Vertical Fast Handoff in Integrated WLAN and UMTS Networks

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***Abstract*— Mobility management and on top of that, vertical handoffs remains as one of the most challenging obstacles in 4G evolution. In this paper, we present Vertical Fast Handoff protocol as a solution to the mobility issues in integrated WLAN-UMTS networks which utilizes Early Binding Update technique to achieve reasonable performance. It contains several key factors including new network modules and procedures. In order to evaluate the performance, an analytical model is presented that includes metrics describing handoff and packet delivery delays, and signaling overhead. Based on the assessments, it is shown that the proposed method exhibits tolerable performance in terms of delays as well as signaling overhead.**

Keywords-vertical handoff; early binding update; packet delivery; latency; signaling cost

I. INTRODUCTION

The coexistence of various communication systems as recommended for the next generation of mobile systems requires mobility solutions for users with seamless inter-technology roaming capabilities; this means that a seamless inter-system handoff is required. Currently, the noticeable ambition toward the convergence of access technologies foreseen by many research bodies has resulted in several approaches for achieving seamless vertical handoffs. The most noticeable discussions in the literature are currently on whether the integration of two standards namely, Media Independent Handover (MIH) proposed by IEEE802.21 and IETF mobility working group (mipshop) will lead to mobility solutions for future mobile networks. Despite the initial wrap-ups of the mentioned standardization bodies independently, only a promise of minimized data interruption during vertical handoffs is made certain by either the integration of the standards or other solutions or other proposals in the area.

Naturally, every inter-system roaming which leads to vertical handoff requires that both link and IP layer handoffs take place, since both network points of attachment as well as the device interface are subject to change. Several initiatives have been made to finally design and implement each of these communications layers. For vertical handoff in a heterogeneous wireless network, the integration and interworking of these two layers with a properly designed timing can directly impact on the performance parameters and subsequently lead to seamless handoffs. In this paper, we propose Vertical Fast Handoff (VFHO) as a new method which is applied at both IP and link layers. VFHO utilizes some features of Fast Handoff for Mobile IPv6 (FMIPv6) in a different manner and manipulate the timing in IP layer including Early Biding Update (EBU) with the Correspondent Node (CN). We then present an analytical model to evaluate the performance of our method. The rest of this paper is organized as follows:

The next section reviews some of the efforts made in the field, followed by a full description of the protocol design in Section 3, while Section 4 describes the protocol in further detail. In Section 5, we present an analytical model for the performance metrics including handoff and packet delivery delay, as well as signaling overhead in form of cost functions. Finally, the paper is concluded in Section 6.

II. HANDOFF IN HETEROGENEOUS NETWORKS

Many handoff protocols promise seamless mobility, focusing mainly on the handoff operation latency, packet loss during the handoff, or similar metrics. However, the issue of seamless mobility becomes more fragile when inter-system or vertical handoff is the case.

IEEE802.21 MIH [1, 2] supports various types of layer-3 mobility management protocols, specifically Mobile IP (MIP), MIPv6 and Session Initiation Protocol (SIP) [3-5]. As this standard focuses mainly on solving media independency problem, it operates closer to link layer than on the mobility management protocols of layer-3. Hence, integration with layer-3 protocols to optimize vertical handoff has been the interest of several proposals [2, 3, 6-11]. For instance, the primitives in MIH to support handoff is far from adequate, hence several works addressing this issue have been proposed (i.e. , in [6]) where a new primitive, namely MIH-PrefixInfo including the prospective Access Router (AR) info was linked to L2 events, and based on modified event triggers, a similar mechanism to FMIPv6 for handoff has been proposed. Although this work originally addressed the issue of anticipation and ping-pong effect in FMIPv6, the method for AR discovery was not indicated and neither was information gathering from the neighborhood. Besides, the proposed handoff mechanism results in more deployment complexities in AR.

Access Router Information Protocol (ARIP) [12] is another proposal based on IETF SEAMOBY working group project [13] defined as Candidate Access Router Discovery

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(CARD). The information on neighboring ARs (ARIP) needed for MN is provided at MN's local or home AR and then sent to the MN. However, the protocol suggests no method on how to collect ARIP information from the neighboring ARs and how the procedure should be initialized. Additionally, maintaining such processes for AR requires more network resources and more AR functionalities while the rest of handoff operations still need to be performed by Mobile Node (MN). Moreover, the protocol still requires AR deployment which is a technology obstacle.

Few other proposals focus on improving the IEEE802.21 proposed Media Independent Information Services (MIIS) [3]. MIIS information primitives are utilized in [9, 11]; this is done by selecting a higher layer mechanism of mobility management, which is a SIP-based mechanism, to obtain information of neighboring networks from different access technologies. The method was tested with an MN with two neighboring subnets. These approaches suggest that the MIH information is obtained through several query/response messages to estimate the network.

III. VFHO DESIGN

VFHO conceptually differs from other handoff methods in the way of service disruption and packet transmission period; this is due to proper interaction of link and IP layers and hence less disruptive mobility and handoff. It includes a procedure to collect and process user and network traffic information from higher layers; this is necessary to select an appropriate network for the next point of attachment. Furthermore, VFHO resolves the issue of packet delivery delay which arises from reroute and retransmissions between the old and new points of attachments. Table 1 lists the new messages and service primitives introduced through the proposal. The message flow diagram of the proposed

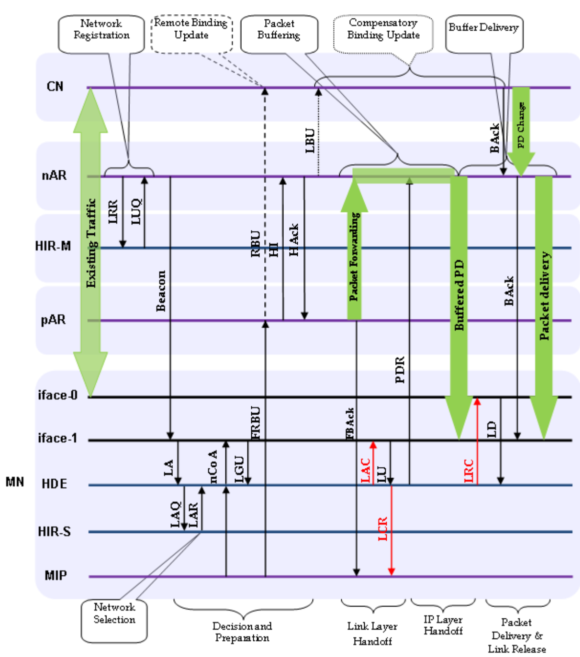

Figure 1. Message Flow Diagram of VFHO

approach is depicted in Fig. 1. The network registration is performed once an AR is switched on and the active ARs send an LUR message to Home Information Register in Master mode (HIR-M) in intervals to preserve their status at HIR-M. If no LUR is received, HIR-M inquires the respective AR using LUQ message and unless it receives a reply from the AR, the status changes to inactive. If the AR does not reply to two consecutive LUQs, the record is deleted from the database. In the following, the process is described through some operational phases which are identified in Figure 1.We assume a mobile user maintaining an ongoing connection with UMTS network approaches an indoor destination with WLAN coverage and switches on the WLAN interface. The base station ID received through beacon is reported to the Handover Decision Engine (HDE) and to HIR-S for information of the discovered AR. After the target network selection, the HIR-S informs HDE using LAR. As the new network is detected, a Link-Going-Up (LGU) event is sent to HDE to start Fast Binding Update (FBU).

A. *Early Binding Update with CN*

Majority of handoff studies, specifically of fast handoff suggest that the Binding Update (BU) procedure be started after the packet delivery from new AR (nAR) to MN. To reduce packet delay, BU should be initiated at the start of packet forwarding. The BU message is formed in nAR using the nCoA and forwarded to the CN's IP. The proposed early BU can be performed in two cases, both prior to link switch. For the first case, the BU message is appended to FBU and sent to previous AR (pAR) which in turn, processes and extracts the BU and sends it to CN. Since the BU in this case is sent through the old network, it is recognized in CN as the Remote BU (RBU). In the second case, it is assumed that the pAR has no signaling message ready to perform BU hence, as soon as a bi-directional tunnel between the two ARs is established, the BU message is forwarded to nAR and thereby, to CN as a Local BU (LBU).

B. *Link Activation and IP Layer Handoff*

Now, HDE can initiate the nCoA activation on WLAN interface and the MIP layer sends a message to nAR to inform that the MN is ready to receive packets. As the main part of IP layer handoff, nCoA has already been configured and validated therefore, the immediate action after the link state changes is to inform the nAR. The event indicated in this process is LU which also triggers HDE to assist issuing the message to nAR. HDE informs the MIP layer using an information message on link switch status which is called Link Change Report (LCR). The packet delivery phase starts immediately after IP layer handoff completion. However, packet forwarding through the old network continues until the CN confirms the BU by sending Binding Acknowledgement (BA). At this time, the HDE commands the release of old link to UMTS interface using Link Release Command (LRC) and the process is completed. While most of handoff methods consider the start of packet

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delivery from the buffer as completion point of handoff process, this proposed model strives to satisfy QoS requirements for various traffic classes by decreasing the packet delay due to handoff.

IV. PERFORMANCE ANALYSIS

The analytical model to assess the proposed handoff protocol is illustrated in Fig. 2. This model was inspired from [14] and leads to obtain a general cost function to describe the metrics.

Table 1. New Message and Primitive Structure for VFHO

Message/Primitive Name	Service Type	Parameters
Link Available (LA)	Event	MN WLAN MAC, Link Type, nAR MAC, Activity Flag
Local Area Query (LAQ)	Command	pAR ID, nAR ID, Usability Code
Local Area Report (LAR)	Information	MN MAC, nAR MAC, BSS ID, Status, Priority Code
Remote AR Query (RAQ)	Command	pAR ID, nAR ID, nAR Prefix
Remote AR Report (RAR)	Information	nAR Prefix, AR Type, Priority Code, Neighbors (Prefix, AR Type, Priority Code)
Local Registration Request (LRR)	Information	BSS ID, AR Prefix, Link Type, Available BW, Cost of Service, Offering Service Codes, Reg. Flag
Local Update Request (LUR)	Information	BSS ID, AR Prefix, Link Type, Available BW, Cost of Service, Offering Service Codes, Upd. Flag
Local Update Query (LUQ)	Command	Link ID, AR (SGSN) Prefix, AR (WLAN) Prefix, Lifetime
Link Release Command (LRC)	Command	Old Link ID, MN UMTS MAC, pAR MAC, Reason Code
Link Activate Command (LAC)	Command	New Link ID, MN MAC, nAR MAC, Priority Code
Link Change Report (LCR)	Information	nAR MAC, MN WLAN MAC, Result Code

A. Handoff Latency

Handoff delay is comprised of several elements including Link and IP layers handoff latencies, and packet delivery delay. It can be concluded that the period of packet buffering and binding update is equal to the time taken to perform link and IP handoffs, and the packet forwarding period. However, unlike the other handoff protocols, the time taking processes are incorporated in VFHO. It can be inferred that the expected handoff latency of VFHO depends highly on transmission periods between MN and nAR as well as process delays in the MN as these processes are scheduled to start early and by special events as described in protocol description. Hence, T_{LH} is only a portion of the actual link layer handoff time, T_{IH} excludes nCoA configuration as another long process, and T_{BU} is a short time as it has started prior to link layer handoff. The total handoff latency therefore, is:

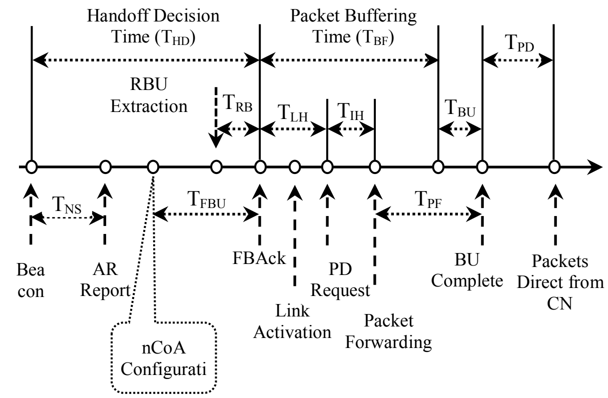


Figure 2. Timing Diagram for Transmissions and Processes of VFHO

$$T_{VFHO} = T_{HD} + T_{BF} + T_{BU} + T_{PD} \quad (1)$$

where, $T_{BF} + T_{BU} = T_{LH} + T_{IH} + T_{PF}$. For identical distances, wireless components, TMN-nAR and TMN-pAR can be expressed as TMN-AR. The handoff delay can be written as:

$$T_{VFHO} = T_{LH} + T_{PD} + 2T_{MN-AR} \quad (2)$$

One of the major delay contributors in IP-based handoffs is the procedure of Duplicate Address Detection (DAD) or TDAD which is performed within binding update procedure. The duration of this procedure is topology dependent and is reported in many IP-based network infrastructures to take between 0.5 and 1 s. As the BU procedure starts some time prior to link switch, DAD is given some time to complete before the IP layer handoff. Hence, the overall handoff latency is independent of TDAD. For the sake of calculations, we assume TDAD = 600ms in Equation 2.

The handoff delay for various wireless link delays and MN speeds are shown in Fig. 3-a. The wireless link delay was varied from 10 to 500ms with different steps. Although 10m/s is a high speed for an MN to move, the handoff latency could be maintained as low as 600ms when the wireless link delay reaches 75ms. However, for lower speeds (i.e. up to fast walking speed of 5m/s), the handoff delay is around 300ms and reaches 400ms when wireless link shows a delay of around 130ms.

B. Packet Delivery

We analyze packet delivery from two main aspects, the cost of delivering data packets and the cost of signaling. We propose an analytical model similar to what was introduced in [15] to determine the packet delivery cost from data transmission aspect which is used to obtain the end-to-end latency during the total handoff process. The packet delivery cost consists of two main elements namely, transmission and process costs. We assume α and β as normalized weighting factors that influence the two cost elements of packet transmission and processing. Hence, the packet delivery cost and the ratio of average size for data and signaling packets can be obtained as:

$$C_{PD}^{D} = \alpha C_T + \beta C_P \quad (3)$$
$$\phi = \frac{\vartheta_P}{\vartheta_P + \vartheta_S} \quad (4)$$

where ϑ_P and ϑ_S denote the data and signaling packet sizes, respectively. The transmission cost of data packets is a portion of total transmission cost by the coefficient ϕ and can be written as:

$$C_T^P = \phi C_T \quad (5)$$
$$C_T = \lambda_p (T_{BU} + T_{BF}) \quad (6)$$
$$C_T^P = \phi . \lambda_p (T_{BU} + T_{BF}) \quad (7)$$

where, λ_p is packet arrival rate (number of packets per time unit) and ϕ is the ratio of data packets to the overall data.

Fig. 3-b illustrates packet delivery delay versus data packet size when packet arrival rate changes. When the data packets form the maximum of 50% of the total packets, it can be seen that the packet delivery cost shows small variations with a maximum of 38 at the rate of 25 packets per second. As data packets increase to above 70%, the cost becomes more sensitive to the arrival rate showing variations of about 35 to 50. Although this shows that the packet delivery is highly dependent on the size and arrival rate of the data packets, even the highest delivery cost hardly causes packet disruption as it is still comparable to the overall signaling cost of around 300 (discussed in next section).

C. Signaling Cost

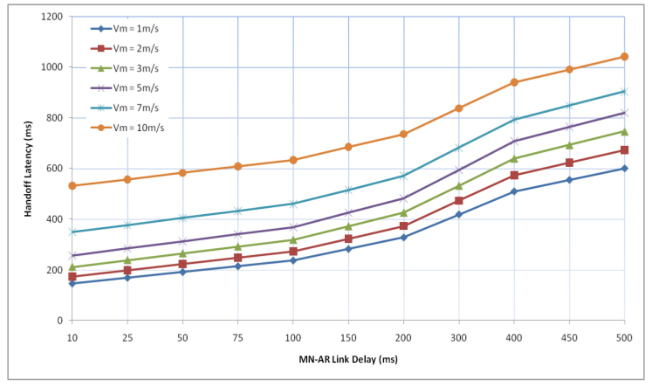
Signaling cost is defined as the total cost of signaling traffic overhead which in turn, is the total number of control messages exchanged between MN and network components (AR or CN). To determine total signaling cost, the main cost equation is extended to signaling costs for the four stages of Handoff Decision, Link Layer Handoff, IP Layer Handoff, and Packet Delivery, and can be expressed as:

$$C_{Sig} = \sum_i C_i = C_{HD} + C_{LH} + C_{IH} + C_{PD} \quad (8)$$

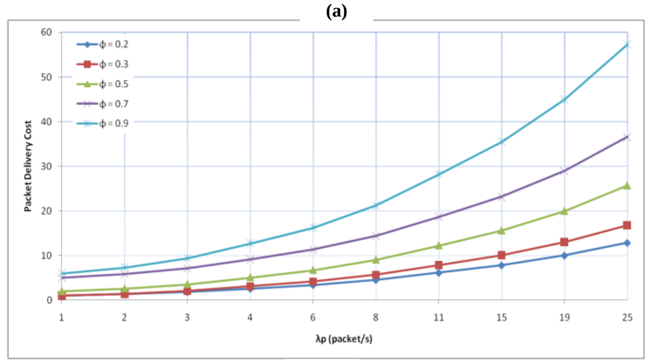
Table 2. Parameters for Analytical Model

α	Β	D_r	D_l	λ_S	w
0.1	0.2	6	4	1	2

We use random-walk mobility model which is generally confined to a limited geographical area and speeds [16]. For random movements over a certain period, the probabilities of the user leaving and staying in a local area are p and q = 1-p, respectively. The user position is defined as state *k* Markov chain. The two transition probabilities $\alpha_{k,k+1}$ and



(a)



(b)

Figure 3. a) VFHO Latency vs. Wireless Delay, b) Packet Delivery vs. Arrival Rate

$\beta_{k,k-1}$ are defined as probabilities that the user approaches or retreats with one random step unit in a hexagonal macro-cell with k surrounding hexagonal micro-cells [17].

$$\alpha_{k,k+1} = \begin{cases} (1-p), & k = 0 \\ (1-p)\left(\frac{1}{3}+\frac{1}{6k}\right), & K \geq k \geq 1 \end{cases} \quad (9)$$

$$\beta_{k,k-1} = (1-p)\left(\frac{1}{3}+\frac{1}{6k}\right), \qquad K \geq k \geq 1 \quad (10)$$

Using Equations 8 and 9, the steady-state probability of state k within the local area with K local areas, $p_{k,K}$, can be obtained in terms of the steady-state probability, $p_{0,K}$ with the conditions $\sum_{k=0}^{K} p_{k,K} = 1$ canbe written as:

$$p_{0,K} = \frac{1}{1+\sum_{k=1}^{K}\prod_{i=0}^{k-1}\frac{\alpha_{i,i+1}}{\beta_{i+1,i}}} \quad (11)$$

The impact of wireless link on overall signaling cost is described based Session-to-Mobility Ratio (SMR) [17], which is defined as the ratio of session arrival rate (λ_S) to session crossing rate (R_S) in a random-walk mobility model [18].

The probability that the user moves through a random-walk mobility model from a local area (l) to a routing area (r), $P_T(r,l)$ can be expressed by:

$$P_T(r,l) = \sum_{k=0}^{K} P_K(k).P_T(K|k).\alpha_{K,K+1} \quad (12)$$

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where $P_K(k)$ is the probability of an incoming session during the time that the user stays in state k for a given number of states K and $P_T(K|k)$ is the probability that a session initiated in state k, continues in state K. These probabilities can be obtained from:

$$P_K(k) = \frac{\bar{t}(k).p_{k,K}}{\sum_{k=0}^{K} \bar{t}(k).p_{k,K}} \tag{13}$$

where, $\bar{t}(k)$ is the mean time the user stays in state, k. finally, the cost of each operation can be expressed as follows.

$$C_{HD} = \lambda_S[P_T(r,l).(D_r + D_l) + D_l(1 - P_T(r,l))] \tag{14}$$
$$C_{LH} = \lambda_S[P_T(r,l).(D_r + D_l)] \tag{15}$$
$$C_{IH} = \lambda_S[D_r.P_T(r,l)] \tag{16}$$
$$C_{PD} = \lambda_S[D_r.P_T(r,l)] \tag{17}$$

Where, $D_r and D_l$ denote two units of signaling cost through wireless link in routing and local areas, respectively, and λ_S is session arrival rate in packets per time unit. We assume typical parameter values that were reported in various studies with similar analytical models [17, 19] as listed in Table 3. The signaling cost in wireless link is defined as the product of the distance between the two nodes and transmission cost in wireless link (w).

Fig. 4 illustrates the resulting total signaling cost under various circumstances. The total signaling cost is shown based on the number of local areas within a routing area as in Fig. 4-a, and based on the number of MNs in the routing area in Fig. 4-b. As shown through the figures, the probability of MN leaving the local area is an important factor in the total cost, and greater values cause increase in the handoff decision element of the total cost. Additionally, increasing both number of WLAN ARs and MNs also causes higher signaling costs.

Fig. 4-c shows the variation of total signaling cost versus SMR through a random-walk mobility model within a routing area. The total cost was determined for SMR values of 0.1, 1, 10, and 100. For the minimum value of SMR, 0.1, the total signaling cost shows very high value. However, as the SMR increases to larger than 1 which implies session arrival rate is higher than mobility rate, the signaling cost decreases but the impact of k factor in the total signaling becomes more chromatic. This is because the packet delivery cost is the dominant factor when the session arrival rate is higher than the mobility ratio.

When the value of cell crossing rate is fixed, the increase of SMR should result in the increase of session arrival rate and thereby, the total cost. This is because the link switch cost is more dominant than packet delivery cost over the total cost. However, the size of routing area as depicted in Fig. 4-d is almost as significant as cell crossing rate in the resulting

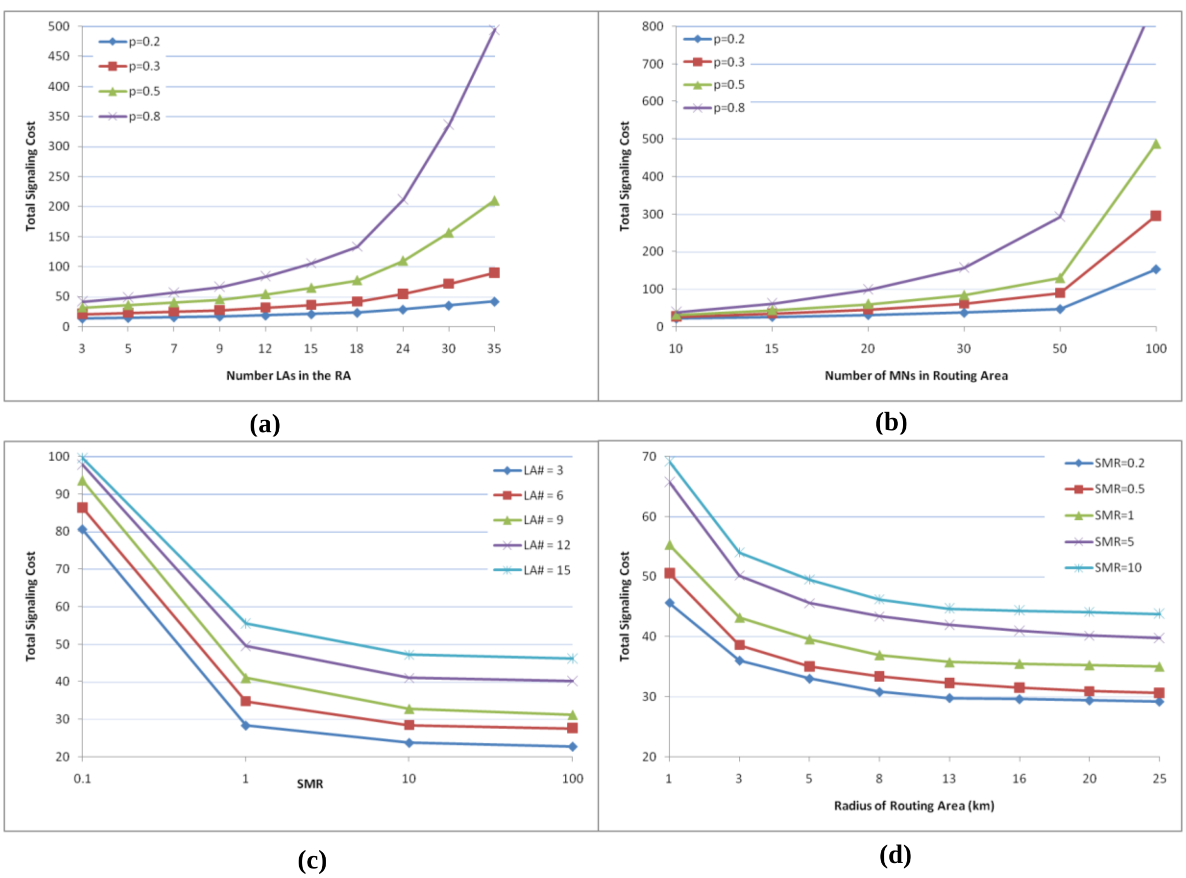

Figure 4. Total Signaling Cost Variations vs. a) Number of LAs, b) MN Density, c) SMR, and d) RA Size

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total cost. For instance, the radius of 25km can cause a total signaling cost of as low as radius of 1km when SMR is decreased by 50 times. As a result, higher SMR values incur higher packet delivery cost, while we can still control link layer switching by adjusting the size of routing area.

V. CONCLUSION

This paper proposes a seamless vertical handoff protocol in heterogeneous wireless network of WLAN and UMTS technologies. The proposed handoff protocol, VFHO, is a combination of link and IP layers operations, which handles media heterogeneity in between these two layers as well as information of application layer. The introduced approach utilizes some techniques such as EBU to guarantee the continuation of packets in heterogeneous networks which has been barely the concern of the existing literature. Hence, through the distinct definition of handoff latency proposed here, as well as costs of signaling, the proposed method performs more affordable than the existing methods upon being built up under identical circumstances. VFHO was analyzed mathematically to examine packet delivery delay and signaling overhead in terms of cost functions. The proposed framework and vertical handoff method show robust performance in terms of tolerable signaling overhead as well as handoff and packet delays.

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