Layer-2 Protocol Adaptation Method to Improve Fast Handoff for Mobile IPv6 Vertical Handoffs

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***Abstract* — Inter-technology roaming is known as one of the interesting challenges toward fourth generation of mobile and wireless communication. While FMIPv6 standardizes the fast handoff solutions in IP layer, the issues of media independency are being investigated through IEEE802.21 project. The integration of these two standards is believed to result in solutions for vertical handoffs between different network technologies. This paper presents an improved link layer mechanism to assist FMIPv6 for seamless vertical handoffs. We introduce a new access router discovery method and propose a vertical handoff algorithm accordingly. Further, we report the implementation details performed through simulations. The simulations evidence performance improvements in terms of latency and packet loss. It is also analytically shown that by enabling access router discovery method and improving link layer event services, an MN can be well prepared for handoff and perform faster movements.**

***Index Terms*—Vertical handoff, Heterogeneous networks, FMIPv6, MIH, Access Router discovery.**

I. INTRODUCTION

Fast handoff for Mobile IPv6 (FMIPv6) provides solutions for intra-system handoffs in wireless Internet Protocol (IP) networks. IEEE802.21 on the other hand, deploys link layer solutions for heterogeneous media in inter-system handoff. Alongside the standards, the integration of these two protocols has been the concern of several proposals which were based on using link layer triggers for access network independency purpose and preparing information for FMIPv6 protocol which in turn, can result in seamless handoffs for heterogeneous networks. Further to the use of specific link layer messages, we believe that the use of a router discovery method in a proper timing fashion enables Mobile Node (MN) to learn about necessary IP layer information and the prospective network ahead of time which results in lower handoff latencies together with smaller losses in packet stream. Hence, we introduce an improved Access Router Discovery (i-ARD) method in this paper together with an improved link layer mechanism that assist FMIPv6 and perform seamless vertical handoffs. It is shown through analysis that by enabling the proposed i-ARD method and the improved link layer event services, an MN can be well prepared for handoff and can perform faster movements. In order to evaluate the performance of the proposed method, we implemented our model and FMIPv6 through simulations and made a comparison in terms of latency, buffering requirements, and as well as packet loss that the two models cause with different types of packet streams. We have shown that within these metrics, the introduced method performs better. The rest of the paper is organized as follows: Section II introduces the structure of FMIPv6 standard and discusses the process IEEE802.21 Media Independent Handoff (MIH), followed by a report on the other related researches in integrating these methods. Section III describes the proposed model and algorithms of i-ARD and improved layer-2 operations in details. In section IV, we report on the simulation implementations of the proposed method which is followed by the results achieved in the latter part. Section V presents an analytical performance inspection of the proposed model and comparisons made to FMIPv6 and finally, the conclusions make the last section.

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II. RELATED WORKS

FMIPv6 has been proposed and standardized as IP layer solution for handoff [1] promising low latency and low packet loss performance while it carries some drawbacks including imprecise movement anticipation which causes falsely-picked prospective Access Router (AR), lack of mechanism to create the mapping table in AR despite using it, possibility of back-and-forth handoffs or ping-pong effect due to improper scheduling

TABLE 1: MIH PRIMITIVES AND RELATED PARAMETERS

Primitive	service	Parameters
Link_Available	ES	AR prefix , Interface ID, MAC, Q level
Link_Going_Down	ES	Interface ID, oAR MAC, Q level
Link_Down	ES	Interface ID, nAR MAC
Link_Switch	CS	HO mode, Interface ID
Link-Up	ES	Interface ID, nAR MAC

of link triggers, and performing handoff in reactive mode due to prolonged new Care of Address (nCoA) configuration and Duplicate Address Detection (DAD) which causes higher delays. As a delay sample, the process of Neighbor Discovery in MN together with the message exchange duration might take several seconds and despite the use of Fast Neighbor Advertisement (FNA) in FMIPv6, the process is likely to take about 800 ms as reported through experiments in [2].

IEEE802.21 is another standard [3] introduced as Media Independent Handover (MIH) and contains considerations of supporting various types of layer-3 mobility management protocols, especially MIP, MIPv6 and Session Initiation Protocol (SIP). Since this standard focuses mainly on solving media independency problem, it operates closer to layer-2 than dealing with mobility management protocols of layer-3. In order to reach an optimized seamless handoff in heterogeneous networks a well-constructed and fair interoperability between layer-2 operations and layer-3 mobility management protocols, particularly handoff management protocols, seems to be inevitable.

A. FMIPv6 and IEEE802.21 Integration

Integrating FMIPv6 and MIH has been the concern of few proposals in optimizing vertical handoff. Inadequacy of MIH Event Service (MIES) primitives was the motivations of the work proposed in [4, 5] to create new primitives and use a handoff mechanism similar to FMIPv6. Some studies have been reported [6] that concerned on discovering the prospective AR and make handoff decision based on the discovery method [7, 8] among those, the protocol of Access Router Information Protocol (ARIP) can be referred [9]. This approach is based on IETF SEAMOBY working group project [10] defined as Candidate Access Router Discovery (CARD). Improving MIIS services was also the concern of few other proposals. Information in MIIS is specified in common formats and these information aid handoff decision-making process. Selecting a higher layer mechanism of mobility management to obtain information of neighboring networks from different access technologies is how MIIS information primitives are utilized in [11-13].

Unlike the proposed solutions in the area, we model the main and required functionalities of MIIS in the form of discovering and selecting the prospective network prior to actual operation of vertical handoff without requiring the whole of 802.21 to be implemented. In case

TABLE 2: I-ARD INFORMATION FORMAT

AR	Link Type	MAC	Prefix	Available BW	Location ID

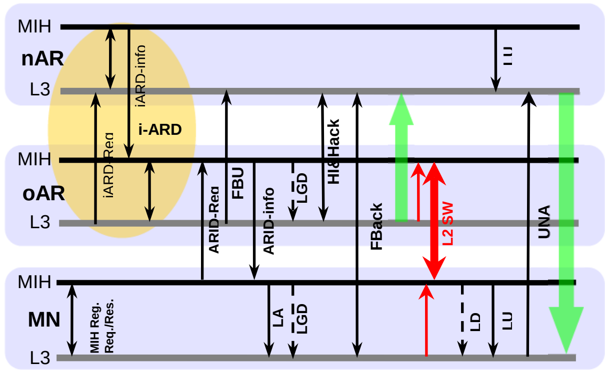

Figure 1: Proposed handoff algorithm

of successful network selection, it is believed that since the target network is cleared earlier, the time-taking processes such as nCoA configuration and validation can be started earlier as well and therefore, the MN can easily wait for nCoA acknowledgement while the vertical handoff is being processed.

III. PROPOSED MODEL

As discussed previously, the inefficiently performed access router discovery method in FMIPv6 results in considerable delay which contributes to the overall delay of handoff procedures. In addition, more problems such as ping-pong effect (back-and-forth handoffs) are bound to happen when the actual target network is not selected precisely. Aiming to reduce the latencies in handoff initiation phase, we propose an improved access router discovery (i-ARD) method to achieve a precise prediction of the prospective serving network. By this means, the message exchange between ARs is initiated using an established tunnel, whereby neighboring ARs are queried for necessary information, and the mapping table at the serving AR is updated according to the MN needs. Consequently, we propose a handoff model in which i-ARD is responsible for acquiring neighboring ARs information as a replacement to MIIS. Therefore, the procedure of information service (MIIS) discovery which consumes much time due to DHCP server delay will be eliminated. For instance, the function of delivering the list of all available links which is usually performed through Link-List trigger is replaced by ARID-Info. In the case of receiving the link details of candidate AR (cAR) from MN, the serving AR identifies this AR as a prospective network based on its network prefix. This means that the existing mapping table in AR is used for two purposes; the information availability for MN's on-demand requests and further handoff preparations by AR as the candidate AR for handoff is determined. Based on these functionalities, by using i-ARD, no mapping table or local cache is needed in MN

TABLE 3: SIGNIFICANT SIMULATION PARAMETERS

Parameter	Value	
	Heavy Load	**Medium Load**
Inter-Request Time	Exponential (360)	Exponential (720)
File Size (Bytes)	Constant (50,000)	Constant (5,000)
Start Time	Uniform (100,110)	Uniform (5, 10)
Model Assumptions		
Beacon interval	0.01 s	
AR trans. power	0.0005 w	
MN rec. threshold	-95 dBm	

since i-ARD protocol is applied mainly between ARs. Therefore, unlike FMIPv6 that specifies the nCoA configuration and FBU initiation from the MN, these procedures take place in the serving AR which

means all the procedure of nCoA validation including DAD will start earlier than actual handoff initiation. In other words, the handoff decision is made in the network and the required processes start in network while the MN receives the nCoA throughout this period. The resulting accuracy of this procedure in selecting target network arises from the fact that MN is not the entity that decides which network it should handoff to. Despite the detected network reported by the MN, the selected network is specified through the configured nCoA.

In our approach, we use specific service primitives in certain schedules aiming to deliver the necessary information to each node at proper time which in turn leads to fair handoff decision and execution with affordable latency and packet loss. Table 1 outlines the primitives and the related parameters we utilized in the protocol.

A. Proposed Algorithm

Figure 1 demonstrates the proposed handoff mechanism using the techniques explained earlier. Prior to any operation, the MN needs to register for MIH services. This can be done while MN has not yet detected its movement and therefore has not initiated any of the handoff process modes including handoff initiation and execution. The i-ARD procedure is the next operation which is usually performed at some intervals or at any new AR activation. Unlike CARD protocol [10] that specifies the address resolution of ARs based on L2 IDs and initiated by MN, in i-ARD the address resolution procedure is performed in the oAR in which MN is currently served by. During i-ARD phase, the oAR enquires all candidate ARs using iARD-Req multicast message and receives the information of active and potential ARs through iARD-Rpl reply message. The list of candidate ARs is a combination of two sources; the ARs reported to oAR by MN in certain intervals and the ARs in the vicinity of the reported candidate Access Routers (cAR) which is determined by oAR. Through this advance discovery method, a new entry for each discovered AR is created in oAR and the mapping table will be updated. These entries are available to MN on every request. Based on selected attributes of each network, ARs are classified and sorted in the mapping table by the technology in use. Table 2 indicates the form that AR data are stored and sorted. The location ID code is used to identify the cARs in geographical vicinity

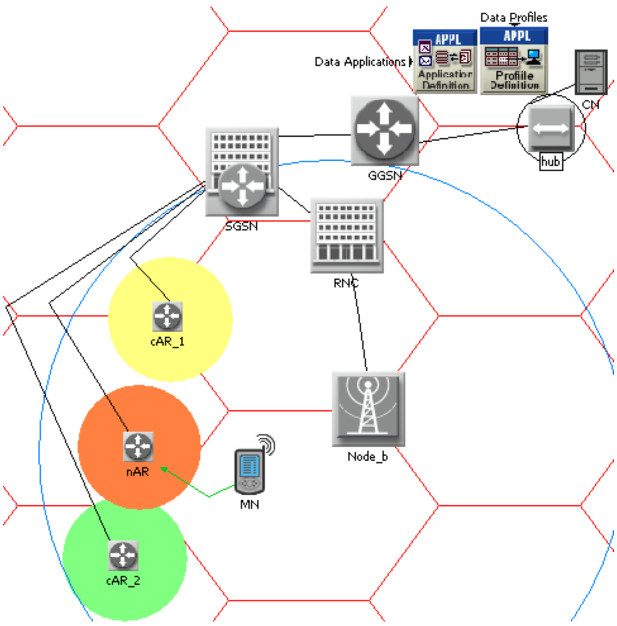

Figure 2: Network topology

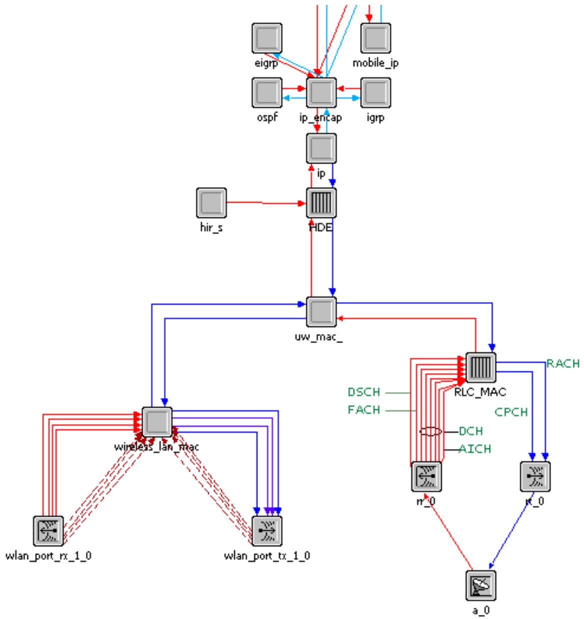

Figure 3: Node model implementation for mobile node

which might be different from network neighborhood.

B. Protocol Description

The actual handoff procedure starts as soon as MN senses an increase in one of the neighboring networks' signal strength. At that instant, the MN sends ARID-Req message to oAR including L2 ID of the new network. By referring to the mapping table, the oAR specifies the candidate network which MN wants to handoff to. This cAR selection job is performed by oAR based on the information obtained through i-ARD. Since the prospective AR is already specified, the oAR then configures an nCoA for MN using the new network prefix and MN link ID, initiates an FBU for the new address, and replies the MN with ARID-info including the information of the cAR which corresponds to the existing L2 ID. These two messages replace router solicitation and advertisement messages (RtSolPr and PrRtAdv) used in FMIPv6 for protocol indications. By this message, MN is informed of its nCoA together with the prospective AR. Referring to Link Type field included in ARID-info, the MN knows that it should configure its second interface with the nCoA it has received. At the time that MN moves toward the new network, a Link-Going-Down (LGD) trigger as a result of signal degradation in the old interface will be issued from MIH to inform IP layer of the link degradation. As the signal indication reduces simultaneously in oAR, an LGD trigger is also issued from MIH to IP layer in oAR and we specify this event as the start of handoff initiation (HI) and tunnel establishment between the two ARs. Since the tunnel establishment and binding update are the most time consuming processes, we introduce an overlapping operation allowing oAR to initiate HI/Hack operation during the waiting time for binding acknowledgement (FBack).

However, the packet forwarding to nAR starts right after the oAR receives and delivers FBack to both nAR and MN. Now that the MN receives FBack, it activates the second interface and establishes a low layer connection to the nAR while disconnecting the old connection. This L2 handoff process is performed through a Link switch (LS) command event which is received by MIH layer at both oAR and MN. The events to issue LS command are the start of packet forwarding and receiving FBack at oAR and MN respectively.

As indicated in Figure 1, there would be enough time for the MN to prepare for L2 handoff and link switch while shorter time is required at oAR for this operation. Thus, we show through simulation that these two events are properly scheduled.

When the Link Up (LU) trigger is received right after new connection establishment, the MN is fully attached to the new network and sends an Unsolicited Network advertisement (UNA) message to the nAR to ensure start of packet forwarding through the new connection. Now the MN can complete binding update with its home network.

IV. SIMULATION DETAILS

In order to evaluate the performance of the proposed protocol, we developed a model in which new modifications were applied to the current AR and MN modules. Using OPNET Modeler [14], three WLAN access routers together with a Serving GPRS Support Node (SGSN) build the ARs of our heterogeneous environment, while an FTP server plays the role of a Correspondent Node (CN). We also developed a special mobile node (MN) with WLAN and UMTS interfaces. The developed network model using OPNET is shown in Figure 2 where the MN moves toward WLAN through a predefined trajectory while communicating with its current point of attachment. The network condition is set to be free of any congestion so that the delays pertaining to long network access due to queue congestions in AR is eliminated.

The ARs are collocated with Access Points (AP) [15] as a true representation of real life situations while Node_b is away from RNC and covers a large cell. The MN uses two interfaces to WLAN and UMTS networks with the related MAC layer in each interface. The MIH layer was created as a node model and placed before the MIP model. Figure 3 depicts the implemented mobile node model with two interfaces -- MIP, and MIH layers. For media homogeneity, a node level entity, called MAC unifier, has been created to recognize, specify, and deliver the messages of each interface prior to entering the MIH module. The same MIH modules together with MIP layer were created on the standard implementation of AR to support MIH messages and triggers and FMIPv6 protocol. Alongside the implemented modules and node models, new process models which implement the new messages and procedures were also created. While ATM links were used between UMTS network entities, because of the nature of device connection in WLAN [16], the connection type between the gateway and AR in WLAN environment was 10Mbps Ethernet. Furthermore, a process model was created to emulate the proposed i-ARD processes. This model which is depicted in Figure 4, includes the procedures of AR table creation and network selection.

The radiuses of the areas under the coverage of ARs and the Node_b were obtained through several simulation tests and were also based on the propagation and receiving parameters set for ARs and MN, respectively. The significant simulation parameters are based on [17] as summarized in Table 3.

V. NUMERICAL RESULTS

In order to measure the performance of the proposed protocol, three metrics namely latency, packet loss and buffer size were considered for the simulation. First we evaluate the buffering requirements in nAR during the complete handoff process. We tested the proposed method together with FMIPv6 for buffer size with two

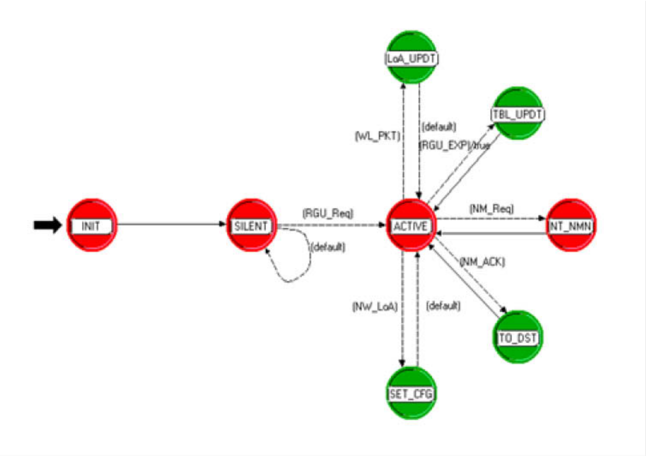

Figure 4: Process model implementation for i-ARD

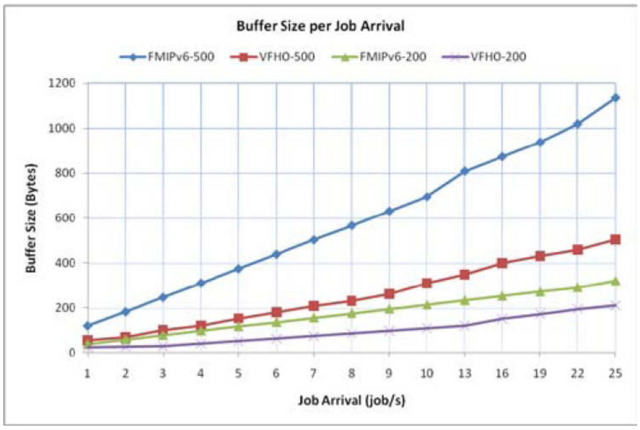

Figure 5: Buffering requirements

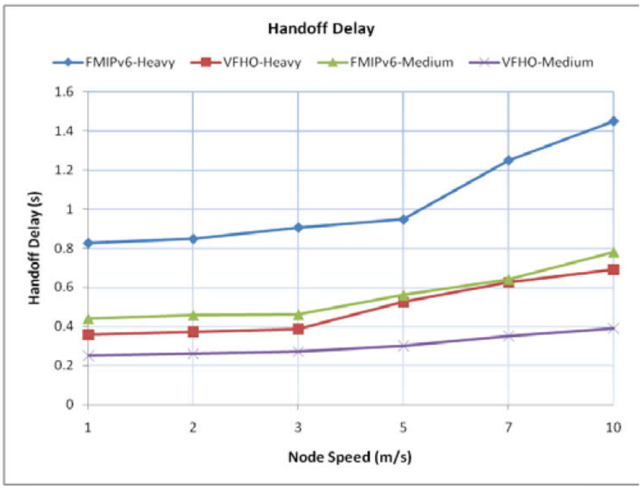

Figure 6: Handoff latency vs. node speeds

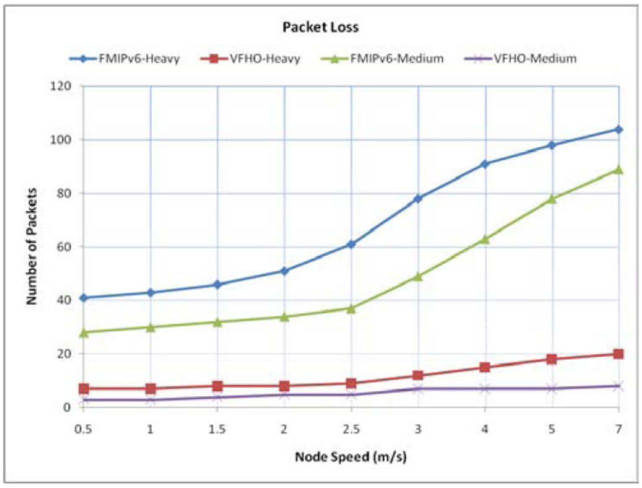

Figure 7: Packet loss

different packet sizes of 200 and 500 Bytes. We created 15 instances of the simulated model for each packet size and different arrival rates using scenario duplication feature of OPENT Modeler. The job arrival rate varied from 1 to 25 jobs per second.

It is important to mention that the analytical comparisons were also made to FMIPv6 in vertical mode. However, we made some numerical comparisons of the proposed method to other approaches on the study area. Since the majority of the mentioned studies have compared their approaches to FMIPv6, we can elaborate the proposed method to those conducted at the same manner of integrating IEEE802.21 and FMIPv6. Figure 5 shows the numerical results obtained after running all the instances of the simulation. As the proposed method guarantees a proactive mode of handoff, a rather shorter time is expected for buffering period compared to FMIPv6. Since the time consuming operations are performed prior to tunnel establishment. As depicted in Figure 4, at arrival rate of 1 job/s and packet size of 500 Bytes, the average buffer size required is about 100 and 200 Bytes using the proposed handoff with i-ARD method and FMIPv6, respectively. However, the buffer size increases dramatically with FMIPv6 with increase of arrival rate, whereas the buffer size in the proposed method merely reaches 2 packets (1000 Bytes) at the rate of 25 job/s. A buffer size of 5 packets are required at the rate of 13 job/s used with FMIPv6 which implies a long period of tunneling and this could result in data expiration.

As for the second metric, the overall handoff delay was obtained based on the MN moving speed and using the statistics defined in a separate probe file. Based on our assumption, roaming toward WLAN network implies that the MN should be a pedestrian whose walking and running speeds are roughly 3 m/s and 7 m/s, respectively. Furthermore, we considered two types of data stream, i.e. medium and heavy loads to test the latency as specified in Table 3. Therefore, we duplicated the simulation model and obtained 20 scenarios with different MN speeds ranging between 1 and 10 m/s with the interval of 0.5 m/s. Figure 6 shows some critical statistics for certain MN speed. For MN moving at walking speed (1-3 m/s) both FMIPv6 and i-ARD methods sustain stable delay wherein FMIPv6 is more sensitive to load type, causing around 850 ms delay; whereas the handoff using i-ARD method can complete in approximately 410 ms. Higher MN speed; handoff with FMIPv6 suffers from higher delays continue to increase drastically as the MN reaches running speed. As a worst case we consider a running speed of 7 m/s and it could be seen that the handoff delay exceeds 1.2 s when using FMIPv6 while at the same situation, handoff using i-ARD can still be tolerated with approximately 600 ms delay. This metric was used to compare an optimized integration of FMIPv6 and IEEE802.21 with FMIPv6 in [11]. While the mentioned approach achieved a delay improvement by 25% compared to FMIPv6, the proposed method shows an improvement by approximately 45% under similar conditions.

Figure 7 shows the packet loss paradigm for the two protocols. The same types of load as for latency analysis were used for the analysis. As shown, packet loss with the proposed model hardly reaches 20 packets in worst case; while the number for FMIPv6 starts with 27 when the speed is as low as 0.5 m/s with medium load, and exceeds 100 at heavy load and the highest speed measured. While the approach in [11] improved the FMIPv6 packet loss by an average of 80% to maintain an average of 15, our approach hardly caused 10 lost packets at the same node speed and packet load.

VI. Delay Analysis and Discussions

In order to evaluate the performance of the proposed algorithm, an analysis on the delays of each process is performed. Because the most significant delays here occur during the processing times in FMIPv6, a comprehensive definition of handoff delay in FMIPv6 is given next. The overall handoff latency for FMIPv6 is calculated thereafter.

Traditionally, handoff latency is defined as the time between losing connectivity from one network to resuming existing communications on the new network using the nCoA. In fact, this definition makes sense in MIPv6 as there is no way for the MN to resume connection until the nCoA has been registered with its HA. However, as discussed earlier, FMIPv6 allows existing communications to continue throughout the entire handoff process (assuming the nAR has sufficient resources to buffer packets until the MN attaches to the new link). Theoretically, the only effect on existing traffic flow for any anticipated handoff mechanism, especially FMIPv6, will be the latency involved when packets are buffered at the nAR. Thus, in reality effective handoff delay can be expressed as:

$$\boldsymbol{t_h = t_{connect} - t_{disconnect}}. \qquad (1)$$

Where the latency experienced by packets is:

$$\boldsymbol{t_h = t_{FNA} + t_{deliver}}. \qquad (2)$$

t_{FNA} is the time for Fast Neighbor Advertisement (FNA) to complete and $t_{deliver}$ is the time it takes for the nAR to deliver the packets to the MN.

However, by this definition of delay for predictable movements, no packet loss should be experienced using FMIPv6. Besides, minimum jitter for real-time streams is expected during the movement time at L2.

One of the open issues with the FMIPv6 is choosing when to tear down the bi-directional tunnel between the MN's pCoA and nCoA. Intuitively, this should be done once the MN has completed the MIPv6 BU procedure with all of its CNs. However, the current FMIPv6 specification does not provide any signaling exchange for the MN to inform the pAR that it can stop forwarding packets.

Thus, a soft state timer in the pAR set to a 'reasonable' value is the most likely solution.

In order to calculate the delay occurring during handoff, the elements are divided in two parts: delay due to the exchange of signaling or message; and node delay or process cost. The assumptions are similar to that proposed in [4] and the following are the parameters:

T_{MO}: One way message travel between MN and oAR.
T_{ON}: One way message travel between oAR and nAR.
T_{MN}: One way message travel between MN and nAR.
P_O: Process cost in oAR.
P_N: Process cost in nAR.
P_M: Process cost in MN.

Based on these assumptions, the handoff delay for different methods can be determined using the message flow diagrams. Using the proposed diagram for handoff algorithm, the following time for message exchange and process costs is applicable and the delay for each stage can be calculated as follows:

$$\boldsymbol{T_{CARD}} = P_N + 2T_{NO}.$$
$$\boldsymbol{T_{DAD}} = 2T_{MO} + P_O + P_{DAD}.$$
$$\boldsymbol{T_{L2}} = T_{CARD} + T_{MO} + 2P_M.$$
$$\boldsymbol{T_{L3}} = P_N + P_M + T_{MN} + T_{DAD}.$$
$$\boldsymbol{T_{HO}} = T_{L2} + T_{L3} = T_{CARD} + T_{DAD} + 3P_M + T_{MO} + T_{MN}. \qquad (3)$$

In case of FMIPv6, there will be additional time for FNA and Fast Neighbor Solicitation (FNS) messages as they are the key for redirecting packets from nAR to MN.

In addition the total time of CARD process is ignored in cost of two round-trip time between oAR and HA ($4T_{OH}$) and a process cost in oAR (P_O). Moreover, FMIPv6 includes two additional messages for RtSolPr and PrRtAdv which require two more transmission time. Hence, the overall delay will be:

$$\boldsymbol{T_{HOF}} = 3T_{MO} + T_{DAD} + 4T_{OH} + 2P_O + 3P_M + T_{MN}. \qquad (4)$$

In the proposed algorithm, i-ARD procedure occurs prior to any trigger and handoff process therefore, the information is already prepared and ready to deliver to MN. This will eliminate the process cost in nAR. In reality, the total process of CARD is reported as 500 ms through several experiments [15] from which the major portion belongs to the processing portion of the algorithm. DAD procedure is reported to take around 1000 ms and each message exchange time between fixed nodes is 10 ms. Round-trip transmission between MN and each of the nodes could vary between 50 ms and 500 ms. Assuming equal situations in a comparative scenario for two methods, total handoff process in the proposed method is reduced by five transmission delay times between MN and either of ARs and additional 2 times process delay in oAR, which is a minimum of 300 ms and a worst case of 2500 ms. This difference in range was also shown through simulation tests as reported earlier. As mentioned earlier, along with the protocol, one of the significant issues addressed here is process timing, especially while using i-ARD or any other alternatives for access router discovery.

VII. Conclusion

In this paper, a method for integrating layer-2 and layer-3 protocols to achieve seamless vertical handoff is proposed. The proposed algorithm improved link layer event services, applied an improved access router discovery mechanism for discovering neighboring access routers, and finally integrated the mechanisms with layer-3 mobility protocol to form a seamless handoff process. It was also shown that proper timing operation sequences can avoid significant processing delays. The proposed algorithm shows lower latency and tolerable packet loss compared to FMIPv6. In order for the proposed approach to be applicable to UMTS systems, the event service primitives should be supported by UMTS link layer in real environment.

Acknowledgement

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