Location Management in a Multi-Network-Operator Environment

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Abstract

We study the signalling cost of different location management schemes under varying user behaviour in the case where one or several networks serve a certain region and where users may roam between these networks. For a user model, which has already been presented in [12], we propose a method for its parametrization. The focus of the studies and of the model is on the geographic distribution of origins and destinations of calls and location updates.

1. Introduction

Several fixed or mobile networks may cover a certain region. Calls have to be routed between these networks and UPT users or users with wireless multi-mode terminals may roam between these networks. In this paper we propose and compare different location management schemes in such a multi-network-operator environment. The criteria for the comparison is the amount of signalling messages which have to be exchanged. We try to minimize signalling traffic by increasing processing costs. Another criteria could be the end-to-delay of certain operations. But this is out of the scope of the paper and the according methodology has already been presented in [12].

In section 2 we describe the basics of location management and introduce some location management schemes. In section 3 we recall and refine the user model from [12] and propose a method for its parametrization. In section 4, section 5 and section 6 we study the influence of different network architectures and location management schemes on the cost of signalling for different parameters of the user model.

2. Location Management

A Basic Scheme

Updating location information (location update) and the provisioning of routeing information for incoming calls are the two most important location management procedures. In this article we focus on signalling which effect the network beyond the current location of a user (i.e. the current assignment of a user to a specific local exchange or *Mobile Switching Centre* – MSC). Procedures which can be performed by using data which is (after a location update) available at the current location of a user are not considered. Examples of those procedures are ciphering, allocation of temporary identifiers, attach/detach procedures, intra-MSC location updates, and user authentication at call setup. Also, handover procedures are not discussed.

A location update (LU) is usually performed in three steps:

- Obtain data which enables authentication of the user who request the location update and execute the authentication procedure
- Transfer a copy of the user profile to the current location
- Update the location information in the network

Before a call can be routed to a mobile user, routeing information has to be obtained. In the following we will assume that routeing information is provided at the current location of the called party only and that call setup is initiated after this information is available at the origin of a call.

Thus, provisioning of routeing information for incoming calls consists of two steps:

- find the current location a user
- bring routeing information from the current location of the user to the origin of the call

B Location Management in GSM and Location Management based on a Distributed Database

In GSM location management is controlled by the VLR at the current location of a user. The user profile and information about the current location is stored in the HLR of the user. Data which enables authentication at location update is either retrieved from the previous location or from the HLR. A copy of the user profile is always transferred from the HLR to the current VLR.

Updating location information in the network is performed by informing the HLR about the new location which in turn informs the previous VLR. If a call has to be routed to the current location of a user, the originating MSC requests routeing information from the HLR, which knows the current location of the user, and retrieves routeing information from there which is then sent to the originating MSC.

In [13] Wang proposes a hierarchically distributed database (DDB) with a tree-structure. A user who is located at his home location is registered only there. If he is located at a location area which is not beneath his home database node, a chain of pointers leads along the nodes of the database tree to the current location. We propose to use this DDB for updating and retrieval of location and routeing information only. Contrary to [13] call set-up is initiated *after* routeing information is available at the origin of a call. HLRs remain in the network and provide user profiles and authentication information. Thus, the according information flow for the location update procedure differs from GSM only in the third step, where location information is updated. A request for routeing information is forwarded along the nodes of the database tree to the current location of the user and returned along the same route.

C Some Possible Modifications and Extensions

Several proposals to modify and extend the GSM scheme have been made: the local anchor scheme [2], forwarding pointers [6] and caching [7]. Their effectiveness usually depends on the call-to-mobility ratio (CMR) which is the ratio between the rate of incoming calls and the rate of location updates. The cost of a location management procedure then often depends on the history of the user behaviour. Here we focus on schemes which are independent of the history of the user behaviour. Furthermore we evaluate the cost of location updates and calls independent of each other and dependent on the distribution of their origin and their destination.

The idea to search for a called user first at the origin of a call has already been presented in [5] and in [11]. We adopt this idea to GSM and search a called user in the VLR at the origin of a call before the according HLR is queried. In the following we will call this scheme GSM*.

The root of the tree in the DDB has not necessarily to be realized as a single node, its function can also be distributed to several nodes. We propose to distribute its function to all or to some nodes which are logically children of the root. Depending on the number of such nodes the cost of a location update may increase due to the fact that all these nodes have to be informed when the root is involved. On the other hand, the cost of obtaining routeing information decreases since one hop in the tree hierarchy is abolished. In the following we will call this scheme DDB*.

Another scheme which we call “ProxyHLR“ will be described in section 6. It is only relevant in a multi-network-operator environment. It is similar to a scheme which we have already proposed in [4],[10] and which has a lot in common with a scheme proposed in [8],[9].

3. User Modelling

The procedures *location update* and *incoming call* are usually triggered by the user behaviour. In order to be able to evaluate the performance of different location management strategies, it is important to know how often and between which network entities these procedures take place. The user model presented here, focuses on these aspects. It is composed of two parts: of a mobility model and of a call model. The mobility model is independent of the call model. The destination of calls may depend on the mobility behaviour of the involved parties. The model intends to describe the behaviour of a group (a class) of users. It models the aggregated behaviour of the group and not necessarily the behaviour of an individual user. We have already presented this model in [12]. Here we give a short overview and present a method for the parametrization of the model.

A The Mobility Model

From the network point of view, the relevant aspects of user location can be expressed in terms of location areas. In the following the assignment of a user to a specific local exchange (or MSC) is regarded as a location area.

User mobility is then modelled by a finite state continuous time semi-Markov chain in steady state which is irreducible and recurrent. The sojourn time within a state u ($u \in \mathcal{S}$) is assumed to be independent of the destination of the following transition and its mean value is denoted $1/\mu_u$. The same mobility model has been used in [3] to model roaming of UPT users. A similar model based on Markov chains has been presented in [1].

The stochastic matrix of the transition probabilities $p_{u,v}$ ($p_{u,u} = 0$) of the semi-Markov chain in steady state shall be called **P**:

$$\mathbf{P} = (p_{u,v}) \qquad (1)$$

The state probabilities are denoted . We define

$$\phi_u = \pi_u \cdot \mu_u \tag{2}$$

as the “flow“ out of state u, and

$$\phi_{u,v} = \pi_u \cdot \mu_u \cdot p_{u,v} \tag{3}$$

as the “flow“ from state u to state v.

Thus, the equilibrium equation for state u under steady state condition can be written in the following form:

$$\sum_{v \in \mathcal{S}} \phi_{u,v} = \sum_{v \in \mathcal{S}} \phi_{v,u} \quad \Leftrightarrow \quad \phi_u = \sum_{v \in \mathcal{S}} \phi_{v,u} \tag{4}$$

which results in

$$\underline{\phi} = \mathbf{P}^{\mathrm{T}} \cdot \underline{\phi} \tag{5}$$

for all states in $\mathcal{S}$, where $\underline{\phi}$ is the vector of „flows“:

$$\underline{\phi} = (\phi_u) \tag{6}$$

For each group k of users ($k \in \mathcal{K}$) we define independent mobility models with parameters $\pi_u^{(k)}$, $\mu_u^{(k)}$ and $p_{u,v}^{(k)}$.

The number of users in group (class) k shall be called $\Pi^{(k)}$. The mean number of users of class k in state u is then given by

$$\Pi_u^{(k)} = \Pi^{(k)} \cdot \pi_u^{(k)} \tag{7}$$

B The Call Model

Distances $d_{u,v}$ are defined between location areas. The mean distance between location areas is assumed to be equal to 1. The according traffic matrix for incoming calls can then be defined dependent on these distances. One location $h^{(k)}$ per user class is selected as the “home location“ of its members.

We identify four types of calls[1]:

- **Type I** calls from parties whose current location is "close" to the home location of the called party.
- **Type II** calls from parties whose current location is "close" to the current location of the called party
- **Type III** calls from parties whose home location is "close" to the home location of the called party.
- **Type IV** calls from parties whose home location is "close" to the current location of the called party.

For each type of call ($i \in \{\mathrm{I}, \mathrm{II}, \mathrm{III}, \mathrm{IV}\}$) we define a conditional incoming call rate matrix ${}^{(i)}\mathbf{R}$ with the components ${}^{(i)}r_{u,v}$. Type I and type II calls are independent of the mobility behaviour of the calling parties. The origin of type I and type III calls is independent of the mobility behaviour of the called party. Thus:

$${}^{(\mathrm{I})}r_{u,v} = {}^{(\mathrm{I})}r_{u,w} \quad \text{for all } u, v, w \tag{8}$$

$${}^{(\mathrm{III})}r_{u,v} = {}^{(\mathrm{III})}r_{u,w} \quad \text{for all } u, v, w \tag{9}$$

We define the (non-negative) call type ratios ${}^{(i)}P_{\mathrm{Call}}$, with:

$${}^{(\mathrm{I})}P_{\mathrm{Call}} + {}^{(\mathrm{II})}P_{\mathrm{Call}} + {}^{(\mathrm{III})}P_{\mathrm{Call}} + {}^{(\mathrm{IV})}P_{\mathrm{Call}} = 1 \tag{10}$$

and (for each class of users) a global incoming call rate ${}^{\Sigma}r$.
The overall traffic matrix of incoming calls $\mathbf{R}$ (for each class of users) can than be calculated by superposition of the four conditional call rate matrices:

$$\mathbf{R} = {}^{\Sigma}r \cdot \sum_{i = \mathrm{I}, \mathrm{II}, \mathrm{III}, \mathrm{IV}} {}^{(i)}P_{\mathrm{Call}} \cdot {}^{(i)}\mathbf{R} \tag{11}$$

A function $f_\delta(d)$ with parameter δ is used to weight the distances between location areas. In the following we will use the function

$$f_\delta(d) = e^{-\frac{1-\delta}{\delta} \cdot d} \tag{12}$$

and will call δ the “call spreading factor“.

For each type of call we define the conditional call rates from u to a user of class k who stays in v:

$${}^{(\mathrm{I})}r_{u,v}^{(k)} = \frac{1}{{}^{(\mathrm{I})}C_v^{(k)}} \cdot f_\delta(d_{u,h^{(k)}}) \tag{13}$$

$${}^{(\mathrm{II})}r_{u,v}^{(k)} = \frac{1}{{}^{(\mathrm{II})}C_v^{(k)}} \cdot f_\delta(d_{u,v}) \tag{14}$$

$${}^{(\mathrm{III})}r_{u,v}^{(k)} = \frac{1}{{}^{(\mathrm{III})}C_v^{(k)}} \cdot \sum_{j \in \mathcal{K}} \Pi_u^{(j)} \cdot f_\delta(d_{h^{(j)},h^{(k)}}) \tag{15}$$

$${}^{(\mathrm{IV})}r_{u,v}^{(k)} = \frac{1}{{}^{(\mathrm{IV})}C_v^{(k)}} \cdot \sum_{j \in \mathcal{K}} \Pi_u^{(j)} \cdot f_\delta(d_{h^{(j)},v}) \tag{16}$$

where the factors ${}^{(i)}C_v^{(k)}$ have to assure that the sum of call rates to a user of class k in state v is identical for all v and that

$$\sum_{u \in \mathcal{S}} \sum_{v \in \mathcal{S}} {}^{(i)}r_{u,v}^{(k)} = 1 \tag{17}$$

which implies

$$\sum_{u \in \mathcal{S}} {}^{(i)}r_{u,v}^{(k)} = \frac{1}{N} \tag{18}$$

where N is the number of states in $\mathcal{S}$.
This results in:

$${}^{(\mathrm{I})}C_v^{(k)} = N \cdot \sum_{u \in \mathcal{S}} f_\delta^{(k)}(d_{u,h^{(k)}}) \tag{19}$$

1 "close" means that the call rate is dependent on some distance.

$$^{(\mathrm{II})}C_v^{(k)} = N \cdot \sum_{u \in \mathcal{S}} f_\delta^{(k)}(d_{u,v}) \tag{20}$$

$$^{(\mathrm{III})}C_v^{(k)} = N \cdot \sum_{u \in \mathcal{S}} \sum_{j \in \mathcal{K}} \Pi_u^{(j)} \cdot f_\delta^{(k)}(d_{h^{(j)},h^{(k)}}) \tag{21}$$

$$^{(\mathrm{IV})}C_v^{(k)} = N \cdot \sum_{u \in \mathcal{S}} \sum_{j \in \mathcal{K}} \Pi_u^{(j)} \cdot f_\delta^{(k)}(d_{h^{(j)},v}) \tag{22}$$

C Parametrization of the Mobility Model

The parameters of the mobility model can not be chosen independently. **P** and $\underline{\phi}$ have to satisfy equation (5). If the Semi-Markov chain is irreducible and recurrent, $\underline{\phi}$ is the only eigenvector of $\mathbf{P}^{\mathrm{T}}$ with eigenvalue 1 and all ϕ_u are non-zero and have the same sign.

In the following we present a method to determine the elements of **P** so that the mobility model is time-reversible (i.e. $\phi_{u,v} = \phi_{v,u}$) and where the ϕ_u can be calculated without explicitly solving the system of linear equations in (5).

Some of the $p_{u,v}$ are explicitly set to zero. This is represented in form of the "neighbourhood matrix" **N** whose elements $n_{u,v}$ are either 0 or 1:

$$n_{u,v} = \begin{cases} 0 & \text{if } u = v \\ 0 & \text{if } p_{u,v} \text{ shall be } 0 \\ 1 & \text{if } p_{u,v} \text{ shall be} > 0 \end{cases} \tag{23}$$

with:

$$n_{u,v} = n_{v,u} \tag{24}$$

Each state is then assigned an arbitrarily chosen weight factor G_u ($G_u > 0$). These weight factors are used to determine the elements of **P**. We set

$$p_{u,v} = \frac{G_v \cdot n_{u,v}}{\sum_{w \in \mathcal{S}} G_w \cdot n_{u,w}} \tag{25}$$

The according „flows" can be then be calculated directly from the weight factors:

$$\phi_u = G_u \cdot \sum_{w \in \mathcal{S}} (G_w \cdot n_{u,w}) \tag{26}$$

(25) and (26) lead to:

$$\phi_{u,v} = \phi_u \cdot p_{u,v} = G_u \cdot G_v \cdot n_{u,v} \tag{27}$$

which satisfies the condition for time-reversibility ($\phi_{u,v} = \phi_{v,u}$) because of (24).

In order to prove (26) we rewrite (4):

$$\begin{gathered} \phi_u = \sum_{v \in \mathcal{S}} \phi_v \cdot \frac{G_u \cdot n_{v,u}}{\sum_{w \in \mathcal{S}} G_w \cdot n_{v,w}} \\ \Leftrightarrow \\ \frac{\phi_u}{G_u} = \sum_{v \in \mathcal{S}} \frac{\phi_v \cdot n_{v,u}}{\sum_{w \in \mathcal{S}} G_w \cdot n_{v,w}} \end{gathered} \tag{28}$$

and make the following substitution:

$$\phi_u^* = \frac{\phi_u}{G_u \cdot \sum_{w \in \mathcal{S}} G_w \cdot n_{u,w}} \tag{29}$$

which leads to:

$$\phi_u^* \cdot \sum_{w \in \mathcal{S}} G_w \cdot n_{u,w} = \sum_{v \in \mathcal{S}} \phi_v^* \cdot G_v \cdot n_{v,u} \tag{30}$$

(30) for all states can be written in the form:

$$\underline{\phi}^* = \mathbf{G} \cdot \underline{\phi}^* \tag{31}$$

where the Elements of the matrix **G** are:

$$g_{u,v} = \frac{G_v \cdot n_{v,u}}{\sum_{w \in \mathcal{S}} G_w \cdot n_{u,w}} \tag{32}$$

With (24) it can be shown that **G** is a stochastic matrix:

$$\sum_{v \in \mathcal{S}} g_{u,v} = \frac{\sum_{v \in \mathcal{S}} G_v \cdot n_{u,v}}{\sum_{w \in \mathcal{S}} G_w \cdot n_{u,w}} = 1 \tag{33}$$

which means that

$$\underline{\phi}^* = \underline{e} = (1, 1, \ldots, 1)^{\mathrm{T}} \tag{34}$$

is eigenvector of **G** to the eigenvalue 1 and thus a solution of (31). From (29) with (34) we get directly (26) – q.e.d.

This method can now be used in different ways. If e.g. the μ_u and π_u (i.e. the ϕ_u) of the mobility model are given and the according $p_{u,v}$ have to be calculated, the system of non-linear equations of (26) could be solved to provide the according G_u which then can be used in (25) to calculate the $p_{u,v}$. If the system of non-linear equations of (26) has no such solution, the ϕ_u could be varied until such a solution exists. This becomes a minimization problem if the deviation from the original ϕ_u has to be kept minimal.

In the following case studies we will use the above presented method in a much simpler way. We choose the G_u according to the function

$$g_\gamma(d) = e^{-\frac{1-\gamma}{\gamma} \cdot d} \tag{35}$$

which is the same function as the one in (12) for the call model and we will call γ the “mobility coefficient“. Thus:

$$G_u = g_\gamma(d_{u,h}) \tag{36}$$

where $d_{u,h}$ is the distance between u and the home (h) of the users which has already been used in the call model. Except for small γ we can choose all μ_u identical and get the π_u directly from (2) and (26). For small γ we normalize the obtained π_u by the factors $g_\gamma(d_{u,h})$ which modifies the μ_u accordingly and leaves the obtained ϕ_u unchanged.

Fig. 1 shows the π_u for different values of γ in a grid of 4x4 location areas where the distances $d_{u,v}$ are proportional to the according manhattan distances and where a location areas has at most eight neighbours in the neighbourhood matrix **N**.

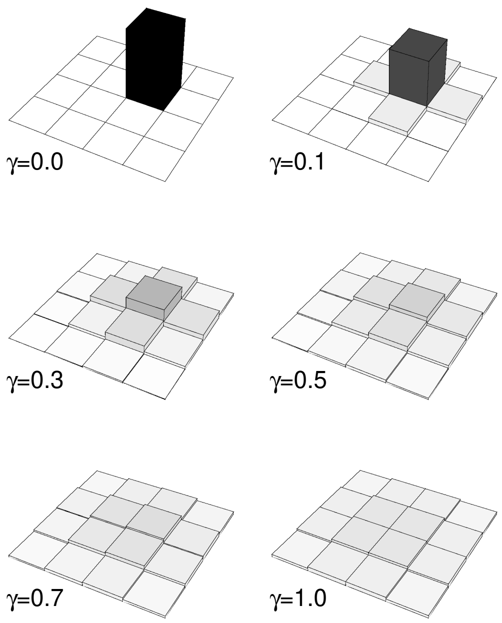

Figure 1: Distribution of users in 16 location areas for different values of the mobility coefficient γ.

4. Location Management in a Single Network

In the following case studies we will look at a region which can be divided in 16 location areas. We define 16 classes of users. Each class is assigned another location area as home location. The parameters of the mobility model are determined as described in the last section (see Fig. 1). The mobility coefficient is varied between 0 and 1. The parameters of the call model are chosen as follows:

$$^{(I)}P_{\text{Call}} : {}^{(II)}P_{\text{Call}} : {}^{(III)}P_{\text{Call}} : {}^{(IV)}P_{\text{Call}} = 1:1:1:1$$

$$\delta = 0.1$$

Like in the mobility model, the distances between location areas are proportional to the according manhattan distances. The home location areas are also the same as in the mobility model.

We look only at the mean number of hops which signalling messages have to travel to perform a location update („LUs“) or to provide routeing information for incoming calls („Calls“) and we call this the cost of an operation.

A The Network Topology

In the first case study, the region is covered by a single network. Each location area is served by an MSC. We consider at the signalling network only. 4 MSC are connected to an STP. The 4 STPs are fully meshed. Fig. 2 shows the according network topology. MSCs are in the first layer of the network, the STPs in a second layer.

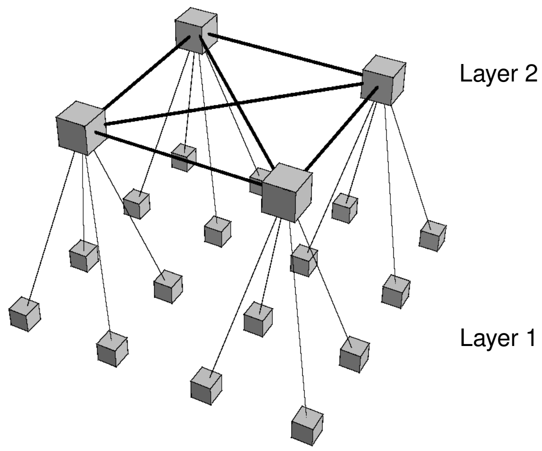

Figure 2: Network topology with 16 MSCs in network layer 1 and 4 STPs in network layer 2

In the DDB scheme and the DDB* scheme all 20 nodes are nodes of the database tree. In the DDB scheme an additional root node has to be placed in a third network layer which is directly interconnected with the 4 STPs. In the DDB* scheme the function of the root nodes is distributed to the four nodes of the distributed database which are co-located with the STPs.

B Placement of Nodes

In this subsection we study the effect of the placement of HLRs on the costs of the different operations. VLRs are always co-located with the MSCs. Two major options and one slight modification of the first option exist:

- **Placement A**: 4 HLRs are co-located with the STPs and users are assigned arbitrarily and independent of their home location to the different HLRs

- **Placement A***: 4 HLRs are co-located with the STPs and users are assigned to the HLR which is closest to their home location
- **Placement B**: 16 HLRs are co-located with the MSCs. Users are assigned to the HLR which is placed at their home location.

Fig. 3, Fig. 4 and Fig. 5 show the costs of the different operations for the different location management schemes. For placement A the costs of the GSM scheme do not depend on the mobility coefficient. For placement A* the costs of the GSM scheme are lower than those for placement A but converge towards these for $\gamma \to 1$.

Placement B performs best for low values of the mobility coefficient and significantly worse than placement A for higher values. LUs are not cheaper than in the case of placement A* but for very low values of γ provisioning of routeing information is cheaper than in the case of placement A*.

Update of location information and provisioning of routeing information in the DDB and DDB* schemes are independent of the placement of HLRs. Only retrieval of authentication information and the transfer of user profiles depend on it. In Fig. 3 cost of LUs for the DDB scheme with placement A is shown.

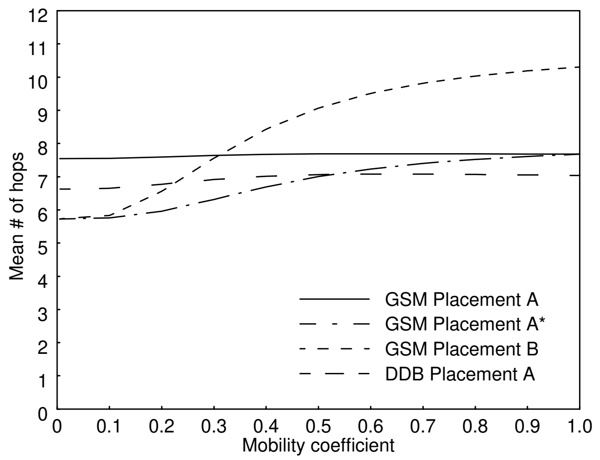

Figure 3: Cost of LUs for different placements of HLRs for the GSM scheme
and for the DDB scheme with placement A.

Costs for LUs for the GSM* schemes are identical to the costs of the GSM scheme. LUs in the DDB* scheme are slightly more expensive than in the DDB scheme. On the other hand, costs for calls are generally cheaper for the schemes GSM* and DDB* than for the schemes GSM and DDB respectively. For higher values of the mobility coefficient DDB* performs slightly better than the GSM* scheme with placement A*.

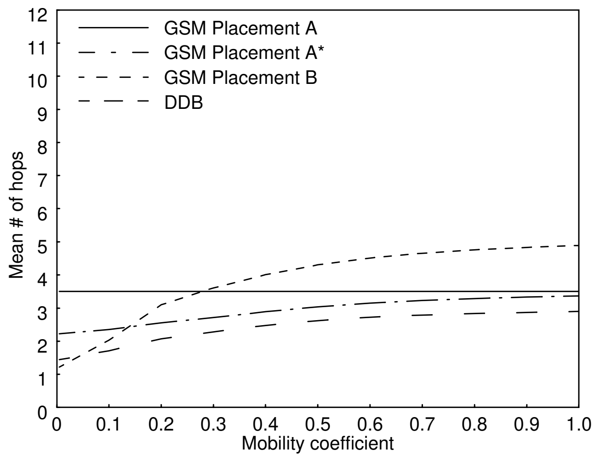

Figure 4: Cost of Calls for different placements of HLRs for the GSM scheme and for the DDB scheme

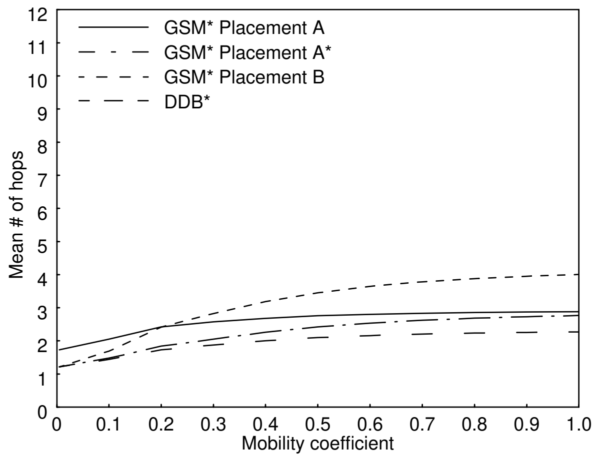

Figure 5: Cost of Calls for different placements of HLRs for the GSM* scheme and for the DDB* scheme

C Comparison of the Different Schemes

In the following we will assume placement A* for all case studies and all schemes. Fig. 6 shows a comparison between the different schemes for the case of a single network serving the region. It can be seen that GSM* can compete very well with DDB and DDB*.

5. Location Management with Several Networks

If a region is served by several networks, calls from and to users have to be routed from one network to another. We assume that it is possible for a foreign network to obtain routeing information from another network before call set-up. This is supposed to become a GSM Phase 2+ feature („Support of Optimal Routeing“). In this case study we assume that users stay within their home network. Calls origins and call destinations are the same as in section 4 and are split equally between the three networks. We assume that all three network are identically structured, serve the same location areas and have the same number of users.

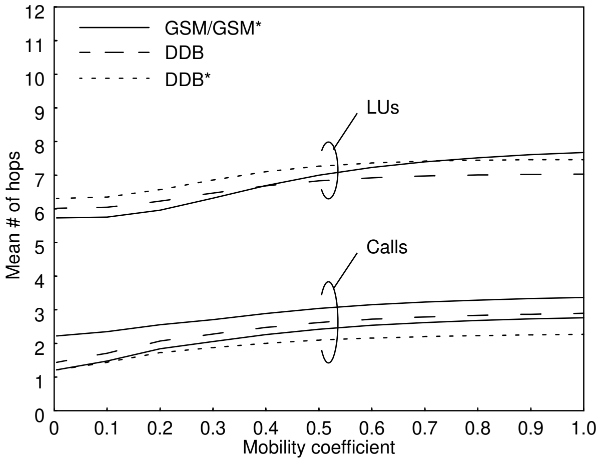

Figure 6: Comparison of the different schemes for placement A*

A Network Interconnection

We look at two possible interconnection topologies of the networks:

- the „**Standard Interconnection**“: the 4 STPs in each network are connected to a new STP in a third layer of the network (for the DDB scheme this node already exists). The three layer 3 STPs are then fully meshed
- the „**Direct Interconnection**“: Each STP is connected to the two other STPs in the two other networks which serve the MSCs which serve the same location areas.

B Comparison of the Different Schemes

Fig. 7 shows the costs of calls are significantly higher than in the case where only one network serves the region. It shows also that the Direct Interconnection performs generally better than the Standard Interconnection. For low values of γ GSM* performs best. For higher values, either DDB or DDB* perform best, dependent on the interconnection topology.

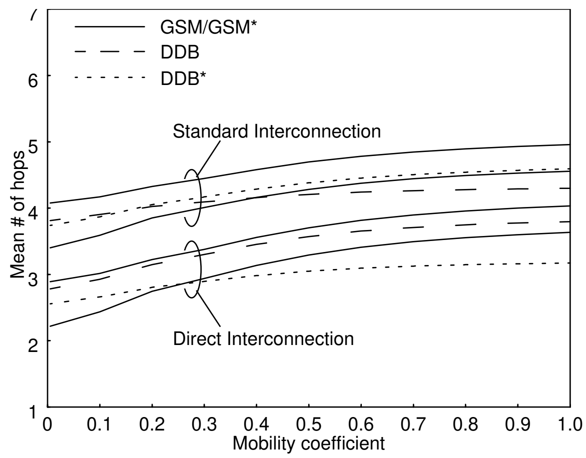

Figure 7: Costs of Calls for the different schemes with different interconnection topologies

6. Location Management with Roaming between Networks

Finally, we study a setting, where users may roam between the three different networks which serve the same region. We adapt the mobility model so that a user moves between the location areas like in section 4 and section 5 but changes networks from time to time. We assume that user have a home network and that on the average 80% of them are currently registered in their home network whereas 10% of them are currently roaming in each of the other networks. We add some „flow“ between the network so that every second move in a foreign network brings a user back to his home network.

In GSM roaming between networks is a standard feature. We therefore study the GSM scheme and the GSM* scheme with the Direct Interconnection topology. The DDB scheme has to be adapted to the multi-network operator environment.

A Adapting the Distributed Database

In order to adapt the DDB scheme to an environment with several networks, the tree of database nodes has to be enlarged. The simplest form is to interconnect the three root nodes of the DDB scheme (which result in the Standard Interconnection topology) and to distribute the function of the new root node between them. In the following we will call this the DDB** scheme. LUs in a DDB scheme with an additional root node would cost the same. Calls are always cheaper in the DDB** scheme.

Another possibility is to regard MSCs in foreign networks as additional leaves of the database tree of the home network. They are then logically connected to the database nodes at the STPs in layer 2 of the home network. Using the Direct Interconnection topology, this makes signalling between the leaves in the foreign network an the nodes in the home network one hop more expensive than the same kind of signalling in the home network. We call this the CommonDDB scheme, and, if the root node is distributed, the CommonDDB* scheme.

B Proxy HLRs

In order to minimize signalling when users roam in foreign networks we propose the ProxyHLR scheme. In [4],[10] we called this the „dedicated Mirror-HLR scheme“. The basic idea is simple. We introduce a node (The ProxyHLR) which behaves towards a VLR like an HLR and towards an HLR like a VLR. Only updates of location information are processed in the ProxyHLR. All other messages are passed through. VLRs and HLRs need no modification of their protocols. Only the SCCP Global Title Translation has to be adapted, so that messages to foreign HLRs always pass a ProxyHLR. This scheme can reduce cost of location updates when a user moves in the foreign network and only the ProxyHLR has to be updated. The same is true for calls from the visited network to a user in the same network if the request for routeing information passes the ProxyHLR.

In this case study, we place 4 ProxyHLRs in every network. They are co-located with the regular HLRs. We assume the Direct Interconnection topology.

C Results

Fig. 8 and Fig. 9 compare the different schemes. The ProxyHLR scheme performs reasonably well for LUs as well as for calls. GSM* (but not pure GSM) and CommonDDB* perform good in providing routeing information but are more costly when handling LUs. The DDB** scheme performs in the exactly opposite way: LUs are quite cheap, calls are rather expensive.

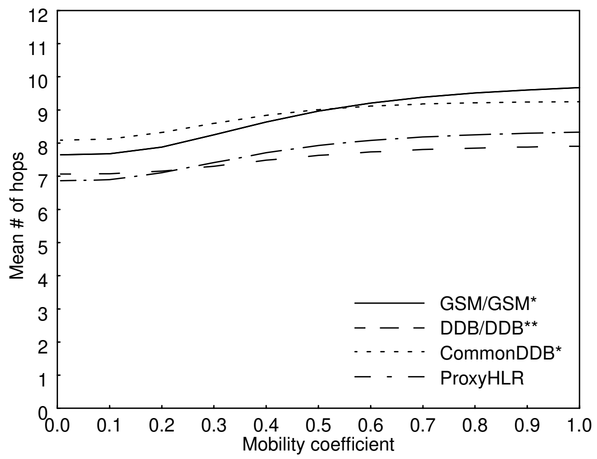

Figure 8: Costs of LUs for the different schemes

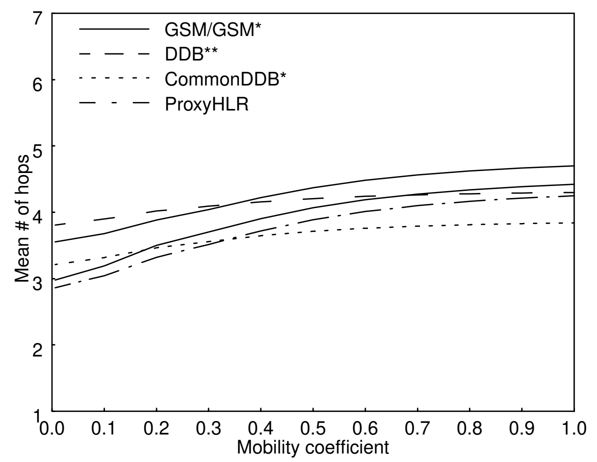

Figure 9: Costs of Calls for the different schemes

7. Conclusion

We have presented a user model and a method for the parametrization of this model. We have proposed several different location management schemes which could be used in a multi-network-operator environment. Finally we have compared the different schemes under varying user behaviour.

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