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MHD-CAR: A Distributed Cross-Layer Solution for Augmenting Seamless Mobility Management Protocols

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1. Introduction

The Next Generation Network (NGN) architecture is evolving into a highly heterogeneous infrastructure composed of a variety of Wireless Access Technologies (WAT). In such a technologically diverse network; one of the key challenges would be to ensure ubiquitous communication services to mobile entities, with varying mobility patterns and speed, irrespective of their location and/or the underlying WAT. This calls for devising efficient mobility management solutions that would provide *location management* and *handover management* services to mobile entities. The location management service is responsible for keeping track of the location of the mobile entities whereas the handover management service enables the mobile entity to change its point of connection in the Internet. The essential mandate of any efficient mobility management solution is to provide effective and fast location monitoring and updating services while enabling seamless inter-WAT handover. The notion of seamless handover implies handovers with minimum latency and packet losses.

Providing seamless handover is an imposing challenge because the location update takes place after the successful execution of the handover. The handover process is executed at both the data link layer (L2) and at the network layer (L3) based on prescribed rules at these respective layers. The *L2 handover* process enables the mobile node (MN) to switch its link connectivity from its serving access point (AP) or base station to the new one. After successfully establishing link connectivity, the MN will then need to perform *L3 handover* process to make the MN IP capable on the new link. Till the completion of the handover, the MN is practically disconnected from the network resulting in loss of data. The amount of data lost depends on the handover latency, which in turn is a sum of delay incurred by handover procedure prescribed at L2 and L3 respectively. This implies that the latency of the L3 handover process is directly dependent on the latency of the L2 handover process and also on the timing of the provisioning of L2 triggers that will initiate the L3 handover process.

Thus to develop seamless handover methodology, it is important to take into account the effect of L2 handover process on the L3 specified handover operations. This calls for devising *cross-layer mobility management solution* that will enable inter-layer communication

(i.e., between L2 and L3) of critical information that will enhance the performance of the overall handover process.

In this chapter we present the details of one such cross-layer solution called *Multi-Hop Discovery of Candidate Access Router (MHD-CAR)* that not only optimises the standard Candidate Access Router Discovery (CARD) protocol (Liebsch et al., 2005) but it also offers inherent cross-layer capabilities that can potentially contribute towards achieving low latency handovers and hence enhance the operational efficiency of seamless mobility management protocols in general.

The details of this novel solution will be presented in the context of Fast Mobile IPv6 protocol. A portion of the work presented in this chapter is based on our previous efforts that has been recorded and published in (Yousaf et al., 2008(b)).

2. Technical Background

To provide mobility management to MNs, IETF has specified Mobile IPv6 (MIPv6) protocol at L3 (Perkins et al., 2004). However, it is an established fact that the handover performance of MIPv6 is not seamless, in that it incurs a high handover latency and packet delay. This is because the MIPv6 operation is based on a *break-before-make* operation in which the MN will initiate the MIPv6 protocol after it has disconnected from its serving AP as it moves out of its coverage range. After the disconnection, the MN will search and connect to the appropriate new in-range wireless AP. After establishing link connectivity (or performing L2 handover), the MIPv6 handover process will be initiated which is based on a sequential execution of a series of sub-processes; namely Care-of-Address configuration, Duplicate Address Detection (DAD) test, Home Registration, Return Routability Test and Correspondent Registration. Each of the sub-process will incur a finite amount of delay (DAD test alone incurs a delay of 1 sec) contributing thereby to the total handover latency. During the execution of the MIPv6 protocol, the MN remains disconnected from the Internet and is unable to transmit or receive packets resulting in data losses. Hence, the MIPv6 handover latency, which is in excess of 1.5 seconds (Yousaf et al., 2008(c)), is unsuitable for delay sensitive and throughput sensitive applications.

To provide seamless handover services, IETF has specified *Fast Mobile IPv6 (FMIPv6)* protocol in RFC 5268 (Koodli, 2008) which extends the standard MIPv6 protocol. The main operational concept of FMIPv6 is based on the ability of the MN to detect and negotiate a handover with the New Access Router (NAR) in advance while the MN is still connected to its Present Access Router (PAR). During handover negotiation with NAR, a bi-directional tunnel is established between the PAR and NAR so that packets arriving at the PAR (and destined towards the MN) are tunnelled towards NAR where they will get buffered. These buffered packets will get forwarded to the MN soon after it establishes link connectivity with the AP associated with the NAR and becomes IP capable on the NAR's link. In other words, FMIPv6 is based on a *make-before-break* concept which not only reduces handover latency but also the packet loss by virtue of the tunnelling and buffering of packets.

However, the key to the success for the FMIPv6 handover operation is the ability of the MN to detect and identify the presence of in-range Candidate Access Routers (CARs) and then select an appropriate NAR from amongst the identified CARs. The FMIPv6 protocol specification only specifies the handover operation by assuming that the MN has already identified and selected a suitable NAR and hence does not provide any specific mechanism

to this end. The method of discovering CARs and selecting NAR is left to the discretion of the user.

Candidate Access Router Discovery (CARD) is one such standard solution (Liebsch et al., 2005) the protocol facilities of which can be utilised by FMIPv6 to enable a MN to discover CARs and hence select NAR.

The summary of the CARD protocol and its interaction with the protocol operation of FMIPv6 is given in the following sub-section.

2.1 CARD Protocol

The CARD protocol is a standard IETF solution the operational details of which are specified in RFC 4066. The protocol provides a generic mechanism that allows a MN to acquire the necessary and relevant information about the ARs that are potential candidates for the MN's next handover. It is based on the exchange of a series of *request* and *reply* messages between the MN and its serving AR and also amongst ARs as well. The messages exchanged between the MN and its serving AR (i.e., PAR) is designated as *MN-AR CARD Request* and *MN-AR CARD Reply* message, whereas those exchanged between the ARs are termed as AR-*AR CARD Request* and *AR-AR CARD Reply* message. These messages are transported as options inside the ICMPv6 message. The format of the CARD Request and CARD Reply message is illustrated in Figure 1 and 2 respectively.
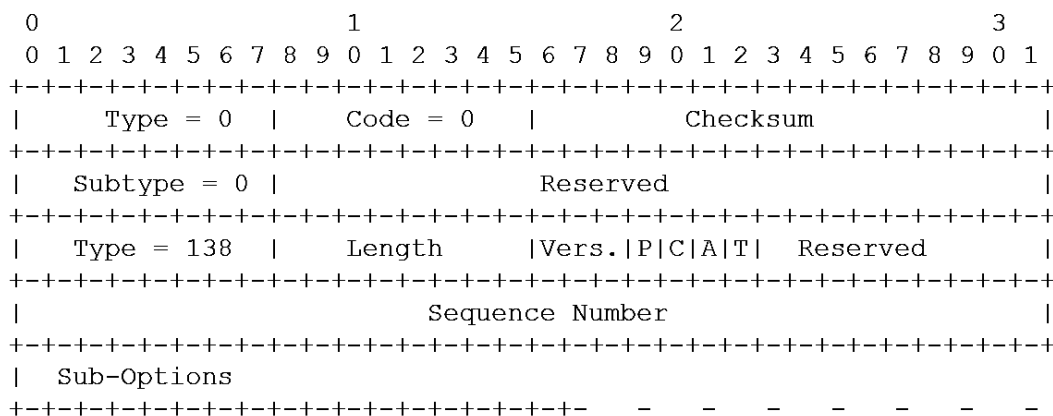
```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 0   |   Code = 0    |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Subtype = 0  |                 Reserved                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 138   |    Length     |Vers.|P|C|A|T|   Reserved      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Sequence Number                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Sub-Options
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   -   -   -   -   -   -   -
```

Fig. 1. Format of the CARD Request Message Carried as an Option in ICMPv6 Message

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 0   |   Code = 0    |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Subtype = 0  |                 Reserved                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 139   |    Length     |Vers.|P|U|L|   Reserved        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Sequence Number                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Sub-Options
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-   -   -   -   -   -   -   -
```
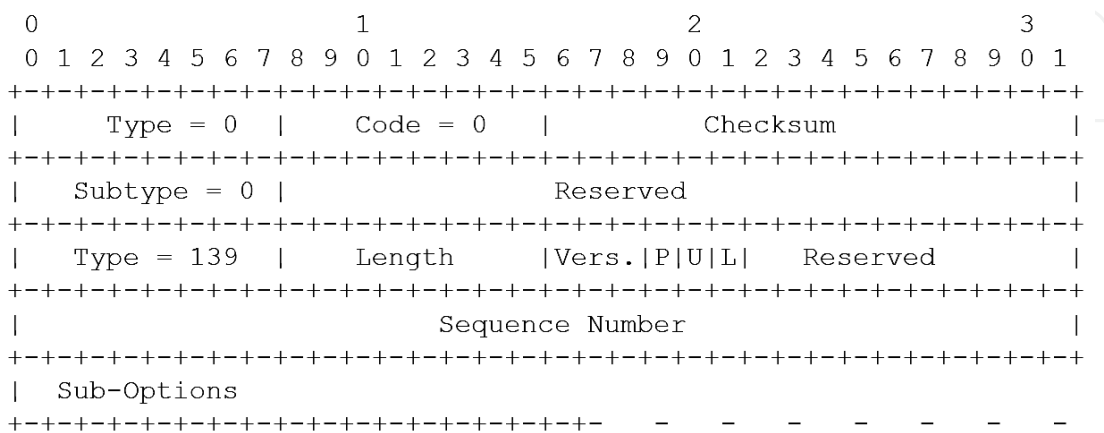
Fig. 2. Format of the CARD Reply Message Carried as an Option in ICMPv6 Message

The CARD protocol is designed to perform the following two functions namely;
1. Reverse Address Translation (RAT)
2. Discovery of CAR Capabilities (DCC)

The *RAT function* enables a MN to map the L2 identifiers (L2-IDs) (e.g., a MAC address for 802.11 networks) of one or more in-range APs to the IP address (L3-IDs) of the associated CAR connected to it. The L2-IDs are typically discovered during the scan operation initiated by the MN as a reaction to the link condition going below a certain specified threshold value of SNR or RSSI.

The *DCC function* on the other hand, allows the MN to acquire the capability's information of the discovered CARs. The notion of *capabilities* implies of the various QoS aspects offered by a CAR that would then be used as input to the MN's target AR (TAR) selection algorithm to make optimal handover decisions. The DCC function will prevent the MN to make inaccurate network selections and hence connections to the wrong one in case of many available CARs.

Central to the CARD operation is a L2-L3 address mapping Table called a *CAR Table*, which is managed and maintained inside each AR. The information content of the *CAR Table* is used to resolve the L2-IDs of a *Candidate AP (CAP)* to the IP address and capabilities of the associated CAR.

RFC 4066 suggests the use of a central entity called a *CARD Server* as one of the strategy to populate the *CAR Table*. During boot up time all ARs within the administrative domain of the *CARD Server* will register their IP addresses and the L2-IDs of the associated CAPs with the *CARD Server*. The *CARD Server* will then be queried during the RAT process.

The functionality of the CARD protocol extends many benefits which are outlined in (Trossen et al., 2002). For example, the information that the MN acquires due to the CARD operation will enable it to select and connect to an appropriate network that would provide the necessary service to the MN based on its application requirements. This can be beneficial to multi-homed MNs as it may also enable the MN to select the least-cost network and enable inter-WAT handoff. It can also be used to perform load balancing by enabling the MN to switch its connection from a heavily loaded AR to a comparatively lightly loaded one.

2.1.1 Operational Summary

The CARD protocol operation, depicted in Figure 3, is typically initiated upon receiving appropriate L2-Triggers or when the MN discovers L2-ID(s) of in-range CAP(s) as part of a scan operation. The MN will be able to discover the L2-ID(s) when it is in the overlapping coverage region of two or more neighbouring AP(s). The MN will then request its current AR to resolve the identity (*RAT* function) and discover the capabilities (*DCC* function) of the CAR(s) associated with the CAP(s) whose L2 ID(s) is carried in the *MN-AR CARD Request* message. The current AR will check in its local *CAR Table* for a corresponding entry against the L2 ID(s). If the current AR fails to resolve the identity of the associated CAR(s), it will send an *AR-AR CARD Request* message (depicted as *AR-Server Req* in Figure 3) to a central CARD Server, to which all the ARs would have registered their identity information (IP address, address prefix or prefix length) during boot up time. The CARD Server will return the IP(v6) address(es) of the CAR(s) via an *AR-AR CARD Reply* message (depicted as *AR-Server Rep* in Figure 3), and the current AR will update its local *CAR Table* with the resolved CAR information. The initial idea of performing RAT function using a centralised server

was first presented in (Funato et al., 2002) which has been adopted by RFC 4066 as one of the probable method.

The current AR, depending on the status of the C-flag (capabilities request flag) in the *MN-AR CARD Request* message, will then directly contact the resolved CAR(s) and perform capabilities discovery via *AR-AR CARD Request/Reply* message pair and then send the resolved identities and capabilities of the CAR(s) to the MN via a *MN-AR CARD Reply* message. It may be mentioned that the identity and capabilities information are carried in specified message sub-options and containers the details and format of which is given in (Liebsch et al., 2005). Based on the capabilities information and preset criteria, the MN will select an appropriate TAR to which it will perform a handover with. This process will ensue every time the handover is imminent.
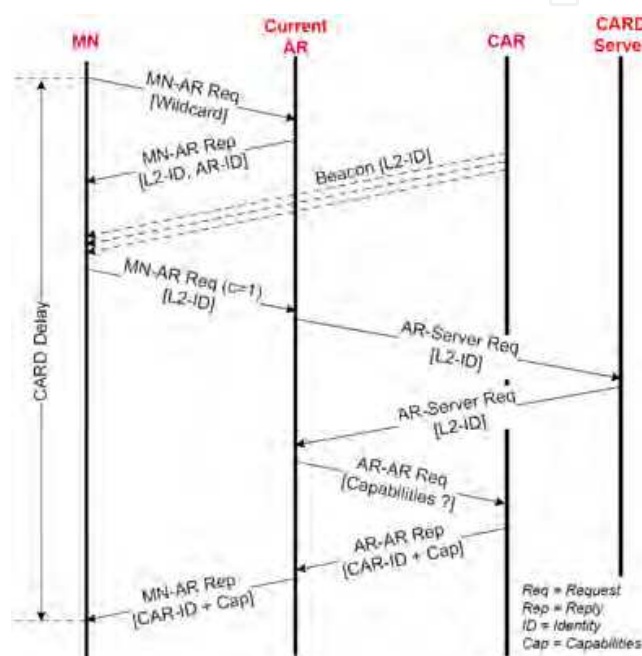
Fig. 3. The CARD Protocol Operation

Upon connecting to the target AR the MN will send a *wildcard MN-AR CARD Request* to obtain the information of its CAR Table in order to improve the prospects of the next CAR discovery. It is observed that the maintenance and management of local CAR Tables is critical to the effectiveness of CARD protocol in terms of assisting seamless and fast handover by way of quick address resolution and capabilities discovery.

2.2 FMIPv6 Operation with CARD Protocol

Figure 4 illustrates the FMIPv6 protocol operation in conjunction with the CARD protocol. The only difference is that the *MN-AR CARD Request* and *MN-AR CARD Reply* message are piggybacked on the FMIPv6 protocol specified *Router Solicitation for Proxy (RtSolPr)* and *Proxy Router Advertisement (PrRtAdv)* messages respectively (Liebsch et al., 2005). The *RtSolPr* and *PrRtrAdv* are ICMPv6 type messages the format of which is specified in (Koodli, 2008).

The MN will start scanning for in-range APs in response to deteriorating link conditions. The MN will then send the L2-ID(s) of the scanned AP(s) to the upper layer (i.e., L3) in the form of L2

trigger which will initiate the CARD operation as described in Section 2.1.1. The PAR after acquiring the identities and capabilities of the available CAR(s) against the L2-ID(s) provided by the MN in the *RtSolPr* message will send this information as [L2-ID, AR-Info][1] tuple appended to the *PrRtAdv* message. The MN will then select a suitable NAR from amongst the discovered CAR(s) based on some TAR selection criteria which is beyond the scope of this chapter.

Based on the identity information of NAR, the MN will auto-configure (Thomson et al., 2007) a prospective New Care of Address (pNCoA) and will send this in a *Fast Binding Update Message (FBU)* message to the PAR indicating the NAR to which the MN wishes to handover its connection. The PAR will then notify the NAR of the pCoA and request for a handover by sending a *Handover Initiate (HI)* message. The NAR in response will acknowledge the handover request by transmitting a *Handover Acknowledge (HAck)* message towards the PAR. The PAR upon receiving the *HAck* will immediately set up a forwarding tunnel with the NAR (referred to as PAR-NAR tunnel) and will start tunnelling subsequent packets destined for the MN towards NAR where they will get buffered. In the meantime the PAR, upon processing the *HAck*, will inform the MN of the NAR's decision via a *Fast Binding Acknowledgement (FBAck)* message. It should be noted that all this operation is executed while the MN is still connected to the PAR.
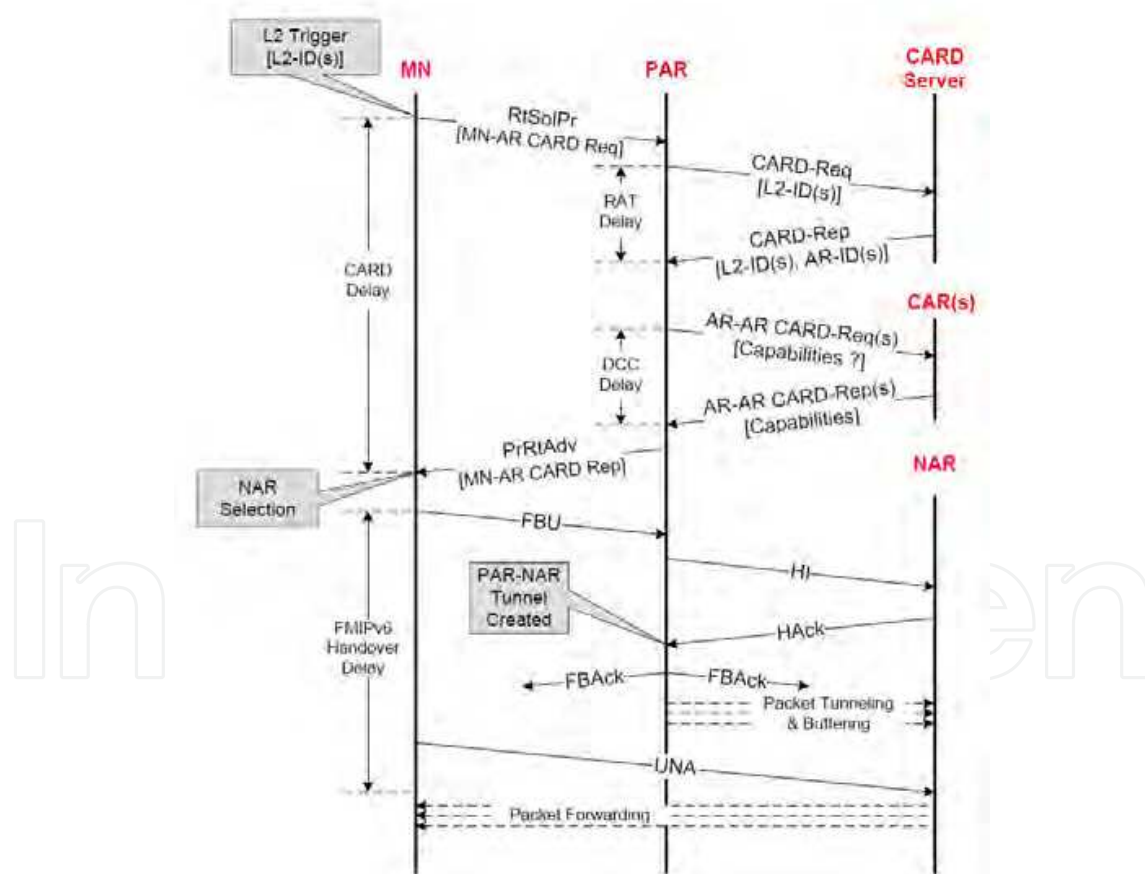
Fig. 4. The FMIPv6 Predictive Handover Operation Utilizing the CARD Protocol for NAR Discovery

[1] The AR-Info corresponds to the identity and capabilities of an AR.

After the MN moves out of the communication range of PAR, it will establish link connectivity with the New Access Point (NAP) and will announce its presence to the NAR by sending an *Unsolicited Neighbour Advertisement (UNA)* message (Narten et al., 2007) to the NAR. The NAR will immediately forward all the buffered packets, and the subsequent packets arriving via the PAR-NAR tunnel, towards the MN. The MN will then inform the HA and the CN(s) of its new location as per the MIPv6 protocol rules (Perkins et al., 2004), after the completion of which the handover is said to be complete.

It should be noted that the FMIPv6 protocol specifies two handover modes namely *Predictive Handover Mode* and *Reactive Handover Mode*, depending on whether the MN receives the *FBAck* on the PAR's link or not. Of the two modes, the Predictive Handover Mode is more seamless and hence is the preferred and default mode.

Besides FMIPv6, the CARD protocol functionality can also be used by the MIPv6 protocol to facilitate the MN's decision to select the appropriate AR for handover that would best serve its QoS requirements. For further details see (Liebsch et al., 2005).

3. Problem Statement

As described previously, central to the success of the FMIPv6 protocol is the ability of the MN to discover and select NAR using the CARD protocol facilities. However the process to discover and select NAR depends on two discovery processes namely:

1. CAP discovery, and
2. CAR discovery.

Both of these processes will influence the overall discovery process in consideration of the inherent process limitations described below.

Candidate Access Point (CAP) Discovery Delay:

The CAP discovery process is undertaken by the technique specified for the underlying WAT, whereas the CAR discovery process is carried out by the CARD protocol after the L2 provides it with the identities of the discovered CAP(s) using specific L2 constructs such as triggers, events, hints etc.

Since the CARD protocol, and hence the FMIPv6 protocol, rely on the *timely* and *accurate* provisioning of these L2 constructs, therefore the performance inadequacies of the L2 specified operations will have adverse consequences on the performance of the CARD and thus the FMIPv6 protocol. For example, in reference to the IEEE 802.11 WLAN, the MN is required to perform scan operations (active or passive) to determine the presence of in-range CAP(s). However, as pointed out in (Mishra et al., 2003), the scan operation accounts for almost 90% of the L2 handover delay and can be approximately up to 400 ms. It should also be noted that during the scan operation, the MN is unable to transmit or receive packets resulting in data loss. Besides packet loss, the CAP discovery delay will translate into the delayed provisioning of L2 triggers which in turn will delay the initiation of the CARD protocol.

Thus in order to reduce the packet loss and ensure the timely initiation of the CARD protocol, the duration of the scan operation must be reduced.

Candidate Access Router (CAR) Discovery Delay:
The CAR discovery process is undertaken by the L3 specified CARD protocol after receiving L2 triggers. As described, the CARD protocol performs RAT and DCC function by the exchange of *CARD Request/ Reply* messages. This incurs a high signalling cost especially over the error prone radio links. Besides signalling cost, each function incurs a finite amount of delay which is also influenced by the location of the CARD Server and its topological distance from the PAR. Besides influencing the delay, the CARD Server is a central network entity that must be managed and maintained thereby increasing the cost of network management. The CARD Server also introduces a potential single-point-of-failure, the failure of which will result in a failed handover.

In consideration of the above performance issues, a unified solution approach is desired that must incorporate the following recommendations;

1. Minimize the duration of the L2 scan operation, and hence the CAP discovery delay.
2. Ensure the timely delivery of L2 triggers to initiate the CARD process.
3. Remove the dependence of the CARD protocol on a central CARD Server.
4. Reduce the signalling load of the CARD protocol, especially over the error
    prone wireless link.

This implies a tightly coupled liaison between L2 and L3 operations and calls for a cross-layer management solution that must incorporate the above recommendations to enable a MN to discover NAR in the shortest possible time with low signalling latency and high probability of success.

4. Related Work

Two approaches for discovering CARs worth mentioning is Push-Mode-Multicast based Candidate Access Router Discovery (PMM CARD) (Dario et al., 2006(a)) and Access Router Information Protocol (ARIP) (Kwon et al., 2005). PMM CARD introduces added complexity of maintaining and managing multicast groups and addresses and its performance is restricted within a single operator's domain, whereas ARIP does not scale to complex network architectures and is not dynamic. Beside introducing additional signalling messages, ARIP requires the ARs to maintain identity information of the adjacent AR's but , similar to (Ono et al., 2003), suggests manual set up by the network administrator or by the automatic learning of the AR's from the handover information offered by the MNs. This makes ARIP unscalable to complex network architectures. Also both the above proposals do not provide any cross-layer management capabilities and have not been designed keeping in view the requirements and dynamics of a fast moving MN in the context of NGN.

In this chapter we present an enhanced and scalable mechanism for discovering CARs that can enable a fast moving MN to discover the identity and capabilities of the CARs which may not be geographically adjacent and/or directly linked to the PAR. We term this new approach as *Multi-hop Discovery of Candidate Access Routers (MHD-CAR)*, which is a simple approach that does away with the complexity and limitations of both PMM CARD and ARIP. The MHD-CAR provides an inherent scalable cross-layer mobility management solution that eliminates the performance issues discussed earlier by incorporating the solution recommendations.

The protocol details of the MHD-CAR protocol is submitted to the IETF as an Internet Draft (Yousaf, Wietfeld, 2008(a)) and the proof of concept presented in (Yousaf et al., 2008(b)).

5. MHD-CAR Operation Summary

MHD-CAR is a distributed mechanism proposed to enhance the operational reliability and robustness of seamless and fast handover protocols without introducing any additional message(s) and/or relying on any central server.

In MHD-CAR ARs dynamically update their local CAR Table with the identity information of not only the neighbouring ARs but also of CARs located multiple wireless-hops away through an iterative exchange of *unsolicited AR-AR CARD Reply* message and without relying on a CARD Server.

The CAR Table information of the current AR is then transferred to a MN on the fly where it updates/refreshes a local cache called *New Access Network (NAN) Cache* allowing the MN to resolve the CAR(s) locally with minimum exchange of Request/Reply messages over the error prone radio link.

The MHD-CAR protocol operation is depicted in Figure 5 and the functional details are discussed in the subsequent sub-sections.
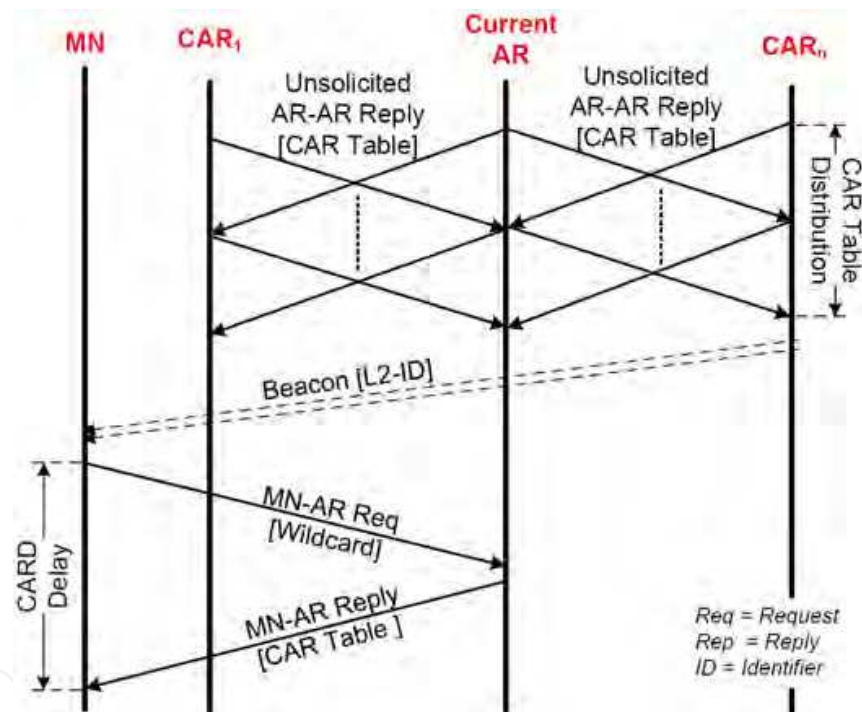
Fig. 5. MHD-CAR Protocol Message Sequence Diagram

5.1 CAR Table Initialization

The composition of the CAR Table in the context of MHD-CAR is different from the one proposed in (Liebsch et al., 2005) in that it offers more detailed information content. Table 1 shows the conceptual design of CAR Table in the context of MHD-CAR that contains not only the identities of the CAP/CAR but also information regarding the type of wireless access technology and the channel number in use by a CAP. It also informs about the capabilities of the CAP in terms of supported bit-rate and SSID (in case of 802.11), and most importantly the '*Distance*' parameter, which is a measure of the distance of a CAR, in terms of the number of wireless-hops, with reference to the local AR maintaining the CAR Table.

At initialization, each AR will populate its CAR Table with its own (and associated AP(s)) identity and capabilities information and set the '*Distance*' parameter to zero, indicating local AR information.

For the MHD-CAR operation, it is imperative that each AR should be aware of the *identity* of the neighbouring AR and the associated AP(s) and store this information in its local CAR Table with a *Distance* value set to 1. The neighbour association can be established dynamically using the handover information of a bootstrapping MN as an input to establish a neighbour relationship. The first handover between any two neighbouring ARs will serve as a bootstrapping handover that would invoke the discovery process between the two ARs. This idea was first presented in (Shim, Gitlin, 2000), (Trossen et al., 2003) and also endorsed by the official CARD protocol standard (Liebsch et al., 2005) , which is adopted by the MHD-CAR operation for CAR Table initialisation and described as follows.

CAR Table		
AP Information	**AR Information**	**Capabilities**
macaddr MAC Address *int* L2 Type *int* Channel Number	*ipaddr* IP Address *prefix* Network Prefix *int* Prefix Length	*double* Bitrate AP *string* SSID *int* Distance *avpair* User Defined QoS AV Pair

Table 1. Conceptual Design of the CAR Table

When some MN performs an inter-AR handover, it will inform its current AR about the identity of the previous AR using a Router Identity message option appended to the *MN-AR CARD Request* message (Liebsch et al., 2005). The serving AR will acknowledge this with a *MN-AR CARD Reply* message and will store the identity of the MN's previous AR in its CAR Table and indicate it as its immediate neighbour. The serving AR will then send an *unsolicited AR-AR CARD Reply* message to the previous AR informing it of its own identity and identifying itself as its neighbour. The previous AR will thus store the identity information of the MN's current AR in its local CAR Table as an immediate neighbour indicated by the *Distance* value of 1. In this way, all the ARs along the motion path of the MN will bootstrap their local CAR Tables with the identity of the neighbouring ARs. Besides the identity information, the two ARs must also exchange the capabilities information with each other. This process will also eliminate the reliance on maintaining a CARD Server. It may be noted that the identity information contains both the IP address of the AR and the L2-Id(s) of the associated AP(s).

5.2 CAR Table Distribution

After the ARs are bootstrapped with the identity and capabilities of the neighbouring ARs, each AR will exchange its local CAR Table information with the neighbouring AR(s) through the iterative exchange of *unsolicited AR-AR CARD Reply Message*, where the number of iterations is equal to the specified maximum distance, in wireless-hops, corresponding to the maximum entries an AR will maintain in its CAR Table.

In the first iteration, the ARs will exchange their local CAR Table information (see Table 1) with their neighbouring ARs, which will add this new information to their local CAR Tables and increment the *Distance* value by 1. Now each AR will have information about the AR(s)

two wireless-hops away and this will be indicated by the *Distance* value of 2. *It should be noted that the ARs do not forward the received inter-AR messages in order to prevent network flooding.*

During the second iteration, the above process will be repeated and the receiving ARs will compare the new information with their present CAR Table entries and if no match is found, it will add the new CAR information to its local CAR Table by incrementing the distance parameter by 1.

Fig. 6. Conceptual Representation of the Iterative CAR Table Distribution Process in MHD-CAR

This new entry will thus be marked with the *Distance* value of 3, indicating that the corresponding CAR is at distance of three wireless-hops.

The above inter-exchange of unsolicited inter-AR Reply messages will continue until each AR has the information about CAR, which is at the specified maximum distance from the current AR, after which the CAR Tables are said to have *converged*. The maximum distance for which an AR is supposed to maintain CAR information is a constant that depends on the network topology and can be specified by the administrator. The ARs will then periodically exchange their local CAR Table information with their neighbouring AR(s) after every 60 seconds, or when there is some change in the contents of it (for example, change in capabilities information). *During CAR Table initialisation and distribution process, the ARs will transmit the unsolicited inter-AR messages at a uniformly distributed random time between 0 and 100 msec.*

The iterative CAR Table distribution process is illustrated in Figure 6, which shows the contents of the CAR Table of an AR for each iteration of the distribution process. The distribution takes place for a *Distance* value of 4, i.e., the iterative distribution process will continue till each AR has information about ARs which are up to 4 wireless hops away. Figure 6 illustrates the process for the reference topology shown in Figure 7 composed of 12 Access Networks (AN) (from *A* to *L*), where the domain of each AN is defined by an AR and an associated AP. For the sake of demonstration and simplicity only the AN *Identity* and *Distance* parameters of a CAR Table are considered in Figure 6. The *identity (Id)* is characterised by the [L3-ID, L2-ID] pair and is denoted by the AN identifier, whereas the *Distance (D)* signifies the topological distance of a CAR/CAP from the local AR in terms of wireless hops. The entries indicated in red signify the new entries that get stored in the CAR Table during the particular distribution iteration. Iteration # 0 signifies the contents of the CAR Table during the initialisation process as explained above.

Figure 7 clearly shows how the ARs (e.g., F) acquire the information of CARs (for instance B & J) that are not immediate neighbours through the iterative distribution of the CAR Tables.

NAN Cache	
CAP Information	**CAR Information**
bool Reachability *macaddr* MAC Address *int* L2 Type *int* Channel Number *double* Bitrate *double* Last Received Beacon time *double* RSSI *string* SSID	*ipaddr* IP Address *prefix* Network Prefix *int* Prefix Length *int* Distance

Table 2. Conceptual Design of New Access Network (NAN) Cache

5.3 Mobile Node Operation

The CARD protocol specification (Liebsch et al., 2005) suggests a MN to maintain address and capability information of CAR(s) discovered during *previous* CARD operation in a local cache to avoid requesting the same information repeatedly and to select an appropriate TAR as quickly as possible when a handover is imminent, but it does not specify the conceptual design of such a cache. Besides, this proposal will only improve the CAR selection if the MN

is *revisiting* some previously visited CAR domain, a situation not very much likely in case of high speed MNs.

MHD-CAR proposes a MN to maintain a local cache called *New Access Network (NAN) cache* (see Table 2) that maintains the identity and capabilities information of not only the neighbouring CAR(s) and associated CAP(s) but those located multiple wireless-hops away. This will allow the MN to perform RAT and DCC functions locally without the exchange of any *MN-AR CARD Request/Reply* message pair with its current AR, or without involving a CARD server, every time handover is imminent.

The information content of the NAN cache, that is expected to enhance the MN's TAR selection process and handover related decision tasks, is derived mostly from the CAR Table that is usually *pulled* by the MN on the fly from its current AR (via a wildcard *MN-AR CARD Request* Message) when the MN senses that it is moving away from its current AR. The MN will then add and/or refresh the relevant entries of its cache. The NAN cache also derives some of the AP related information from the periodic beacon signals received from the in-range wireless APs.
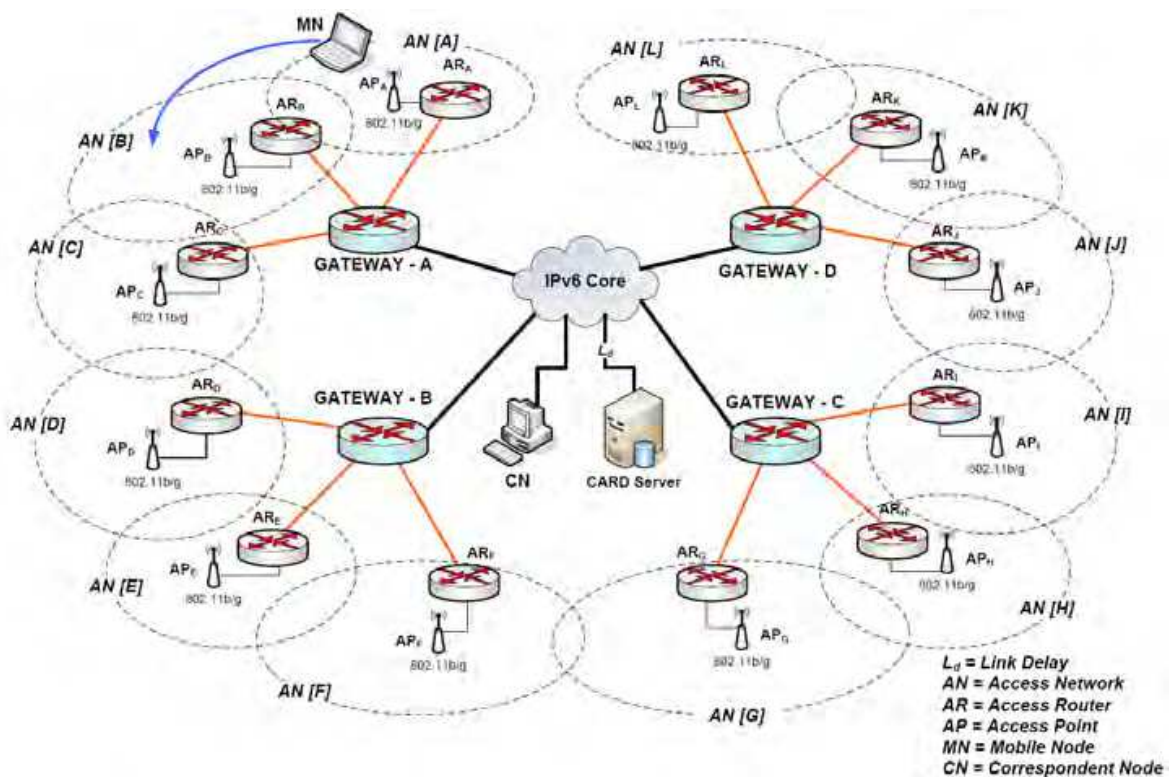
Fig. 7. Simulation Topology

6. Performance Analysis

In this Section we present the results of the simulation experiments comparing and analyzing the performance of the proposed MHD-CAR mechanism to that of the IETF's CARD protocol using the CARD server. Both the protocols are modeled in our mobility management framework (Yousaf et al., 2008(c)) developed in OMNeT++ (OMNeT++) and using realistic message structures and timer implementations.

The simulation experiments and its analysis is similar to the one presented by us in (Yousaf et al., 2008(b)) with the difference that in this chapter we have extended our simulation model to realise a more realistic *hierarchical network topology* instead of a *flat network topology* in which all the ARs were directly connected to their immediate neighbours via Ethernet links. In a flat network topology, the ARs will be able to derive the identity of their neighbouring ARs by simply sending relevant messages directly and hence populate their local CAR Tables. In contrast, to realise the MHD-CAR protocols in the hierarchical network topology, we have extended our simulation framework with the bootstrapping mechanism (see Section 4.1) that would enable the ARs to discover the IP address of the neighbouring ARs. With this major difference, the same experiments were repeated and found the results to match those presented previously in (Yousaf et al., 2008(b)).

The simulation network topology is shown in Figure 7 and the experiments are carried in a homogeneous 802.11b wireless environment using a free space propagation model at 2.4 GHz for a radio channel over a total coverage area of 800m x 800m. To initialise the CAR Tables, in ARs a bootstrapping MN is moved across the reference network at the beginning of the simulation enabling each AR to become aware of the IP address of the previous neighbouring AR. The results expressed in this Section will also apply equally to a heterogeneous environment because the MHD-CAR operation is defined at the network layer.
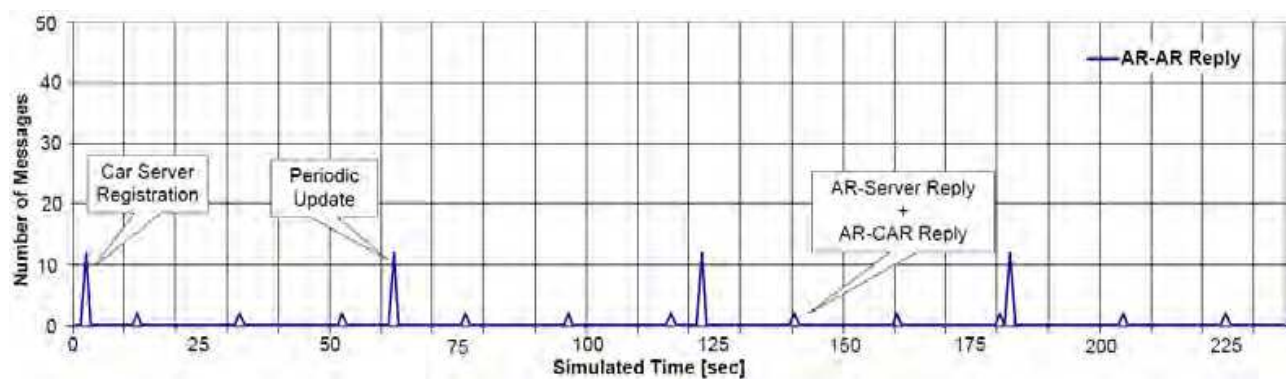
(a) AR-AR Message Throughput in CARD
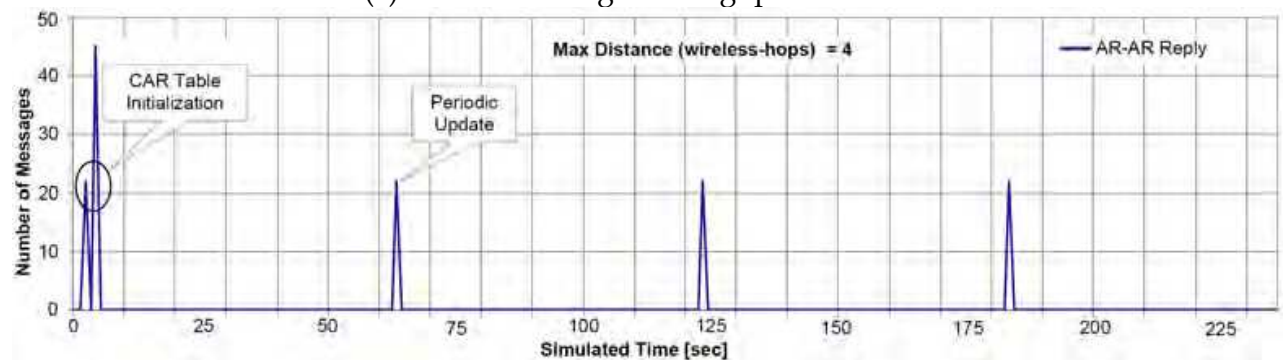
(b) AR-AR Message Throughput in MHD-CAR

Fig. 8. Inter AR Message Throughput in (a) CARD, and (b) MHD-CAR

A single simulation run consists of a MN moving across 12 ARs, starting from AR$_A$ and undergoing 11 handover instances, discovering and resolving the next CAP(s)/CAR(s) while it is still connected to its current AR. The experiments are repeated 100 times for each

of the 25 seed values generated using the OMNeT++'s *sedtool* thereby constituting a total of 2500 runs each for simulating CARD and MHD-CAR protocol. The results are then expressed as average sum of the measured parameters.

6.1 Impact of MHD-CAR on Signaling Load
The average signalling load over the wireless link (MN-AR Messages) and the wired links (AR-AR Messages) for both the CARD and MHD-CAR is compared in Figure 10 and the results tabulated in Table 3. The ARs in both CARD and MHD-CAR periodically update their CAR Tables after 60 seconds and in our simulation this update takes place three times.

6.1.1 Signaling load over the Inter-AR links
In CARD each AR, during boot-up time, register its identity information with the CARD server and keeps the CARD server updated by sending *unsolicited AR-Server Reply Messages* periodically after every 60 seconds. The number of *unsolicited AR-Server Reply Messages* transmitted during boot-up time and during periodic updates remains equal and corresponds to the number of ARs. In between the periodic updates, the current AR will exchange *AR-AR CARD Request/Reply* message pair with the CARD Server for performing RAT function (upon MN's request) and *AR-AR CARD Request/Reply* message pair with the resolved CAR(s) for performing the DCC function. This is seen in Figure 8(a) where we show the occurrence of the average inter-AR (Server & CAR) reply message throughput.

In MHD-CAR however, since the MN is able to locally resolve the identity and capabilities of CAR(s) based on the information in NAN Cache (see Section 4.2), the AR does not need to exchange any request/reply message pair with some server or neighbouring AR(s) thereby resulting in 100% reduction of inter-AR signalling load related to discovering CAR(s). This is depicted in Figure 8(b) where the ARs only exchange *unsolicited AR-AR Reply* messages with their neighbouring ARs as part of the periodic update of the local CAR Table after every 60 seconds.

	Messages			
	MN-AR		AR-AR [2]	
	Requests	Replies	Requests	Replies [3]
CARD	23	23	22	58
MHD-CAR	12	12	0	66
Message Load (%)	-47.8 %	-47.8 %	-100 %	+13.8%
Total Load Reduction (%)	47.8%		17.5%	

Table 3. MN-AR & AR-AR Message Load Comparison

Since there is no central server, the inter AR *update message* throughput in MHD-CAR is 83.33% higher than CARD but overall recording a 17.5% reduction in the *post boot-up* exchange of inter-AR message (see Table 3).

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[2] *The inter-AR messages are inclusive of the AR-Server messages for the CARD operation*

[3] *The AR-AR Reply messages take into account only the replies messages exchanged after the initialization and distribution process.*

During boot-up MHD-CAR records a much higher throughput than CARD due to the iterative inter-AR exchange of local CAR Tables (see Section 4.1 & 4.2) till the Table entries have converged to the maximum specified distance, which is four in our scenario. Evidently the value of maximum distance will have a direct impact on the number of inter-AR messages, but this is of no serious consequence as it happens only once and that too during initialisation via bootstrapping, afterwards which the CAR Tables converge very quickly. Figure 8(b) shows a sharp surge of inter-AR messages during CAR Table initialisation and distribution period but it is seen that the ARs converge within the first 3-4 seconds. Table 3 lists and compares the average number of inter-AR messages exchanged for both the protocols and depicts the percentage reduction in the overall inter-AR messages induced by MHD-CAR.

6.1.2 Signalling load over wireless link

As depicted in Figure 9, a MN in a CARD protocol will exchange *MN-AR CARD Request/Reply* message pair with its current AR twice, once in the beginning (soon after connecting to it) to request a list of CAR(s) information maintained in its CAR Table; and the second time when handover is imminent and the MN will need to resolve the L2-ID(s) (received in the beacon messages from in-range AP(s)) that may not have been present in the current AR's CAR Table, and/or to find out the capabilities of the CAP(s)/CAR(s), so that the MN may select a suitable target AR based on some selection criteria (Dario et al., 2006(b)). This approach is suitable for a slow moving MN with a long dwell time in a single cell but not suitable for a fast moving MN.
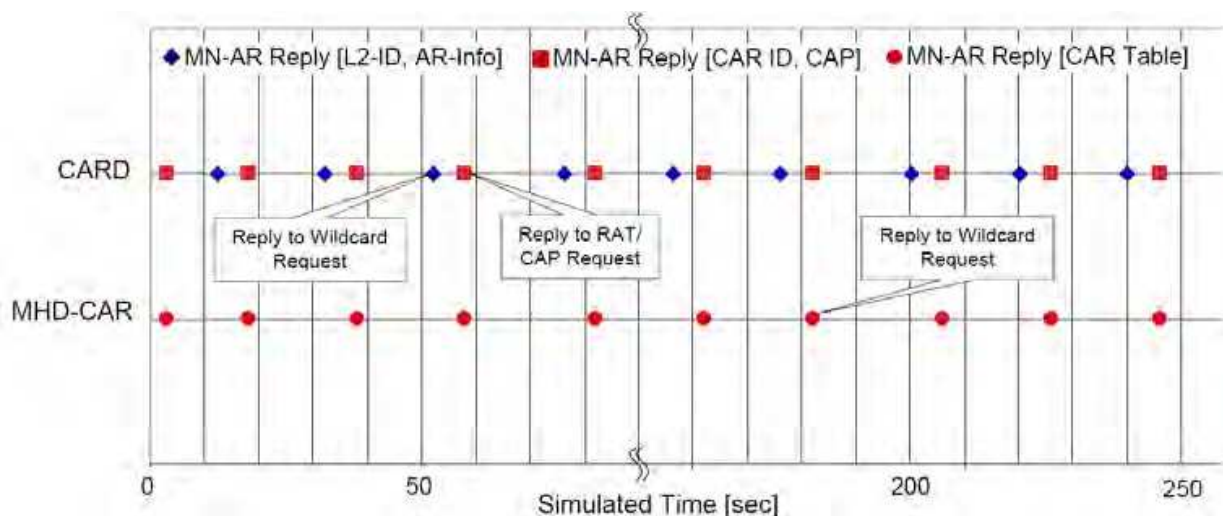

Fig. 9. MN-AR Reply Message Timestamps for CARD and MHD-CAR over the Wireless Link

In contrast, MHD-CAR requires only a single exchange of *MN-AR CARD Request/Reply* Message pair, in which the MN sends a wildcard request and the current AR will send the contents of its CAR Table (see Table 1) in the corresponding reply message and the MN will cache the information in its NAN Cache (see Table 2). This will contribute towards the reduction of the signalling load over the wireless link by almost 48%, as seen from the comparison of the message timestamps of *MN-AR Reply* messages transmitted by the CARD and MHD-CAR depicted in Figure 9 and hence the throughput reduction achieved by MHD-CAR over the wireless link is clearly evident. Table 3 lists and compares the average

number of MN-AR messages exchanged over the wireless link for both the protocols and depicts the percentage reduction of message load induced by MHD-CAR with reference to the scenario depicted in Figure 7.

6.2 Impact of MHD-CAR on Scanning Delay

It is a known fact that the L2 handover delay is a major delay component adding to the overall handover latency for MIPv6 (Yousaf et al., 2008(c)) and thus a major impediment to the performance of higher layer mobility management schemes. The main contributing factor to the L2 handover latency is the delay incurred by the *channel scan* operation as part of the CAP discovery process (see Section 3). Typically a MN *after* losing its connectivity with its current AP will perform the 802.11 *all-channel scan* (active/passive) on, in our case, 13 frequency channels. This scan-delay is certainly not suitable for attaining seamless handover performance for fast moving MNs and various methods have been proposed in this respect. One of the consensus solutions to reduce the L2 handover delay is to perform scanning on selective channels (Park et al., 2004) or perform a pro-active scan, i.e., before a MN loses its connection with its current AP (Haito et al., 2007).
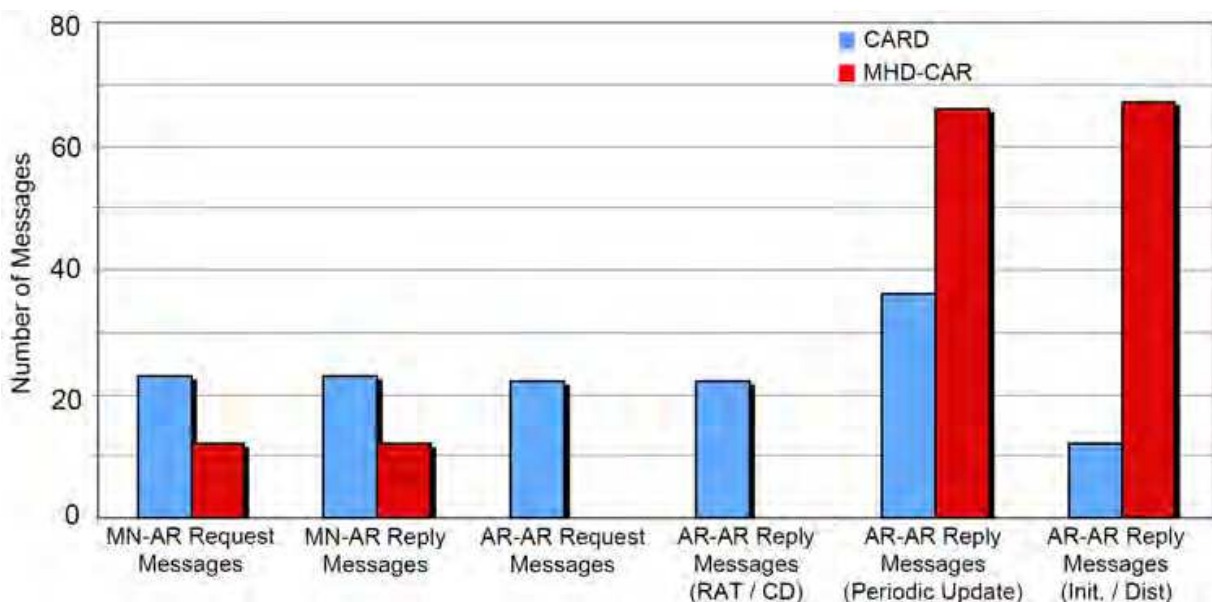
Fig. 10. Signalling Load Comparison of CARD and MHD-CAR

The MHD-CAR based on the information available in the NAN Cache proposes to reduce the scan delay by enabling a MN to perform *target scanning* on selective frequency channels. The MN, instead of waiting to disconnect from the current AP, will start to scan for only those channels that correspond to the nearest CAP(s) as specified by the *Distance* parameter in the NAN Cache, and if the CAP(s) are not located (or are out of range) will proceed to select and scan the next set of frequency channels corresponding to next farther CAP(s). The MN will typically start the scan process when the RSSI from the current AP falls below a certain threshold. Figure 11 compares the performance of MHD-CAR's target scanning with the 802.11 all-channel scan.

From the Figure 11 it is evident that the performance of MHD-CAR's target scanning incurs less delay than the full channel scan, however the delay performance is a function of the size

of the NAN Cache and location of the MN. For example it is observed that when the *Distance* value is 4 and MN is undergoing the 7th handover, target scanning incurs more delay. This increase in delay, however still less than the full-channel scan, is due to the fact that the MN is at AR_G and the CAR Table in the AR_G will have a total of 8 CAR entries and thus the MN has to scan all the 8 channels.
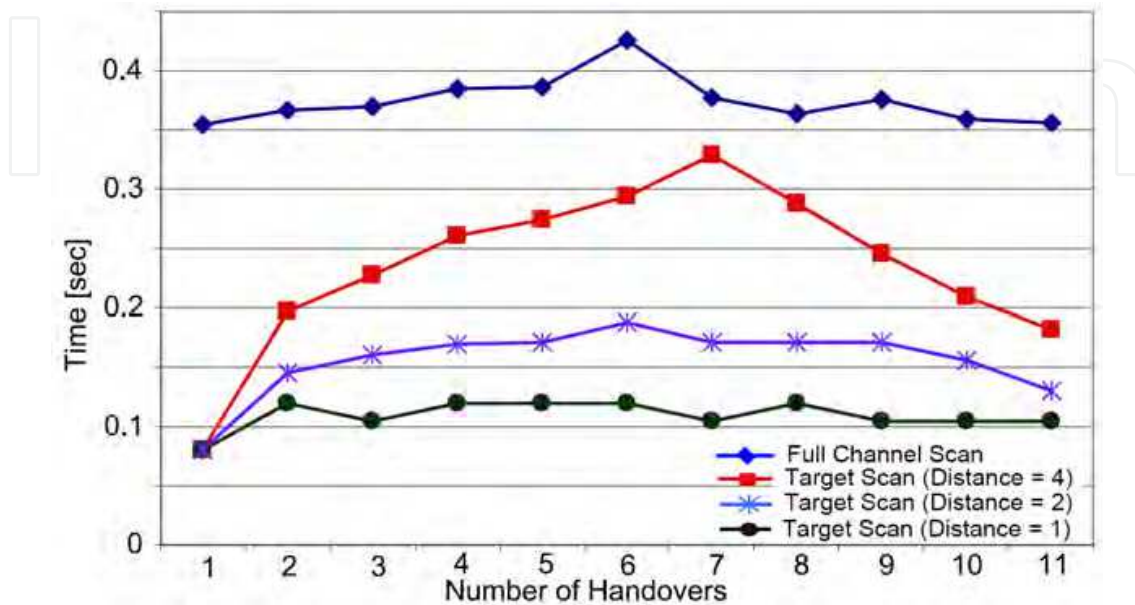

Fig. 11. Performance of MHD-CAR's Target Channel Scanning

7. Comparison with IEEE 802.21 MIHS

The IEEE 802.21 is an emerging standard (IEEE Std 802.21) that aims at imparting seamless mobility to MNs traversing diverse radio access technologies in a heterogeneous network environment. The motivation is to facilitate inter-WAT handover between IEEE 802 and non-IEEE 802 access networks in such a way that the process negotiation is independent from the specific features of the underlying access network technology. In other words, IEEE 802.21 is being designed to provide *Media Independent Handover (MIH)* service that is tasked with the *handover initiation* and *handover preparation* whereas leaving the task of *handover execution* to other protocols like FMIPv6. The prerequisite to preparing a MN for a handover is the discovery of new links in the vicinity and this, according to (George et al., 2008), may involve maintaining a remote information server (similar to a CARD Server) that can be queried to get information about the available networks in the area of a specific MN and/or relying on the MN's scanning operation to select the network of its choice.

The MIH services are being realised by defining *Media Independent Handover Function (MIHF)*, which is implemented as a separate protocol stack located between the *Network Layer* and the *Data Link layer* as shown in Figure 12. The MIH operation is dictated by the MIHF exchanging events, commands and information messages with the adjacent layers. It should be noted that the MIHF is supposed to be located within the protocol stack of both the MN and the Network Node mandating major revision of the present network infrastructure and nodes. This would also mean major enhancements and modifications to the individual media specific technologies (802.11, 802.16, CDMA, UMTS, GSM, GPRS, etc)

in the form of defining and developing new SAPs and primitives that would interface with the generic SAP and primitives defined for the IEEE 802.21 before a MN can take advantage of the MIH services (Eastwood & Migaldi, 2008). This would entail a major re-engineering effort involving the upgrade of the whole network infrastructure and protocol standards. Besides, the IEEE 802.21 model diverges from the standard ISO/OSI reference protocol model by introducing an intermediate layer between L2 and L3.
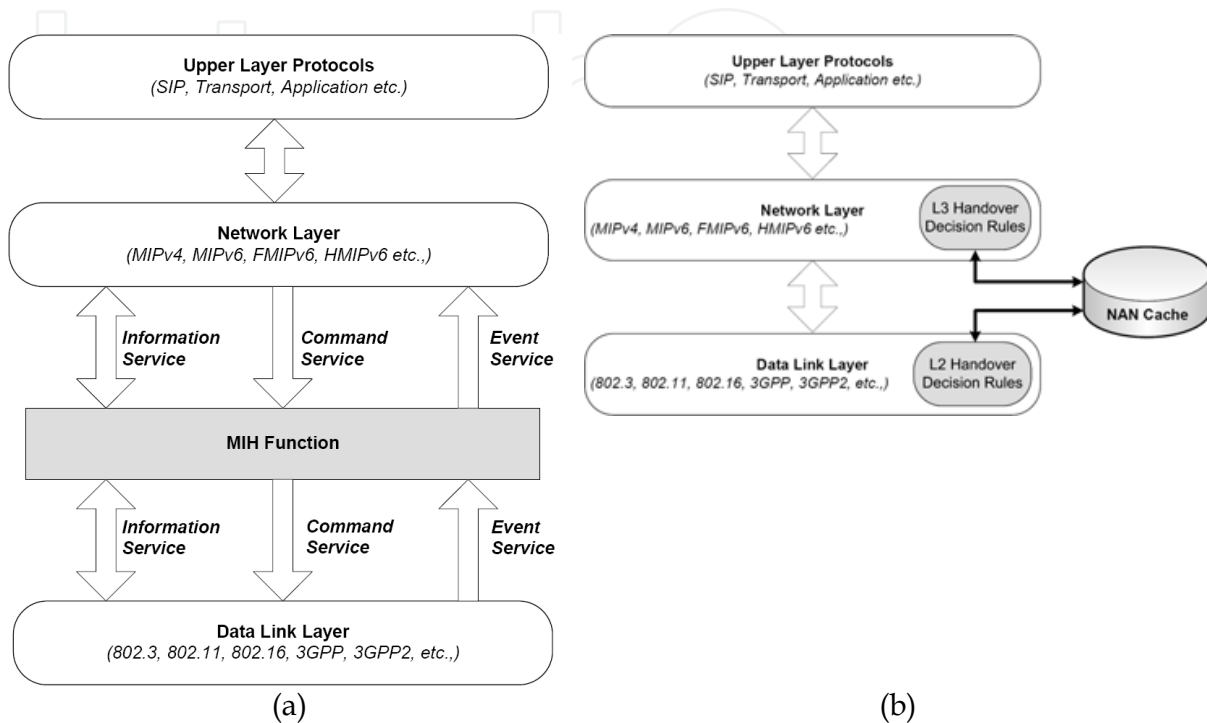

Fig. 12. Conceptual Models of (a) The IEEE 802.21 MIH Service Model, and (b) The MHD-CAR Protocol

Similar to IEEE 802.21, the operational scope of MHD-CAR is to provide a mechanism to enable a multi-homed MN to undergo inter-RAT handover by providing the requisite information content that would enable a MN to choose the best network that would suit its application service requirements. However, in sharp contrast to IEEE 802.21 service model depicted in Figure 12(a) which is implemented as a protocol stack, the MHD-CAR is based on managing and maintaining a NAN Cache inside the MN that can be accessed by the mobility functions defined at the network layer and the data link layer. This translates into defining simpler interfaces at L2 and L3 for interaction with the NAN cache rather than demanding major revisions from the access technologies as in the case of IEEE 802.21 highlighted above. The NAN Cache thus provides cross-layer capabilities.

In contrast to IEEE 802.21, the MHD-CAR protocol is simply an optimised version of the existing CARD protocol without introducing any new messages, interfaces and/or network entities, or deviating from the reference ISO/OSI reference model making it scalable and deployable and without any burden on the network itself.

8. Conclusions

In this chapter we have provided operational and functional details of a proposed protocol called MHD-CAR that has been designed in view of the stringent performance requirements imposed by fast moving MNs in terms of seamless and fast handovers in a heterogeneous wireless network environment. MHD-CAR optimises the standard CARD protocol in enabling a MN to discover on the fly the identity and capabilities of not only the neighbouring CARs but also CARs that may be located multiple hops away, and all this is achieved with minimum reliance on the network. This is expected to augment the performance of seamless handover protocols like FMIPv6 by ensuring accurate selection of NAR with minimum discovery latency.

The MHD-CAR is a distributed mechanism in which the ARs are able to inter-communicate their identities and capabilities information to neighbouring ARs and to ARs that are located multiple wireless-hops away without relying on maintaining and managing a central CARD server. Each AR stores this information in their local CAR Tables which are then communicated to the MN upon request. Due to the distributed mechanism, MHD-CAR is more efficient, reliable, survivable and scalable protocol than the CARD protocol. Since the MHD-CAR does not introduce any new protocol messages it can therefore be easily integrated into the present deployment infrastructure.

It exhibits far better performance over the IETF's CARD protocol in terms of the substantial reduction of signalling load over both the inter-AR links (by 17.5%) and crucially over the error prone wireless link (by 48%), while utilizing the CARD protocol messages. This reduction in signalling load is achieved because the MN is able to perform RAT and DCC functions locally, based on the information content of the NAN cache, and without relying on the network.

Another very important aspect of the MHD-CAR scheme is that it provides cross-layer liaison between L2 and L3 mobility function. This is achieved by having a NAN cache in the MN, which provides the MN with a topological snapshot of the identity and capabilities of the access networks that may be multiple hops away from its present point of attachment. This enables a MN to perform target scanning on selected channels greatly reducing the CAP discovery latency and enhancing the accuracy of the TAR selection process. This alone will have a direct impact on the overall handover latency and fast moving MNs will greatly benefit from it.

In contrast to the IEEE 802.21 standard, it is observed that the MHD-CAR is a light weight and much simpler alternative solution that provides the main functional services of the 802.21 MIHS. Although MHD-CAR has not been designed as an alternative to 802.21 but it does share its motivational, operational and functional scope. The IEEE 802.21 WG was developed to provide a unified global mechanism by defining a common MIH layer sandwiched between the Network Layer and the Data Link Layer and defined common triggers that would be generated independent of the underlying access technology. The motivation was to enable the MN to make accurate selection of the network and to provide triggers that would aid the IP mobility protocols like FMIPv6. However all this is being introduced at the cost of high complexity while deviating from the base ISO/OSI prescribed layered approach by introducing a new layer between the L2 and L3. Also it would mandate changes to the existing access technologies to confirm to the MIHS scheme of signalling. For example different SAPs are required to be defined for each of the access technology. It

would also involve the exchange of signalling message between the network and the MN, even over the air interface.

MHD-CAR therefore provides the same conceptual functionalities defined for MIHS but without transgressing the functional boundaries of the standard OSI/ISO protocol reference model and with a much simpler and scalable approach.

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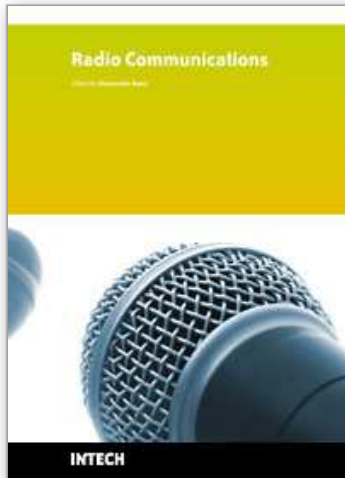
Radio Communications

Edited by Alessandro Bazzi

In the last decades the restless evolution of information and communication technologies (ICT) brought to a deep transformation of our habits. The growth of the Internet and the advances in hardware and software implementations modified our way to communicate and to share information. In this book, an overview of the major issues faced today by researchers in the field of radio communications is given through 35 high quality chapters written by specialists working in universities and research centers all over the world. Various aspects will be deeply discussed: channel modeling, beamforming, multiple antennas, cooperative networks, opportunistic scheduling, advanced admission control, handover management, systems performance assessment, routing issues in mobility conditions, localization, web security. Advanced techniques for the radio resource management will be discussed both in single and multiple radio technologies; either in infrastructure, mesh or ad hoc networks.

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