HIERARCHICAL MOBILE IPV6 AND REGIONAL REGISTRATION OPTIMIZATION

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Abstract

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, and the management consists of two parts: location management and handover management [1]. The first one enables to originate and receive calls for the mobile terminals; the second is responsible for administering base station changes. In our work, we have created a network design algorithm and an agent (GMA/MAP) router selection algorithm in Regional Registration and Hierarchical Mobile IPv6 to optimise the handover management in IP based next generation mobile networks.

1. Introduction

While mobility management in current systems, like GSM is handled in the second layer (Data Link Layer), the new tendency is to solve such problems in the network layer [2]. This support must be transparent to mobile users and also has to be scaleable, which means that despite the growth of the number of mobile terminals, the amount of signalling overhead must not increase significantly [3].

Reduced radio cell sizes (increasing the number of handovers) and more complex protocols and services in next generation mobile networks increase the signalling overhead, causing significant signalling delay. This is critical in the case of timing-sensitive real-time media applications that call for mobile QoS [4].

Mobile IPv6 [5] is an extension to IP to manage the mobile node's mobility, but not capable of supporting real-time handovers. 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. Other solutions are Hierarchical Mobile IPv6 [6], or Regional Registration [7]. The basic idea of these hierarchical approaches is to use domains organised in the hierarchical architecture with a mobility agent on the top of the domain hierarchy.

The standard does not address the realisation considerations in detail of the hierarchical tree during the network design. The implementation details of the hierarchy are entrusted to the engineer.

Several important questions arise: what kind of principles must be used to configure the hierarchical levels, how to group cells under a given router [8], and in which hierarchical level is it advisable to implement the MAP/GMA function. We give planning principles, which can help to plan optimal networks. In our work we present a method, showing how to configure these hierarchy levels in order to reduce signalling traffic. We propose a graph-theory algorithm, which takes into consideration the mobile node's mobility model.

This paper is organised as follows: principles and a presentation of our domain-forming algorithm are introduced in Section 2. The explanation of our results follows in Section 3. In Section 4 we draw some conclusions from the obtained results.

2. Protocol Optimisation

In this chapter, we introduce a solution to minimise the amount of administrative messages leaving the domain. Our method consists of two parts:

- The *domain-forming algorithm* is aiming at forming optimal domains, by optimising access router and base-station associations (section 3.2).
- The *mobile node agent selection algorithm* introduces guidelines for mobile terminals on how to select the optimal agent from the agents available on the agent advertisement lists (section 3.4).

2.1 The Domain Forming Algorithm

The main concept of the algorithm is to connect adjacent radio cells with high mutual handover probabilities to the same access router. As a result, most handovers will take place between base stations belonging to the same access router, so the number of care-of address changes – and the amount of related signalling messages, handover delays, etc. – are reduced. The task of this algorithm is to form the lowest hierarchy level, by collecting base stations in groups, and attaching them to appropriate access routers. Besides user movement characteristics – contained in the handover vector – the load has to be balanced between the access routers.

The algorithm is described mathematically as follows: in a graph-modelled network, the cells are the nodes of the graph (C) and the possible directions of the cell boundary crossing between adjacent cells will be the edges (E). c_1 and c_2 are adjacent points (cells), if $\{c_1, c_2\} \in E$. We must divide the $G = (C, E)$ graph into $G' = (C', E')$ subgraphs, so that the subgraphs contain the maximal weight spanning tree.

We define weights to the graph's edges, not negative real numbers in the range [0,1], based on the direction probability vector (the handover vector), namely the weights of edges will be equivalent to the probabilities of the movement directions (see figure 1).

We choose the edges one by one in the following manner: first we choose one of the edges with the biggest weight: $G = (C, E)$. The two nodes (cell), which are connected to this edge, $G' = (C', E')$, can be joined, and after that we manage them as if they are one, $\{c_1, c_2\} \in E$. From the six edges (eight edges come out from two nodes, four direction two times, but one edge is common) outgoing from the two joined nodes, we must choose one with the biggest weight value, c_2, and the belonging node becomes the member of the common set, $C' = \{c_1, c_2, c_3\}$. From the eight edges (twelve edges come out from three nodes, but two edges are common) belonging to the nodes, which are in the common set, we choose the next one so as to make a circle in the graph, namely if we have an $(c_1, e_1, c_2, e_2, ..., c_k, e_k, c_{k+1})$ edge series, then $c_1 = c_{k+1}$. In this way, we can avoid the domains becoming too entangled and far-reaching. We can continue this algorithm, until the element number of C' reaches M, $c_1 = c_{k+1}$, because the router can manage the traffic of only *M* number of cells, so one domain will consist of *M* cells. When we cover the entire G graph with not-connected $G'_1, G'_2, ... G_N$ subgraphs, the algorithm of forming domains is finished.

By that way the lowest hierarchy level can be formed, covering every cell.

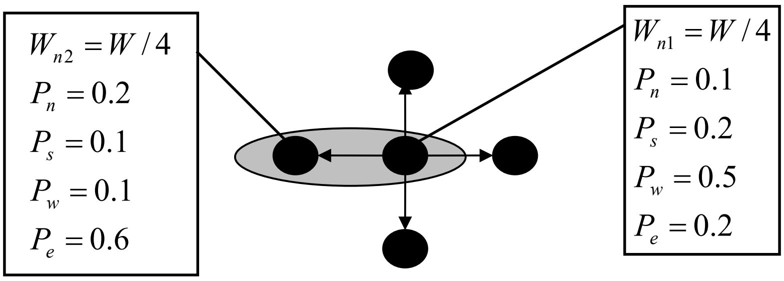

Fig. 1. The graph with weighted directions

2.2 Relation between the mobile node's speed and the hierarchical levels

There are several potential GMA (Gateway Mobility Agent) routers inside a HMIPv6 capable domain. The MN chooses one GMA from the list attached to the Router Advertisement. In the list there are Regional Care-of-Addresses (GMA addresses). While the MN is moving in the domain area, it can choose another GMA router. Every GMA change must be reported to the Home Agent. For the best result the selection of the GMA must depend on the movement speed of the mobile node.

If the MN often changes its Access Router, a high level GMA must be chosen while a GMA on low hierarchical levels advertises Binding Updates too often.

For a slow moving MN the situation is the opposite. It is advisable to choose a GMA near the Access Router. Because of the slow moving, the change of the Regional CoA is rare, and the incoming packets get to the MN in a shorter way.

We give an algorithm, which selects the optimal Regional CoA (GMA) from the list.

It is noticeable that increasing the movement speed, the probability of the GMA changing is increasing too, if the MN selects the GMA randomly. The effect is the same, if the number of the hierarchy levels is increasing. Using the algorithm, in a router hierarchy, which has three levels, up to 50% gain can be achieved (section 3.2.).

3. Analytical Examination

3.1 Analytical examination of domain forming algorithm

We have examined analytically, how the number of signalling messages changes using a randomly formed lowest hierarchy level and the one, which is formed by our algorithm, to see if the algorithm really decreases the administrative overload generated by the handover.

The comparison was made in the following environment: in our examination we have modelled the cover of a busy avenue and its surroundings. In our model we have approximated the cells with quadrates, because of easier calculation. One router managed four cells, $M = 4$, and we had 36 cells in the modelled network, so we needed nine routers.

We adjusted probabilities to the handover directions, modelling a realistic traffic on the given system of roads (avenue and its side streets). The probabilities gave us the information in which direction (north/south/west/east) and with what relative frequency the mobile users will cross the cell boundary, based on online measurements. For such probabilities preliminary measurements, observation and then processing of measured values (databases of mobile providers) are needed.

The required bandwidth, if the mobile node changes a domain, is:

$$B = K \cdot N \cdot L + 2 \cdot L = L \cdot (K \cdot N + 2), \tag{1}$$

where N is the number of the foreign Correspondent Nodes, L is the size of the Binding Update message, and K is the number of Binding Updates which was sent to one foreign Correspondent Node.

In the first case, we made a random arrangement of four cell groups and we calculated how many domain handovers it causes when the mobile node is travelling on significant routes on our system of roads. One change of domain requires $K \cdot N + 2$ number of Binding Updates, and the bandwidth is defined by (1).

In the second case we used our domain-forming algorithm to see whether it really reduces the number of domain changes for the same significant routes.

The results are given in Table 1.

Table I. Number of domain changes

Route	***Random***	***Algorithmic***
(a)	5·L·(K·N+2)	3·L·(K·N+2)
(b)	3·L·(K·N+2)	2·L·(K·N+2)

Based on the results obtained with the help of the domain forming algorithm the handover signalling load can be reduced by 30-40% on average (see Table I.), which makes it possible to improve the QoS parameters (for example in real time applications). The domain changing update traffic was calculated for other significant routes, too.

3.2. Analytical examination of GMA/MAP selection

We have examined how the number of re-registrations at the Home Agent changes using a random GMA/MAP selection and our selection algorithm.

For simplicity in the three-layer hierarchy network, all of the routers are GMA/MAP capable routers. In this network, the MN can always choose from three different GMA/MAP routers. In this case, the MN receives a Regional Care-of-Address Extension message. In this message there are three different GMA/MAP router addresses from which the MN must choose one. In random mode the MN chooses the optimal GMA/MAP in our sample network with p=1/3 probability.

In this sample the whole speed interval is partitioned in four smaller intervals (v_a, v_b, v_c, v_d). If we know in which interval the speed-rate is, we can choose the optimal GMA/MAP router.

We have calculated the probability of GMA/MAP changes in case of random GMA/MAP selection, in the examined network. As the results show, the probabilities that the MN changes its GMA/MAP router once, twice, and so on are given in Table II.

Table II. Probability of GMA changes in random selection

GMA change	V_a	V_b	V_c	V_d
1	1	2/3	1/3	1/3
2	-	1/3	4/9	1/3
3	-	-	2/9	7/27
4	-	-	-	2/27
Σ	1	1	1	1
$M(\xi)$	1	1,33	1,88	2,07

The expected number of GMA/MAP changes can be calculated with (2) using the results from Table II:

$$M(\xi) = \sum_{i=1}^{n} p_i \cdot x_i \tag{2}$$

It is noticeable that in case of random agent selection, as the speed of the terminals increases (or when the hierarchical tree has more levels), the number of GMA/MAP changes also rises. As a result, the amount of signalling overhead is increasing significantly compared to the optimised scenario.

4. Conclusions

Seamless mobility management in IP is an important task. It has come obvious early, that Mobile IP (MIP) in itself is not capable of supporting real-time handovers under mobile scenario: the long lasting address registration process results is an intolerable interruption to user's data flow during handoff. The demand for global QoS support has brought the more enhanced hierarchical solutions (like HMIP and Regional Registrations) into being. However these proposals are quite recent: less data is available on testing and optimisation.

There are details that the existing versions of the proposals are not dealing with, like the optimal network structure and the selection of GMA/MAP routers. We gave an algorithm on the first problem, and analysed the efficiency of our solution in a simple test network. Comparing the signalling traffic load of a random network and the optimised one, the results show a significant reduce of the signalling traffic. An agent selection algorithm is also proposed, and its advantages are studied in comparison with a random agent choosing method. These results help to support global QoS in next generation networks.

Our future plan is to use computer simulations (like NS2 or OmNet++) to analyse the algorithms, which will help us to get more results. Even if further studies necessary, next generation IP based mobile networks will surely benefit of the enhanced IP mobility management solutions.

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