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A HIERARCHICAL NETWORK DESIGN SOLUTION FOR MOBILE IPv6

VILMOS SIMON LÁSZLÓ BOKOR SÁNDOR IMRE
Budapest University of Technology and Economics
Department of Telecommunications (BME-HT)
Mobile Communication and Computing Laboratory – Mobile Innovation Center
Magyar Tudósok krt. 2, H-1117
Budapest, Hungary
{svilmos, bokorl , imre@hit.bme.hu}

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Over the past years a number of IP micro-mobility protocols have been proposed as an extension or complement of Mobile IP. Although the development of these protocols has generated considerable interest in industry and academia, none of them have been widely deployed. The main reason of this lack of real-life usage of micro-mobility proposals is that the RFCs or drafts of these protocols do not address the problems regarding the realization of the micro-mobility structures in detail during the procedures of network design. This shortage is true in case of Hierarchical Mobile IP as well (RFC 4140), which is one of the most significant micro-mobility solutions aiming to reduce the signaling delay and the number of signaling messages of Mobile IP.

In order to provide guidelines for network designers we propose a new a hierarchical network design algorithm (HIENDA) based on the structure given by a Location Area planning algorithm, aligned with a MAP allocation algorithm in Hierarchical Mobile IPv6 to optimize the mobility management in Mobil IP networks. HIENDA considers the topology constraints, and takes the available mobility pattern and Access Router handover rate information as input, and finds a near optimal hierarchical structure for which the total signaling cost will be minimal. From the simulation results the conclusion could be drawn that HIENDA outperforms the other existing hierarchy optimizing solutions in the term of Location Update Cost, at the same time keeping the Packet Delivery Cost on a low level.

Key words: network designing, IP Mobility, Mobile IPv6, Hierarchical Mobile IPv6, micro-mobility, location area planning, algorithmic optimalization, Hierarchical Network Design Algorithm (HIENDA), location update cost, packet delivery cost, simulated annealing
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1 Introduction

While IP is declared as the key technology of the future's wired and mobile communication, the currently used version of IP, IPv4 itself is not suitable to be used in mobile scenarios. Next generation mobile users require special support to provide connectivity, although they change their place of attachment to the network frequently. The task of mobility management is to provide this support by introducing two main functions: location management and handover management [1]. The first one enables mobile terminals to originate and receive calls; the second is responsible for administering changes of wireless network points of attachment.

While mobility management in current systems, like GSM is handled in the second layer (Data Link Layer), the new tendency of emerging wireless architectures (like 3G and WiMAX) is to solve such problems in the network layer or the upper layers [2], [3], [4]. This support must be transparent to mobile users and also has to be scalable, which means that despite the growth of the number of mobile terminals, the amount of signaling overhead must not increase significantly. The increasing trend towards smaller cell sizes makes efficient mobility management strategies indispensable for radio resource management and network planning in next generation cellular networks [6]. The common practice in designing radio resource management or network planning techniques is to apply static mobility models which do not take the dynamics of user mobility into account. However, this does not reflect the realistic behavior of mobile clients, because their handover rate, location area change rate, dwell time, etc. are dependent on their interaction. Therefore, the network signaling load will be very different depending on the location and the user density dynamics. For a given environment, the cellular network needs to be designed with these user mobility characteristics in mind, such that it is able to guarantee the necessary quality of service level to its customers.

The delay and the delay variation are one of the most important QoS parameters in next generation micro-cell IP based mobile networks. The performance of such networks can be threatened by high handover frequencies and an increasing handover signaling overhead [7]. This affects the delay variation experienced by the users, which is critical in the case of time sensitive real time media applications. The handover signaling overhead is due to the management of the mobile users' location information: when they change location areas, their home agents need to be updated. The popularity of the Internet multimedia services (voice mail, video telephone, etc.) provides strong incentive to service providers to support seamless user mobility.

Mobile IPv6 [5] is an integrated part of IPv6 [8] to manage the mobile node's mobility, but not capable of supporting real-time handovers. It is a simple and scalable global mobility solution; however it is not a satisfactory solution for mobile users with high mobility rate [9]. Mobile IP requires that whenever a Mobile Node (MN) moves from one subnet to another one, its location and routes must be updated by sending a location update to its home Home Agent (HA). As the number of MNs increases significantly the location updates may cause an excessive signaling cost [10]. Moreover, if the MN is far away from his/her HA or the HA processing capability is overwhelmed by the huge volume of location update messages, the signaling delay for the location registration could be very long, which will result in the loss of a huge amount of in-flight packets and losing the capability to guarantee quality of service (QoS). For example, many real-time wireless applications (e.g., voice over IP) would experience noticeable degradation of service with frequent handoff.

A solution is to make Mobile IPv6 responsible for macro-mobility, and to have a separate protocol to manage local handovers inside micro-mobility domains [11]. While macro-mobility is for the case when an MN moves across different administrative domains or geographical regions and it occurs less frequent, the micro-mobility means the MN is roaming across multiple subnets within a single network of domain. For these cases, which occurs quite often, a separate protocol is needed, to improve the shortcomings of the Mobile IPv6.

This paper is organized as follows. Section II presents the related work; Section III describes the optimization problem, while in Section IV the cost functions are introduced. In Section V, we present our new Hierarchical Network Design Algorithm (HIENDA). The performance evaluation the proposed algorithm is discussed in Section VI. Finally, we conclude the paper in Section VII with the scope for the future research.

2 Related Work

Over the past several years a number of micro-mobility protocols (using host-based routing and hierarchical approaches as well) have been proposed, designed and implemented that complement the base macro-mobility protocols (e.g. Mobile IP). The development of these protocols has generated considerable interest in industry and academia, as an attempt to improve global mobility management mechanisms.

The Cellular IP protocol [12] was developed at Columbia University and Ericsson Research, and it supports paging and a number of handoff techniques. To minimize control messaging, regular data packets transmitted by mobile hosts are used to refresh host location information. A similar approach is the handoff-aware wireless access Internet infrastructure (HAWAII) [13], which is a separate routing protocol to handle micro-mobility. In TeleMIP [14] a mobility agent is used to reduce the location update traffic, leading to a new architecture. TIMIP [15] (Terminal Independent Mobility for IP combines some advantages from CIP and HAWAII, where terminals with legacy IP stacks have the same degree of mobility as terminals with mobility-aware IP stacks. Nevertheless, it still uses MIP for macro-mobility scenarios. IDMP [16] (Intra-domain Management Protocol) is a modular and simple micro-mobility method which extends the base intra-domain protocol used in TeleMIP. AUM [17] (Auto-Update Micromobility) exploits the hierarchical nature of IPv6 addressing and uses specialized mechanisms for handover controll, while µHIP [18] integrates micro-mobility management functionalities into the Host Identity layer and uses macro-mobility capabilities of HIP for global mobility. M&M [19] (Multicast-based Micromobility) is a local mobility management method where a visiting node gets multicast address to use while moving inside a domain, and intra-domain handover is realised using multicast join/prune mechanisms. Anycast-based Micromobility [20] is similar to M&M: a mobile node obtains a unique anycast Care-of Address, forms a virtual anycast group, and lets the underlying anycast routing protocol to handle the intra-domain movements. Other layers of the ISO/OSI architecture can also be used to provide micro-mobility support [21].

However, one of the most significant micro-mobility solutions to reduce the number of signaling messages to the home network and also to reduce the signaling delay is the Hierarchical Mobile IPv6 [22]. The basic idea of this hierarchical approach is to use domains organized in the hierarchical architecture with a mobility agent on the top of the domain hierarchy. Hierarchical Mobile IPv6 is an extension of Mobile IPv6, aimed at reducing the amount of signaling overload and speeding up handovers in cases when the Mobile Node (MN) is located far away from its Home Agent and Correspondent Nodes. HMIP utilizes a hierarchical network of routers and introduces a new Mobile IPv6 node, called the Mobility Anchor Point (MAP). It can be located at any level in a hierarchical network of routers, including the Access Router (AR), which is the Mobile Node's default router, aggregating the outbound traffic of MNs. The deployment of MAP concept will further reduce the signaling load over the air interface produced by Mobile IPv6, by limiting the amount of Mobile IPv6 signaling outside the local domain.

The MN has two kinds of care-of addresses: the Regional Care-of Address (RCoA) and the On-link Care-of Address (LCoA). MN obtains the RCoA from the MAP of the visited network, which remains unchanged as long as the MN is roaming within the given domain. The LCoA identifies the current position of the terminal, and if it changes within the logical domain, it must update the LCoA only at the MAP (the MN sends a Binding Update). The Home Agent and Correspondent Nodes are not aware of this change, the visible care-of address (RCoA) remains the same for them while the MN keeps changing its point of attachment inside the visited domain. Therefore the RCoA does not change as long as the MN moves within a MAP domain. The MAP captures the messages sent to the MN's RCoA, and forwards them to the MN's LCoA using local routing mechanism. A MAP domain's boundaries are defined by the Access Routers (ARs) advertising the MAP information to the attached MNs (via Router Advertisements). In this way the MAP can help providing seamless mobility for the MN as it moves from one AR to another. As a result of this, the amount of signalling messages leaving the domain is reduced significantly, and so is the resulting delay.

3 The Optimization Problem

The problem is that the RFC 4140 or other drafts do not address the realization of the hierarchical structure in detail during the network design. It is not clear and usually hard to determine the size of a regional network (i.e. locally administrated domain). Several important questions arise: what kind of principles must be used to configure the hierarchical levels, how to group cells under a given AR, and in which hierarchical level is advisable to implement the MAP function. The MNs traffic load and mobility may vary, therefore a fixed structure is lack of flexibility.

In our earlier papers we already gave mobility management solutions for Location Area domain forming [23], [24], which are capable of reducing the signalling overhead caused by the cell boundary crossing. The location area structure dictates that several cells are joined into one administrative unit, a so-called location area (LA). The cell border crossings inside this domain will remain hidden for the upper hierarchical levels, thus reducing signalling overhead. Only when an LA border is crossed, the location is updated; not on each cell handover. Therefore with these Location Area planning algorithms, we can obtain the optimal partition of cells to under a given Access Router, which will represent a Location Area router.

A key issue is how to group these Access Routers on the next level of hierarchy, and on which level of hierarchy to implement the MAP functionalities, actually how many Access Routers should be beneath a MAP within a domain. The number of ARs under a MAP is very critical for the system performance. An obvious solution is to group those ARs into one domain, which has a high rate of handovers among each others. In that way the number of AR changes for the MNs will be decreased. But joining too much ARs into one domain would degrade the overall performance since it will generate a high traffic load on MAPs, which results in a high cost of packet delivery [10]. Contrarily a small number of ARs will lead to a huge amount of location updates to the home network. Similarly to the LA planning [23], we will need to search for a tradeoff compromise between the location update and the packet delivery cost.

The LA optimizing solution can minimize the signalling load; however there are some differences between optimization methods for old fashioned mobile systems and those for using all–IP(v6) architectures. In non all-IP mobile networks the above mentioned optimization questions are geographically oriented, while the distance between two end points in a Mobile IPv6 based mobile system (extended with HMIPv6 for micro-mobility support) has nothing to do with the geographic location of these two points. Therefore in our analysis the distance unit will be the number of hops packets travel. Another issue is that in common cellular networks upon an arrival of a call, the MN is searched with a paging procedure within the cells of a LA, while in a MIPv6-HMIPv6 architecture the

HAs or the MAPs know the adjusted AR of each MN. But because of possible triangular routing scenarios, the packet delivery cost will generate an additional transmission and processing cost. Based on this, we introduce a regional update and packet delivery cost structure, and the goal is to have a tradeoff between the two cost reductions.

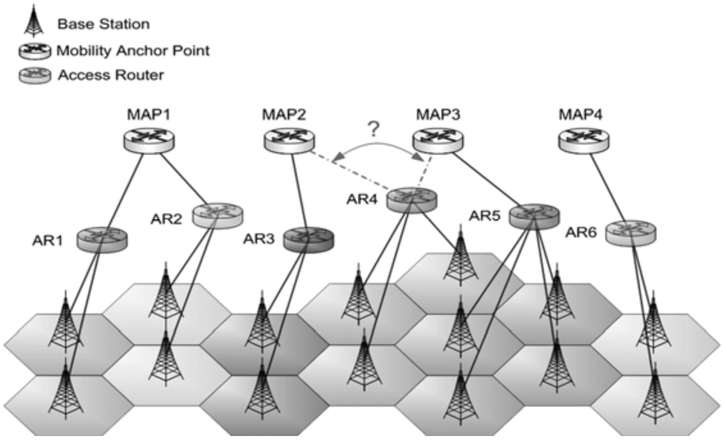

Figure 1 A Hierarchical Mobile IPv6 network MAP optimization

Therefore we created a hierarchical network design algorithm (HIENDA) based on the structure given by the LA planning algorithm [23], aligned with a MAP allocation algorithm in Hierarchical Mobile IPv6 to optimize the mobility management in Mobil IP-based networks. The signaling cost is proportional to the number of handovers among different hierarchical entities; therefore the signaling cost can be minimized by designing a network extended with HMIPv6 in a way where the ARs (or the LAs assigned to them) belonging to one hierarchical entity have the lowest boundary crossing rates among each other (see figure 1). In this way the signaling messages will be sent only one level up in the hierarchy, and not high towards the top of the hierarchy. Accordingly our goal was to develop hierarchical entity forming algorithms, which consider the topology constraints, and take the available mobility pattern and LA boundary crossing information as input, and find an optimal (or near optimal) hierarchical structure for which the signaling cost will be the minimum.

4 The Cost Structure

According to the differences between common cellular networks and a MIPv6-HMIPv6 environment presented above, we defined the location update cost and the packet delivery cost for micro-mobility domains (i.e. HMIPv6-controlled segments).

4.1 The Location Update Cost

If we examine the location registration message flow in HMIPv6 between the home network and the MN covered by a MAP function, we can calculate the cost of a MN movement from one subnet to another:

$$C_{LU} = 2 \cdot T_{HA-MAP} + 2 \cdot T_{MAP-AR} + 2 \cdot T_{AR-MN} + p_{HA} + 2 \cdot p_{MAP} + 2 \cdot p_{AR} \tag{1}$$

where

T_{HA-MAP} : the transmission cost of location update between the HA and the MAP
T_{MAP-AR} : the transmission cost of location update between the MAP and the AR
T_{AR-MN} : the transmission cost of location update between the AR and the MN
p_{HA} : the processing cost of location update at the HA
p_{MAP} : the processing cost of location update at the MAP
p_{AR} : the processing cost of location update at the AR

If the MN is moving within a local MAP domain the RCoA remains unchanged, it only needs to register the new LCoA, but the Correspondent Nodes and the Home Agent will not be informed about this local change. That means if a MN is changing an AR, but not a MAP, a localized location update cost will be produced:

$$C_{LUl} = 2 \cdot T_{MAP-AR} + 2 \cdot T_{AR-MN} + p_{MAP} + 2 \cdot p_{AR} \tag{2}$$

We can make an assumption, that the transmission cost is proportional to the distance between the source and the destination in terms of the number of hops packets travel (n_{S-D}) and the proportionality constant is K_T , then the transmission costs can be expressed as:

$$T_{HA-MAP} = n_{HA-MAP} \cdot K_T \tag{3}$$

$$T_{MAP-AR} = n_{MAP-AR} \cdot K_T \tag{4}$$

The transmission cost of the wireless link is usually higher, than that of the wired link (μ times higher), therefore the transmission cost between the AR and the MN is:

$$T_{AR-MN} = \mu \cdot K_T \tag{5}$$

If we consider that the only an ε fraction of the MNs subnet changes (when the MN moves from an AR to another) is a MAP change, then the total amount of the registration signaling cost can be expressed as:

$$C_{LUtotal} = (1-\varepsilon) \cdot q \cdot C_{LUl} + \varepsilon \cdot q \cdot C_{LU} \tag{6}$$

$$C_{LUtotal} = q \cdot \left(2 \cdot \varepsilon \cdot n_{HA-MAP} \cdot K_T + 2 \cdot n_{MAP-AR} \cdot K_T + 2 \cdot \mu \cdot K_T + \varepsilon \cdot p_{HA} + (1+\varepsilon) \cdot p_{MAP} + 2 \cdot p_{AR}\right) \tag{7}$$

where q is the number of AR changes (resulting LA boundary crossing) in the system in the given time period, introduced in [24].

4.2 The Packet Delivery Cost

As we mentioned earlier in cellular networks equipped with paging mechanisms upon an arrival of a call, the MN is searched with a paging procedure within the cells of a LA, while in a MIPv6-HMIPv6 system the HAs or the MAPs know the adjusted AR (i.e. the current location) of each MN. But because of the operation of HMIPv6, a part of IP packets destined for the MN is first intercepted by the HA and then tunneled to the MAP where this MN is registered and then the MAP will forward the packets to the current serving AR of the MN. This will produce the upper estimate of an additional transmission and processing cost:

$$C_{PD} = \sum_{k=1}^{N} \theta_i (D_{HA-MAP} + D_{MAP-AR} + h_{HA} + h_{MAP}), \qquad (8)$$

where

N : the number of the MNs in the system

θ : the number of arriving packets to the MN in the given time period

D_{HA-MAP} : the transmission cost of packet delivery between the HA and the MAP

D_{MAP-AR} : the transmission cost of packet delivery between the MAP and the AR

h_{HA} : the processing cost of packet delivery at the HA

h_{MAP} : the processing cost of packet delivery at the MAP

Similar to the location registration cost, the transmission cost is proportional to the number of hops packets travel between the source and the destination, with a K_D proportionality constant for packet delivery and then the packet delivery cost will be:

$$C_{PD} = \sum_{k=1}^{N} \theta_i (n_{HA-MAP} \cdot K_D + n_{MAP-AR} \cdot K_D + h_{HA} + h_{MAP}) \qquad (9)$$

4.3 The Total Signaling Cost

After defining the two cost functions, the total signaling cost for a given time period will be:

$$C_{SC} = C_{LUtotal} + C_{PD} \qquad (10)$$

Assigning too much ARs to one domain would generate a high traffic load on MAPs, which results in a high cost of packet delivery, but a small number of ARs will lead to a huge amount of location updates to be sent towards the home network. That means the total cost should be reduced in a way, which will meet the optimal tradeoff between the two costs. Therefore the mobility patterns of users should be taken into consideration, when the hierarchical network is designed.

5 The Hierarchical Network Design Algorithm (HIENDA)

An analysis of the location registration and packed delivery cost was carried out in the above section, showing that the only way to reduce the overall cost is to minimize the number of the AR changes which are at the same time MAP changes too. The hierarchy of the ARs, MAPs and network routers should be designed in a manner which will take into account the mobility parameters of the users, specially the AR handover rates of the MNs. Accordingly if we join those ARs which have a high handover rate among each other into one MAP domain, the number of MAP domain changes will decrease significantly. Therefore this should be the design principle of an optimized HMIPv6 network.

Thus our goal was to develop an algorithm, which will assign an optimal tree structure to a given source of AR handover rates. We modified some already existing information theory solutions to apply them for hierarchy planning.

5.1 Definitions

The optimal tree hierarchy of HMIPv6 for a given source of AR handover rates could be described as a probability tree, where the probabilities of the terminal nodes will be the handover probabilities of the ARs. This means the HMIPv6 probability tree is a finite tree-graph and for every node of the tree-graph a non-negative number is assigned, based on the next definitions (see an example on figure 2):

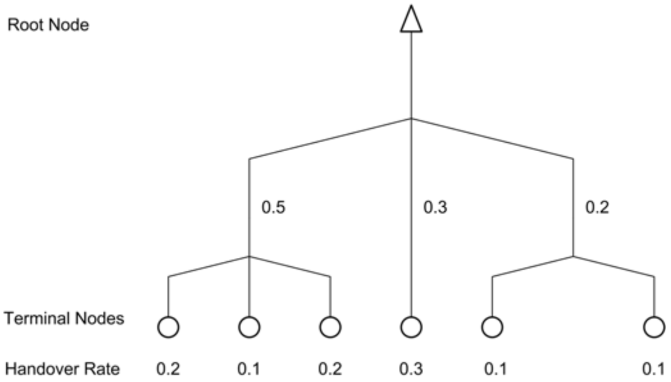

Figure 2 An example of a HMIPv6 probability tree

- The probability of the root node is equal 1.
- Probability of every node is equal with the sum of the probabilities of the belonging sub-tree (a tree originating from this node).
- The probabilities of the terminal nodes are calculated on the base of the AR handover rates: the ratio of the given AR handover and the total amount of handovers. This ratio will give us the rate of outflow from the given AR region, the number of exterior cell boundary crossing for that domain.

Lemma:

The average distance $\mathrm{E}[L]$ of the terminal nodes from the root node (where L is a probability variable of the route length) is equal to the sum of the probabilities assigned to the non-terminal nodes, considering the root node as a non-terminal node too.

5.2 The Algorithm

As above explained, our goal is to reduce the number of hops packets travel, in this way we can minimize the Location Update Cost. With the right placement of MAPs, the Packet Delivery Cost can be reduced too, simultaneously. However the mobility patterns of MNs and the handover rates of ARs should be considered also.

Therefore the objective is to define an algorithm, which will build a probability tree, where the average distance $\mathrm{E}(L)$ of the terminal nodes from the root node is minimal for a given AR handover rate probability distribution ($P_H(h_i)$) and given number of terminal nodes (T). That means, on the basis of Lemma, a probability tree should be created with terminal nodes, such as the sum of the non-terminal node probabilities is minimal. For this purpose, we can use the Huffman-algorithm [25], but we need to modify it for this kind of hierarchy optimization. Accordingly we propose a Hierarchical Network Design Algorithm (HIENDA), based on a modified Huffman-algorithm and a MAP allocation scheme.

The initial step of the algorithm is to define how much ARs (i.e. how much terminal nodes of the tree) should be aggregated in every step of the algorithm, beginning from the first level of the optimized probability tree. This number depends on the topology constraints of the given network. First the two terminal node aggregation case is introduced, which means always two terminal nodes will be joined on the next level of the hierarchy. It consists of the following steps:

1. Map the AR topology of a given HMIPv6 network to a T number of terminal nodes, assigning the ratios of the given AR handover rate and the total amount of handovers to the belonging terminal nodes as probabilities on the lowest level of the tree. If the ARs are adjacent in the HMIPv6 network, the belonging terminal nodes should be neighbors too. These nodes will be called active nodes.
2. Create a new node on the upper level, by aggregating the two adjacent active nodes with the lowest probabilities, and assign the new node a probability, which will be the sum of these two probabilities. Delete these two nodes from the list of active nodes, and add this new node to the list of active nodes. In this step should be examined if

$$p_{\min 1} + p_{\min 2} \geq K_{MAP} \tag{11}$$

This means if the sum of handover probabilities exceeds a calculated constraint, a MAP must be deployed on this level of hierarchy, to reduce the signaling load on this branch. Namely if the sum of handover probabilities is too high, there will be a lot of AR changes, which will generate a huge number of Location Update messages. In this way the MAP will hide this AR change from the upper levels, therefore the Location Update Cost will be decreased. In this point a reasonable idea would be to deploy in every aggregated node a MAP, accordingly to minimize the Location Update Cost. But in this case the Packet Delivery Cost would increase, causing unacceptable delay variations. To have a fair tradeoff between this two costs, the K_{MAP} should be carefully calculated, on the basis of the network characteristics.

The final step of the algorithm is:

3. If there are no any active nodes left, then the last aggregated node should be assigned to the root node and stop the algorithm. If there are still active nodes, go back to step 2.

This was the case when two nodes were aggregated in each step of the algorithm. We generalized this algorithm for S number of aggregated nodes. For this the number of unused terminal nodes need to be determined, these nodes will not represent any ARs (0 probability will be assigned to them), they are needed only for building the S aggregation level probability tree.

The steps:

1. Map the AR topology of a given HMIPv6 network to a T number of terminal nodes, assigning the ratios of the given AR handover rate and the total amount of handover to the belonging terminal nodes as probabilities on the lowest level of the tree. If the ARs are adjacent in the HMIPv6 network, the belonging terminal nodes should be neighbors too. These nodes will be called active nodes.
2. Determine the number of unused terminal nodes: $T_{un} = R_{S-1}\left[(T-S)\cdot(S-2)\right]$, where R is the residue operator. These unused terminal nodes will have 0 value of possibility and they will not represent any AR, after the creation of the optimal tree, they should be deleted.
3. Create a new node on the upper level, by aggregating $(S-T_{un})$ adjacent active nodes with the lowest probabilities, and assign the new node a probability, which will be the sum of these $(S-T_{un})$ probabilities. Delete these $(S-T_{un})$ nodes from the list of active nodes, and add this new node to the list of active nodes. In this step should be examined if

$$p_{\min 1} + p_{\min 2} + \ldots + p_{\min(S-T_{un})} \geq K_{MAP} \tag{12}$$

then in the same way as in the previous algorithm, a MAP should be deployed in the aggregated node.

4. If there are no any active nodes left, then the last aggregated node should be assigned to the root node and stop the algorithm. If there are still active nodes then set $T_{un} = 0$ and go back to step 2.

On the end of the HIENDA algorithm, we will get a near optimal probability tree where the average distance $\mathrm{E}(L)$ of the terminal nodes from the root node is minimal for a given AR handover rate probability distribution ($P_H(h_i)$) and given number of terminal nodes (T). This means the number of hops packets travel is minimal, in this way we can minimize the Location Update Cost, simultaneously keeping the Packet Delivery Cost low by the MAP deployment, obtaining an optimal tradeoff between the two main costs of such a hierarchical micro-mobility environment.

6 Simulation Results

The HIENDA algorithm is developed to optimize the hierarchy of the ARs, MAPs and network routers in a manner which will take into account the mobility parameters of the users, especially the AR handover rates of the MNs. Accordingly if we join those ARs which have a high handover rate among each other into one MAP domain, the number of MAP domain changes will decrease significantly.

Therefore we designed a simulation examination scenario for comparing the performance of the HIENDA algorithm together with another hierarchy optimizing solution introduced in [26], henceforward Multi-Level HMIPv6. It is an analytic model based on a multilevel HMIPv6 architecture, while in terms of AR and MAP location, they assume that the ARs are uniformly located in each leaf MAP domain. For example, let's assume that there are 128 ARs and the hierarchy level is determined as 3 in binary tree architecture. Then, the number of leaf MAPs is $2^3 = 8$ and the number of ARs in a leaf MAP domain is 128/8 = 16. The assignment technique of AR groups to MAPs is not clarified, but we assumed that the ARs with the highest handover rates are placed into one MAP domain, decreasing the number of MAP handovers in this way.

For the generation of the mobility patterns we used the mobility environment simulator already introduced in [23]. Also the LA forming process was performed by the LAFA and CEREAL algorithms described in [23]. By employing these two algorithms the input for the HIENDA algorithm was created, adjusting the cell groups to the given ARs (see the overall AR-cell group assignment process in Appendix 1).

The cells marked by identical colors will be connected to the same AR. We ran the HIENDA algorithm on the above presented AR structure, assigning the ratios of the given AR handover rate and the total amount of handovers in the AR topology to the belonging terminal nodes as probabilities on the lowest level of the tree. The second, the third and the fourth level of the hierarchy viewed from above after running the HIENDA algorithm can be seen in Appendix 2.

For the simulated MN movements (AR and MAP handovers) the Location Update and the Packet Delivery Cost was calculated for both hierarchical structures (created by the HIENDA and the Multi-Level HMIPv6 scenario).

Figure 3 shows the Location Update Cost for the two hierarchical scenarios, in the function of the aggregated ARs (for $S = 2$ and $S = 3$). In the case of $S = 2$ when two terminal nodes were aggregated in each step of the algorithm, the HIENDA algorithm outperforms the Multi-Level HMIPv6 scenario in point of the location update signaling load. When three ARs are aggregated in each step of the hierarchy building, the difference gets significant; the hierarchical structure created by the HIENDA algorithm is producing only half of location update messages then the Multi-Level HMIPV6 does.

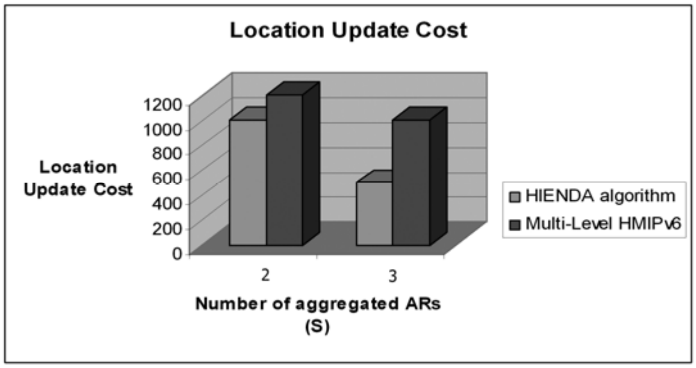

Figure 3 The Location Update Cost for the two hierarchical structures

Another important issue is the Packet Delivery Cost, because if the hierarchical structure is designed in a manner to reduce the Location Update Cost but simultaneously it is increasing the signaling load caused by situations of triangular routing, it is not effective anymore. Therefore the

Total Signaling Cost is an important performance evaluation parameter too, because it keeps maintaining a tradeoff between the two cost functions.

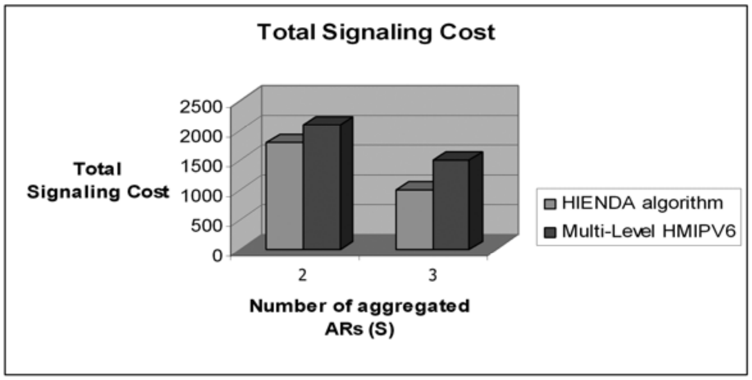

Figure 4 The Total Signaling Cost for the two hierarchical structures

Figure 4 shows the Total Signaling Cost for the two competitive hierarchical scenarios in the same mobility environment, in the function of S. The HIENDA is outperforming again the Multi-Level solution, it can be seen that they are producing almost the same Packet Delivery Cost, but the Location Update Cost is much lower in both cases when HIENDA is used. This means that in this way we can minimize the Location Update Cost, simultaneously keeping the Packet Delivery Cost low by the MAP deployment, obtaining an optimal tradeoff between the two costs.

7 Conclusions

Our aim in this paper was to highlight the main questions and optimization problems of designing mobile Internet architectures based on Hierarchical Mobile IPv6, and to present a novel hierarchical network design algorithm (called HIENDA) in order to optimize mobility management in MIPv6-HMIPv6 networks. The main goal of HIENDA is to assign an optimal tree structure to a given source of Access Router handover rates. Therefore HIENDA considers the topology constraints, and takes the available mobility pattern and Access Router handover information as input, and finds a near optimal hierarchical structure of the micro-mobility domain for which the total signaling cost will be minimal.

A HMIPv6 simulation environment was implemented integrating the cost functions and network designing schemes in order to extensively analyze and evaluate the capabilities of our hierarchical optimization technique, comparing them with other solutions. From the simulation results the conclusion could be drawn that the HIENDA is outperforming the other existing hierarchy optimizing solution in the terms of Location Update Cost, at the same time keeping the Packet Delivery Cost on a low level.

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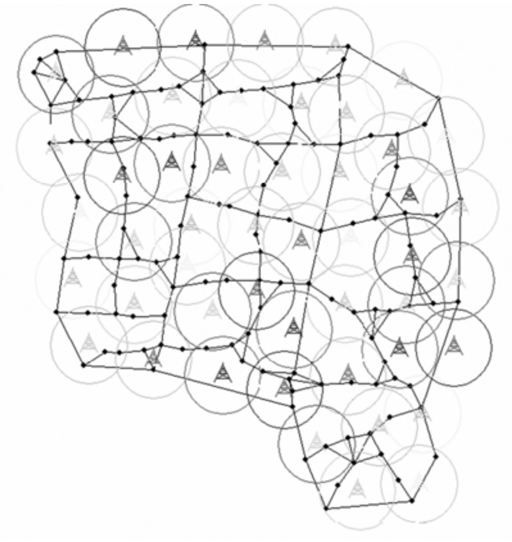
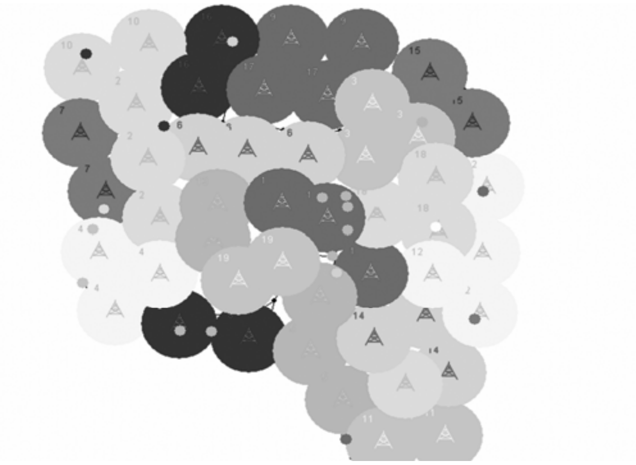
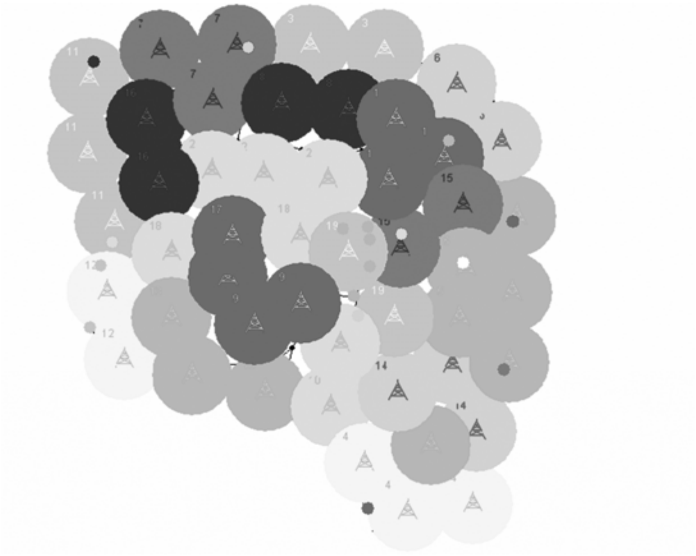
Appendix 1: Overall AR-cell group assignment process



The designed mobility environment

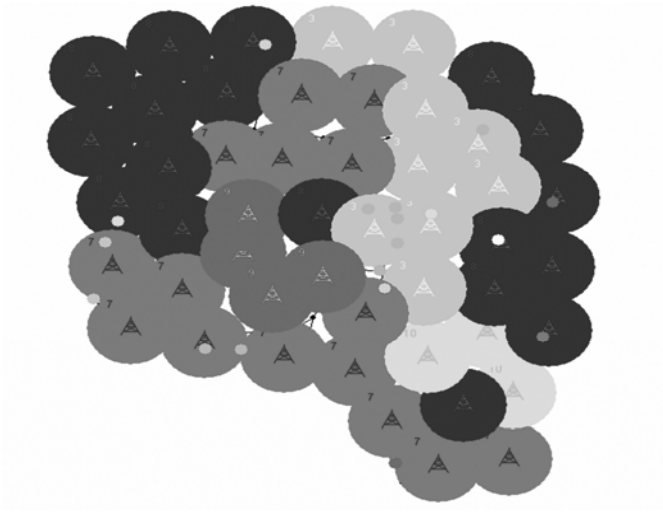


The LA structure after the LAFA algorithm

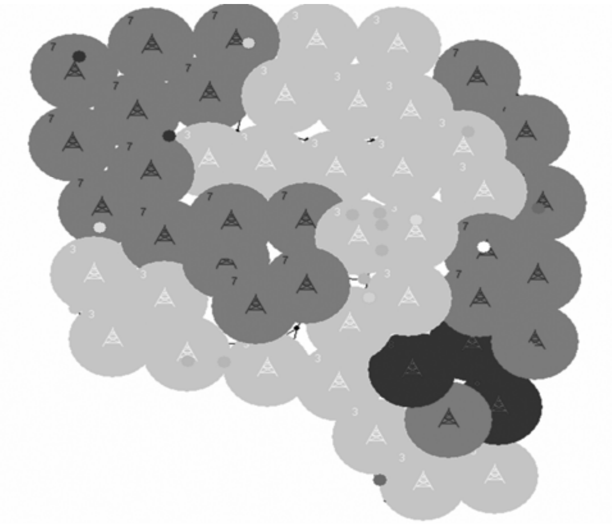


The LA structure after the CEREAL algorithm

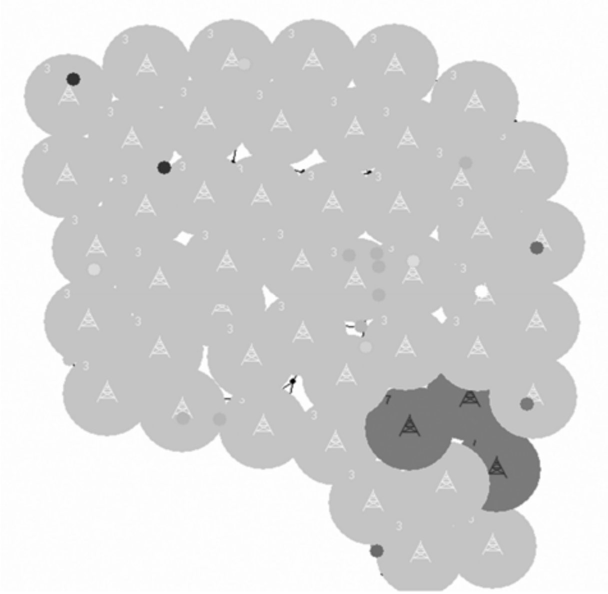
Appendix 2: The 2nd, 3rd and 4th level of the hierarchy viewed from above after running HIENDA



The second level of the hierarchy viewed from above



The third level of the hierarchy viewed from above



The fourth level of the hierarchy viewed from above