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Re:	IEEE 802.21 Session #10 in Garden Grove, CA
Abstract	This document first gives a list of handover performance metrics and link layer parameters that can be used to quantify the quality of a link. Thereafter, the document aims at exploring the effect of key link layer and router configuration parameters on handover performance. Finally the previous results motivate the choice of which value is considered as better.
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1 Acronyms

AP: Access Point

AR: Access Router

BS: Base Station

BSS: Basic Service Set

BSSID: Basic Service Set Identifier

L2: Layer 2

L3: Layer 3

MIH: Media Independent Handover

MN: Mobile Node

ND: Neighbor Discovery

RA: Router Advertisement

RS: Router Solicitation

WLAN: Wireless Local Area Network

2 Parameters for IEEE 802.11 Link Layer Quality

We propose a list of parameters to characterize the quality of the IEEE 802.11 link layer and that can constitute a basis to compute the Link Down and Link Going Down events. These parameters can be used in both simulation modeling and real implementations.

- **Data rate**: this represents the theoretical bit rate that an interface is able to operate on. Since the coverage area is generally larger for lower data rates, devices may adapt their transmission rates according to the received signal strength. If the AP is capable of supporting different bit rates, then it might change its data rate with a particular station in order to maintain the association with this station. Therefore, the change of the data rate used between an AP and a MN might be an indication that the MN is getting far from the AP.
- **RSSI (Received Signal Strength Indicator)**: the RSSI measures the signal strength of the received frames. This parameter is a function of the distance between the MN and its AP and can be used to detect that a link is going down. However the RSSI also depends on the environment, interference, noise, channel propagation properties, antenna design. A drop of the RSSI does not necessarily mean that the MN is about to leave its AP's cell, but it can be due to temporary interference for example.
- **Packet error threshold or number of packets with errors**: when a MN is loosing its association with its AP, the number of packets received with errors increases. Therefore, the number of packet with errors might be a criterion to determine that the link is going down.

- **Missed beacon threshold or number of missed beacons**: when a MN is out of range of its current AP, it can not receive the beacon messages that are periodically sent by the AP. A MN is able to determine the number of beacon messages that it has missed because the beacon interval is included in each beacon. Therefore, the number of consecutive beacon messages missed by a MN might be a criterion to determine that a link is down.
- **Number of retransmissions**: if the number of retransmission needed to successfully send a frame to the AP is increasing, it means that either the data frame is lost or the acknowledgment is lost. When the MN is getting close to the border of its AP's cell, more errors can be introduced in packets and therefore more retransmissions are incurred.
- **Number of duplicate frames**: if the MN is receiving multiple instances of the same data frame, it means that the acknowledgment packets are lost. Therefore, it might indicate that the AP is not receiving correctly the MN's frames and might indicate that the link is going down.

3 Handover Performance Metrics

In this section, we discuss the performance metrics used to measure the effects of handover on the MN performance.

3.1 Handover latency

The handover latency is the time needed to complete a handover. It includes the movement detection, the decision process, the new address creation/validation if needed and the redirection latency that includes a round trip time with the correspondent. The starting point of the handover is the moment when the MN enters / leaves the cell.

During a handover, a MN is not able to use the interface on which it is redirecting its flow, until the handover is completed. However, during a handover, a MN might be able to send and receive data packets through another interface, which is still available for data communication.

3.2 Disconnection factor

The disconnection factor is the ratio of the disconnection time, when a MN is not able to receive its data traffic over any of its interfaces, over the handover latency. The disconnection time varies between 0 and the handover latency. For example, if one of a MN's interfaces goes down, the MN will be disconnection until it completes a vertical handover on another interface. In this case, the disconnection time will be equal to the handover latency.

3.3 Packet loss

The packet loss is the ratio between the packets discarded because of errors at the receiver and the total number of packets expected during a handover.

3.4 Number of out-of-order packets

The number of out-of-order packets is the number of packets appearing out of sequence at the higher layer. If the interface the MN is using an interface that is still available while t performing a handover to another interface, packets may be received through both interfaces for a short period of time.

3.5 Movement detection efficiency

Since the link triggers are supposed to speed up the movement detection in preparation for a handover, the movement detection efficiency represents the ratio between the time required to detect a movement with respect to the total amount of time required to perform a handover.

3.6 Probability of wrong link trigger generation

The generation of a wrong link trigger may dictate a MN to perform some operation such as a handover. As some link events (e.g. Link Down event) are generated from packet loss or signal quality measurement, a MN may generate a wrong link trigger because of a collision or a temporarily interference.

3.7 Preferred Usage Efficiency

The preferred usage efficiency measures the ratio of the actual time a preferred interface is used over the total time it could have been used based on availability and coverage area. User satisfaction is higher if the preferred interface usage is maximized.

4 Simulation model

In this section, we describe the simulation model using NS-2 version 2.28 (http://www.isi.edu/nsnam/ns/).

4.1 Key modifications to NS-2

To support our simulations, different modifications and improvements to NS-2 have been necessary. The modifications include:

- Migration of UMTS module into the core (see section 4.3), and hierarchical addressing support
- Design of multiple heterogeneous interface node
- Dynamic address assignment (currently only supported for 802.11 nodes)
- Improvement and bug fixes to the 802.11 implementation as defined in section 3.2

We also developed different modules:

- Neighbor Discovery agent to provide Layer 3 discovery mechanisms
- Media Independent Handover agent implementing 802.21 events and commands
- Interfaces Manager to support handovers and flow redirection

- Handover modules supporting different policies

4.2 IEEE 802.11

The 802.11 Model available in NS-2 has been modified to fit our needs of mobility requirements. The following features have been added to the model:

- Beacon messages transmission by AP
- L2 triggers (see section 4.5)
- Association Request/Response and multiple channel scanning (see below).

A L2 handover procedure consists of the following three stages: (1) a discovery stage where the MN is determining the set of APs that are operating in range, (2) an authentication stage where the MN and the AP authenticate themselves according to the IEEE 802.1X and IEEE 802.11i protocols, and the (3) association stage where the MN requests an association to the AP. The simulation model used currently does not include the authentication stage. The details of the simulation model implementation are given below.

1. **Discovery Stage**: There are two methods that can be used in order to discover a new AP depending on the MN mode of operation. In the passive mode, a MN listens passively to the beacon messages sent by the APs operating in its range. The condition for successfully receiving a beacon message from an AP in range is for the MN to operate on the same channel as that particular AP. Therefore, the MN has to periodically change operating channels in order to discover available APs. In the active mode, the MN explicitly requests an advertisement message from the AP in range. Thus, it sends a Probe Request message and waits for a Probe Response message. If a Probe Response message is received within a MinChannelTime, the MN remains on the same channel for a MaxChannelTime and periodically sends Probe Request messages (every MinChannelTime). However, if during a MaxChannelTime interval, no AP is found, the MAC stops its search or switches to another channel, depending on the command received from the upper layers.
2. **Authentication stage** There are no authentication mechanisms implemented at this time.
3. **Association stage** The association stage consists of an exchange of an Association Request message sent by the MN and an Association Response sent back to the MN. The Association Response sent by the AP contains among other parameters a status code that indicates whether the MN is accepted in the cell. A status code with a value "0" indicates a successful association. The association stage is triggered either after a discovery stage when an AP is found and selected, or upon the reception of a connect command at the MAC layer.

4.3 UMTS model

The UMTS model used is based on the EURANE model (http://www.ti-wmc.nl/eurane/). The main assumptions in this model are as follows. All nodes are reachable all the time and the UMTS cell covers the entire map unless specified otherwise.

4.4 MIH model

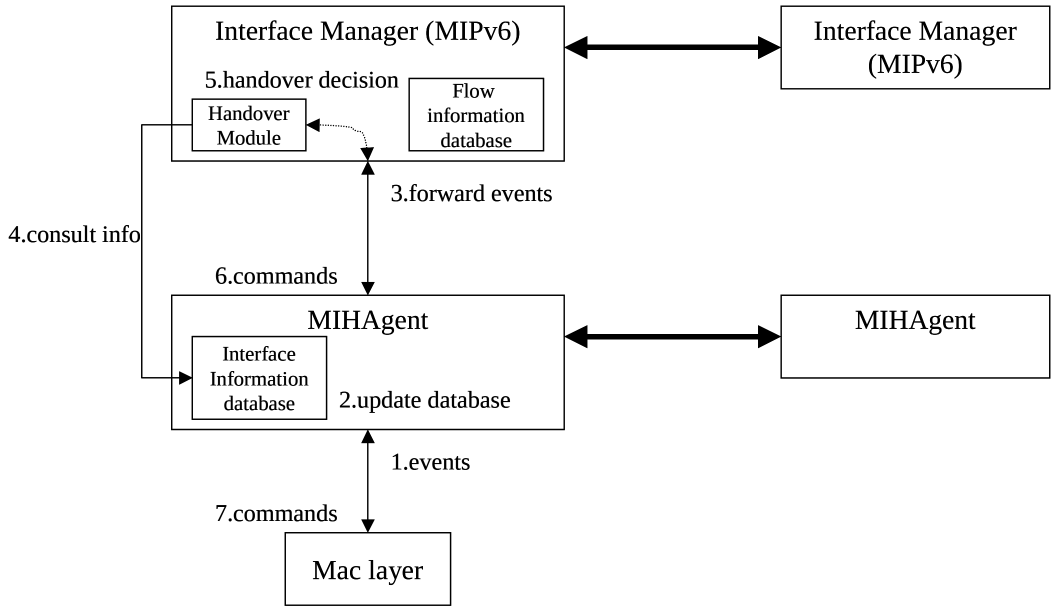

Figure 1: MIH Model in NS-2

In order to model handover mechanisms between multiple technologies, an implementation of the 802.21 MIH Function (according to the draft submitted in May 2005 in the document entitled 21-05-xxxx-00-0000-One_Proposal_Draft_Text.doc) has been developed in NS-2. Figure 1 presents the architecture used.

The following features are currently implemented in the model:

Table 1: List of MIH features implemented in NS-2

Category	Function
Event Service	Link Event Register Link Event Deregister Link Detected Link UP Link Down Link Going Down Link Event Rollback
Command Service	MIH Poll MIH Handover Initiate

MIH Protocol	Event Registration Link Events Handover Initiate (request/response) Poll (request/response)

4.5 Link Trigger Generation Model

The following triggers have been implemented on the MN in the 802.11 simulation model.

4.5.1 Link Detected

At the MAC layer, a Link Detected event is generated upon the reception of a beacon message originating from another AP than the current AP of the MN (passive mode). If a MN is operating in the active mode, then it reports the result of the probe phase to the handover module. A Link Detected event is then generated for each AP that has been found.

4.5.2 Link Up

A Link Up is generated upon the reception of an Association Response message with a status code indicating that the MN is accepted in the cell.

4.5.3 Link Down

A Link Down event is generated when the MAC of the MN is disconnected from the AP. This occurs for any of the following cases:

- N consecutive packets have arrived with errors. By default N is set to 5. Section 5.4.3 gives the effects of varying N on the handover performance.
- An Association Response message is received indicating that the MN is rejected from its current AP (i.e., status code field is different from "0" or unsuccessful).
- The BSSID has expired. The BSSID is advertised only in the Beacon message. By default, the BSSID expires if the MN does not receive a Beacon message during an interval greater than 3 times the Beacon interval, which is by default 3 x 100ms. Section 5.4.2 determines the effects of different BSSID timeout intervals on the handover latency.
- The MN MAC is requested to connect to one AP. This decision can be either local or remote and leads to the generation of a link Down event for the current AP.

4.5.4 Link Going Down

A link Going Down is generated when the power level between two consecutive packets at the receiver is decreasing. Let P_n (in Watt) be the power level of the nth packet received, and P_{Th} be the power level threshold required for receiving packets without errors, a Link Going Down is triggered, if the following two conditions hold true:

$$P_n < \alpha P_{Th} \quad (1)$$

$$P_n < P_{n-1} \quad (2)$$

where α is a tuning parameter. Note that P_{Th} depends on the noise level of the operating environment and vendor fact sheets describing the receiver performance (for example, BER as a function of E_b/N_o). In the following, α will be called power level threshold coefficient.

4.5.5 Link Rollback

A Link Rollback is tightly coupled with a Link Going Down event. If a packet with higher power level is received immediately following a Link Going Down event, then the MAC layer generates a Link Rollback event to cancel the last link Going Down event generated. Thus, a Link Rollback event is generated if the following three conditions hold true:

$$P_{n-2} > P_{n-1} \quad (1)$$

$$P_{n-1} < \alpha P_{Th} \quad (2)$$

$$P_n > P_{n-1} \quad (3)$$

4.5.6 Link Handoff Imminent

A Link Handoff Imminent event is generated at the MAC layer when changing AP.

4.5.7 Link Handoff Complete

A link Handoff Complete is generated upon the reception of an Association Response message that indicates that the association with the target AP is accepted (i.e., status code field is set to “0” for successful association).

5 Simulation results

In this section, we first describe the default simulation parameters and scenarios considered, we then discuss the performance results obtained.

5.1 Simulation parameters

Table 2 summarizes the parameter values used by default in the simulations. Figure 2 illustrates the generic network topology used.

Table 2: Default Simulation parameters

Parameter	Value
Network Topology	
UMTS cell coverage	Entire simulation map
WLAN cell coverage	disk with a radius = 20m
Propagation delay CN – MN (s)	0.09 for the RTT plus the Mac access delay
Number of stationary nodes in the WLAN hotspot	0 to 20 – default = 0
Router Configuration	
MIN_RA_DELAY (s)	200
MAX_RA_DELAY (s)	3 times MIN_RA_DELAY
Router lifetime (s)	3 times MIN_RA_DELAY
Min_Delay_Between_RA (s)	0
802.11 MAC Layer Configuration	
WLAN beacon interval (s)	0.1
Default scanning mode	Passive
MinChannelTime (s)	0.02
MaxChannelTime (s)	0.06
ProbeDelay (s)	0.002
UMTS Configuration	
Transport channel	Dedicated Channel (DCH)
Signal quality	External file (not used in our simulation)
llType	UMTS/RLC/AM – acknowledgment mode
downlinkBW (kb/s)	384
uplinkBW (kb/s)	384
downlinkTTI (s)	0.02
uplinkTTI (s)	0.02
Mobility Model	
Velocity (m/s)	1
Path	Straight line
Application Traffic for Mobile Node	
Type	UDP
Packet size (bytes)	500
Packet interarrival time (s)	0.02

Here, it may be important to make few observations on the simulation parameters used. First, we note the operation of the Neighbor Discovery module. Each AR is configured to periodically send multicast RA messages on its link. Each RA transmission is uniformly distributed between MIN_RA_DELAY and MAX_RA_DELAY. Moreover, each AR sets the Advertisement Interval Option in its RA messages (section 7.3 of RFC3775). This option indicates the maximum amount of time between two consecutive RAs sent by an AR (i.e. MaxRtrAdvInterval).

We also point out that the MN is operating in the passive mode and is listening to same channel as the one the WLAN AP is operating on. This allows the MN to detect the WLAN cell via the beacon messages sent by the AP.

For some scenario, the WLAN hotspot will be loaded with several stations. For this purpose, 0 to 20 stations can be configured to receive application traffic from a CN in the Internet.

5.2 Simulation scenario

The scenario considered for the simulation results that follow consists of one WLAN cell located inside a UMTS cell. This scenario is depicted in Figure 2. It is assumed that one MN (equipped with multiple interfaces) is connected to UMTS before it traverses the WLAN coverage area. The WLAN interface is assumed to be the preferred interface, meaning that if both the WLAN and the UMTS interfaces are available, the MN is set to use the use the WLAN interface for its application flows. Therefore, in this scenario the MN performs two handovers. The first handover from the WLAN cell to the UMTS cell is performed when the MN enters the coverage area of the WLAN AP. The other handover between the WLAN cell and the UMTS is performed when the MN leaves the coverage area of the WLAN AP. Note that when the MN enters the WLAN hotspot, it still has a connection trough the UMTS interface. Therefore, while the association is being established with the WLAN AP, the MN can still use the UMTS interface for its data. On the other hand, when the MN leaves the WLAN cell, the MN is not be able to use the WLAN interface during the time required to redirect the data flow on the UMTS interface.

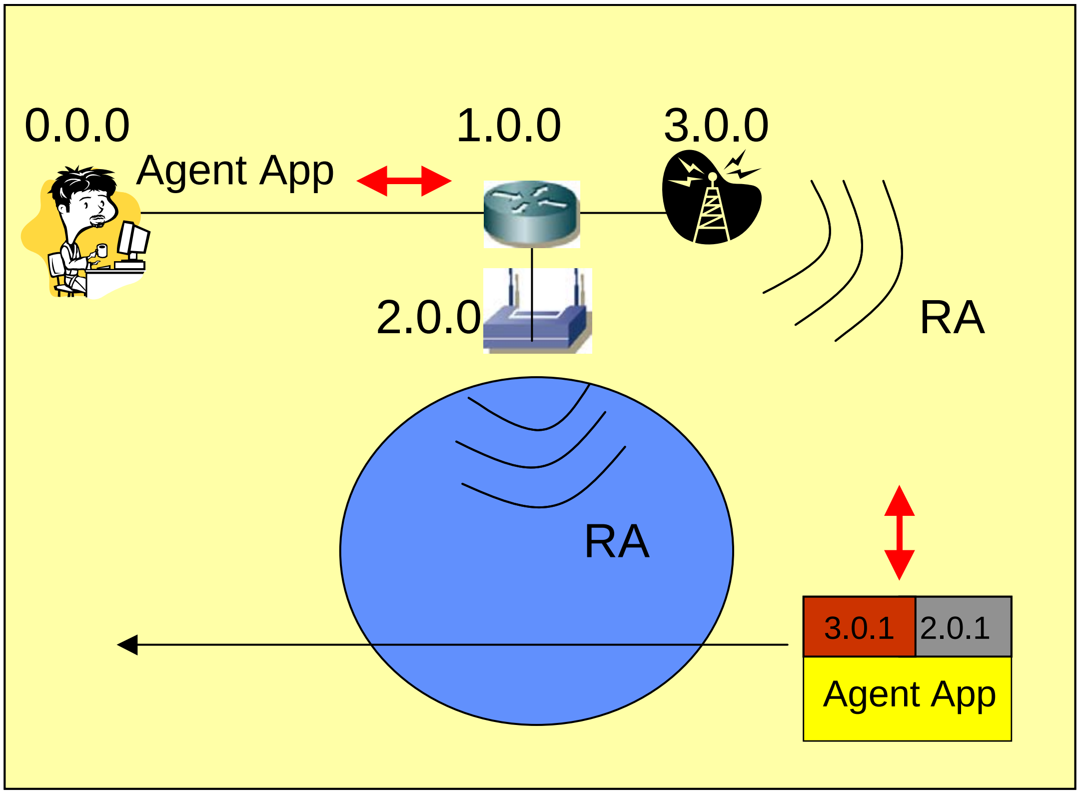

Figure 2: Handover between a UMTS and a WLAN hotspot

In the context of this scenario, we identify three different ways for the MN to determine that a new link is available. Our objective is to show the benefit of using L2 triggers, and how they may impact performance. More specifically, we consider the following methods for movement detection:

- **Case 1**: The MN does not implement any L2 triggers or MIH capability: movement detection is performed through the receipt of Router Advertisement messages sent periodically by the AR.
- **Case 2**: The MN uses Link Detected/UP/Down events to detect the availability of an interface.
- **Case 3**: The MN uses Link Detected/UP/Going Down events to detect the availability of an interface.

For each case, we vary the parameter used for the movement detection in order to evaluate its impact on the handover performance.

5.3 Case 1: Movement detection is based on RA

In this scenario, the MN does not make use of any L2 triggers or MIH capabilities. Therefore, there is no specific interaction between the L2 and the L3 to optimize the movement detection. Figure 3 depicts this scenario. The AR periodically sends RA messages, which contain the IP prefix valid for the link.

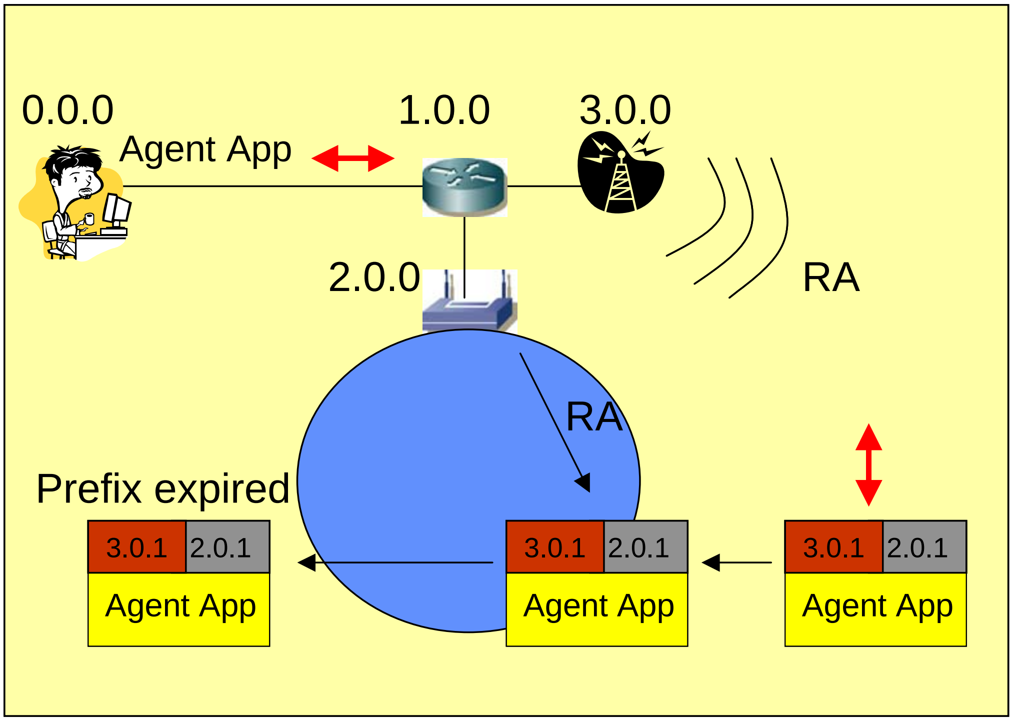

Figure 3: Case 1 - Movement detection is based on RA

The detailed procedures for the handover are as follows.

a) The MN starts in the UMTS coverage area and is moving towards the WLAN hotspot. The MN uses the UMTS interface for its data flow.

b) Once the MN enters the WLAN hotspot, it receives a beacon from the AP and connects to it. It is assumed that the MN is operating in the passive mode and that once the AP is discovered, the MN triggers the Association Request / Response messages exchange.

c) After a Layer 2 connection is established, the MN is able to receive IP-level packets. The MN waits for the RA message sent periodically by the AR in order to receive the IP prefix valid for the link.

d) Upon the reception of an RA message, the MN builds a new address and redirects the flow to the WLAN interface because the WLAN interface is now considered available for application traffic.

e) When leaving the WLAN cell, the IP prefix on the MN's WLAN interface expires, which triggers the redirection of the application flow on the UMTS interface.

The sequence flow diagrams further detailing these procedures are found in Figure 4 and Figure 5.

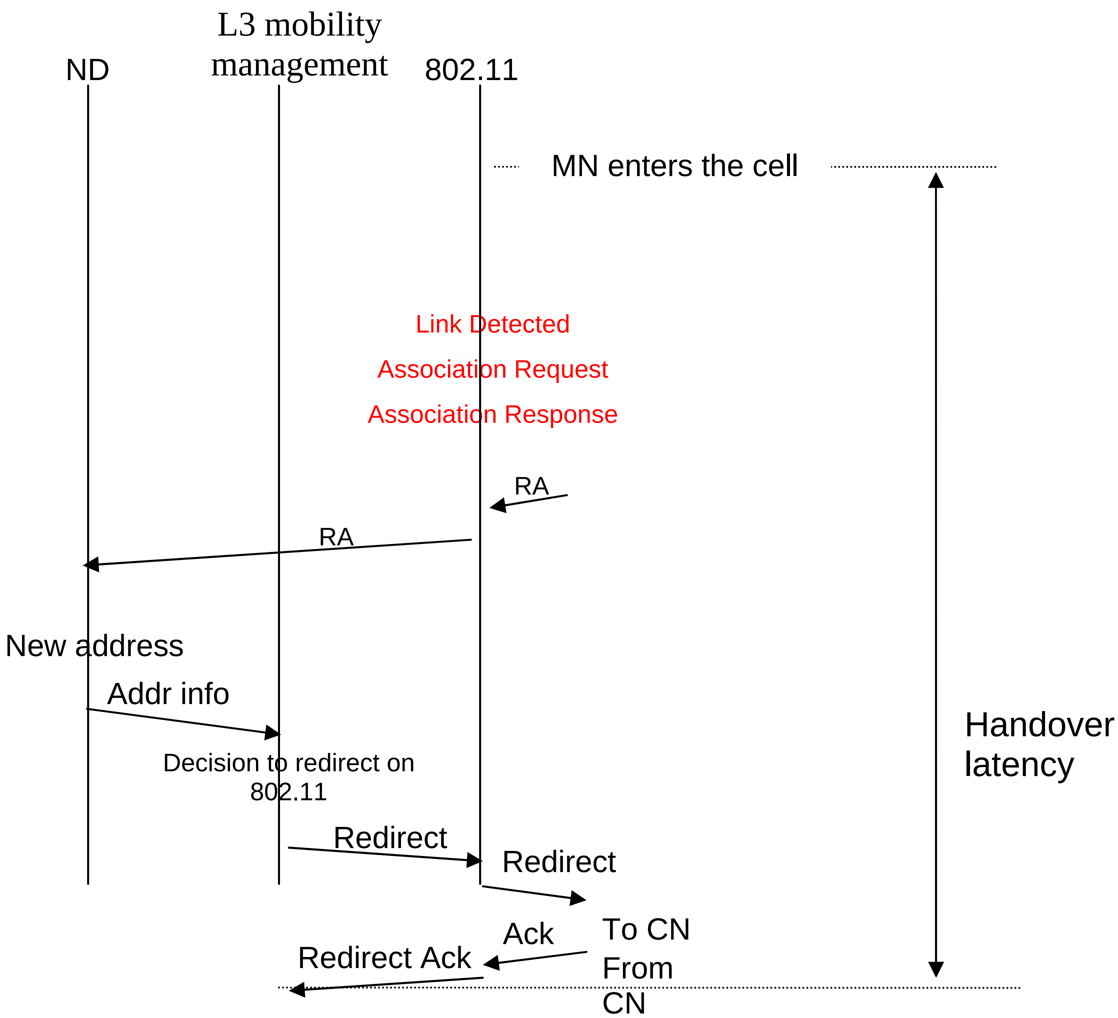

Figure 4: Case 1 – MN is entering the WLAN hotspot

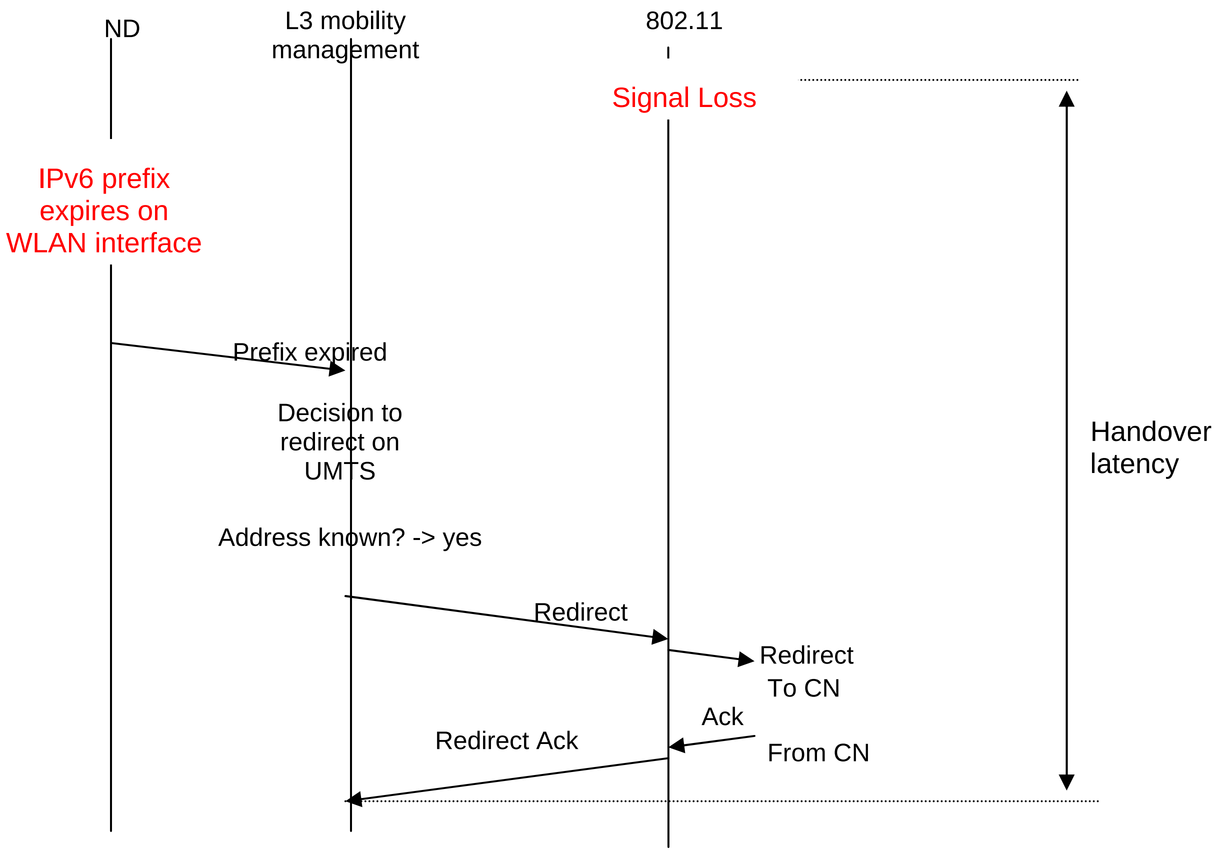

Figure 5: Case 1 - MN leaves the WLAN hotspot

5.3.1 Effects of RA interval on the UMTS to WLAN handover

In this case, it is evident that the delay to detect the WLAN hotspot availability depends on the values chosen for the RA interval, namely, the MIN_RA_DELAY and the MAX_RA_DELAY values. Figure 6 shows the impact of the RA interval on the handover latency when the MN enters the WLAN hotspot. The handover latencies are given as a function of the MIN_RA_DELAY. MAX_RA_DELAY is set to 3*MIN_RA_DELAY.

Figure 6 clearly shows that the handover latency is severely impacted by the choice of the RA interval. The handover latency varies from 0.120 s to 12.8 s. Without L2 trigger events, it important to increase the RA frequency in order to achieve an acceptable performance. The default values selected in RFC3775 where the Router Advertisement messages are sent between 30 and 70ms seem to be a fair trade-off between the bandwidth consumed and the handover latency.

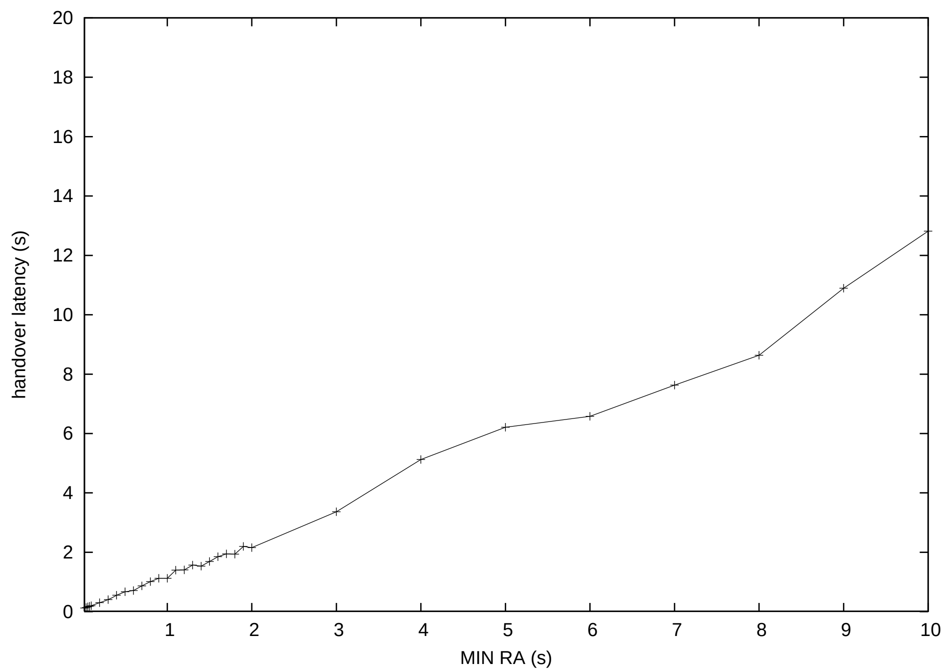

Figure 6: Case 1 - Effects of RA interval on the UMTS-WLAN handover

Note that during the time the handover to the WLAN is performed, there is no packet loss since the data traffic can still be received on the UMTS interface. Large handover latencies in this case only reduce the amount of time the WLAN interface is used. On the other hand, if in some scenarios the UMTS connection is assumed to become unavailable when as the MN is entering the WLAN hotspot, this type of handover can lead to packet loss.

5.3.2 Effects of router lifetime on the WLAN to UMTS handover

Without any L2 trigger events, the MN relies on the router lifetime to determine that an interface is no longer available. When the IPv6 prefix expires on the WLAN interface, it triggers a handover to the other interface available, which the UMTS interface in this case. Figure 7 shows the handover latency when the router lifetime varies from 0 to 90s. The router lifetime is set to 3*MAX_DELAY_RA. It is evident that the handover latency is directly proportional to the router lifetime. All packets that should have been received during the handover are lost. The curve of the handover latency is not exactly the identity function because the MN may stay in the WLAN hotspot after it has received the last Router Advertisement message. Figure 7 also clearly shows that without the L2 trigger events, the Router Advertisement frequency should be increased.

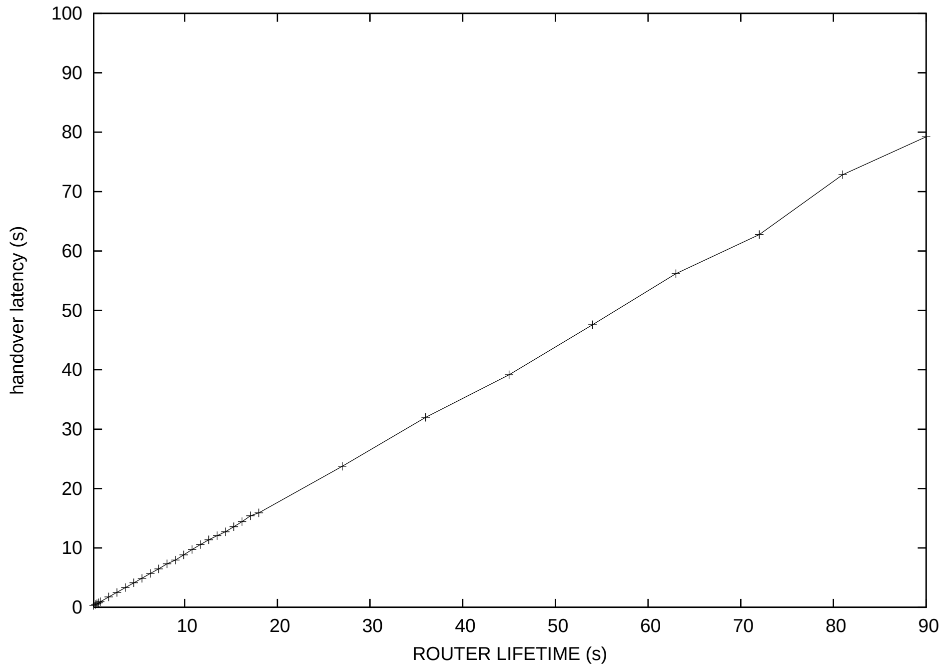

Figure 7: Case 1 – Effects of RA lifetime on the WLAN to UMTS handover

Figure 8 shows the effects of router lifetime on the movement detection efficiency. When the router lifetime is greater than 1s, the movement detection efficiency represents more than 90% of the handover latency.

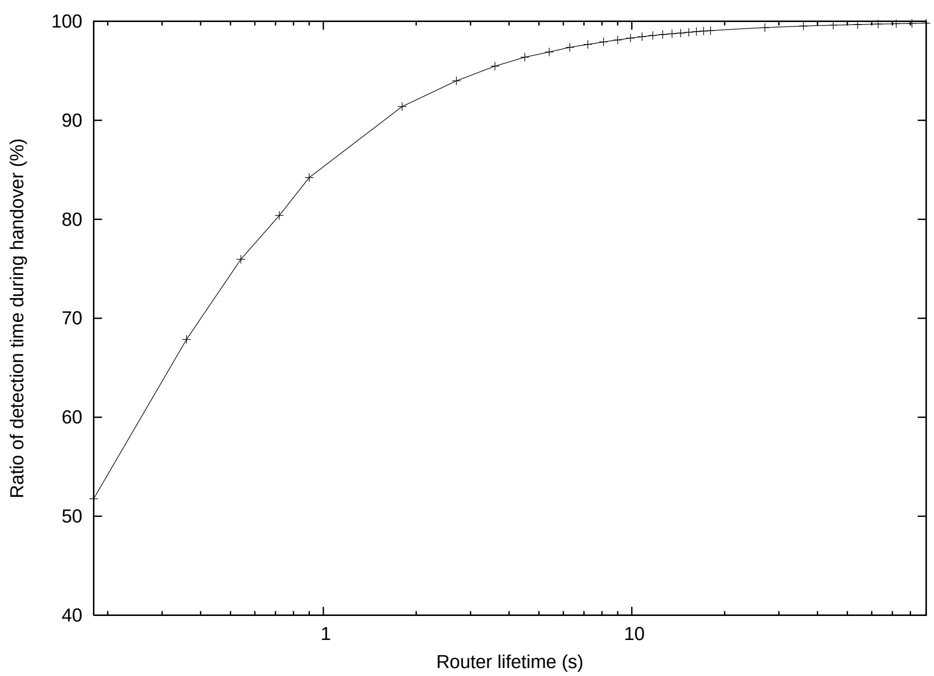

Figure 8: Case 1 - Movement detection efficiency in a WLAN to UMTS handover

5.4 Case 2: Movement detection is based on the Link Detected/Link UP/Link Down events.

In this case the MN uses link events to detect the availability of its WLAN interface.

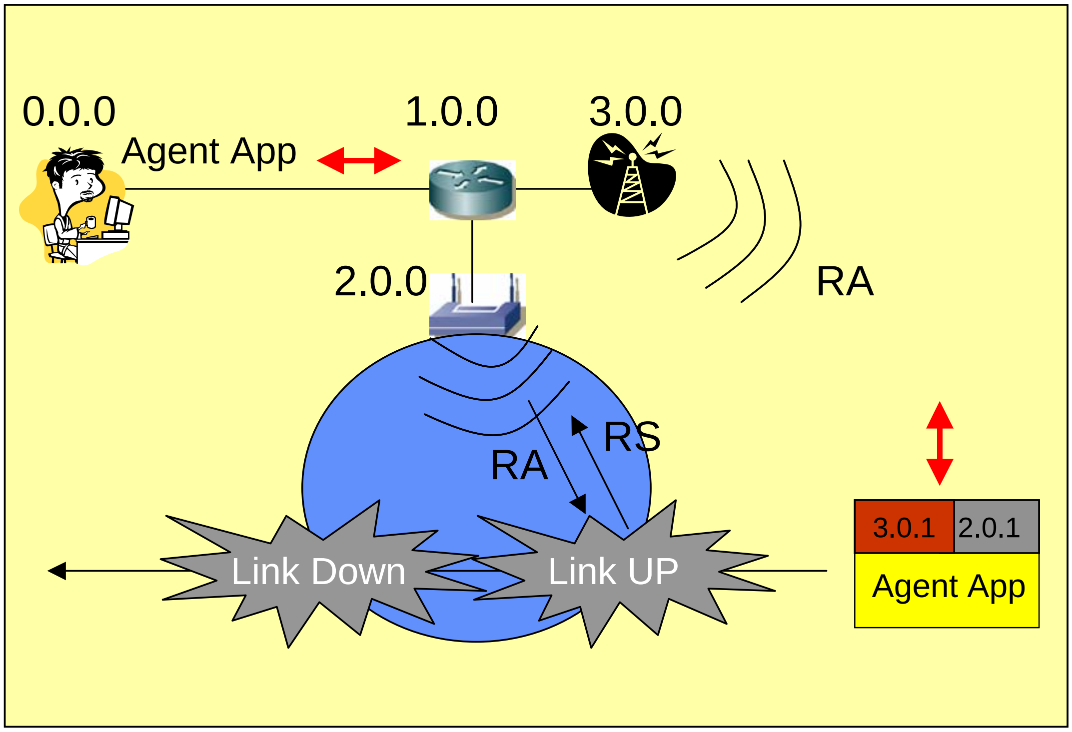

Figure 9: Topology using L2 triggers: Link Detected/UP/Down

The detailed procedures are illustrated in Figure 10 and Figure 11, and are as follows:

a) The MN starts in the UMTS coverage area and is moving towards the WLAN hotspot.

b) Once the MN enters the WLAN, it receives a beacon from the AP and sends a Link Detected event to the MIH module.

c) The MIH module queries the Handover module about the preferred interface to use.

d) Since the WLAN interface is the preferred interface to use, the handover module requests a connection to the AP and the redirection of the MN traffic flow on to the WLAN interface.

e) The MIH module sends a connect command to the MAC. This triggers the association stage (details of the association state are given in 2)

f) Once a layer 2 connection is established, a Link UP is generated by the MAC and sent to the MIH module. The MIH then triggers a RS message in order to discover the IP prefix of the new link.

g) The AR replies to the RS message following the rules defined by the ND module (i.e. dependent on the MAX_RA_DELAY_TIME and MIN_DELAY_BETWEEN_RA as defined in RFC2461).

h) When the MN receives the RA message, it redirects the flow on to the WLAN interface.

i) When leaving the cell, the MN receives packets with errors. When the number of consecutive packets received in error reaches a select threshold, a Link Down event is generated and the MAC is disconnected.

j) The Handover module receives the Link Down event and redirects the flow on to UMTS (through the MIH module).

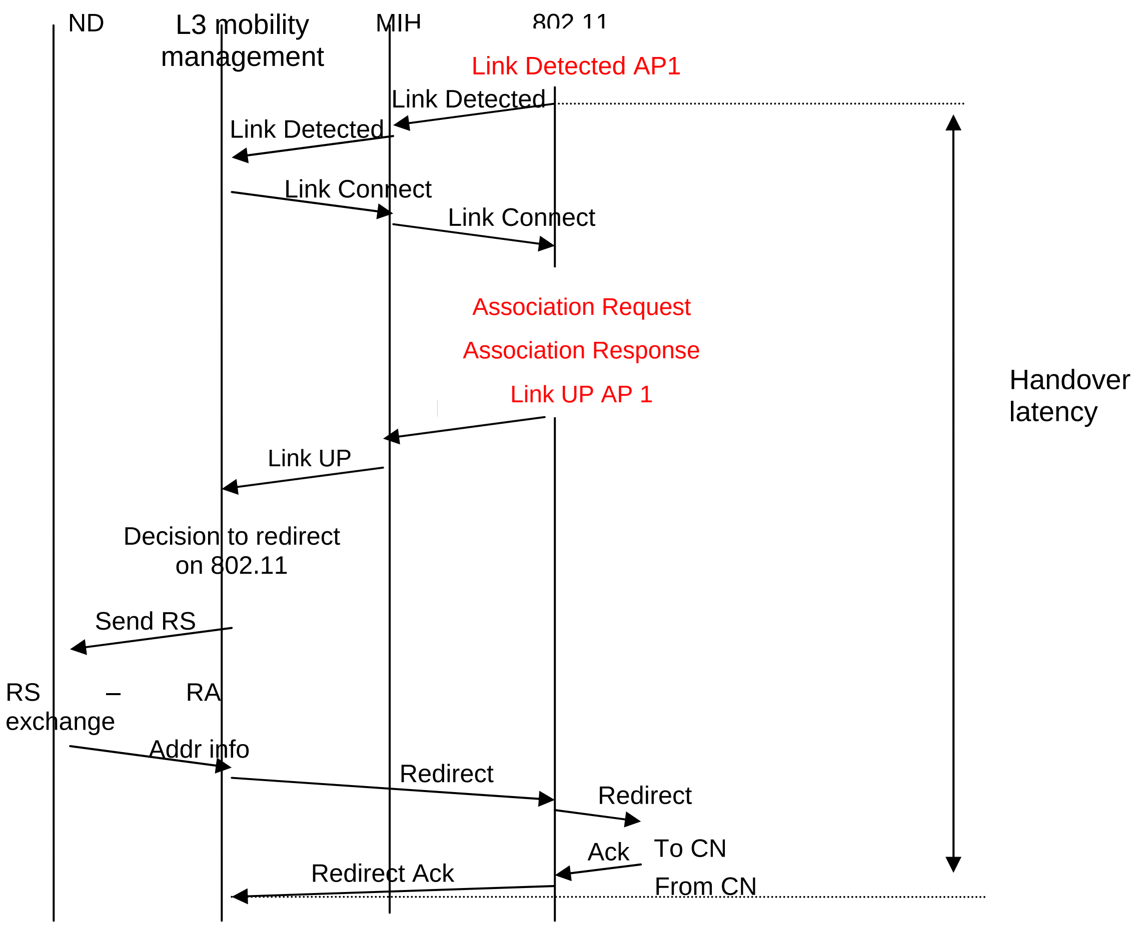

Figure 10: case 2 – MN enters the WLAN cell

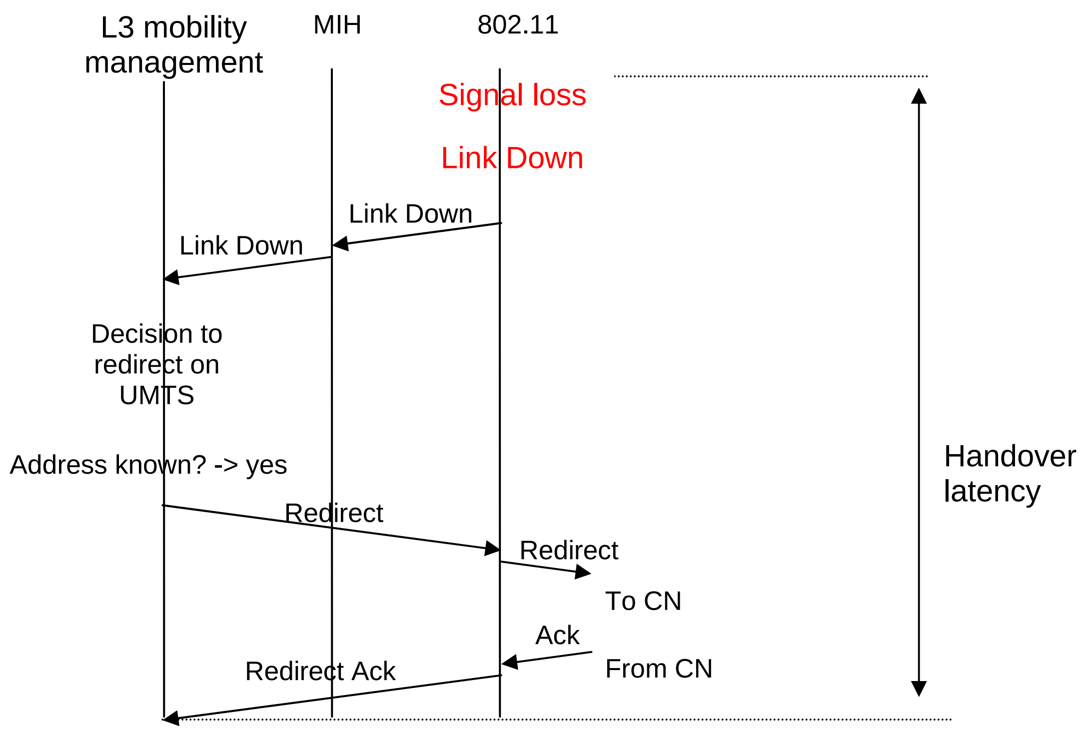

Figure 11: case 2 – MN leaves the WLAN cell

5.4.1 Effects of the MAX_RA_DELAY_TIME on the handover performance

When the MN enters the WLAN cell, a Link Up event is generated as soon as the L2 connection is established (reception of a successful Association Response message), and a RS is issued. Movement detection is completed when the MN receives the first RA message. The only variable in this process is the delay introduced by the AR when it responds to a RS message, which depends on the MAX_RA_DELAY. Figure 12 shows the impact of the MAX_RA_DELAY_TIME on the handover latency, when the MAX_RA_DELAY_TIME varies from 0 to 0.5s.

Figure 12 shows that the handover latency varies linearly from 110ms to 350ms when MAX_RA_DELAY_TIME varies from 0 to 0.5s. The reason why a random delay is needed before sending a multicast RA is to avoid collisions when several routers are operating on a link. This random delay also allows a router to gather several solicitations and respond with only one RA message to several solicitations received within a short period of time.

If we compare the results from Figure 12 with those presented in Figure 6, we can see that for all values of MAX_RA_DELAY_TIME, the handover latency in case 2 is less than the one observed in case 1 for a MIN_RA_DELAY greater than 200ms.

For example, in case 2, the worst handover latency obtained is 350ms (for all MAX_RA_DELAY_TIME values). On the other hand, the handover latency in case 1 is 405ms for a MIN_RA_DELAY equal to 300 ms. The handover latency may be lower in case 1 when RA messages are sent more frequently (for example, the handover latency is

142ms when RAs are sent randomly between [40; 120ms]). It is important to note here that the use of the Link Up event allows one to reduce the bandwidth consumption due to the RA messages. Also, if MAX_RA_DELAY_TIME is configured appropriately (should depend on the number of routers present on the link), the handover latency can be reduced up to 110ms.

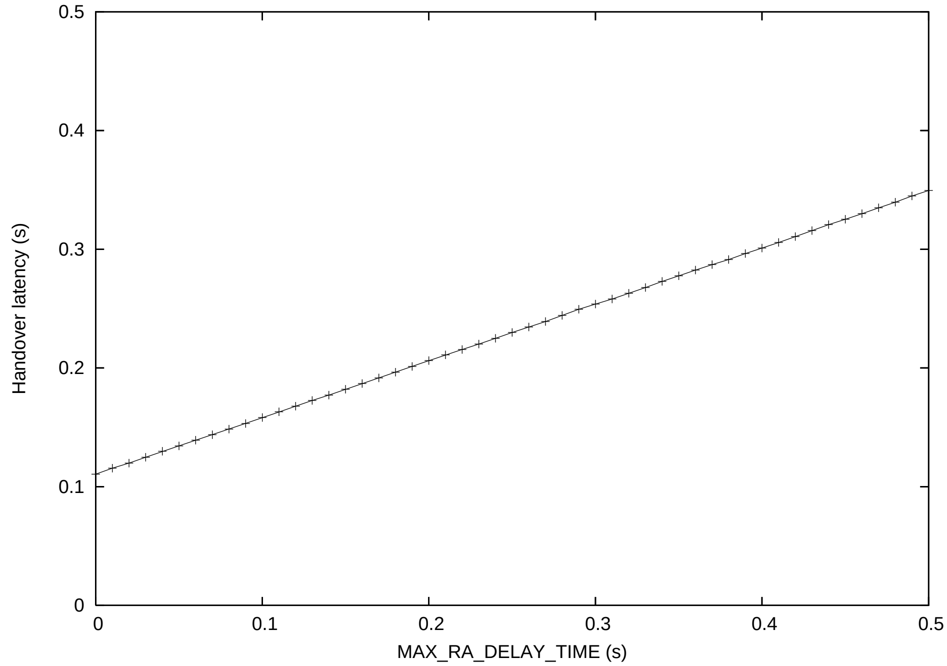

Figure 12: Case 2 - Impact of MAX_RA_DELAY on UMTS to WLAN handover latency

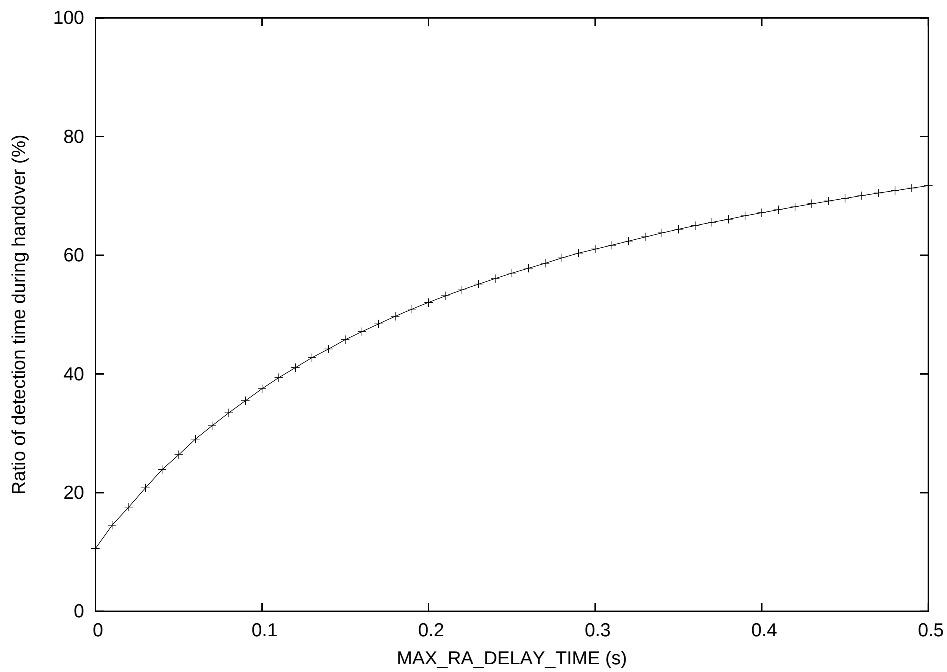

Figure 13: Case 2 - Impact of MAX_RA_DELAY on the movement detection efficiency during the UMTS to WLAN handover

Figure 13 shows the movement detection efficiency. It varies from 15% when there is no delay in the RS response, to 70% when a random delay between 0 and 500ms is introduced.

5.4.2 Effect of the missed beacon threshold

When the MN leaves the WLAN cell, it generates a Link Down event using the conditions described in section 4.5.3. Thereafter, the MN redirects its traffic flow on the UMTS interface, which is already configured (i.e., there is no need to discover a default router or to create a new address). In this section, we consider the case where a Link Down event is generated after a number of consecutive beacons is missed.

Figure 14 shows the impact of the number of consecutive missed beacon messages on the handover latency. Basically, each additional beacon a MN misses before generating a Link Down event increases the handover latency by 100ms. Figure 15 shows the movement detection efficiency, which varies from 38% to 84% of the handover latency.

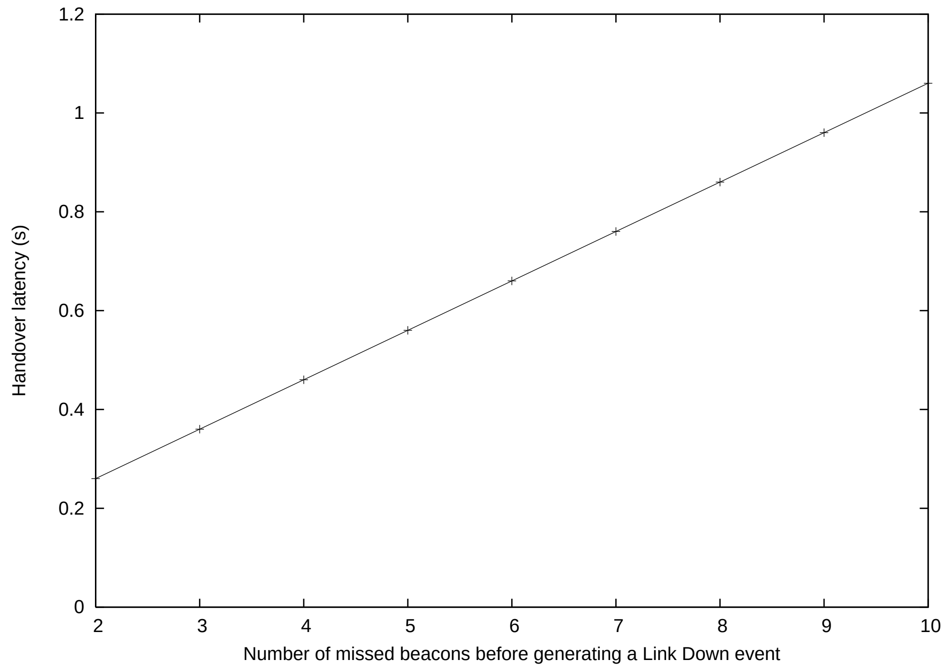

Figure 14: Case 2 - Impact of the number of consecutive beacons missed on the WLAN to UMTS handover

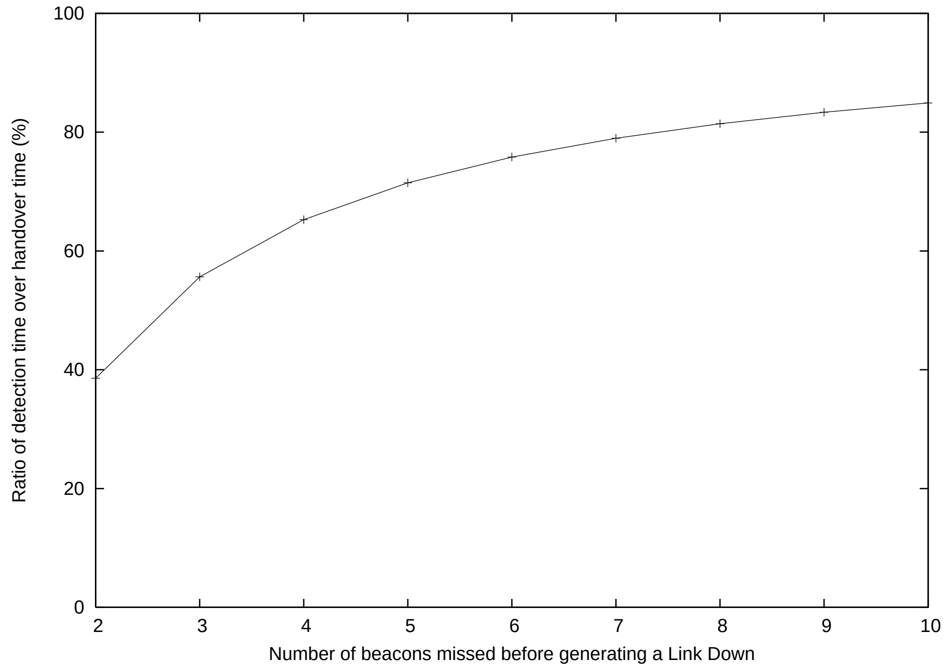

Figure 15: case 2 - Impact of the number of consecutive missed beacon on the movement detection efficiency during the UMTS to WLAN handover

In order to motivate the choice for the missed beacon threshold, Figure 16 shows the probability that a false Link Down event is generated with respect to the number of consecutive beacon missed messages. In this case, the number of stationary stations in the WLAN hotspot varies from 1 to 20. The results in Figure 16 are given for different offered loads per station.

When only one beacon is considered for the missed beacon threshold, the probability of generating a false Link Down event is high. When the WLAN hotspot contains more than 5 stations, the probability to miss one beacon message is between 1/100 and 1/10 when the offered load per station is set to 80 kbit/s. The probability of a false event is around 1/10 for offered loads of 200 and 400 Kbit/s. If a Link Down event is generated after two consecutive missed beacon messages, the probability to generate a false event is always under 1/250. When the number of stations in the hotspot is less than 6, the probability to generate a false event is even less than 1/1000. If three consecutive missed beacon messages are needed to generate a Link Down event, the probability to generate a false event becomes negligible (in the order of 1/100000).

In conclusion, it is recommended to the WLAN hotspot offered load (if known) in order to determine the threshold tolerated for missing beacon messages before a Link Down event is generated. From the simulation results obtained, this threshold can be set to 2 by default.

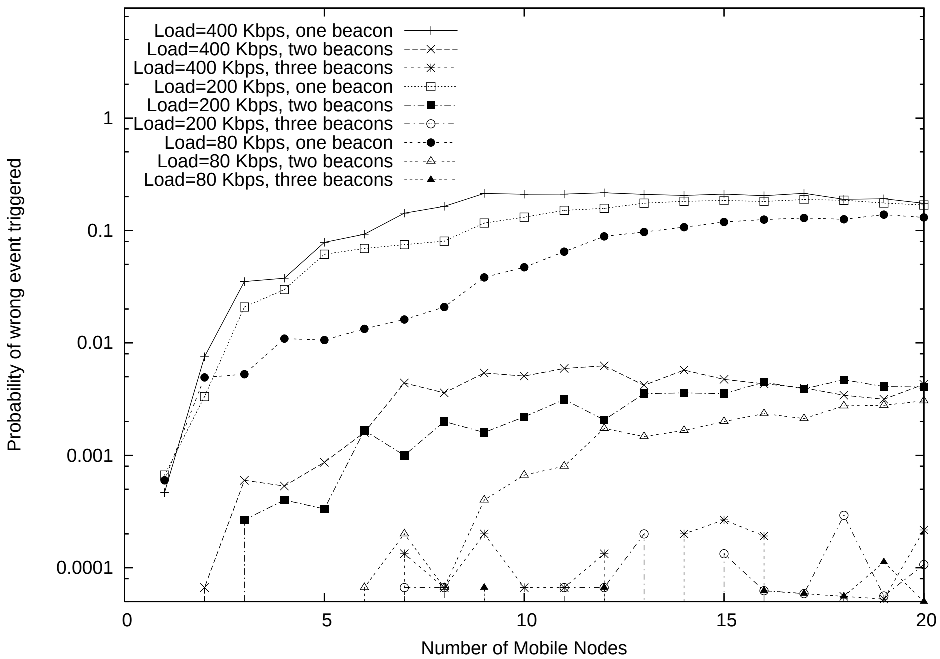

Figure 16: case 2 - probability of generating a wrong Link Down event when Link Down event is based on the number of missed beacons

5.4.3 Effects of the packet error threshold

Figure 17 shows the impact of the packet error threshold on the handover latency. The handover latency increases from 160ms to 358ms when the packet error threshold varies from 1 to 50. Figure 18 shows the movement detection efficiency during the whole handover procedure.

Figure 17 and Figure 18 exhibit a sawtoothe behavior attributed to MAC retransmission mechanism. For the first 4 packet retransmissions corresponding to the first 4 packets lost at the MN receiver, the size of the backoff window remains small (less than 120 slots), therefore the handover latency remains is relatively unaffected. As the backoff window increases for retransmissions greater than 4, the handover latency is increased. After the 7^{th} packet retransmission the data packet is discarded, leading to a reset in the backoff window size.

Figure 19 shows the probability to generate a false Link Down event for various offered loads of a single AP. The probability to generate a false event for a packet error threshold of 3 is negligible (roughly 1/10000). In fact, a packet error threshold of 4 was never observed in all the simulation runs conducted. Therefore, we recommend that the packet error threshold value be set to 4.

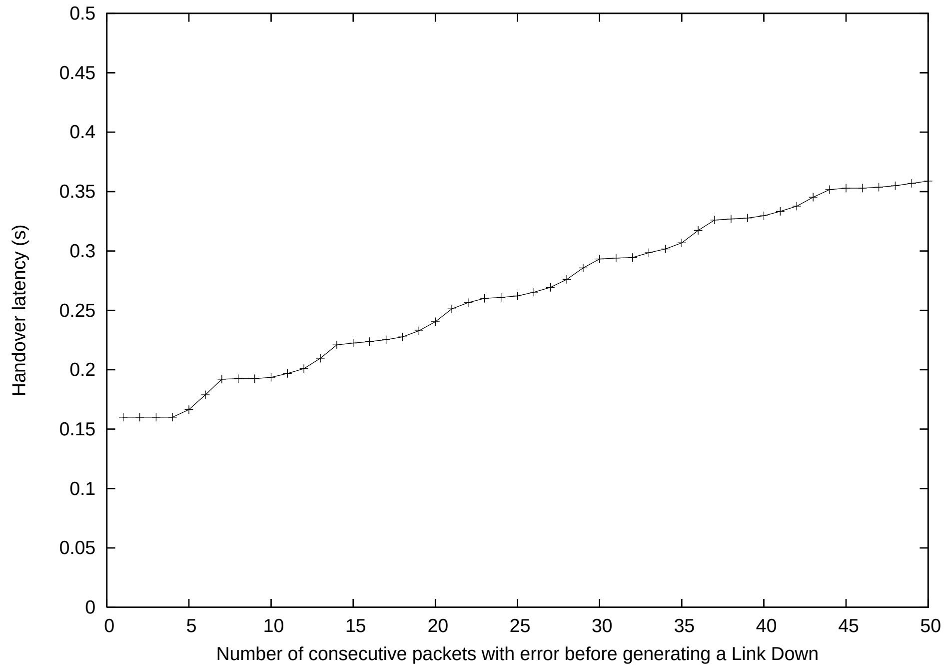

Figure 17: case 2 - impact of the number of consecutive packets received with errors on the UMTS to WLAN handover

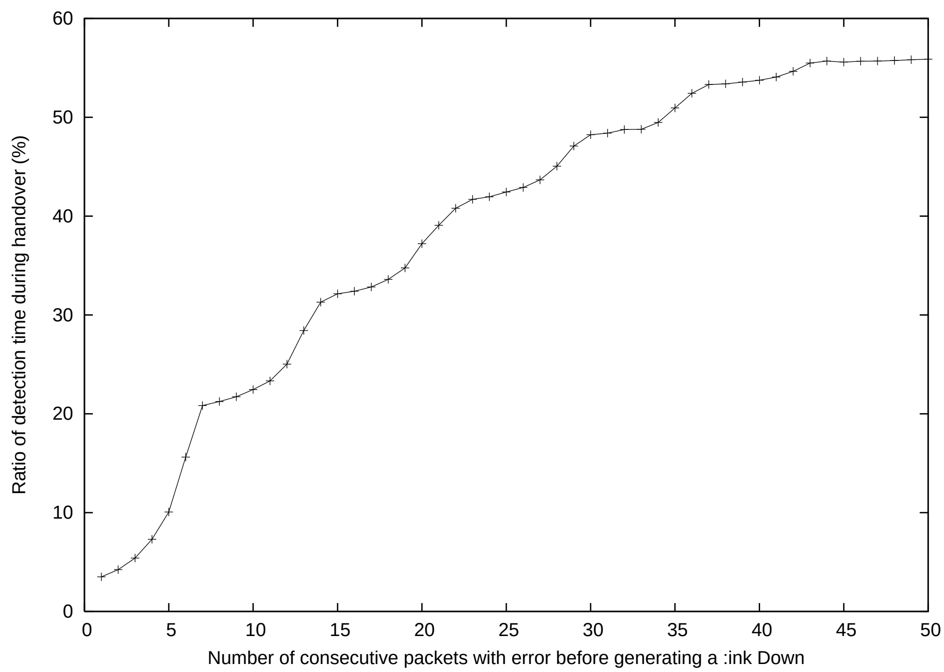

Figure 18: case 2 - impact of the number of consecutive packets received with errors on the ratio of movement detection during the UMTS to WLAN handover

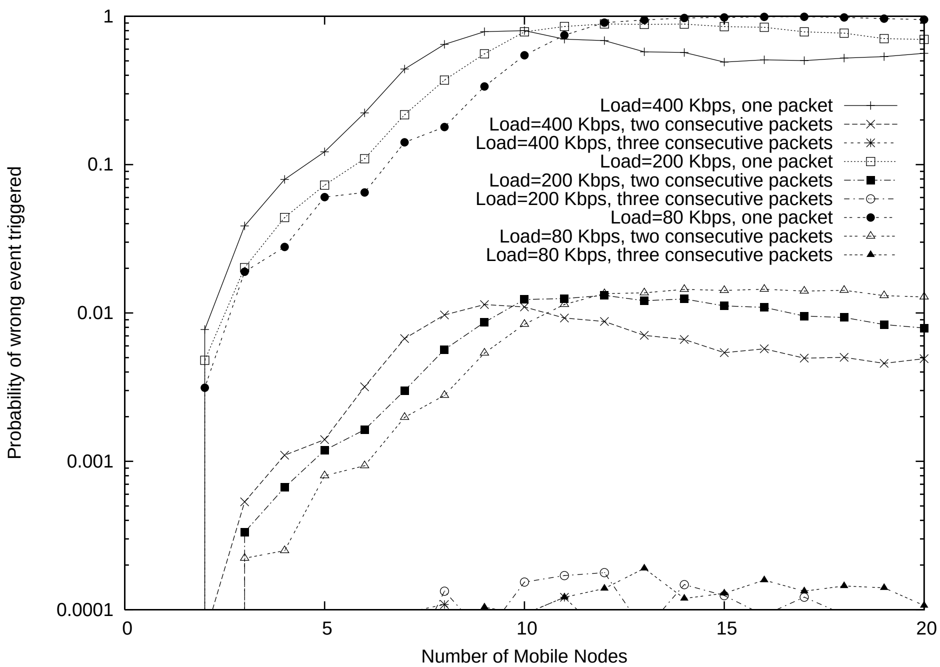

Figure 19: Case 2 - probability for generating a wrong Link Down event,, when Link Down is based on the number of packets with errors

5.4.4 Conclusion and recommended values

Based on the simulation results presented above, the following table summarizes the recommended parameter values for link triggers and router configuration.

Table 3: Recommended Parameter values

Parameter	Function	Value
MIN_RA_DELAY	Router configuration	200s
Router lifetime	Router configuration	1800s
MIN_DELAY_BETWEEN_RA	Router configuration	0.03s
MAX_RA_DELAY	Router configuration	0
Missed beacon threshold	Link Down generation	2
Packet error threshold	Link Down generation	4

5.5 Case 3: Movement detection is based on the Link Detected/Link Up/Link Going Down events

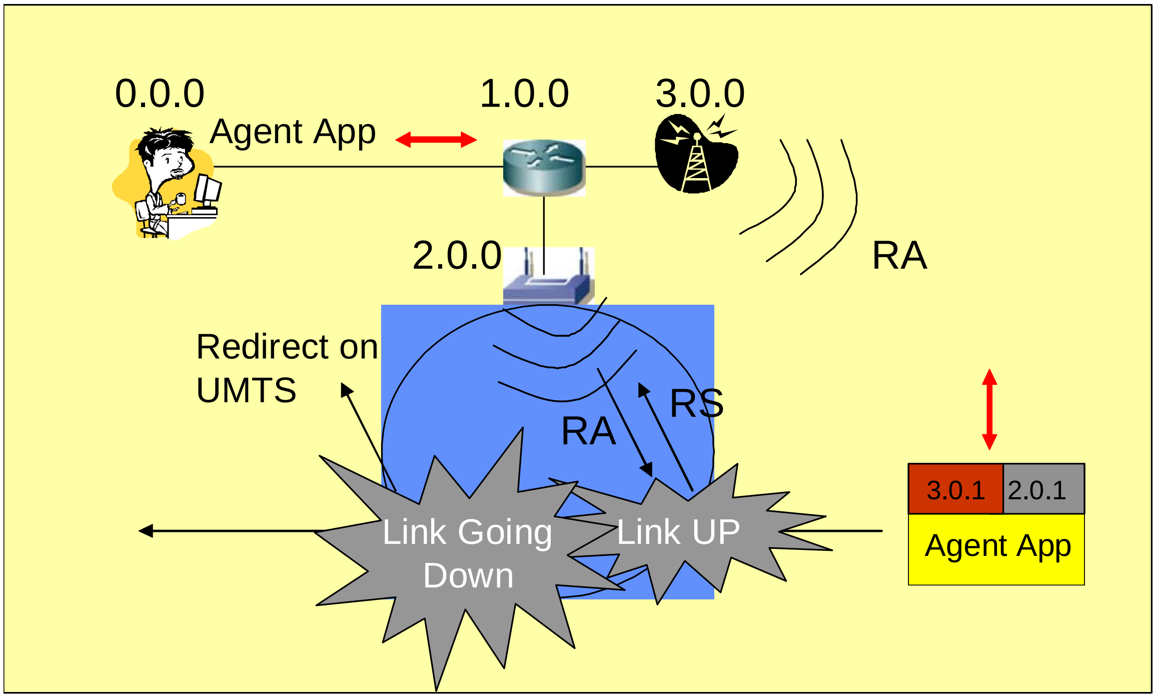

Figure 20: Case 3: Topology with use of Link Detected/UP/Going Down

The difference between this case and case 2 is mainly in the use of a Link Going Down event that replaces the use of Link Down event.

As in case 2, when the MN arrives in the WLAN hotspot, the same method for movement detection is used. Upon a Link Detected event, the MN triggers the association with the WLAN AP and solicits a RA message.

However, when the MN is leaving the WLAN hotspot, it will no longer wait for losing its connection with the AP in order to trigger a handover. Rather, the MN anticipates the degradation of signal quality and generates a Link Going Down event as it gets close to the AP's coverage area boundary.

The detailed procedures when the MN is leaving the WLAN hotspot are illustrated in Figure 21 and Figure 22, and are summarized as follows (the procedure when the MN is entering the WLAN hotspot is described in section 5.4):

a) The MN is in the WLAN coverage area and is moving out.

b) As the MN is approaching the border of the WLAN hotspot, the MAC generates a Link Going Down event based on the power level threshold.

c) Upon the receipt of a Link Going Down event, the MIH forwards the information to the Handover module, leading to a flow redirection on to the UMTS interface.

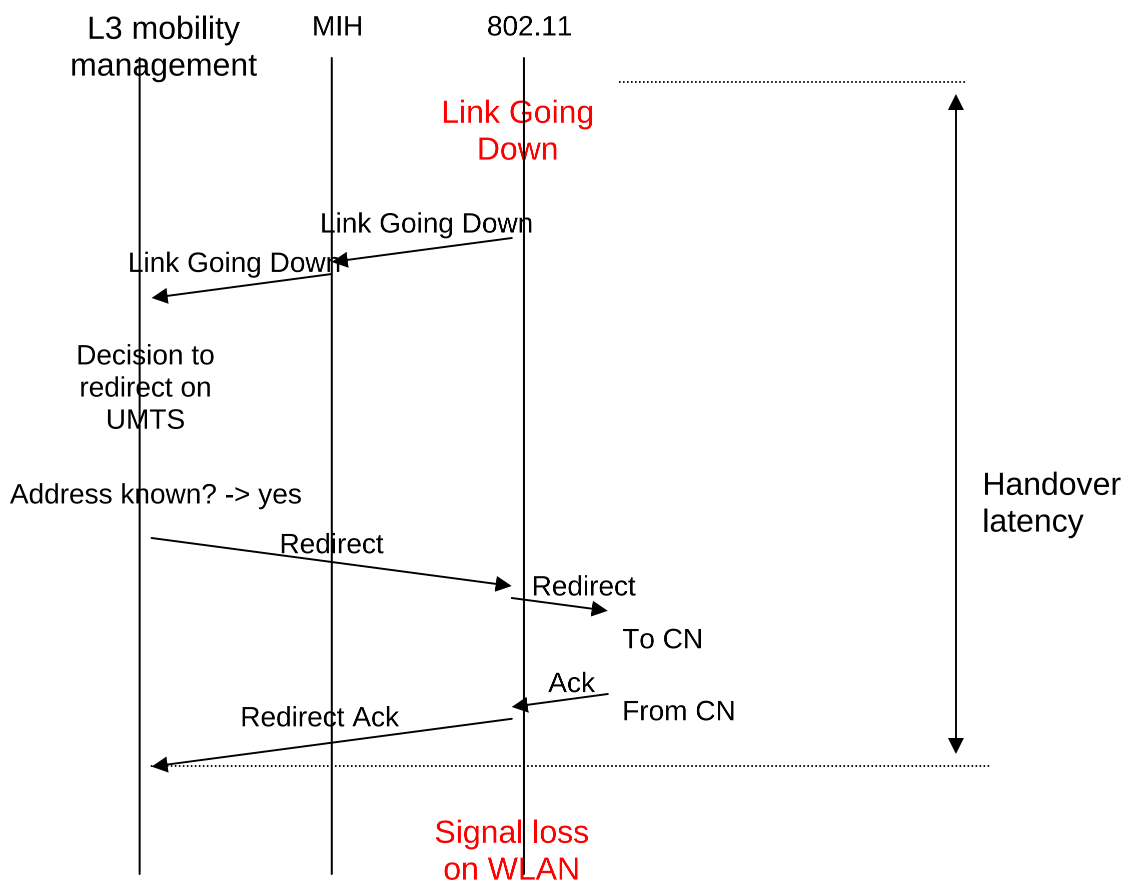

Figure 21: case 3: MN leaves the WLAN cell

5.5.1 Effect of the power level threshold

Using a Link Going Down event in order to trigger the WLAN to UMTS handover anticipates the loss of the WLAN connection. Therefore, if the anticipation is made soon enough, the handover can be smooth, (i.e. without any packet loss). If the redirection of the traffic flow can be completed before the MN disconnects from the WLAN hotspot, the traffic flow is uninterrupted and is resumed on the UMTS interface. However, the sooner the anticipation is performed, the less time the MN will use the WLAN hotspot.

Figure 22 shows the disconnection factor for different MN velocities. It is to note that the handover latency is constant for all cases and is evaluated to be 154 ms. If the disconnection factor is 0, it means that the handover is smooth, and that the MN has completed the handover to the UMTS before the connection to the WLAN hotspot is broken. As the disconnection time approaches the handover latency, this signifies that the Link Going Down event is more like a Link Down event. In other words, the MN begins its handover when it is disconnected from the WLAN hotspot. Note that if the power level threshold coefficient for generating a Link Going Down event is higher than 1.1, then the handover is always completed before the MN leaves the WLAN hotspot. Note however that a Link Going Down event may be generated too early while the signal quality may be still acceptable. Figure 23 shows the corresponding packet loss, which is proportional to the disconnection factor in Figure 22 since packets are lost only during the disconnection time.

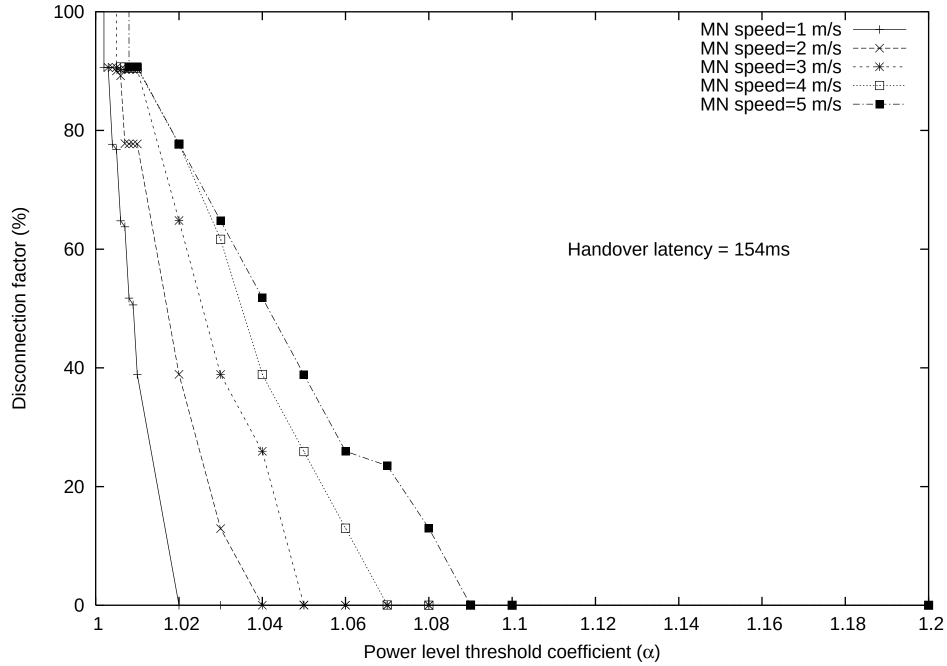

Figure 22: case 3 – Effects of power level threshold coefficient on Disconnection time during a WLAN to UMTS handover

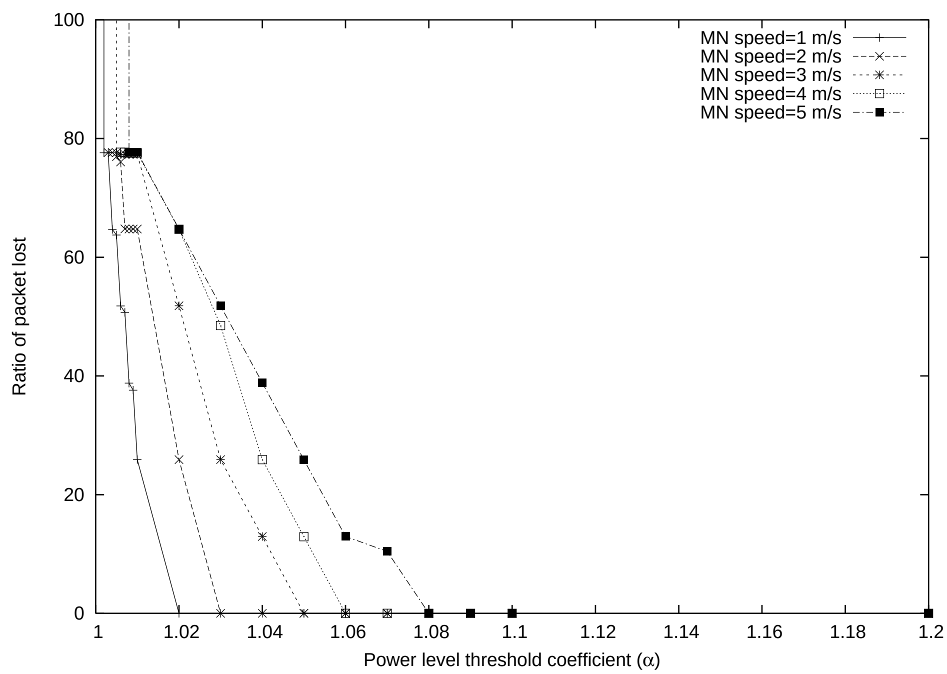

Figure 23: case 3 - ratio of packet loss during a WLAN to UMTS handover

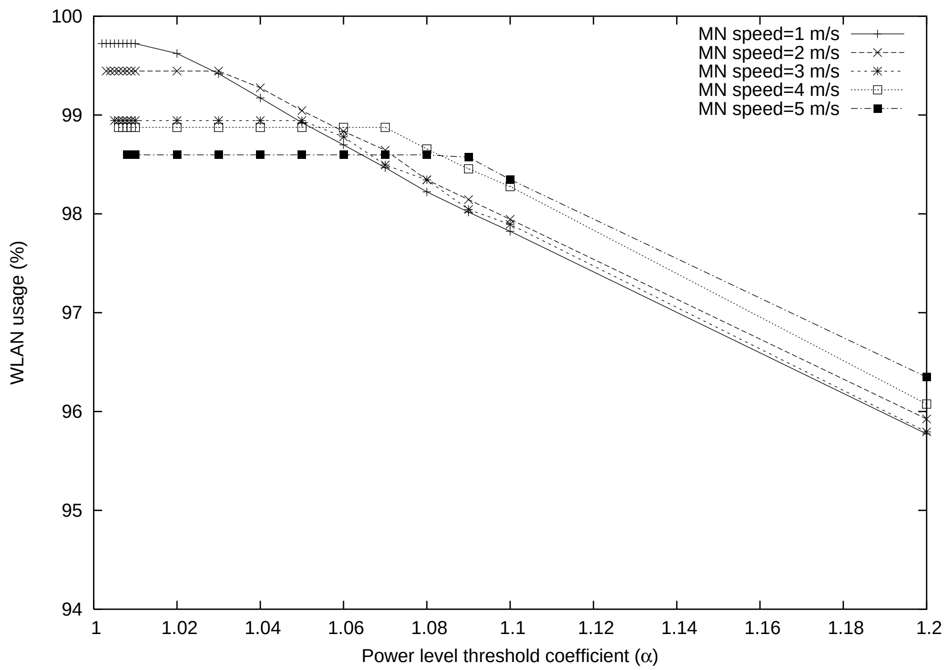

Figure 24: case 3 - ratio of time using the WLAN cell

Figure 24 shows the preferred usage efficiency, which can be used to measure the effectiveness of the Link Going Down event. Indeed, when the MN is using a Link Going Down event, it anticipates its movement and leaves the WLAN cell sooner than if it had waited for a Link Down event. This figure shows that if the power level threshold coefficient to generate a Link Going Down event is 1.1, then the ratio of WLAN usage is greater than 97% regardless of the speed of the MN. Curves for different speeds cross over due to the trade-offs between the handover completion times at the WLAN hotspot entry and exit. For faster speeds the MN spends less time in the WLAN hotspot.