Evaluating different Mobility Management Methods

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Abstract

This paper deals with the comparison of different mobility management methods. Several methods from the literature are presented and compared. An assessment of the location algorithms is necessary to find the best methods for the individual behaviour of the subscribers. Since the behaviour is described by the movement pattern and the traffic characteristic, mobility and traffic models are discussed.

A cost function is derived as the basis for the comparison to calculate the saving of the different mobility management methods. This cost function takes the air interface and the fixed network links into account.

Since the analytic model of the behaviour of the users does not fulfil all the requirements for the estimation of the performance of the location algorithms in reality, simulations are necessary. Simulations are used to find a relation between the user characteristic and the location algorithm. Reference models are proposed as a basis for comparison.

1 Introduction

Future telecommunication systems have to provide the service of mobility to every subscriber in every part of the world. Today, only mobile network equipment is able to provide this service. Also, in order to stay in competition, a fixed or meshed network provider should offer mobility to his customers. The amount of signalling traffic due to mobility management will increase significantly, in mobile networks because of the rising volume of subscribers and the demand for higher transmission rates, and in fixed networks due to the deregulation of the market, because of the possibility for the subscriber to change the service provider by keeping his or her personal communication number. Both examples show the difference between possible user mobility processes: some users are highly mobile, whereas some are nearly static, but they should be able to change their location. To meet these highly variable demands, different mobility management algorithms have to be implemented depending on the user's mobility process. The changing demands on mobility management will alter methods of maintaining and processing the user's mobility data. A main objective of future research activities is to minimise signalling traffic. New intelligent location tracking mechanisms can cope with this task.

Location management in telecommunication networks consists of two operations, location updating and paging. Paging is used to search for the subscriber in case of an incoming connection request. Location updating is used to inform the network of a movement of a subscriber. There is a trade-off between both operations, that means minimising one of the operations means maximising the other operation. An optimum exists between these extremes which has to be found in order to minimize the total amount of signalling.

Mobility management methods need to be optimized. The criterion to assess the optimum depends strongly on the kind of user behaviour. For that reason mobility and traffic models are discussed in the following. After that the evaluation criterion, the cost function, is derived. The last two chapters deal with evaluation and simulation of the methods.

2 Mobility Management Methods

Several mobility management methods are proposed in the literature. In most cases, they are analysed with theoretical assumptions about the user's motion process and call arrival process (see chapter 3). These theoretical assumptions cannot cope with real behaviour. For comparison purposes the performance of the different methods has to be determined based on different distributions that approach the behaviour of real subscribers in future networks. Not all of these distributions allow us to examine the method analytically, so for that reason simulations are necessary. Rose and Yates give a theoretical view of the performance comparison of mobility management methods [1]. They propose using bounds to evaluate different methods. These bounds are intended to indicate the optimum performance that is attainable independently of the locating algorithm. The calculation of the bounds is based on theoretical probability distributions for traffic and mobility characteristics. This approach is useful but does not meet all the requirements that are necessary for meaningful evaluation as mentioned above.

In the following paragraphs an overview of the state of the art in mobility management methods is presented and the various concepts and the comparability of these methods are discussed.

The classical method that is used widely in current networks uses fixed and network wide location areas. All subscribers have the same cell borders to send location updating messages. That leads to a signalling traffic burst on the signalling channels of cells that are on the location area border, whereas other cells have idle control channels. The paging area is the same as the location area; for that reason the location of the subscriber is well known and he is found within one paging attempt, which minimises the paging delay. This knowledge is paid for at the price of a high volume of signalling.

To optimise the signalling traffic several enhanced paging methods are proposed. Adaptive strategies are evaluated in [2] and [3]. These methods use fixed interval registration, which means no location areas are necessary, because the mobile terminal updates his location using time criteria. Paging areas are set up around the last known location; in the worst case the whole service area has to be paged. As an enhancement a table with the historical search results is drawn up to minimise the paging attempts. A second proposal is the optimal search method, which uses paging areas that do not correspond to the location areas; however, the concept of fixed location areas is still used. The paging operations are reduced by using the theory of optimal search and learning from historical search results [4]. Paging strategies for highly mobile users are discussed in [5]. These methods lead to better performance with respect to the signalling cost for paging operations. The maximum paging delay has to be fixed using these methods to guarantee the quality of service. For that reason it is necessary to define an upper bound on the number of paging attempts. Location updating messages are not saved with the optimal search methods. When using the adaptive methods, saving depends on the mobility characteristics of the user.

Brown proposed a method which uses dynamic registration areas [6]. These areas are formed at a distinct distance around the cell the user was last registered. For that reason no location area planning is necessary. The mobility model consists of short micro moves and very large macro moves, motivated by empirical data. This is a first approach to taking a real movement pattern into account to evaluate a mobility management method with realistic data.

A method which uses reporting cells and nonreporting cells is proposed in [7]. Only the reporting cells inform the network of the location change. The number of cells in which the subscriber is located is always known. The simulation shows better performance than using the strategies *always update*, that means sending a location update upon every cell border crossing, and *always search*, which means paging in the whole service area each time an incoming call request is busy. These results are to be expected.

The Alternative Location Strategy sets up a table to relate a location probability to a time value. Each time an incoming connection request is coming, the system looks in the table to find the most probable location and pages the subscriber in order of descending probability. If the user is not found in one of the locations recorded in the table the whole service area has to be paged. This method makes intensive use of the historical movement pattern and reduces the signalling due to mobility management [8]. Pollini and Chin-Lin showed that the performance in comparison with the classical strategy is better for all possible user movement statistics. This was the expected result [9]. This algorithm is useful when the subscriber has a movement pattern which is repeated at the same time of the day.

A method which uses the order of states in the mobility pattern to predict the future location is the Mobile Motion Prediction Algorithm. Similarly to the Alternative Strategy, a table is set up but in this case not the time but the order of states is recorded. If there is a paging request the state chains are compared and the most likely chain is used to predict the next location [10]. The time is not relevant in this algorithm, but only movements that are found in the database are used for prediction.

Time and state dependence can be integrated, by using neural networks to predict the location. As mentioned in the above paragraphs, the historical movement pattern is recorded. A neural network is trained with these data in parallel or after an observation period. To find the possible location of a subscriber, the last known locations and the actual time are presented to the neural network, which provides an output to predict the next location [11]. This method makes greater use of computational power but is able to save more signalling messages than the other methods for specific user behaviour.

3 Modelling

3.1 Mobility Model

The mobility model is a very important part of the evaluation. In the literature some analytical models are assumed to show the performance of the proposed algorithms. The models often used are fluid flow, random walk and brownian motion. They are all used one-dimensionally for reasons of simplicity.

The fluid-flow model gives a macroscopic view of the network. It provides the flow expressed as the density of moving subscribers through the cells [12]. This model is not useful for the evaluation of memory-based methods because they take the individual subscriber movement pattern into account.

The random walk model is very often used to model subscriber movement. Random walk behaviour is when at each time step the direction of the next move is chosen randomly [13]. The problem in using this model is the unrealistic behaviour. A subscriber to a telecommunication service does not move randomly. This model serves for the simulation to generate a user movement pattern, but after generating the pattern, no random behaviour is to be expected.

Brownian motion is used as the movement model in [1]. It served originally to describe the movement of a particle in a liquid caused by collisions and other forces [13]. This model may be used to evaluate a single strategy but it is not useful with memory based methods. For that reason it serves only to generate the motion pattern as explained above.

These models are used to evaluate memoryless methods. Since not all authors use the same model and since performance comparison with these analytical models only makes sense for memoryless methods, other mobility models have to be found. Memory based methods use the repeating patterns in the subscriber movement as they exist in reality. These regularities in the behaviour get lost when using the random functions introduced above. Mobility models that are used in the simulation are either derived from real movement data from a network provider or generated using random processes.

3.2 Traffic models

To model the incoming and outgoing traffic, a Poisson process is used in most of the publications. This is done for reasons of simplicity, because this often allows an analytic solution. Since the evaluation studies the minimisation of the signalling traffic for single users, a Poisson process is not the appropriate distribution for traffic modelling. Instead, other distributions that are more realistic have to be used for evaluation. Generating this data may be derived from measurements in existing networks.

4 Cost Function

The term cost factor is used in several publications on the mobility management problem. The meaning of cost in this context is an evaluation of a physical resource in terms of initial and recurring cost. They depend on the resource use; for that reason a function for the cost has to be devised.

For the exact evaluation of the different methods, not only the volume of signalling messages has to be taken into account but also a factor which expresses the resource consumption of the different signalling messages on the different links. As resources have their price, the associated consumption indicator is called the cost factor. In general, there is more than one resource involved in one signalling connection. For this reason a formula for the cost function to assess the expenditure of the signalling message volume for the mobility management has to be derived. This function depends on the type of link and the message type. In the literature there are some approaches which do not take all the aspects into consideration. Some of them only consider the air interface or the fixed signalling network to set up the function. The right approach would take both aspects into account (see equation 2). The total cost in a specific time interval consists of the sum of paging and location updating cost:

$$C_{total} = n \cdot C_{pag} + m \cdot C_{lup} \tag{1}$$

$$C_{pag} = C_{pag,air} + C_{pag,net} \quad \text{and} \quad C_{lup} = C_{lup,air} + C_{lup,net} \tag{2}$$

Unfortunately, the costs of sending messages are difficult to determine. For comparison purposes the absolute values are not relevant, which means that only the relative cost between the different resources have to be estimated. In a real environment it is left to the network operator to state the absolute or relative costs. The subject to be optimised should be the sum of the paging and location updating costs in the whole network, which includes the fixed part of the network and of the air interface. This total sum can be subdivided into the individual sums for all the users in the network.

In the case of a relative cost function that is not dependent on time or traffic load, it should be noted that the individual sums per user are independent of each other. For that reason the simulation has to track only one user to determine the best mobility management method with the aim of minimising the traffic. If the distribution of the traffic on the signalling channels of the different cells is the aim, the sum of the traffic of all subscribers has to be taken into account.

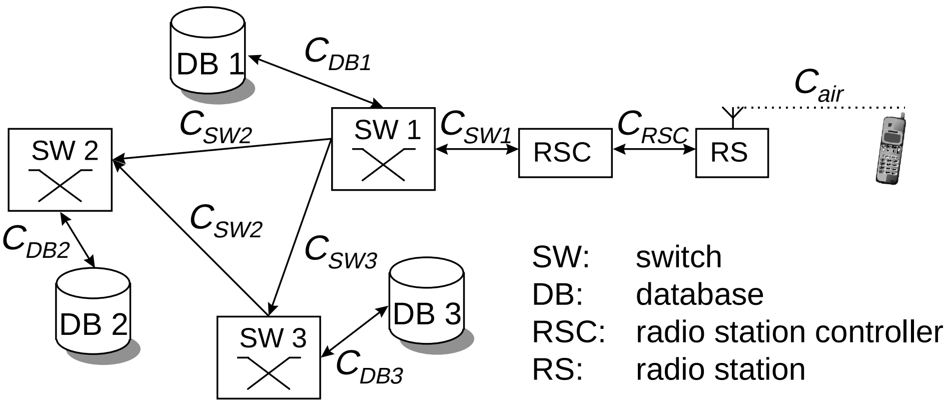

Figure 1: Example of a Mobile Network

On the air interface, the product of the necessary bandwidth *B* and the duration of sending a message *t* influences the costs [14]. The air cost of the two different operations are as follows:

$$C_{pag,air} = B_{pag} \cdot t_{pag} \cdot c_{pag,air} \tag{3}$$

$$C_{lup,air} = B_{lup} \cdot t_{lup} \cdot c_{lup,air} \tag{4}$$

In the fixed network the resource allocation to the various communication links and the processing time in the nodes yields the costs

$$C_{pag,net} = \sum_{i=1}^{I} C_{pag,DB_i} + \sum_{j=1}^{J} C_{pag,SW_j} + C_{pag,RSC} \tag{5}$$

$$\text{with} \quad C_{pag,XX_i} = C_{pag,XX_i,proc} + C_{pag,XX_i,link} \qquad (6)$$

where I and J are the number of the physical network resources involved.

A single signalling connection consists of one air interface link and the sum of the fixed network link (see equation 2). In general fixed network links have lower cost than air interface links, because the capacity on the air interface is much shorter than in the fixed network.

The same terms of equation 5 and 6 apply to the location updating cost by changing the index into “lup”.

5 Simulation

For the simulation the relative cost may be estimated. For example, a cost relation of ten for the cost of air interface links to the cost of fixed links may be used in the simulation. This example serves only to indicate the significant difference between air interface and fixed link cost. In the simulation this factor is one parameter to vary to show the influence of this factor on the performance of the mobility management methods. Since this factor is difficult to determine, a sensitivity analysis may show the effect on the total cost of the different algorithms.

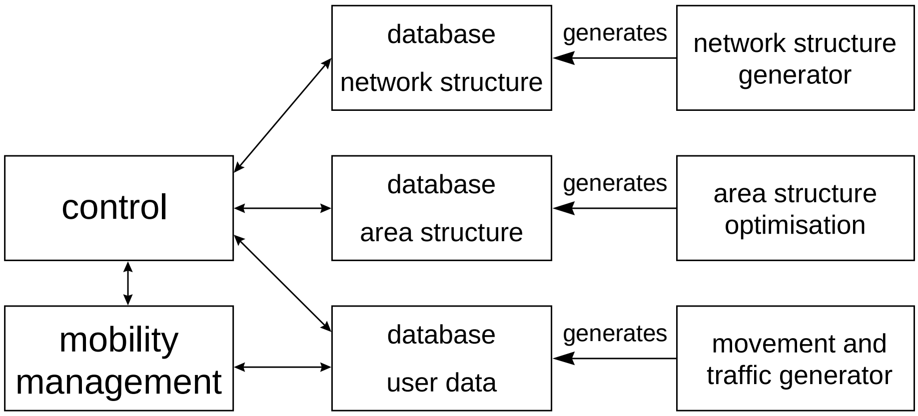

Figure 2: Structure of the simulation software

Simulation software needs input data for the network architecture, the outgoing and incoming traffic, the user motion pattern and the mobility management method. These data have to be generated or derived by measurements in existing networks.

Figure 2 shows the structure of the software of a simulation tool that we are implementing to evaluate the various mobility management methods. The control block serves to control the entire simulation; it counts the messages and calculates the cost according to equations 1 to 6. Block mobility management makes the different methods available to the control block to simulate their performance. Additionally, three databases with the necessary input data for the simulation have to be generated. For simulation purposes with theoretical data, the databases may be generated automatically.

For the simulation some assumptions about the cost coefficients in equation 6 have to be made. In a real network environment, the network operator can estimate these values in his network. In the simulation reasonable values are used, but there is no guarantee that they reflect real costs.

6 Evaluation

For the evaluation, reference models of the user behaviour have to be defined. This can be done by classifying a given set of user behaviour variants into several classes. The various mobility management methods are then simulated on the basis of these reference models. The results of the simulation are evaluated separately for each behaviour class in order to obtain the desired relation between user characteristic and the best locating algorithm.

The mobility management methods to examine are methods with and without memory (see chapter 2). Methods without memory need no observation phase, which means they are able to work from the first moment a user is registered, but for that reason they do not make use of the repeating patterns in the user's movements, whereas the memory-based methods need an observation phase in which the user's movement is observed and recorded in a personal movement database. These methods show the same performance in the observation phase as the conventional ones, because they have to use the same signalling. In the following recall phase, the performance is better than in the observation phase, because some of the location updating or paging messages are unnecessary. The individual performance depends on the prediction algorithm, the user movement process and the calling rate of the user.

A quasi-static user movement process will lead to a simple table look-up in combination with the classical location updating method, whereas a dynamic user motion process will lead to a method which saves location updating messages by predicting the actual location in case of an incoming call. The changing rate of the user's movement pattern influences the performance of the prediction algorithm. If there are not many repeating patterns in the user's movement process, the prediction algorithms may result in a very poor performance.

Regarding the qualitative investigation of the influence of the calling rate on the signalling volume, two cases have to be distinguished. With a low calling rate, that means the subscriber is called with a very low frequency, it may be better to page in a very large area than to obtain many location updating messages. When a user is called very often, his or her exact location is important in order to save signalling volume. In that case a very small location area could be proposed.

An index to describe traffic and mobility behaviour is the call-to-mobility ratio [1]. It serves to give an impression of the subscriber behaviour. But as this is only an average value and the accompanying probability distribution is not given, this index is not suitable as the basis for an evaluation.

7 Conclusions

Future telecommunication networks will integrate several methods for identifying the location of a subscriber in the case of a connection request. For that reason the major mobility management methods have been discussed. The kind of algorithm used for a specific subscriber depends strongly on the user behaviour. The behaviour consists of the traffic distribution and the movement pattern. The probability distributions used to describe the traffic in most papers to calculate the performance of the proposed algorithm have been introduced. For the evaluation, reference models should be used to obtain a common basis for the comparison of the methods. To obtain a relation between the mobility management methods and user behaviour, simulations with different data have to be carried out.

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