance. Each technology provides its own enhancements to support minimum service disruption when switching from one point of access to another but inter-technology handovers are not yet well supported.

To support vertical handovers between heterogeneous technologies, the IEEE 802.21 WG has designed the Media Independent Handover (MIH) architecture [14]. This framework facilitates the exchange of information across the different entities of the mobility management protocol stack within a node and between different network entities via the MIH Protocol. The information exchanged includes abstracted lower layer data, also called L2 triggers, commands to control the behavior of the lower layers, and information about neighboring networks.

The delay and reliability of MIH messages are key elements to performing seamless handovers. If the information is not provided on time, the Mobile Node (MN) may lose its current connection prior to completing all the necessary signaling. Furthermore, the connectivity requiring handoff is most likely suffering from increased packet loss. A requirement for the transport protocol is to be able to maintain its performance under conditions of high packet loss and congestion.

The IETF [1] provides requirements and guidelines for the transport protocol selection of MIH messages. The current solutions use protocols that were designed for wired networks, namely User Datagram Protocol (UDP) and Transmission Control Protocol (TCP), and have limitations in a

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[1] IETF - Internet Engineering Task Force, www.ietf.org

mobile and wireless environment. In this paper we propose a solution to transport MIH messages using the Stream Control Transmission Protocol (SCTP). SCTP is a recent protocol that was designed with unique features, such as multihoming and multistreaming, making it an excellent candidate for heterogeneous and mobile networks. SCTP allows two end-hosts to establish a session and exchange a set of multiple IP addresses. Any of these IP addresses can then be used to exchange data packets, which provides support for multihoming. In addition, a SCTP session supports more than one stream, which means that within a single connection, several flows can be exchanged.
The rest of this paper is organized as follows. In Section 2 we present the MIH architecture. In Section 3 we review the current proposed transport solutions and their limitations. Section 4 provides an overview of the SCTP protocol and its major amendments for partial reliability and handover support. Section 5 contains the solution to transport MIH messages via SCTP while using the MIH Services to optimize the behavior of SCTP. Section 6 provides numerical results demonstrating the performance of the proposed solution. Conclusions are given in section 7.

2 IEEE 802.21 Media Independent Handover Services

The goal of the MIH framework [14], developed by the IEEE 802.21 Working Group, is to facilitate handovers between heterogeneous technologies. This is done by providing mechanisms to easily exchange information about the network. For example, a node with dual cellular/WiFi interfaces could use its cellular connection to request the list of hotspots that are available before turning on its WiFi interface and perform channel scanning. In this section we provide an overview of the MIH architecture, the services it provides, and its protocol to help understanding the type of information that is exchanged.

2.1 Architecture

The MIH Function (MIHF) is the core element of the MIH architecture. It provides its users with an abstract view of the network devices and handles communication with peer MIHFs. The data format used between the MIHF and the MIH Users is the same regardless of the underlying technologies.

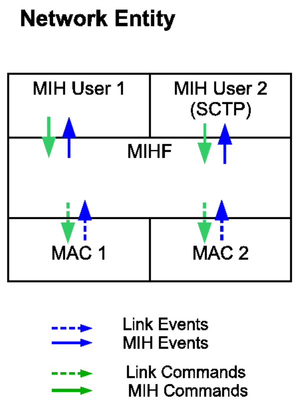


Fig. 1 MIH architecture

As shown in Figure 1, the MIHF can be seen as a layer 2.5 in the mobility control plane. It is located between the lower layers, namely the MAC and PHY layers, and the upper layers, namely IP and above. It facilitates cross-layer and cross-entity interactions. An MIH User can be any entity that needs access to cross layer information, ranging from the IP layer to the application.
The MIHF is located in different nodes of the network. In the MN, it is used to notify the mobility protocols of changes in the network conditions. It is also used to communicate with other entities in the network to discover information about surrounding networks. In the network, the MIHF can be used to perform network initiated handovers and support the MN's handover process. The MIHF in the MN may communicate with other MIHFs located in other nodes, namely PoSs. These PoSs may be located anywhere in the network and provide different services as explained in the next subsection.

2.2 MIH Services

The MIHF provides three services to its users: an abstraction of media dependent information called Media Independent Event Service (MIES); a set of primitives to control the behavior of the lower layers called Media Independent Command Service (MICS); and mechanisms to retrieve information about surrounding networks called Media Independent Information Service (MIIS).

2.2.1 Media Independent Event Service

This service enables MIH capable nodes to generate and distribute layer 1 and layer 2 events to the upper layers. There are two types of events: The Link Events, which are media dependent information exchanged between the lower layers and the MIHF, and the MIH Events containing media independent information exchanged between the MIHF and the MIH Users. In most cases, there is a one-to-one mapping between Link Events and MIH Events. By a registration mechanism, an MIH User indicates the list of events it wishes to receive. This registration may be for a local or a remote MIHF. The MIH standard distinguishes events, whether Link Event or MIH Event, according to the type of information they carry. A *State change* event represents a change in the state of the interface such as a Link Up or Link Down. A *predictive event*, namely Link Going Down, indicates a possibility of losing the connection in the near future. A *Link Parameters* event indicates that a measurement has crossed a configurable threshold. The parameters can carry information such as signal strength or Quality of Service (QoS) values. A *Link Handover* indicates a change in the Point of Attachment (PoA). Finally a *Link Transmission* event is used to indicate success or failure of a packet transmission. Those events provide cross layer information in order to speed up the movement detection of the MNs.

2.2.2 Media Independent Command Service

This service allows an MIH user to control the behavior of the lower layers. This includes turning the interface on or off, performing scanning, or changing PoA. This service also allows an MIH User to request instant status and to configure thresholds for event generation. Similar to MIES, there are two types of commands: Link Commands issued by the MIHF to the lower layers and MIH Commands issued by MIH Users to the MIHF. We can note that Link Commands are always local and destined to one interface while MIH Commands may be for a local or remote MIHF. Furthermore, MIH Commands may contain actions regarding multiple links.

2.2.3 Media Independent Information Service

The MIIS enables MIH Users to collect information about surrounding networks without connecting to them. Discovering potential target networks and their capabilities can facilitate handovers. The information is structured in Information Elements (IEs) grouped into three categories:

- General and Access Networks (ANs) information: provides a general view of surrounding networks. They include information such as network operator, security, or supported mobility management protocol.
- PoA information: list attributes of PoAs located in a geographical area. These IEs specify location, address, and channel range information.
- Vendor specific information: the IE structure is extensible and allows vendors and operators to include their proprietary information.

The information can be located in the node itself if it has been pre-provisioned or previously learned. When the information is not available, the MIHF will contact an Information Server (IS). These servers may be located anywhere in the network and discovery is possible using mechanisms defined in [2, 11]. Furthermore, IS supports secured and unsecured access. The latter one is useful to provide certain information that would help the MN to make a rapid decision during a handover without compromising the network security.

2.3 MIH Protocol

The MIH protocol is defined to carry the messages for the services described previously. MIHFs use the protocol to perform discovery of other MIHFs along with their capabilities, and to register with remote entities. The MIH message header contains the MIH service, action, and a unique identifier called Transaction ID (TID). This TID is used to match request and response message and detect duplicate messages. The transport mechanism to carry the MIH messages is not part of the MIH specifications. The IEEE 802.21 WG only specifies that messages can be carried over layer 2, layer 3, or any layer above, thus requiring the MIH protocol to be very flexible. The protocol can provide reliability by using an acknowledgement mechanism. A sender MIHF can set the ACK-Req bit in the MIH header requesting an acknowledgement message (MIH-ACK) to be sent. The sender may retransmit the message if no response is received. Additionally, the MIH protocol also specifies a flow control mechanism to handle congestion. All the traffic sent by an MIHF is subject to a rate limiter. The acknowledgement mechanism and rate control are optional if the MIH protocol is run over a reliable and congestion aware transport protocol such as TCP or SCTP.

3 Current Transport Solutions

The research community and standardization groups have shown an increasing interest in heterogeneous handovers and the MIH architecture. In this section we describe the problems related to the transport of MIH messages. We also present a summary of the performance analysis using UDP and TCP published in [7].

The requirements for exchanging the information between an MN and its PoS are strict. If messages are not carried in a timely manner, connection may be lost before obtaining information that would allow seamless handovers. A key point to determine the transport protocol to use is the network conditions over which the messages are exchanged. Handovers occur because the network conditions are degrading and the connectivity is at risk. Therefore the events notifying a change (i.e. low signal strength) or predicting a connection loss (i.e. Link Going Down), along with the commands to perform handovers will be exchanged over a weak connection and the packet loss might be high. Other messages such as MIIS requests are likely to be exchanged soon after a node attaches to a new network.

We described in Section 2.3 the MIH mechanisms that may provide reliability and flow control, namely message acknowledgement and rate control. The use of those capabilities depends on the transport protocol used by the MIHF. The MIPSHOP [11] (Mobility for IP: Performance, Signaling and Handoff Optimization) Working Group at the Internet Engineering Task Force (IETF) provides requirements and guidelines for transport protocol selection. For now, only UDP and TCP are mandated and investigated. These protocols are very well known and deployed in all network devices. However, they have limited capabilities in the context of mobile devices that have simultaneous connectivity to multiple access networks, also called multihoming. Both UDP and TCP provide connection between two IP addresses. Firstly, when a node is moving to a different network and needs to change its IP address, the session must be maintained via layer 3 mobility protocols such as the Mobile IP protocol suite [10]. Secondly, if the node is multihomed, UDP or TCP does not provide quick mechanisms to use the most appropriate interface. There are many benefits to multihoming including increased bandwidth, redundancy, and load sharing. However, it is a complex problem and Mobile IPv6 provides limited support to multihoming [1]. Among the multiple proposed solutions [16], the most promising is SHIM6 [13], a multihoming protocol for IPv6. SHIM6 is a host-centric solution located at the network layer, thus making the multihoming capability transparent to the transport layer. Unfortunately, as with most multihoming solutions, it was shown that SHIM6 support for mobility is limited [6].

In [4], the authors propose a generic signaling solution using the Next Steps in Signalling (NSIS) framework. While the solution allows for the MIH to communicate with a single transport protocol, the General Internet Signaling Transport (GIST) layer runs over standard protocols such as UDP, TCP, or SCTP. Therefore, the performance of this solution is dependent on the actual underlying protocol used to carry the MIH messages.

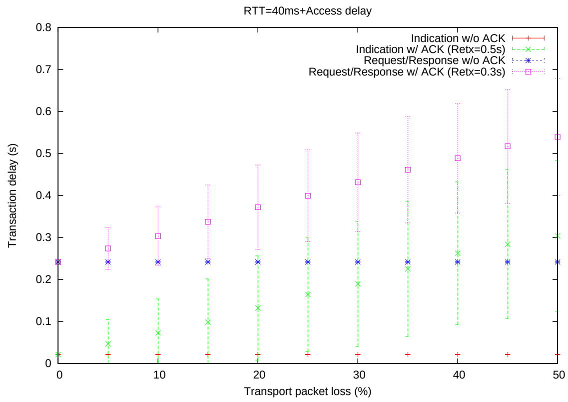
In the next subsections we present an overview of the advantages and drawbacks of using UDP and TCP as transport solution. We evaluated the performance of each protocol to carry MIH messages when the connection between the MN and its PoA suffers from a particular packet loss. The simulations were carried out using NS-2 [15] simulation tool and Table 1 lists the configuration parameters. The measurements include the delays to receive an indication or a response to a request, also called a transaction, and the message reliability.

3.1 UDP as transport solution

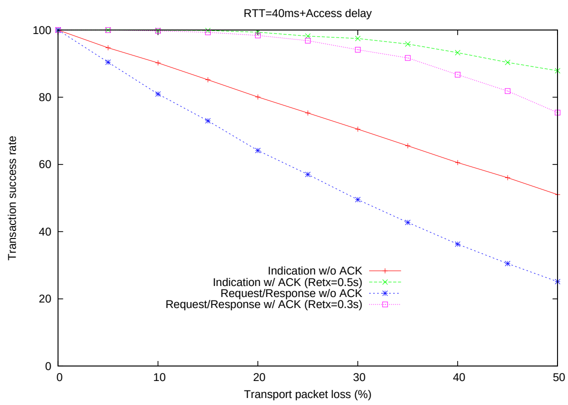
UDP is an unreliable protocol that encapsulates each packet with source/destination port numbers and a checksum. Due to its simplicity, UDP is used for real time applications such as Internet Protocol Television (IPTV) and Voice over IP (VoIP). UDP is often combined with Real-time Transport Protocol (RTP) to provide sequence numbering and stream synchronization. When using UDP, the MIHF protocol must provide reliability using message acknowledgement, retransmission, and reordering. It must also be aware of the network congestion and adjust its transmission rate. This makes the implementation of MIHF more complex but the MIHF has full control over its data transmission. Figure 2(a) and 2(b) show the performance of UDP for various packet losses. It also demonstrates the impact of the MIH acknowledge-

Table 1 Simulation Parameters for UDP/TCP evaluation

Topology	
Access technology	802.11b
Wired link speed (Mb/s)	100
One way delay (s)	0.02 + access delay
UDP	
Max packet size (byte)	1000
Header size (bytes)	8
TCP	
Max Segment Size (bytes)	1280
Min RTO (s)	0.2
Max retransmission	Unlimited
Queue size	Unlimited
Header size (bytes)	20
IP header	
IPv6 header (bytes)	40
MIH Function	
Transaction timeout (s)	none
No. retransmissions for UDP	2
Retransmission timeout (s)	0.2
Simulation configuration	
Duration (s)	6005
loss probability, p	variable [0, 50%]
$RTO_{\max}$ (s)	0.2, 0.3, 0.5, 0.75, 1
Indications/s	2
Requests/s	2
MIH Packet size (bytes)	200



(a) Impact of packet loss on the transaction delay



(b) Impact of packet loss on the transaction success rate

Fig. 2 Performance of UDP as a transport protocol for MIH messages

ment mechanisms on the delays and reliability. As shown in Figure 2(a), the delays to transmit messages is kept low since the retransmission mechanism uses a fixed timeout value as opposed to a traditional exponential backoff implementation. We observe a maximum delays of 0.6 s when the connection suffers from 50 % packet loss. This delay includes processing time of 0.2 s for the request before sending a response. The drawback is that the reliability provided by the MIH acknowledgement is limited, as shown in Figure 2(b). This is due to a default maximum number of retransmissions set to two as defined by the IEEE 802.21 standard. The success rate stays close to 100 % for packet loss not exceeding 10 % and drops to less than 80 % if the packet loss is 50 %. In [12], the authors presented a framework using UDP as transport protocol for network controlled handover. Their results also confirm that a solution using MIH retransmission over UDP does not impact handover performance if the packet loss is kept low (7 %). Prior to a handover, the packet loss is likely to increase suddenly therefore UDP protocol cannot sustain the level of reliability required to successfully transmit the MIH messages.

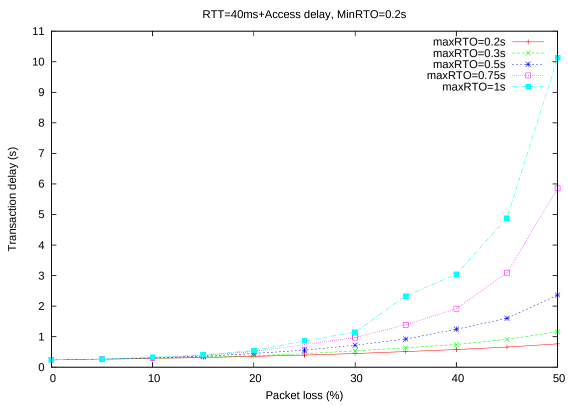


Fig. 3 Delays to transmit an indication using TCP as transport protocol

3.2 TCP as transport solution

If the MIHF uses TCP, the retransmission and congestion control are already implemented at the transport layer. As described in [7], using MIH acknowledgement mechanism in addition to TCP generates unnecessary messages and increases the delays thus should not be used. Though TCP provides full reliability, the delays increase exponentially as the packet loss increases. To compensate for unlimited retransmissions we reduced the upper bound of the TCP retransmission timer, also called maxRTO. The results shown in Figure 3 demonstrate that with a maximum retransmission timeout of 1 s and 50 % packet loss, the delays to successfully send an indication reach 9 s. These delays are too high to perform seamless handovers. We note that the default maximum value for the TCP retransmission timer is 240 s, which would lead to even higher delays.

We conclude that in the case of handovers with weak connectivity, solutions combining UDP with the MIH acknowledgement mechanisms provide unsufficient reliability. On the other hand, solutions using TCP cannot provide the low delays required for seamless handovers. In addition, neither UDP nor TCP were designed with multihoming capability. Due to those limitations, we propose an efficient solution to exchange MIH messages using SCTP.

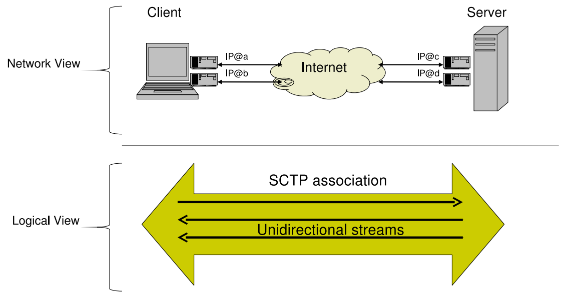


Fig. 4 SCTP architecture

4 Overview of SCTP and its extensions

In this section we introduce SCTP as defined in [19] and its two major extensions to support partial reliability [20] and dynamic address reconfiguration [22].

4.1 SCTP

SCTP is a recent transport protocol developed by the Signaling Transport (SIGTRAN) IETF working group. It was originally created to support signaling in Voice over IP (VoIP) applications. It has since been generalized and provides several enhancements to TCP, including security and robustness. SCTP is a reliable message oriented protocol with multihoming and multistreaming capabilities. As shown in Figure 4, the protocol allows end points to communicate via multiple addresses, often due to the presence of multiple network interfaces. SCTP uses multihoming for failure recovery. One of the peer's addresses, called primary path, is selected as default destination address. Upon packet loss on the primary path, retransmissions use an alternate destination address. Performance of multihoming have been studied in [17] and [18] and results show reduced packet latencies when packet loss occurs. Figure 4 also shows that an association between two end points is an aggregation of unidirectional streams. The multistreaming capability removes the Head Of Line (HOL) effect of TCP, where packets are queued waiting for every segment to be acknowledged. In a multistreaming environment, packets of different streams operate independently. SCTP uses selective acknowledgement (SACK) to indicate the Transmission Sequence Number (TSN) of each data chunk received.

Regarding security, SCTP provides a 4-way handshake during the initialization of a new association. A COOKIE information is embedded in order to authenticate the end points. While the connection is alive, Heartbeat messages are periodically exchanged to determine the reachability of the advertised IP addresses. The COOKIE is used to identify potential address stealing as detailed in [21].

Finally, the Application Programming Interface (API) allows an SCTP-aware application to control the number of streams and the addresses to advertise during initialization. Applications can also specify the packet lifetime, ordering, and context identifier for each message sent. The context identifier is used by SCTP when providing feedbacks to the application.

4.2 SCTP Partial Reliability extension (PR-SCTP)

SCTP is a reliable transport protocol. If a data chunk has been sent, it will be retransmitted until successfully received and acknowledged by the peer node. The packet lifetime argument passed by the application is valid for messages that SCTP has not yet tried to transmit. PR-SCTP [20] provides partial reliability capability to SCTP allowing it to skip the transmission of a given data chunk. A new chunk called FORWARD-TSN is defined to indicate the new TSN to be used by the receiver who resumes as if the packets with TSN smaller than the FORWARD-TSN have been received. PR-SCTP must be supported by both end points and the capability is advertised during session initialization.
As a framework, PR-SCTP allows for various mechanisms to generate a FORWARD-TSN chunk. The default mechanism introduced by PR-SCTP modifies the definition of the packet lifetime parameter. The new definition applies the lifetime to both queued messages and transmitted chunks not yet acknowledged. If the lifetime expires for a chunk that is not acknowledged, the sender triggers a FORWARD-TSN informing the receiver that this chunk must be skipped.

4.3 SCTP Dynamic Address Reconfiguration

During an SCTP connection setup, each end point provides the list of available IP addresses by which it can be reached. If a node is mobile, it is likely to perform handovers and its IP addresses have to be updated. Two options are available to maintain the connectivity after a change of address: the first one requires the IP layer to hide the changes using a Layer 3 mobility protocol such as Mobile IP [10]. The second option is to have the transport layer indicate to the remote node that the IP address has changed, which is called a Layer 4 handover. It has been shown [23] that handover aware transport protocol provides greater performance since it only involves the end points and does not rely on other network elements such as Home Agents (HA). The specifications defined in [22] allow an SCTP end point to advertise changes about its local addresses while the association is alive. With this mechanism the remote node does not wait for the expiration of HEARTBEAT mechanisms to determine that an address is invalid. The performances of both options have been studied in [17]. Results show that using a congestion aware mobility protocol, i.e. SCTP with Dynamic Address Reconfiguration, the transport performance is improved during handovers.
The Dynamic Address Reconfiguration document defines a new chunk type called Address Configuration Change (ASCONF). This chunk is used by an end point to indicate its accessibility via a new IP address or to indicate it is not reachable via a previously advertised address. Another use of the ASCONF chunk is to specify which local IP address should be used by the peer node as primary destination. In a multihoming scenario, the quality of each wireless connection may change over time. Informing the peer node about the best interface to use improves the overall performance by reducing packet loss and retransmissions. In [9] the authors show that changing the primary path before the connection is lost reduces packet loss. New solutions introduce the use of MIH triggers to initiate the sending of ASCONF chunk. A typical implementation, as presented in [3] and [24], uses a *MIH_Link_Going_Down* event to change the primary path before the handover occurs. On a *MIH_Link_Down* event, the IP address of the interface is removed and after the handover has completed, the new IP address is registered.

Next we present a solution using SCTP to provide a reliable and efficient transport mechanism to carry MIH messages. The solution optimizes the SCTP mechanisms presented in this section and allows the MIHF to indicate when messages should be discarded.

5 Proposed MIH transport solution via SCTP

In this section, we present a solution to efficiently carry MIH messages using the SCTP protocol. The proposed solution is based on a strong interaction between MIH and SCTP, where each layer is enhanced by using the capabilities offered by the other one. On the one hand, in the mobility control plane, SCTP is an MIH User and is located above the MIHF. SCTP uses MIH services such as events and commands to be aware of changes at the lower layers, adapt its transmission parameters, and select the best interface. On the other hand, MIHF sends and receives MIH messages by using SCTP as a transport protocol. Therefore, in the data plane, the MIHF is located above SCTP in the TCP/IP model. These two representations of the proposed architecture are shown in Figure 5.

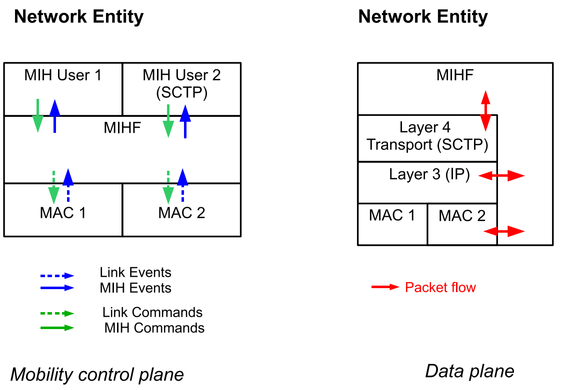


Fig. 5 Role of MIHF in control and data planes

The rest of this section describes the enhancements to SCTP in the mobility control plane with the definition of a path selection algorithm as well as the data plane with modifications to the partial reliability capability and the prioritization of the messages.

5.1 Interface selection algorithm for multihoming

In the mobility control plane, we propose that SCTP implements an interface selection algorithm that minimizes the delays to transmit the packets by using the MIH services. When the sending node is multihomed, SCTP can decide which address to use to transmit messages. This address can be registered as primary path for the peer node. It can also use an alternative address to retransmit messages. We propose a new interface selection algorithm that estimates the average delay to transmit a packet using one interface and includes one retransmission on another interface. Let RTT_i be the measured Round Trip Time using interface i. Let RTO_i be the current value of the retransmission timer for chunks sent via interface i. Finally, let L_i be the current packet loss measured on interface i.
The RTT and RTO are measurements already collected via the exchange of the HEARTBEAT messages within SCTP. The algorithm also makes use of the MIH Services, specifically the primitive *MIH_Get_Link_Parameters* of the MICS, to retrieve the current packet loss at the interface.
If the transmission succeeds using interface i, with a probability $1 - L_i$, the delay is RTT_i. If the first transmission fails, with a probability L_i, and succeeds when retransmitting using interface j, with a probability $1 - P_j$, the delay is $RTO_i + RTT_j$. We can deduce the average delay:

$$Delay(i,j) = (1 - L_i) * RTT_i + L_i * (1 - L_j) * (RTO_i + RTT_j) \tag{1}$$

In [8], the authors present an adaptive primary path switching algorithm based on the Round Trip Time (RTT) measured on each path. The results show that a switching coefficient, i.e. the difference between the RTT on the primary path and the alternate paths that need to occur before switching, should vary depending on the gaps between the RTT values. We also introduce a switching coefficient α (with $\alpha \geq 1$). This coefficient helps reducing frequent updates, also known as ping-pong effect, when multiple combinations of i and j return similar values of $Delay(i,j)$.
Let a be the current primary interface and let b be the interface to retransmit in case the chunk is lost. We execute the following algorithm to determine which interface SCTP will use for sending packets:

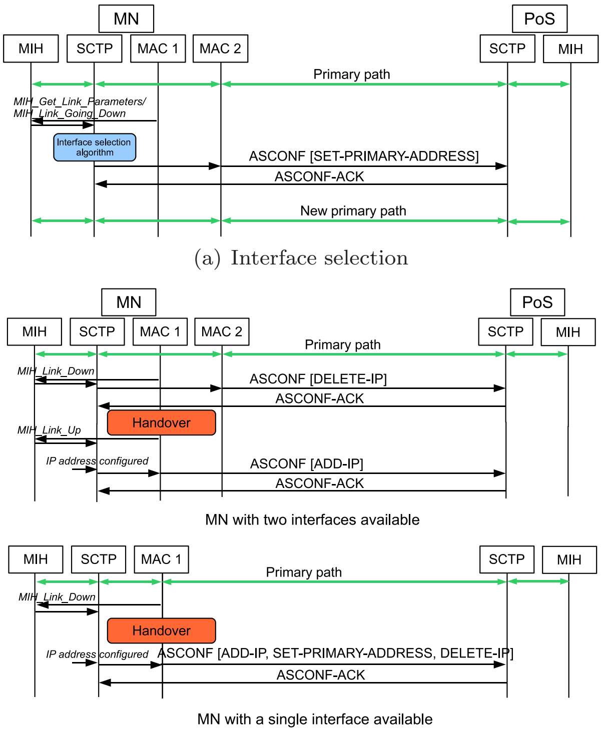
```
foreach Interface i do
    foreach Interface j (j ≠ i) do
        Calculate Delay(i,j);
        if Delay(i,j) ≤ α * Delay(a,b) then
            a = i;
            b = j;
        end
    end
end
```

Algorithm 1: Path selection

When the primary interface a changes, it triggers the sending of an ASCONF chunk to inform the remote node to change its primary destination address.

5.2 Fast movement detection using MIH services

In this section, we define when SCTP executes the interface selection algorithm, which is done by monitoring the quality of the connection and detecting the reachability of the peer node. We explained in Section 4.3 that an SCTP end point can advertise local changes to switch the primary path and avoid the long HEARTBEAT mechanisms. The proposed solution uses the algorithm presented in Section 5.1 to determine the appropriate primary path. SCTP retrieves the current packet loss using the *MIH_Get_Link_Parameters*



(a) Interface selection

(b) Signaling during handovers

Fig. 6 SCTP signaling using MIH Services

from MICS. The polling is done periodically (every few seconds) and upon receiving *MIH_Link_Going_Down* events. As shown in Figure 6(a), if the best interface is different after running the algorithm, SCTP sends an ASCONF chunk containing a SET-PRIMARY-ADDRESS option.
To be aware of the node's movement, SCTP can use Layer 3 movement detection based on Router Advertisement (RA) [5]. However, this solution is slow and optimizations are difficult to deploy. In the proposed solution, SCTP will use the MIH Services to increase its response time by registering for *MIH_Link_Down* events. As shown in Figure 6(b), upon receiving the *MIH_Link_Down*, SCTP sends an ASCONF chunk with DELETE-IP option to the peer node if there is another interface available. If the node only has one interface, SCTP will wait until the connection is reestablished to update the peer node. SCTP also interacts with the IP protocol to receive indication that a new address has been configured. When the new address is available, SCTP sends an ASCONF chunk with ADD-IP option to register the new address. We note that using *MIH_Link_Up* event is not sufficient to indicate the new address. Per definition, it only indicates that the Layer 2 is ready to send up-

Table 2 Priority and maximum number of pending MIH Events

MIH Event type	Maximum number of pending events	Priority
Synchronous	1	1
State	1	1
Prediction	1	2
Parameters change	N	3

per layer messages. SCTP also needs the IP layer to be configured.

5.3 Reliability

In the data plane, when the MIHF sends packets via SCTP, we propose to take advantage of SCTP Partial Reliability and add a new function to explicitly cancel the transmission of expired messages. The validity of MIH messages varies according to the information carried. MIIS messages describing network infrastructure have an extended lifetime and retransmissions will not invalidate the data. Events represent changes in the lower layers. As the MN moves, there can be many changes occurring at once, thus generating multiple messages. Furthermore, if the connection is weak and the MN has to retransmit lost messages, new events will be queued. Commands are reactions to events therefore if the events reported are delayed or invalid by the time they are received, the handovers might fail.
The lifetime parameter, included in the SCTP's send method, is used by PR-SCTP to determine when to stop sending a packet and replace it with a FORWARD-TSN chunk. This assumes the application has knowledge of the message validity prior to sending. If we take the example of MIH Events, the information reported is valid as long as a new event does not invalidate it. We propose to extend the SCTP user interface to allow the application to cancel the transmission of a message. This function requires one parameter: the context identifier that was passed with the message to send.

5.4 MIHF control of SCTP

In the data plane, we propose that the MIHF makes use of the multistreaming capability of SCTP to prioritize messages. An SCTP-aware application, in our case the MIHF, can configure the number of streams and the list of addresses to use. It can also

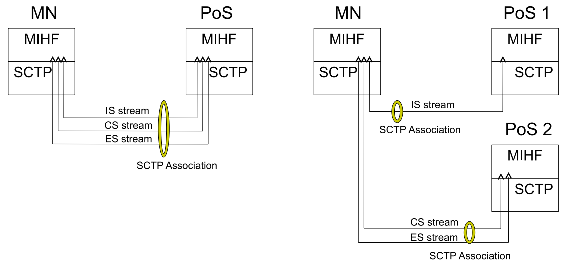


Fig. 7 MIH Service deployment

indicate the lifetime and ordering of each packet. The proposed solution exploits those capabilities. MIH services, namely MIES, MICS, and MIIS are independent of each other and have different constraints. As shown in Figure 7, the MIH services can be co-located or provided by different PoSs. When an MIHF creates an association with a PoS, it will only create streams for the supported services. Since SCTP maintains state information for each stream, limiting the number of streams reduces the resources used.

As expressed in Section 5.3, the lifetime of an event varies upon the generation of future events. We propose to have the MIHF maintain information about the events sent to SCTP and indicate when they are no longer valid. The solution is based on event priority as shown in Table 2. In this table, a lower priority value indicates a higher priority. We distinguish four types of events with slight changes to the categories defined by the IEEE 802.21 WG: *Link State* events indicate a change in the state of the interface; *Link Synchronous* events indicate that the lower layer is starting or has completed a handover; The *Link Prediction* events indicate the link may go down; finally, the *Link Parameters* events indicate changes in network conditions.

We argue that the importance of the information carried varies according to the type of events. Furthermore, the generation of an event may implicitly indicate that some other events have occurred. The values in the column Maximum number of pending events shown in Table 2 are determined based on the following assumptions: An interface can be only in one state, up or down, and can perform only one handover at a time. Additionally, there is only one valid prediction at a certain time. If the lower layer generates a new *Link_Going_Down* event then the new value takes precedence over the previous event and therefore there is no need to send the previous prediction. The value N for Parameters change event is assigned according to the resource availability in the node and timing requirements for sending parameter changes. The larger the value of N, the more memory it will use and the longer SCTP will try to transmit those events. The multiplicity for the Parameters change events is due to the fact that an event may contain multiple parameters and therefore would require finer granularity and more complex processing to differentiate them.

The MIHF maintains the list of events sent in each category for each link. The following algorithm is used to decide when the MIHF informs SCTP that a message is no longer valid:

1. *When a new message must be sent, look up its priority*
2. *Cancel all messages that have lower priorities*
3. *If the multiplicity is 1, then cancel the message from the same category; otherwise if there are already N messages in the sending list, cancel the oldest event in the list.*

By using the proposed mechanism, MIHF removes low priority and obsolete messages. It is necessary to note that SCTP may have successfully transmitted the messages that the MIHF is indicating as expired and will just ignore the command. To avoid handling multiple identifiers, the MIHF uses the TID contained in the MIH message header as context identifier when sending a message and when indicating SCTP to skip the message.

6 Performance evaluation

To evaluate the performance of the proposed solution, we extended the mobility framework for NS-2 [15]. The extension includes implementation of PR-SCTP, Dynamic Address Reconfiguration and integration with the MIH framework. This section contains simulation results evaluating the transport of MIH messages via SCTP and its impact on handover signaling delays. It shows the performance improvements obtained with our proposed solution.

6.1 Scenarios

The topology and network configuration used to perform the evaluation are shown respectively in Figure 8 and Table 3. We study the signaling delays to perform a handover with an MN equipped

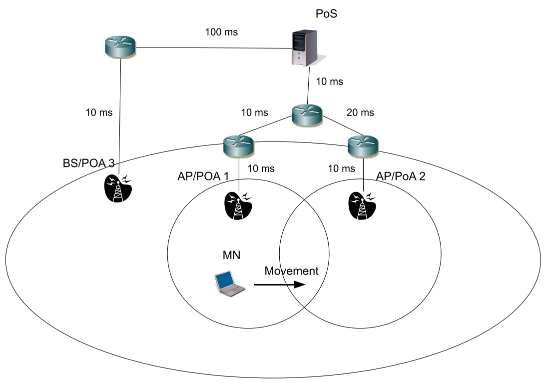


Fig. 8 Simulation topology

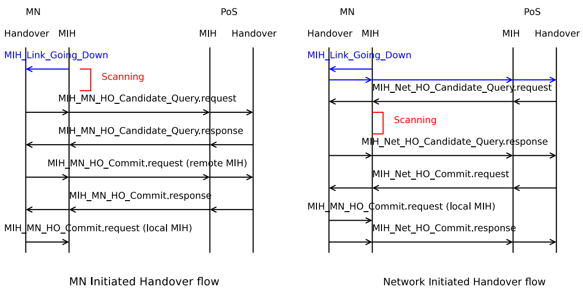


Fig. 9 Message flow during handover

with multiple interfaces. We perform the analysis of two representative cases differentiated by the availability of an alternative technology that can be used to support the signaling. In the first case, the MN does not have multihoming capability. This situation can occur when the MN only has one interface, when the other interfaces are turned off, or when there is no current coverage for the other interfaces. In this case, the MN can only connect to an 802.11 Access Point (AP), namely AP1 or AP2. In the second case, the MN has a second available interface of type 802.16, which allows it to connect to the 802.16 Base Station (BS), namely BS3. In all cases, the MN is first connected to AP1 and is moving away at constant speed. When the measured signal strength decreases below a pre-configured threshold, we set a fixed packet loss on the 802.11 link between the MN and AP1 for the rest of the simulation. To study the impact of packet loss, we select the loss between 0 % and 40 %. Additionally the lower layer periodically generates *Link_Going_Down* events along with parameter reports.

We analyze the performance of the proposed solution for MN initiated and Network initiated handovers. The message flows are shown in Figure 9.

For MN initiated handover, the reception of a local *MIH_Link_Going_Down* triggers a scanning to find potential target AN. Then the MN communicates with the PoS via *MIH_MN_HO_Candidate_Query* request/response to obtain information about potential target networks. Upon receiving the response, the MN decides which target AP to use and informs the PoS via *MIH_MN_HO_Commit* request. When the PoS acknowledges the request, the handover is executed. In the case of Network initiated handover, the MN first sends a remote *MIH_Link_Going_Down* to the PoS. The PoS tells the MN to search for potential targets via the *MIH_Net_Candidate_Query* requests, triggering a scan. The result of the scan is reported to the PoS, which performs the target selection. The decision is transmitted to the MN via an *MIH_Net_HO_Commit* request. When receiving the request, the MN performs the handover and sends a confirmation to the PoS.

In our evaluation, the MIH handover signaling delay is defined by the time between the generation of the first *MIH_Link_Going_Down* event to the time the handover is triggered (*MIH_MN_HO_Commit* request). We observe that the signaling is independent of the target network selected and the signaling delays will be identical whether the resulting handover is horizontal or vertical.

We study the impact of packet loss and frequency of events generated on different MN's capabilities, namely multihoming, use of MIH services, and the control of SCTP by the MIHF.

6.2 Numerical results

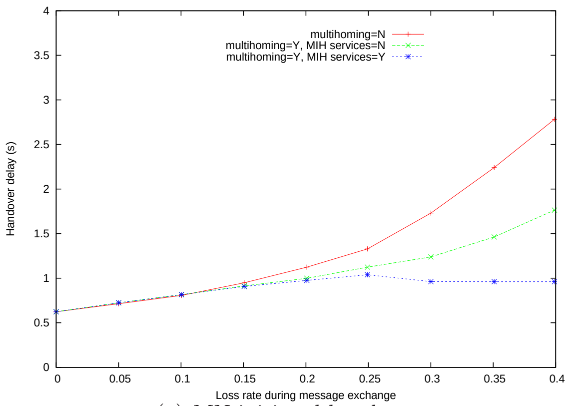
The results in this section show the mean MIH handover signaling delays and MIH handover signaling delay distribution of the proposed solution to carry MIH messages for different packet loss conditions. We repeat the simulations until we obtain a 95 % confidence interval for each measurement point. To facilitate the reading of the figures, overlapping curves are merged into a single curve and only the impacting parameters are indicated.

6.2.1 Impact of the packet loss on the MIH handover signaling delay

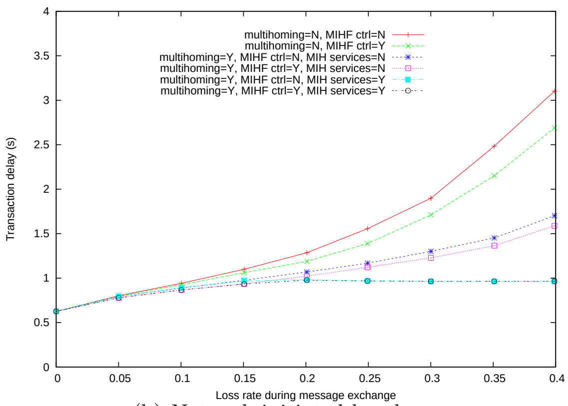
The results in Figures 10(a) and 10(b) show the average MIH handover signaling delays for the MN and Network initiated handovers respectively.

Table 3 Generic simulation parameters

Parameter	Value used
Network topology	
WLAN cell coverage	disk with a radius = 50 m
WIMAX cell coverage	disk with a radius = 500 m
Link delays (s)	Fixed, as shown in Figure 8
802.11 MAC Sublayer Configuration	
Data rate (Mb/s)	11
Default scanning mode	Active
Default propagation model	TwoRayGround
Packet loss	0-40 %
802.16 MAC Sublayer Configuration	
Modulation	64 QAM 3/4
Default propagation model	TwoRayGround
Packet loss	0 %
Mobility Model	
Velocity (m/s)	1
Path	Straight line
SCTP Configuration	
Segment size (bytes)	1448
Default number of streams	1
Event configuration	
Event rate interval (s)	0.15

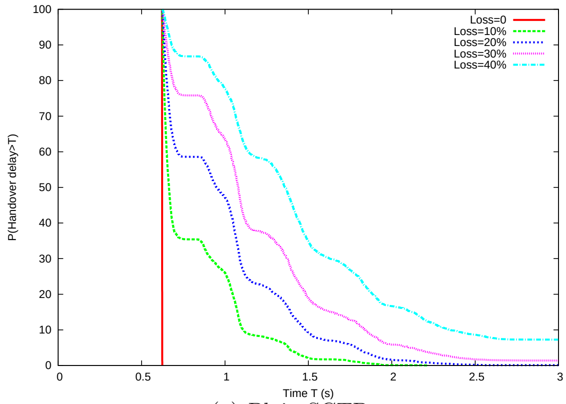


(a) MN initiated handover

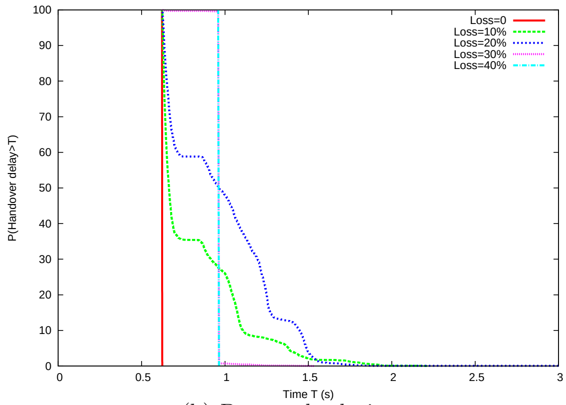


(b) Network initiated handover

Fig. 10 Impact of the packet loss on the MIH handover signaling delay



(a) Plain SCTP



(b) Proposed solution

Fig. 11 MIH handover signaling delay distribution for various packet losses in MN initiated handovers

- *Influence of the multihoming capability*
The highest delays occur when the MN has only one interface. With a packet loss of 40 % we measure delays up to 3.2 s for both MN and Network initiated handovers. When the MN is multihomed the handover signaling delays are decreased because SCTP makes use of the second interface to transmit packets. When MIH services are not used, SCTP uses the second interface for retransmission but does not change the primary path. We observe delays up to 1.6 s when the primary connection suffers from 35 % of packet loss. On the other hand, if MIH Services are used, the adequate path is computed according to the algorithm described in Section 5.1. This leads to delays up to 1 s in both MN and Network initiated handovers.

- *Influence of using MIH services*
The results confirm that cross-layer optimization does not provide better performance when the MN is not multihomed. Even though the connection is weak, retransmissions must occur on the same interface. We notice that if the packet loss is less

than 15 %, all solutions perform the same with delays between 0.6 s and 1 s. This is because using the 802.11 interface still provides better results than changing the primary path to the 802.16 interface. Beyond 15 %, the interface selection algorithm estimates it is beneficial to change the path.

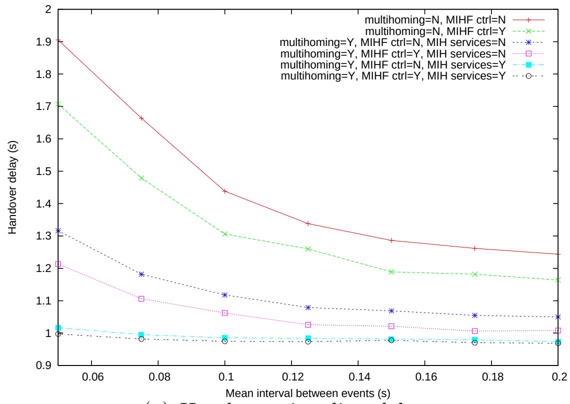
- *Influence of MIHF controlling SCTP*
In the case of MN initiated handovers there are only commands sent (no remote events). The results are identical whether the MIHF controls SCTP or not, thus the curves overlap. For Network Initiated handovers, we can see that if the MIHF indicates when events are outdated, the delays are reduced by up to 20 %. This is especially true when the MN only has one interface. If the MN is multihomed, the impact is less due to existing lower transmission delays.

6.2.2 MIH handover signaling delay distribution

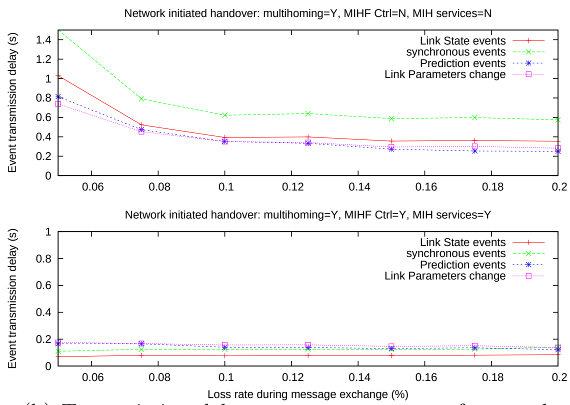
Figure 11(a) and Figure 11(b) show the distribution of the delay to complete an MN initiated handover respectively for a plain SCTP implementation and for an implementation using the proposed solution when the MN is multihomed. Because the delays of the links in the network are fixed, the delay variations are caused by the various retransmissions at the wireless link layer (where the packet loss occurs) and at the SCTP layer when the wireless link did not succeed to transmit the packet. We notice that in Figure 11(a) the delays are highly impacted by packet loss. For 10 % packet loss, the probability that the handover exceeds 1 s is 0.25 while for 40 % packet loss, the probability that the handover signaling delays take more than 1 s is 0.75. On the other hand, when SCTP uses the proposed solution, the delays become less sensitive to packet loss. The probability that the handover signaling delays exceed 1.0 s is less than 0.5 regardless of packet loss. We observe similar results for Network initiated handovers.
The results show that by enhancing SCTP's capabilities with an interface selection algorithm, cross-layer information, and MIHF support we can reduce the impact of packet loss on handover signaling delays.

6.2.3 Impact of event rate on MIH handover signaling delays

The proposed solution enhances SCTP's partial reliability capability by allowing the MIHF to indicate when MIH event messages are no longer



(a) Handover signaling delays



(b) Transmission delays per event category for a multihomed MN with standard SCTP (top) and proposed solution (bottom)

Fig. 12 Impact of event rate generation in Network initiated handovers

valid. Figure 12(a) shows the impact of the MIH event rate generation on the handover signaling delays by varying the interval between two consecutive events from 0.05 s to 0.2 s. The event generation rate typically depends on the MIH User configuration for periodic updates and the node's movement. We observe that the delays are low and almost constant (around 1 s) when the MN is multihomed and MIH Services are used. We notice that due to the low delays, the MIH control of SCTP does not provide any gain. This is not true if MIH Services are not used or more importantly if the node is not multihomed. In the former case, the handover signaling delays are reduced by up to 10 % while in the latter case, we observe reduction up to 17 %. If the node is not multihomed and the solution is not implemented, there is a high impact of the event rate on the handover signaling delays. If events are generated every 0.05 s, handover signaling delays exceeds 1.8 s. This is due to the transmission of events blocking the exchange

of MIH commands.
Figure 12(b) refines the results by showing the delays for each type of events. The top figure represents the results for an implementation that does not use MIH Services nor SCTP control of MIHF whereas both are used in the bottom figure. In both cases, the MN has multihoming capability. When the MIHF does not indicate that MIH events are not longer valid, MIH messages are queued for transmission thus increasing the transmission delays up to 1.5 s for Link Synchronous events when the interval between events is set to 0.05 s. When the interval is less than 0.1 s, the delays to transmit each event increases exponentially as the interval decreases. We further notice that events generated later in the handover process suffers from higher delays. If the MIHF implements the proposed solution, SCTP will only try to transmit the most up to date events or events with higher priorities. The result is a lower transmission delays, under 0.2 s, for all types of event. Additionally, the figure shows that packets with higher priority have lower delays. We also notice that the delays between the two cases converge when the event rate decreases. This is because SCTP has more time to retransmit messages before a new event arrives.

7 Conclusion

In this paper, we presented the MIH framework currently developed at the IEEE 802.21 WG. This architecture focuses on providing seamless handovers in heterogeneous environments when an MN is capable of connecting to multiple access networks via multiple interfaces. This is achieved by exchanging information across multiple layers of the same entity and by sharing information between nodes in the network. Therefore the delays to exchange MIH messages are critical to achieve low handover signaling delays. After discussing some of the performance tradeoffs for transport solutions using UDP and TCP, we introduced SCTP and its capabilities, namely multihoming, multistreaming, partial reliability, and address reconfiguration. We then proposed a complete solution to use SCTP as an efficient transport solution for MIH. The solution combines a path selection algorithm and the use of MIH Services to optimize SCTP's behavior. It also extends the Partial Reliability feature to allow an SCTP user, i.e. the MIHF, to dynamically indicate when a message is no longer valid. Simulation results show that the proposed solution reduces the impact of the packet loss and the event generation rate on the transmission delays. We observed that the proposed solution reduces the delays even when the MN does not have multihoming capability.

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