DEMAPS: A Load-Transition Based Mobility Management Scheme for an Efficient Selection of MAP in Mobile IPv6 Networks

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***Abstract*— A major concern for mobile networks consists in finding efficient ways to handle the user mobility so that the handover process has minimum effect on users' ongoing sessions. Given the dominance of Internet-based applications in next-generation mobile networks, Mobile IP (MIP) has become an important protocol to accommodate the IP mobility.**

To overcome the excessive delay and signaling involved in the first version of Mobile IP, the Hierarchical Mobile IPv6 (HMIPv6) protocol has been introduced. The key concept behind HMIPv6 is to locally handle handovers by the usage of an entity called Mobility Anchor Point (MAP). While the new protocol provides a more efficient way for the mobility management in IP networks, it does not control traffic among multiple MAPs in the network. As a result, in many cases the selected MAP is overloaded and extensive delays are experienced during the routing process.

To tackle this problem, this paper proposes a new technique called *Dynamic and Efficient MAP Selection (DEMAPS)*. The proposed scheme works similar to HMIPv6 when the network is not overloaded. When the network becomes under heavy loads, the selection of MAPs becomes based on an estimation of MAP load transition using the Exponential Moving Average (EMA) method. Simulation results demonstrate that DEMAPS can efficiently balance the signaling traffic load among MAPs and provides a superior network performance compared to traditional HMIP schemes.

***Index Terms*— Mobile IP, MIPv6, HMIPv6, MAP, mobility management, and EMA.**

I. INTRODUCTION

ALONG with the exponential growth of the Internet and the continuous success of wireless communication networks, the telecommunications industry has entered a new era where communication needs are no longer limited to wired/wireless networks and have moved towards a new paradigm: pervasive access to Internet services anywhere anytime. Communication over mobile systems has been thus gaining ground at a tremendous pace during the last few years [1] [2]. The Internet-based applications and the data traffic load generated from these applications have changed the path for the mobile network into an all-IP configuration. Therefore, finding efficient and optimum solutions for handling the IP mobility has become an important topic of research.

As originally specified, the IP protocol does not support mobility for a number of reasons related to the protocol syntax and semantics. To support global mobility in IP networks, the Mobile IP Working Group within the Internet Engineering Task Force (IETF) proposed a packet-based mobility management protocol, called Mobile Internet Protocol (MIP) [3]. It has been subsequently modified, in line with the new version of IP, towards the so-called MIPv6 [4]. In MIP, Mobile Nodes (MNs) are identified with two different IP addresses. One is referred to as Home Address (HoA) and the other is dubbed as Care of Address (CoA). The former address indicates a unique and permanent name of the MN. It remains constant even when the node moves from subnet to subnet. CoA specifies a temporarily address for the MN based on the current position of the node in the network and changes as the MN roams to a network other than its home network. The MN can obtain the CoA of the visiting subnet by issuing a Router Solicitation (RS) message to its Foreign Agent (FA). The standard MIP consists of two procedures, namely Binding Update (BU) and data delivery. The binding operation aims to associate the HoA and CoA addresses of each MN.

It is well understood that the MIP protocol does not represent an effective solution for environments in which MNs frequently change their points of attachment to the network. Applying MIP to a wide population of users with relatively high mobility features will result in the generation of a large number of BU requests, all most likely in a single burst [5]. To process such bursts of BU requests, an important amount of network bandwidth and computational load is required. Consequently, this BU cost becomes huge and the system ultimately turns to be unscalable to operate. In case of mobile users roaming far away from their home networks, the system performance gets further aggravated and the signaling delay for BU increases. This results in the loss of a significant amount of in-flight packets which eventually affects the overall Quality of Service (QoS) of the system. Since it is all but impossible to avoid such bursting occurrences of handovers in mobile networks, mitigation of BU frequency can only be done by the development of new mobility management strategies.

In order to make the MIP scalable for a large and highly mobile network, and at the same time reduce the amount of signaling and the length of signaling paths, the signaling points can be arranged in a hierarchical pattern. Therefore, IETF has proposed the Hierarchical Mobile IPv6 (HMIPv6) protocol [6] [7]. Fig. 1 depicts the key components of the HMIPv6

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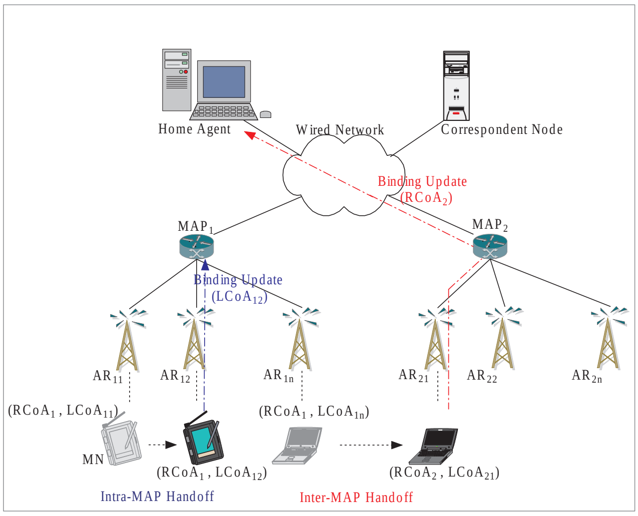

Fig. 1. HMIPv6 overview

protocol. The key idea behind the HMIPv6 protocol is to separate local mobility from global mobility. HMIPv6 is based on the deployment of a number of local agents called Mobility Anchor Points (MAPs). MAPs can be located at any level in a hierarchical network of routers. Each MAP administrates a set of Access Routers (ARs) forming a single network domain.

One important issue, which is highly missed in the design of HMIPv6, is on the traffic load and processing power distribution over multiple MAPs in a large mobile network. Indeed, in case a single MAP administrates a large domain, the distance between mobile nodes and the MAP can add significant delays to packets and affect route optimization as mobile nodes move away from the MAP. Operators of large mobile networks may thus choose to deploy several MAPs in one domain. In such large networks with multiple MAPs, it is easily possible that some MAPs become congested while others are underutilized. To cope with such an issue, which affects the overall network performance, a dynamic MAP management strategy is required. In this paper, a dynamic and efficient method for the selection of the most appropriate MAP is proposed. The operation of the proposed scheme consists of two steps. Initially, the proposed scheme behaves in the same way as the traditional distance-based MAP selection scheme of HMIPv6. In a given domain, MAPs with loads less than a predefined threshold are sorted. The furthest MAP (among these MAPs) is selected first as in the distance-based selection scheme of HMIPv6. When all MAPs have loads exceeding the threshold, the selection of MAPs becomes based on an estimation of MAP load transition using the Exponential Moving Average (EMA) method. Distant MAPs with load decrease tendency are selected first. The proposed selection scheme is dubbed *Dynamic and Efficient MAP Selection (DEMAPS)*.

Extensive simulations are conducted to evaluate the performance of the proposed scheme. Simulation results demonstrate that the scheme reduces the number of packet drops, guarantees shorter service delays, makes better utilization of the network resources, and maintains a fair and efficient distribution of the network load.

The remainder of this paper is structured as follows. Section II highlights the relevance of this work to the state-of-art in the context of mobility management. The key design philosophy and distinct features that were incorporated in the proposed scheme are described in Section III. Section IV portrays the simulation environment and reports the simulation results. Section V discusses the applicability of the proposed scheme. Following this, the paper concludes in Section VI with a summary recapping the main advantages and achievements of the proposed scheme.

II. RELATED WORK

Since its standardization, the MIP protocol has been the focus of extensive research work. This section describes the main post-standard improvements that have been devised in recent literature to improve the performance of MIP in mobile networks.

By-and-large, mobility management techniques may be classified into two categories: Micro-mobility and Macro-mobility [8]. In the former, handoffs are handled locally without any involvement of Home Agents (HAs). Notable examples are Cellular IP [9] [10] and Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) [11]. Cellular IP is specifically designed to support handoff for frequently moving hosts. It is applied on a local level and can interwork with MIP to support wide area mobility, that is, mobility among Cellular IP networks. The HAWAII protocol divides the network into hierarchies based on domains. The functioning of HAWAII hinges on the assumption that users' mobility is local to domains. For each host, the HA and any Correspondent Node (CN) are unaware of the node's mobility within the host domain. Each domain has a gateway, called the domain router, and each host has an IP address and a home domain. In HAWAII, host based forwarding entries are installed in gateways using a set of specialized path setup schemes. These entries help to reduce both the data path disruptions and the number of BUs. A major credit for micro-mobility management techniques consists in their reduction of handoff signaling delays. [12] presents a set of IP micro-mobility protocols and compares among their performances. It also contains more detailed descriptions of the two mechanisms presented above.

In macro-mobility, when a mobile node roams to a different network area, the node solicits for a new CoA. A BU message is then sent to the HA. The major issue with macro-mobility pertains to the significant handoff signaling delays for users roaming far away from their home networks. These delays disrupt active connections each time a handoff to a new attachment point of the network is performed. Therefore the time required for the establishment of a new connection between MNs and their CNs becomes remarkably long and the loss of in-flight packets may become significant.

To cope with packet losses that may occur during handoffs due to the broken data path from the source to the destination, a set of mobility management techniques has been proposed in recent literature. They can be classified in turn into two categories: *caching-based* and *smooth handoff* techniques. In the first category, when a handoff occurs, the old AR caches and forwards the packets to the new AR based on a request to forward the packets. The most pioneering example that uses this technique is Fast Handovers Mobile IP [13]. In the second category, packets are routed to multiple nearby ARs around the MN to ensure delivery of the packets to the node. In addition to the recently proposed multi-path smooth handoff scheme [14], multicast mobility support [15] and bicast used in Cellular IP [16] use this technique. A combination of the smooth handoff and buffering techniques is proposed in [17]. A detailed description of most of these techniques and comparison among their performances are given in [8].

In the sphere of attempts to reduce handoff-signaling delays in macro-mobility, a large body of prior work was proposed. The central theme in these pioneering studies pertains to the adoption of hierarchical management strategies using local agents. HMIPv6 and TeleMIP for Cellular IP [18] are notable examples. Most proposed protocols employ hierarchies to localize the binding traffic. Determination of the optimal size of local networks is one of the most challenging tasks in hierarchical management procedures. To deal with this task, Xie *et al.* propose an analytic model based on the average total location update and packet delivery cost [19]. In [20] and [21], decision of the optimal size of regional networks is based on mobility patterns, registration delays, and the CPU processing overhead loaded on the local mobility agents. While most hierarchical techniques are intended to reduce the BU traffic by localizing handoff signaling, they cause additional issues related to network traffic management. Effectively, some local agents get congested with traffic while others are not efficiently utilized. To overcome this deficiency, the choice of network hierarchies should be performed in a dynamic manner. In this regard, Pyo *et al.* propose a dynamic and distributed domain-based mobility management scheme [22]. In this scheme, a group of ARs forms a domain. A *domain list* indicating the ARs that belong to the same domain is stored at each AR. Mobile nodes residing in a given domain maintains that *domain list*. If a mobile node changes its point of attachment to a new AR within a different domain, the node will then update its *domain list* to that of the new AR and the latter will serve as a MAP for the node. Ma *et al.* propose another dynamic hierarchical mobility management scheme for MIP networks [23]. In this scheme, when a mobile host connects to a new subnet via a new AR, the new AR notifies the new CoA of the host to the previous AR. The new AR serves then as a new location management hierarchical level for the node. One major drawback of these two schemes is that they both deliver packets to users via multiple levels of ARs, a fact that leads to long packet delivery delay and congestion of the selected ARs with redundant traffic. One possible solution to this issue is to reduce the size of the subnet domains. However, this would lead to frequent inter-domain handoffs and consequently excessive BU cost.

Another approach to solve the issue of traffic distribution in HMIPv6 is possible by referring to the mobility pattern of users [24], [25]. In [24] for instance, users are classified based on their velocity. Users receive thresholds from the network and compare their velocity to those thresholds. Users with velocities exceeding the propagated thresholds simply register with higher levels of the MAP hierarchies. While this idea is straightforward, it still does not solve the issues of traffic distribution among MAPs. Indeed, in case all users have the same feature of mobility, they end up by registering with the same MAPs. This will intuitively overload the selected MAPs with traffic whereas other MAPs remain underutilized. Additionally, the velocity range for each MAP is fixed. To cope with this issue, Chung et. al. [26] considered a dynamic setting of the velocity range of each MAP depending on the actual velocities of MNs which are currently serviced by the MAP. However, a general requirement for mobility management schemes, that are based on the velocity of mobile nodes, consists in the guarantee of a high accuracy in the estimation of the velocity of mobile nodes. Such a task is not always simple, resulting, more frequently, in the selection of inappropriate MAPs.

In [27], the moving range of a mobile node is the main factor in the MAP selection. In this scheme, mobile nodes are assumed to keep track of their moving area. The lowest MAP that covers the entire moving area is deemed to be the most appropriate one for registration. In this scheme, issues related to how to define the moving range of each mobile node, in addition to how the scheme can be applied to mobile nodes that keep changing their moving areas, are yet to be solved. In [28], a distributed location management scheme is proposed. The key idea behind this scheme is to allow a mobile node to roam over an area covered by a number of MAPs (amongst which the farthest MAP is distant from the mobile node by a threshold of hops) without triggering regional BUs. While this operation achieves load balancing to some extent and reduces the BU cost, it comes at the price of longer delivery delays. In [29], a newly-defined factor, dubbed session to mobility ratio (SMR), is used as a factor for the selection of the serving MAP. SMR is defined as the ratio of the session arrival rate to the handover frequency. In the SMR-based scheme, the highest MAP is selected for mobile nodes with small values of SMR. An interesting analysis among the above-mentioned approaches can be found in [30].

III. DYNAMIC AND EFFICIENT MAP SELECTION SCHEME

This section gives a detailed description of the proposed scheme, *Dynamic and Efficient MAP Selection (DEMAPS)* scheme. As previously discussed, operators of large mobile networks may need to deploy several MAPs in one domain. In such networks, while most dynamic hierarchical mobility schemes reduce the frequency of BU messages to HAs, they do not efficiently balance load over these multiple MAPs. Such a deficiency overloads some MAPs with traffic and causes higher packet delivery delays, while it leaves other MAPs underutilized. To tackle this issue, an efficient management strategy of MAPs load is required. Based on this strategy, mobile users residing in hierarchical mobile networks should be able to select the most appropriate MAP for communication based on its current resources utilization. Fig. 2 depicts the major steps in the proposed MAP selection method.

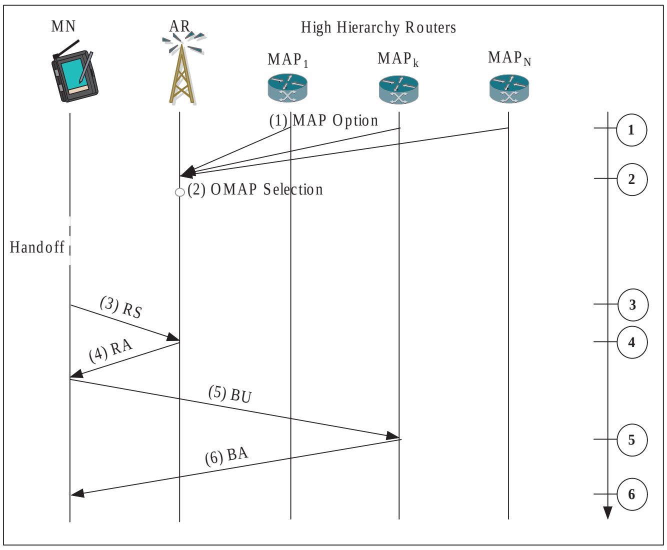

Fig. 2. Major steps in the proposed scheme

The proposed scheme operates as follows. Similarly to HMIPv6, DEMAPS adopts the dynamic MAP discovery approach. Indeed, each AR receives MAP option messages from high-layer MAPs every Δ period of time (step 1, Fig. 2). Unless otherwise specified, Δ is set to $1s$. Using information included in MAP option messages and based on a given computational model, each AR selects the optimum MAP for communication (step 2, Fig. 2). This MAP is referred to as OMAP. Details on the used computational method will be given later in this section.

Upon performing handoff, a MN sends a RS message to the new AR (step 3, Fig. 2). MNs can be designed not to submit RS messages in case ARs multicast Router Advertisement (RA) messages on a regular basis. In response to the RS message, the AR notifies the MN of the OMAP selected previously (step 4, Fig. 2). It should be emphasized that a MN is notified of OMAP only when it changes its point of attachment to a new AR. This incurs no additional energy consumption (compared to HMIPv6) and shall have no effect on the critical battery life of mobile nodes.

After receiving information on the OMAP, the mobile node compares between the selected OMAP and the Previous MAP (PMAP) being used prior to handoff. If the former is the same as the latter, the MN judges the handoff as an intra-domain movement and sends a BU message to only the OMAP (step 5, Fig. 2). This aims to minimize the handoff-signaling delay and to reduce the signaling traffic for users roaming far away from their home networks. In case the OMAP is different from the PMAP (e.g., inter-domain handoff), the MN sends three BU messages to OMAP, HA, and its CN, respectively. In response to the BU message, the OMAP acknowledges the MN of a successful BU via a Binding Acknowledgment (BA) message (step 6, Fig. 2).

As stated earlier, each access point receives MAP option messages from high-layer MAPs every Δ period of time. In DEMAPS, we consider the inclusion of information on instant loads of MAPs in the MAP option messages[1]. Examples of parameters that can define a MAP load are memory size, CPU processing power, used bandwidth, etc. For the sake of simplicity, we denote the load of the i^{th} MAP, as seen from its k^{th} downstream node, at the n^{th} time slot as $M_{i\rightarrow k}[n]$, and define it as the integer part of the percentage of the ratio of the number of packets processed on the link connecting the i^{th} MAP to its k^{th} downstream node to the total number of packets that can be processed by the MAP on the same link during the computation period of time ($[n \cdot \Delta, (n+1) \cdot \Delta]$), as shown by the following equation.

$$M_{i\rightarrow k}[n] = \lfloor \frac{(p_{i\rightarrow k}[n] + W \cdot q_{i\rightarrow k}[n])}{C_{i\rightarrow k} \cdot \Delta} \cdot 100 \rfloor \qquad (1)$$

where $C_{i\rightarrow k}$ denotes the data processing speed of the i^{th} MAP on the link to its k^{th} downstream node. It should be noted that a network element along the communication path can function as either a MAP or a mere router. The former case concerns packets destined to mobile nodes that are registering with the network element as their MAP, whereas the latter case relates to packets destined to nodes having other network elements as MAPs. In this vein, $p_{i\rightarrow k}[n]$ and $q_{i\rightarrow k}[n]$ denote the total number of data packets forwarded by the i^{th} MAP to its k^{th} downstream node as a mere router and the number of data packets destined to mobile nodes registered with the i^{th} MAP, respectively, both at the n^{th} time slot. Intuitively, the computational load required by a mere router to forward a data packet and that required by a MAP to transmit a data packet to a node registered with it are different. W is a weight factor that is used to reflect the difference in these two computational loads. It is assumed that access points have prior knowledge on the two parameters $C_{i\rightarrow k}$ and W for each i^{th} MAP and for each respective k^{th} downstream node. Upon computation of their loads, MAPs notify access points of this information via the seven bits of the reserved (RES) field carried in the packet header of MAP option messages as will be explained later.

Having a potential number of MNs connected to the same MAP for communication may likely lead to congestion of the MAP in question and result in an inefficient distribution of the network traffic. To avoid congesting MAPs with traffic, ARs should advise newly arriving mobile nodes with the most appropriate MAP. MAPs should be thus aware of on-going dynamics in network conditions and should reflect these dynamics in their signaling messages that they send to ARs. Based on these dynamics, ARs sort MAPs according to their availability, in other words their loads with respect to the ARs, and advise newly arriving MNs with the most optimum MAP.

To notify ARs of possible changes in network conditions, MAPs use the Exponential Moving Average (EMA) method to predict possible future transitions in their loads. The underlying reason beneath the choice of EMA consists in the fact that EMA is a cut-and-dry approach for analyzing and predicting performance, easy to implement, and requires minimal computational load. As mentioned earlier, the traffic

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[1] For each MAP option message destined to a downstream router, the included MAP load information refer to the load of the MAP as seen from the downstream router.

load is measured periodically every Δ period of time in the proposed scheme. Let $M_{i \to k}[n]$ and $E_{i \to k}[n]$ denote the measured load value and the EMA value of the i^{th} MAP load with respect to its k^{th} downstream node at the n^{th} time slot, respectively. By definition, $E_{i \to k}[n]$ is expressed as follows:

$$E_{i \to k}[n] = \frac{\sum_{k=0}^{\infty}((1-r)^k M_{i \to k}[n-k])}{\sum_{k=0}^{\infty}(1-r)^k}$$

where r is the exponential smoothing constant ($0 < r < 1$). Considering the fact that $(\sum_{k=0}^{\infty} \theta^k = \frac{1}{1-\theta})$, $E_{i \to k}[n]$ can be easily computed in a recursive manner as follows:

$$E_{i \to k}[n] = rM_{i \to k}[n] + (1-r)E_{i \to k}[n-1] \tag{2}$$

To give more weight to the latest data, r is set to 0.9 throughout this paper.

The key idea behind the proposed method is to use the EMA value to predict the transition tendency of the MAP load on each available link. This prediction is based on comparison between the two values $E_{i \to k}[n]$ and $M_{i \to k}[n]$ for each i^{th} MAP and each respective k^{th} downstream node. Indeed, in case $(E_{i \to k}[n] < M_{i \to k}[n])$, the load of the i^{th} MAP on the link to its k^{th} downstream node has more tendency to increase (Load Increase (LI) tendency), whereas in case $(E_{i \to k}[n] > M_{i \to k}[n])$, the MAP load on the same link may likely decrease (Load Decrease (LD) tendency). Upon prediction of their load transitions, MAPs notify ARs of this information via the seven bits of the reserved (RES) field carried in the packet header of MAP option messages. One bit of the RES field is used as a flag to indicate the load transition tendency of the MAPs; one for LI and zero for LD. The remaining six bits are used to indicate the MAP loads. A MAP i sets the six bits of the RES field (of the MAP option message destined to its k^{th} downstream node) to null if its load is smaller than 36%[2]. Otherwise, it sets the six bits of the RES field to the integer part of the difference between the load and 36% as follows:

$$RES_{val} = Max(0, \lfloor M_{i \to k}[n] - 36 \rfloor) \tag{3}$$

Based on this information, ARs decide the most appropriate MAPs for future visiting mobile users. This operation is performed following two stages. Indeed, when the network is not overloaded, the selection of MAPs is conducted based on distance as in HMIPv6. In a particular domain, MAPs with loads less than a predefined threshold β are sorted. The parameter β indicates the level of congestion that a network operator can tolerate. Unless otherwise specified, β is set to 80% throughout this paper. The furthest MAP, among the sorted MAPs, is selected first as in the traditional distance-based selection scheme of HMIPv6. This operation is repeated till the loads of all MAPs exceed the threshold. At this stage, the selection of MAPs becomes based on the estimation of the MAP load transition using the EMA method. High-hierarchies MAPs with LD Tendency are preferably selected as MAPs for communications. In case of multiple MAPs with LD tendencies, the MAP router at the highest hierarchy is chosen. This aims to create large MAP domains for mobile nodes so as that their future handoffs can be locally handled. This ultimately minimizes the handoff signaling cost. In case all high-hierarchy routers have LI tendencies, ARs select the high-hierarchy MAP router with the minimum traffic load, that is, the lowest value of RES_{val}.

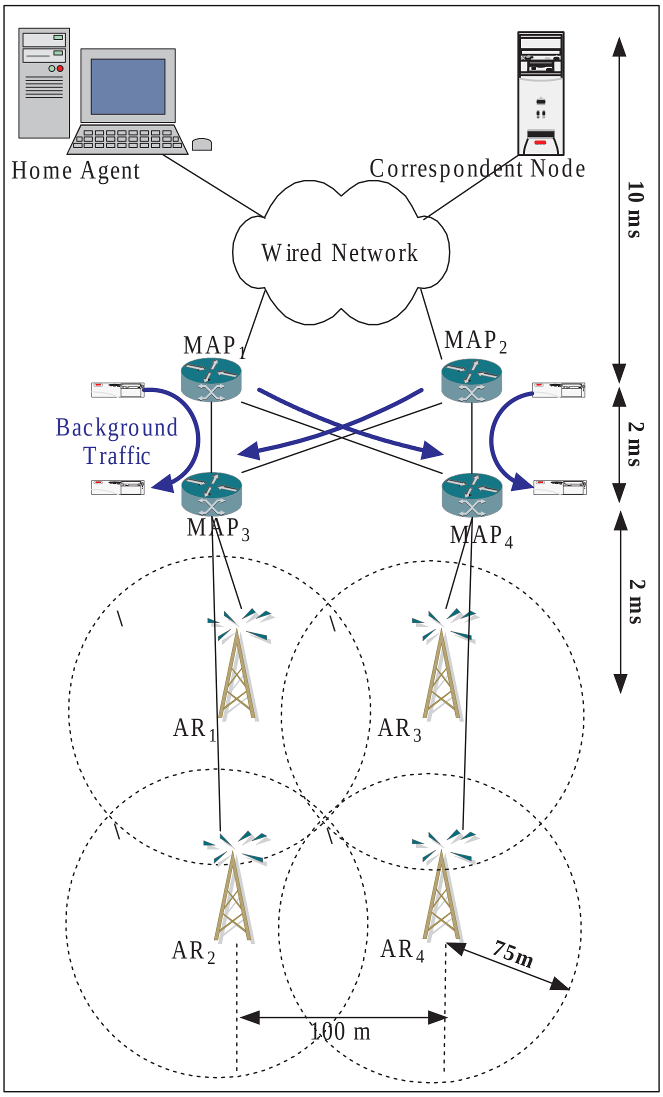

Fig. 3. Simulation environment.

IV. PERFORMANCE EVALUATION

A. Simulation Setup

Having described the details of the proposed scheme, focus is now directed on its performance evaluation through extensive simulations using the QualNet 4.0 Simulator [31]. Particular attention is paid to the design of an accurate and realistic simulation setup, which is described below, justifying the choices made along the way. Unless otherwise noted, the parameters specified below are those used in all the experiments throughout the paper.

The abstract configuration of the considered network is depicted in Fig. 3. The wireless part of the network consists of four neighboring wireless cells. The coverage radius of each wireless cell is set to 75 meters. The distance between two

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[2] Note that $36 = 100 - 2^6$

neighboring ARs is fixed to 100 meters. These parameters are chosen with no specific purpose in mind and do not change any of the fundamental observations about the simulation results. The four ARs are connected to the wired network through a two-layers network made of four MAPs. To form *cross-links* among the MAPs, MAPs 1 and 2 are both connected to MAPs 3 and 4. The choice of such a two-layers MAP (three-tiered) network with cross-links represents a general and simple case [32]. Furthermore, in [33] it is demonstrated through a mathematical model that a three-tiered architecture represents the optimum hierarchy level for hierarchical mobile environments. In the considered topology, MAP 3 serves ARs 1 and 2, while MAP 4 serves ARs 3 and 4. The MAP network is connected to a HA and a server (CN) via a wired network. The one-way propagation delay over the wired network is set to $10ms$. As for other links, the delay of each is set to $2ms$. In general scenarios, wireless links have smaller bandwidth compared to their wireline counterpart. In the simulations, the capacity of wired network is set to $100Mbps$ and the capacity of inter-MAP links, “MAP-to-AR” links, and wireless links is set to $20Mbps$. In this regard, it shall be stressed out that setting the bandwidth of wireless and wireline links to different rates should have no effect on the fundamental observations about the proposed scheme. In addition, simulating similar or disparate bandwidths for inter-MAP or “MAP-to-AR” links should not affect the system performance either as the MAP selection in DEMAPS is based on the loads of MAPs rather than the links’ capacity.

A population of 50 nodes is simulated and is randomly scattered over the wireless communication area. To avoid forming bottlenecks at the wireless network, each MN receives UDP (user datagram protocol) packets from CN at a rate approximately equal to $390kbps$. The UDP packet size is set to $1kB$. Due mostly to its simplicity and its wide usage in today’s switches and routers, all routers use Drop-Tail as their packet-discarding policy. All MAPs are assumed to have buffers of $250kB$; an amount of data worth the bandwidth-delay product. The buffer size is chosen with no specific commercialized standards in mind. For the sake of simplicity, the computational load required by a mere router to forward a data packet and that required by a MAP to transmit a data packet to a node registered with it are assumed to be the same. The parameter W is thus set to one. To better investigate the interactions of the proposed scheme with different levels of the network congestion, we run some background traffic over inter-MAP links. Over each inter-MAP link, the rate of the background traffic is randomly chosen from within 40% to 70% of the link capacity. All simulations are run for a duration of $600s$, a duration long enough to ensure that the system has reached a consistent behavior. The first $60s$ are used to initialize the simulations and the last $60s$ are used to stabilize the results. All results are an average of multiple simulation runs. Table I shows a complete list of the simulation parameters.

In the performance evaluation, we consider two mobility models available in QualNet: the random waypoint model and the group mobility model. In both models, the MN speed is set between the range $[0m/s, 2m/s]$ and the pause time is set to null. In the group mobility model, four groups are simulated; each consisting of 12 or 13 mobile nodes. In the performance evaluation, HMIPv6 and the velocity-based MAP selection scheme proposed in [25], referred to as HMIPv6-UP, are used as comparison terms. In HMIPv6-UP, the velocity threshold is set to 0.5 m/s. In this scheme, if the velocity of a mobile node exceeds the velocity threshold, the mobile node registers with an upper MAP, otherwise it registers with a lower MAP.

TABLE I
SIMULATION PARAMETERS

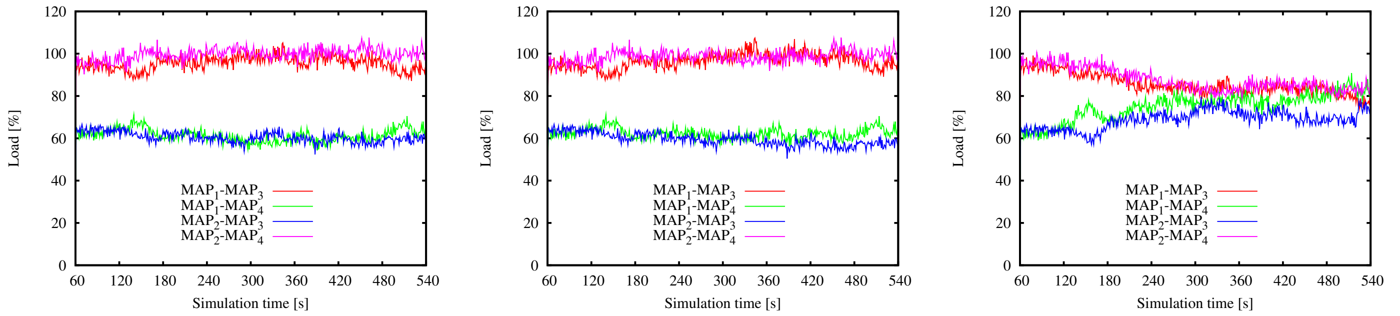
Factor	Simulation Parameters
Total number of mobile nodes	50
UDP traffic rate	390kbps
Background traffic rate	8Mbps - 14Mbps
Simulation time	600 s
Wired network delay	10 ms
Wired network capacity	100 Mbps
Inter-MAP and MAP-AR link delay	2 ms
Wireless link capacity	20 Mbps
Buffer size	250 kB
Cell Coverage Radius	75 m
Distance between neighboring ARs	100 m
MAP option transmission period Δ	1 s
Exponential smoothing constant r	0.9
Packet size	1 kB
MAP load threshold β	80%
Parameter W	1

The following quantifying parameters are used for comparison:

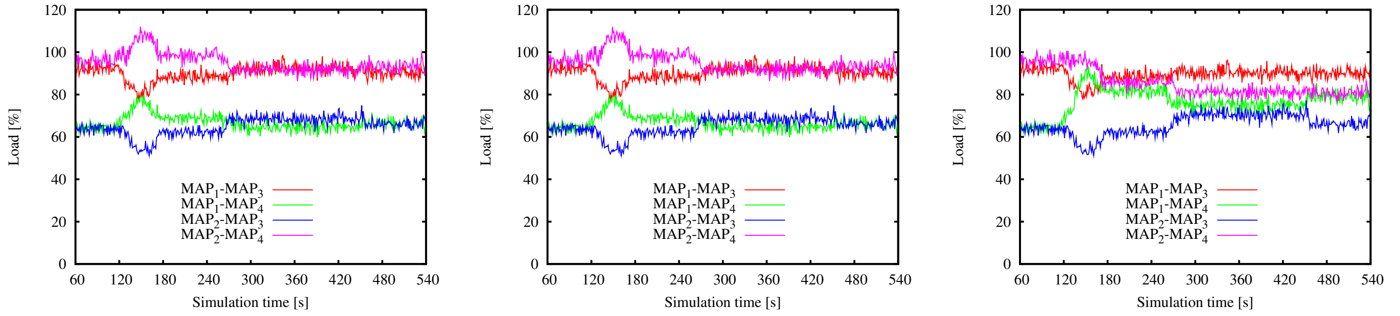
- Individual packet delivery delay: This measure shows the average packet delivery delay experienced by each simulated MN.
- Individual MN throughput: This metric indicates the throughput achieved by each MN.
- Processed load: This measure involves the total bytes, including signaling packets and UDP data packets, processed at a specific network element during the simulation time.
- Processed data packets: This measure refers to the count of data packets processed by a specific network element during the simulation time.
- Packet drops: The total number of packets dropped at a specific network element during the simulation time.

B. Simulation Results

Firstly, we investigate the load transitions of the four inter-MAP links in case of the two mobility models and when the three schemes are in use. Fig. 4 graphs the load transitions of the four links. It demonstrates that the proposed scheme enables a better distribution of traffic among all links and that is in the case of the two simulated mobility models. We next investigate the behavior of individual mobile nodes. Given the fact that the three schemes exhibit the same behavior regardless of the simulated mobility model and due to space limitations, we present the results of only the group mobility model. Figs. 5(a) and 5(b) graph the individual delay and throughput achieved by the simulated 50 nodes, respectively. The two figures show that the improvements,



(a) HMIPv6 (b) HMIPv6-UP (c) DEMAPS



(d) HMIPv6 (e) HMIPv6-UP (f) DEMAPS

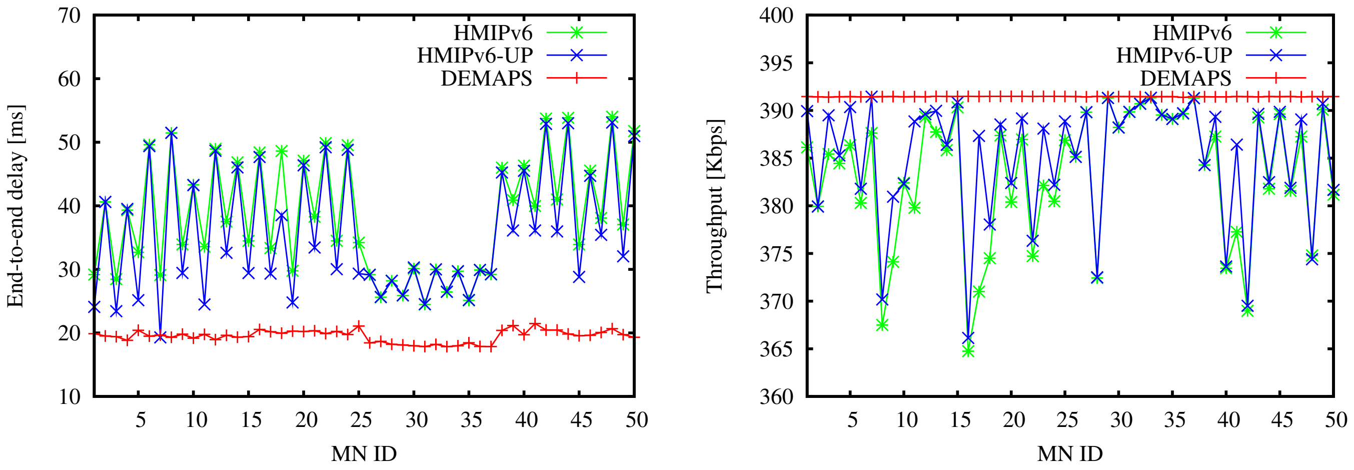
Fig. 4. Load transitions of the four inter-MAP links in case of the random waypoint mobility model (UP) and group mobility model (DOWN).

in terms of increasing the throughput and reducing the end-to-end delay, achieved by DEMAPS are highly encouraging. Indeed, the packet delivery delay was reduced for MNs in case of DEMAPS. This performance is mostly attributable to the selection of the most appropriate MAP for communication. Effectively, in the case of HMIPv6, when mobile nodes roam from one AR to another AR for instance, each mobile node always selects the same MAP that was used previously even if the MAP has heavy packet processing load. This event also occurs in case of HMIPv6-UP when mobile node's mobility pattern does not change. This ultimately causes higher values of packet delivery delay. Fig. 5(b) indicates another achievement of the proposed scheme: DEMAPS significantly increases the throughput of each MN. The reason behind this performance underlies beneath the fact that in DEMAPS, MAPs with LD tendency are preferably selected, whereas in HMIPv6 and HMIPv6-UP, in-flight packets travel over congested links, a fact that overloads some MAPs, causes packet drops, and ultimately affects the individual MNs throughput.

The aggregate performance is sometimes more interesting as it is often more useful for network provisioning. We therefore direct our focus now to the aggregated behavior of MNs and the overall network performance. Figs. 6(a) and 6(b) plot the processed traffic load (in bytes) and the number of packet drops at each inter-MAP link. The figures clearly show that compared to HMIPv6 and HMIPv6-UP, DEMAPS achieves better distribution of traffic load among the MAPs. Packet drops are almost null when DEMAPS is used. This is mostly due to the transmission of packets over congested links upon handoff occurrences. Given the limited buffer size of routers, an important amount of these packets are dropped. This justifies the high values of packet drops experienced in HMIPv6 and HMIPv6-UP, as shown in Fig. 6(b). It should be noted that the plotted DEMAPS traffic includes both UDP data packets and signaling packets. Despite this fact, Fig. 6(a) shows that the overall bandwidth consumption in the case of DEMAPS (including signaling packets) is almost the same compared to that of HMIPv6 and HMIPv6-UP. This confirms that the additional cost due to signaling packets is minimal. In addition, the obtained performance gains are worthwhile and can be used to advocate the small overhead that may be incurred by frequent transmission of MAP option messages.

We next evaluate the performance of the three schemes in terms of BU traffic and BU latency. Figs. 7(a) and 7(b) graph the number of BU messages at each network element and the BU latency experienced by each MN and averaged by the number of BUs. Fig. 7(a) indicates that HMIPv6 and HMIPv6-UP reduce the frequency of BU messages to HAs. However, these schemes do not consider the load distribution among multiple MAPs, many data packets drop at congested links as we described earlier. Whilst DEMAPS certainly increases the frequency of BU messages to HAs, it significantly reduces the packet drops and achieves the highest throughput for MNs compared to the other two schemes. Fig. 7(b) shows that the average BU latency for some MNs in case of HMIPv6 and HMIPv6-UP is higher than in case of DEMAPS. This is due to the selection of heavily loaded MAPs, which ultimately leads to high queuing delays and results in high BU latencies.

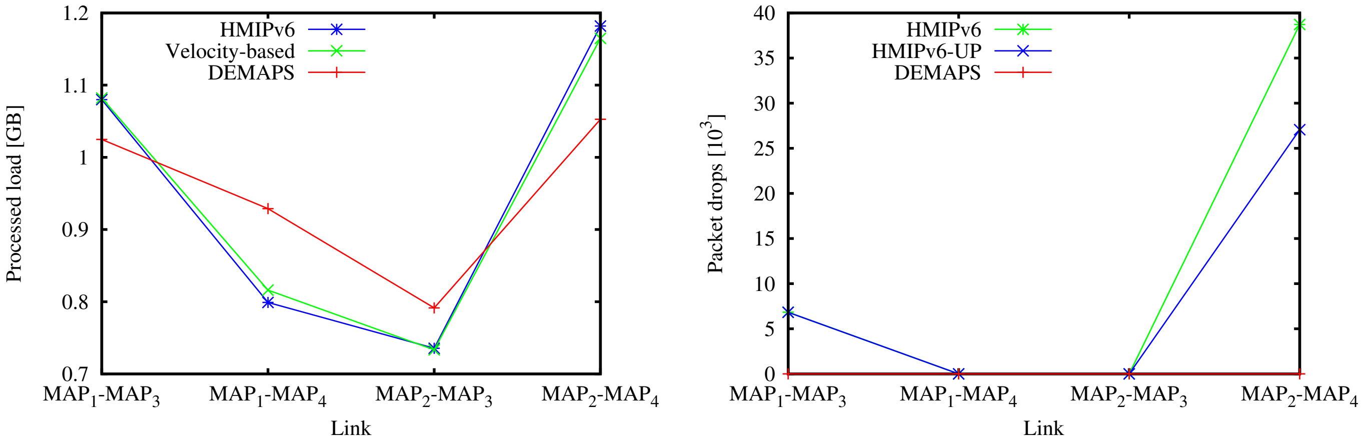
In the proposed scheme, information on load transition is sent to ARs every Δ time interval. In the simulations conducted so far, Δ was set to $1s$. To investigate the effect



(a) Individual packet delivery delay

(b) Individual throughput

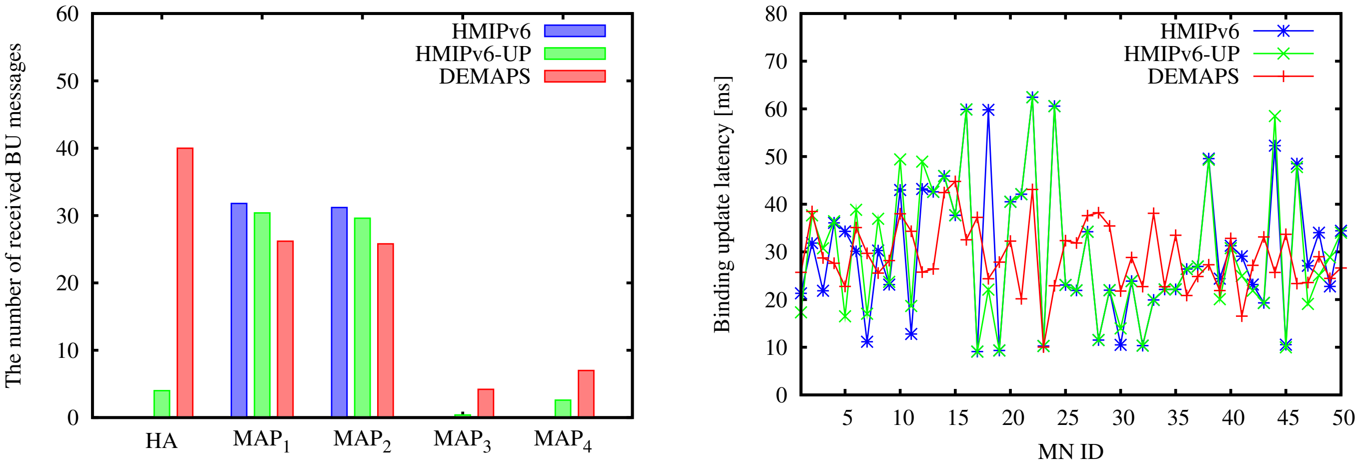
Fig. 5. Behavior of individual MNs in terms of packet delivery delay and throughput.



(a) Traffic load processed at each network element

(b) Number of data packets dropped at high-hierarchies network elements

Fig. 6. Aggregate performance in terms of transmission efficiency: Better traffic distribution and avoidance of packet drops.



(a) The number of received BUs at HA and each MAP

(b) Average BU latency for MNs

Fig. 7. Aggregate performance in terms of binding update traffic at HA and each MAP and BU latency for MNs.

of Δ on the DEMAPS performance, we plot the number of packets processed by inter-MAP links for different values of Δ in Fig. 8(a). The figure demonstrates that setting Δ to higher values results in a poor distribution of network traffic among MAPs. The choice of Δ is a compromise between enhancing the traffic distribution and reducing the frequency of MAP option messages. Indeed, small values of Δ would efficiently distribute the data traffic on the network, whereas large values of Δ would reduce the number of MAP option messages sent over the communication time.

To illustrate the idea with more clarity, the following index is used [34]:

$$\Phi = 1 - \frac{\sum_{i=1}^{N} |\alpha_i - \bar{\alpha}|}{2\bar{\alpha}(N-1)} \tag{4}$$

where α_i is the number of packets processed by the i^{th} link and N is the number of inter-MAP links. $\bar{\alpha}$ is the average value of $\{\alpha_i, i = 1 \cdots N\}$. Φ captures the efficiency of traffic distribution over the network and ranges from zero to one. Low values of Φ represent a poor distribution of network traffic and lead to significant packet drops. Fig. 8(b) graphs the value of Φ for different values of Δ. The figure demonstrates that setting Δ to values larger than $30s$ degrades the traffic distribution over the network. On the other hand, results of Fig. 6(a) show that the system overhead remains minimal when setting Δ to $1s$. It should be emphasized that similar experiments were conducted considering different traffic mobility patterns and identical results were obtained. To conclude, $(\Delta = 1s)$ represents a good trade-off between an efficient distribution of data traffic and a reduced frequency of MAP option packets.

Another credit of small values of Δ consists in the guarantee of high prediction accuracy of the EMA method. To illustrate the idea at hand, we investigated the variation of the actual data traffic and the estimated value of EMA ($E[n]$) during a period of the simulation time. Figs. 9(a) and 9(b) graph the variation of the measured load and the EMA value for two different values of Δ, $1s$ and $10s$ respectively. The figures demonstrate that having Δ set to high values results in a deviation of the EMA estimation from the actual data load. This obviously affects the prediction accuracy of the load transition. However, setting Δ to small values provides more accurate prediction of the load transition. All in all, it should be concluded that carefully-chosen values of Δ maintain an efficient distribution of the network traffic, guarantees higher accuracy of the load transition prediction, and minimizes the system overhead by reducing the transmissions of MAP option packets.

So far, the exponential smoothing constant (r) has been set to 0.9. This setting purposed to give more weight to the latest data in the load transition prediction. Admittedly, the constant r plays a major role in the prediction of the load transition, and it may be therefore thought that it largely affects the distribution of the network traffic. To investigate such a possible impact, the variation of the traffic distribution index Φ is plotted for different values of r (Fig. 10). The figure demonstrates that the system guarantees an efficient traffic distribution for all the values of r and reaches its optimum when r takes large values (e.g., in the vicinity of 1.0). This efficient distribution is manifested in the form of high values of Φ ($\Phi > 0.93$).

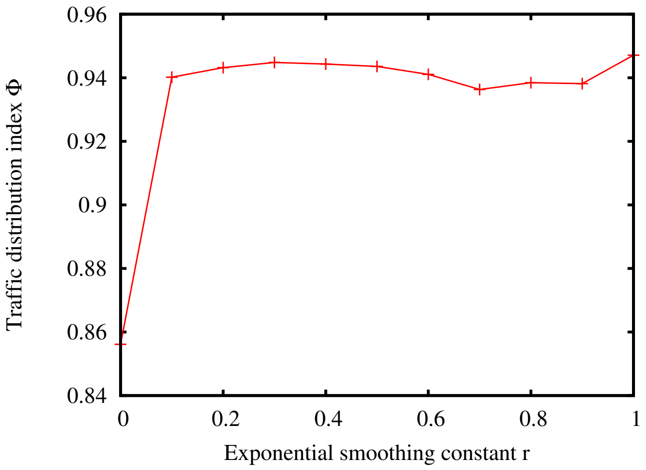


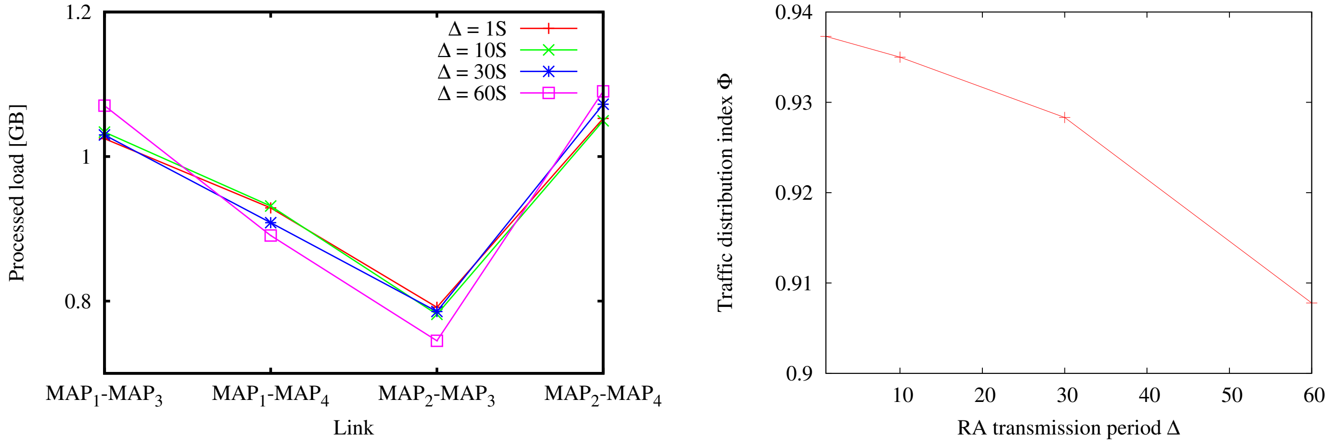
Fig. 10. Traffic distribution index Φ for different values of the exponential smoothing constant.

V. DISCUSSION

As previously discussed, the DEMAPS scheme notifies mobile nodes of the most optimal MAP to use upon handoffs. For this purpose, the DEMAPS scheme does not generate any new signaling packet, does not modify the HMIPv6 protocol itself, nor does it require any modifications at the mobile terminals. From this point of view, the implementation of the proposed scheme is practical and can be widely accepted.

A scenario that may put limitation on the performance of DEMAPS is when a mobile node is asked (by an AR) to register with a new MAP, different than the old MAP it was previously using, whereas it could have kept using the same old MAP without fearing any congestion of the latter. Such a scenario will ultimately oblige the MN to register again with its HA and CN. All of these steps are admittedly unnecessary and may defeat the purpose of having HMIPv6 in the first place. As a remedy to this issue, MNs should be given freedom in choosing the MAPs to which it registers. For example, an AR can list all the available MAPs it is connected with, along with information on their resources utilization, in the router advertisements. Upon reception of the router advertisement, the mobile node first verifies if the old MAP it has been using is among the list. If yes, it refers to the resource utilization and load transition tendency of the MAP. It then decides whether it should keep the registration with the same MAP or change it to another MAP, obviously with lighter traffic load. If the load of the old MAP is not at a critical point, the MN can keep registering with it. It accordingly saves itself from sending BU messages to the HA and CN. If the previous MAP is not available at the list or is handling a relatively higher load compared with other MAPs, the MN selects another MAP from the list and updates its binding following the update procedures of HMIPv6.

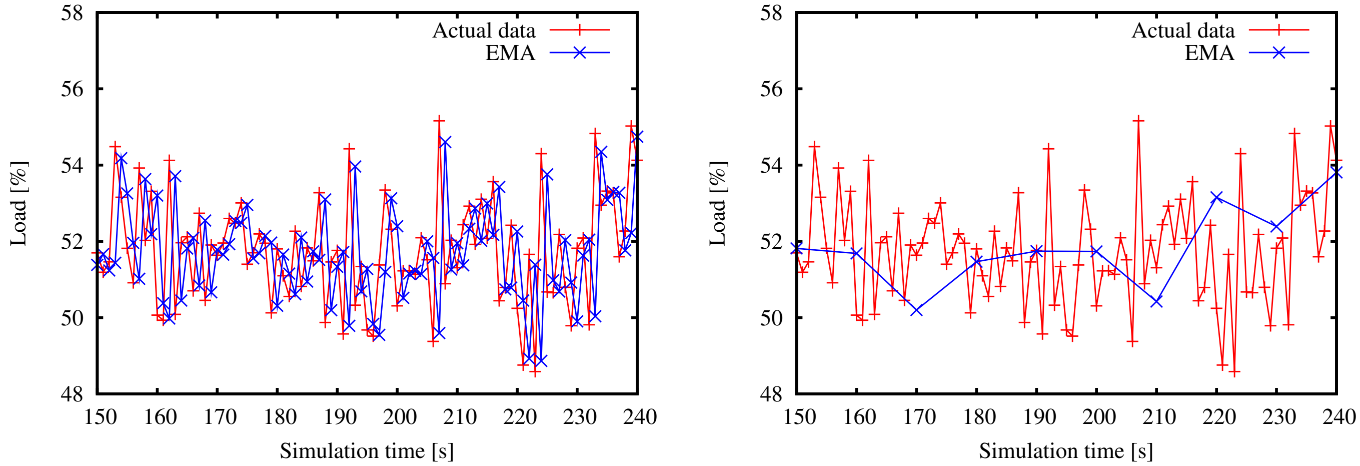
The selection of MAP may require some energy at the mobile node. This operation is, however, performed only



(a) Number of data packets processed at each inter-MAP link for different values of Δ

(b) Traffic distribution index Φ for different values of Δ

Fig. 8. Impact of Δ on the performance of DEMAPS.



(a) $\Delta = 1s$

(b) $\Delta = 10s$

Fig. 9. Prediction accuracy of EMA for two different values of Δ.

upon handoff and the consumed energy shall be minimal. The MAP selection may slightly affect the battery life of the mobile node only in case of fast moving nodes that perform frequent handoffs or keep flip-flopping over the overlapped area between the coverage areas of multiple ARs. While this scenario is unlikely to happen, the energy issue can be mitigated by implementing the MAP decision-making mechanism at access routers. In such a case, the mobile node should notify the AR of the old MAP it was using prior to handoff. This notification can be done via the router solicitation message.

The working of DEMAPS can be further enhanced by anticipating the occurrence of MN handoffs. This anticipation is possible using cross-layer protocols [36], along with predicting the user movement based on the user mobility patterns [37]. On the other hand, the proposed scheme whilst has been tested in Mobile IPv6 with fixed routers, can be easily applied with minor modifications to the networks with mobile routers, as such used for seamless Internet access in public transportation as well as in wireless metropolitan networks (e.g. Worldwide Interoperability for Microwave Access (WiMax), IEEE 802.16 [35]). Indeed, in such environments, the network topology of mobile routers can be considered dynamic through the concept of dynamic virtual topology [38]. In this way, the network can be modeled as a set of time-discrete snapshots of network topologies of fixed routers over short slots of time (say a few seconds). This idea is similar in spirit to most routing concepts proposed for Ad Hoc and mobile sensor networks in the recent literature [39] [40]. Given the fact that in the proposed scheme, the load transition prediction is performed over short periods of time ($\Delta = 1s$), the application of the proposed scheme can be efficiently applied to these snapshots of the mobile network topology, and ultimately to the entire network while it is on the move. Performance evaluation of the proposed scheme for such scenarios can be an interesting topic for future investigations.

VI. CONCLUDING REMARKS

In this paper, we have proposed a method that significantly improves the performance of Hierarchical Mobile IPv6 in large mobile networks. In such large networks, operators may need to deploy a set of MAPs over a given domain. The proposed scheme provides a reliable and balanced traffic load among these MAPs. While most of the strategies proposed earlier in the literature attempt to solve the macro-mobility issues and provide fast transition performance, they create a complex landscape for network traffic management. Indeed, some routers are overly congested with packets while others are underutilized.

The proposed DEMAPS is a dynamic and efficient technique to select the most appropriate MAP for registration. It functions as HMIPv6 when the network is not overloaded. When the network is running under heavy loads, the MAP selection is based on an estimation of MAP load transition using the exponential moving average method. Information on load transition is notified to access routers via the transmission of MAP option messages. The proposed scheme is easy to implement and the additional cost required by signaling packets is proved to be minimal.

Extensive simulation results demonstrate that the proposed scheme has the potential of substantially improving the average communication delay, reducing the number of losses, and making better utilization of the network resources. All of these achievements are highly important for the implementation of Integrated or Differentiated Services (DiffServ) architectures to support QoS over mobile IP networks. This represents a major goal of the research carried out in most of the IETF Working Groups. The actual enhancements that the proposed DEMAPS scheme can indeed bring to the DiffServ area of research deserve further study and form the basis for our future research work.

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