Pixel Oriented Mobility Modelling for UMTS Network Simulations

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ABSTRACT

This Paper presents a new methodology for modelling mobility in dynamic simulations of mobile communication networks. Deviating from the widely used mobile based approach, where each mobile has its own mobility pattern independent of its physical position, the position based approach is utilized in the new model. Mobility parameters are assigned to pixels and every mobile dwelling in a particular pixel acquires the parameters attributed to that pixel and thus the pixel dictates the mobility pattern of the mobile station. In order to discriminate between diverse modes of movement, distinct mobility types are defined and integrated into the model. The conditions required to maintain the stationary behaviour of the system are presented. Further, a matrix equation is derived to express the mean number in each pixel in terms of arrival rates, transition probabilities and mean dwell times.

I. INTRODUCTION

The 3G telecommunication systems, such as the Universal Mobile Telecommunication System (UMTS), are to offer a mix of services covering both Circuit Switched (CS) as well as Packet Switched (PS) traffic.

One very important aspect of traffic modelling in such systems is the mobility modelling. Simple, but sufficiently accurate mobility models are very vital in simulation studies as mobility driven handovers play an important role in network planning and should thus be properly included [4].

This paper proposes a new approach to model the mobility in sections 3 and 4, after discussing the basics of a Markovian model in section 2. In section 5 the conditions for stationary behaviour of the system are discussed, including estimation of crossing rates from pixel to pixel. An equation for the mean number of active users in a pixel is derived in section 6, and section 7 closes the paper with some concluding remarks.

2. THE MARKOVIAN MODEL

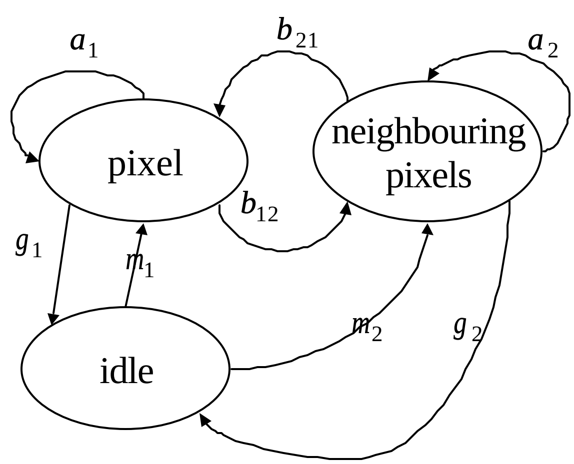

Figure 1: The Markovian model

In most of the mobility models for mobile stations each mobile has its own mobility pattern, independent of its position. This approach can also be transferred into a Markovian type model as shown in Figure 1. In the most simple form we can define three states 'idle', 'pixel' and 'neighbouring pixels'. The transition probabilities a_1, a_2, β_{12} and β_{21} depend on the mobility pattern and the dimensions of the pixel. The other probabilities μ_1, μ_2, $?_1$ and $?_2$ are related to service arrival and departure rates.

This approach can be easily extended to many-pixel scenarios. However, this model is essentially memory-less and thus disagrees with the real situation in two ways. Firstly, the dwell time in a pixel becomes negative exponentially distributed deviating from the real situation. Secondly, The next pixel is completely independent of the direction of entry to the current pixel, whereas in real situations user movement is mostly target oriented.

3. PIXEL ORIENTED MOBILITY MODELLING

In the mobile based implementations of mobility models it is quite a difficult task to model mobility of each and every user separately, especially when there is a large number of active users at any given instant in the simulation. The amount of data that need to be administered may take prohibitive proportions in a large scale simulation. A new approach, where all mobility parameters are attributed to the pixels, is introduced here, which elegantly overcomes the difficulties identified above. In this approach each user dwelling in a particular pixel takes over the mobility parameters attributed to that pixel. When a mobile station enters a new pixel it automatically picks the mobility parameters of that pixel. Thus the mobility parameters once assigned to the pixels remain unchanged throughout the simulation and the amount of mobility related data remains constant regardless of the number of mobile stations, which is subject to variations with time.

Further, this model allows to overcome the limitations identified in the Markovian model in section 2. There are no restrictions imposed on the distribution of dwell times. It is also possible to incorporate a short memory into mobility parameters by making transition probabilities dependent on the direction of entry into the pixel, as shown in Figure 2 below:

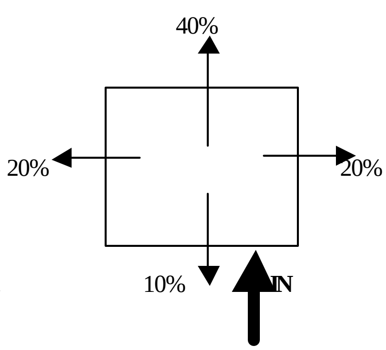

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Figure 2: Short Memory Model

An active user entering from south (bottom) of the pixel is more likely to leave towards north (top) rather than west (left) or east (right). It is least likely that the user turns back and exits to south (bottom) itself. The transition probabilities shown in Figure 2 illustrate this behaviour.

Another feature of the proposed approach is that we integrate the arrival and departure processes of the calls also into this model. That is, we exclude the idle users and model only the active users. Some of the active users entering the pixel in Figure 2 terminate their calls before leaving it. Thus the termination probability can be calculated for this case and works out to 10% for the example transition probabilities shown.

4. MOBILITY TYPES

The fact that the mobile stations move using different modes of movement can also be incorporated into this model. For this we group all modes into a finite set of mobility types and handle each type separately. As an example, the different types can be

- High speed vehicle (120 km/h),
- Medium speed vehicle (50 km/h),
- Pedestrian (3 km/h),
- Not moving.

With this extension each pixel gets a set of parameters for each relevant mobility type. Each mobile station is assigned with its mobility type at the point of generation, so that it can pick the correct set of mobility parameters whenever it enters a new pixel.

In reality, a limited proportion of mobile stations can switch over their mobility from one type to another during the active period. Theoretically this effect can be integrated into the model. However, in a stationary system, switch-overs occur in both directions in a balanced manner and thus this effect can be neglected without much impact on the final results [5].

5. CONDITIONS FOR STATIONARY BEHAVIOUR

In a simulation study we usually consider the traffic situation during the busy hour in order to assure that the network performance meets the requirements even during peak hour traffic. In addition, we assume that the system is stationary throughout. In other words we assume that all system parameters remain constant with respect to time. In return also the system properties, expressed in terms of distribution functions or simply mean values and standard deviations, do not fluctuate with time. Further, we can assume that the mobility of the active users does not deviate from the mobility of the idle users in the same mobility category. This assumption allows us to observe the stationary behaviour of user movement and traffic generation completely decoupled from each other.

Let us first consider the user movement pattern. The mean number in any selected area of space, let it be a cell or a pixel, cannot change with time. This is guaranteed if and only if the total of the mean crossing rates in and out of the cell/pixel are equal. Here we consider a square pixel and define average crossing rates to be the number of active users crossing an edge (north, south, east or west) of the pixel per unit time to (in) or from (out) the pixel. This leads to four outgoing crossing rates, denoted by $?_{out\text{-}n}$, $?_{out\text{-}s}$, $?_{out\text{-}e}$ and $?_{out\text{-}w}$, as well as the inward crossing rates $?_{in\text{-}n}$, $?_{in\text{-}s}$, $?_{in\text{-}e}$ and $?_{in\text{-}w}$. Thus the following equation holds for each pixel for a given mobility type:

$$?_{in\text{-}n} + ?_{in\text{-}e} + ?_{in\text{-}w} + ?_{in\text{-}s} = ?_{out\text{-}n} + ?_{out\text{-}e} + ?_{out\text{-}w} + ?_{out\text{-}s}. \qquad (1)$$

With this, the number of active users who enter the pixel balances out with the number of active users who leave the pixel. Now, to keep the mean number of active users constant within the pixel, the rate of call arrivals, denoted by $?_s$, should also balance with the rate of call terminations. Some of the calls, which emerge in the pixel, terminate in the same pixel before the calling terminal moves out of the pixel. The probability for that is denoted by P_{ST} and thus the rate of emerging calls moving out of the pixel is equal to $?_s\,(1 - P_{ST})$. This should be balanced by the calls, which enter the pixel and terminate there. To quantify this we assume that the probability that an entering call terminates within the pixel, denoted by P_T, is independent of the incoming direction of the calling terminal. Now, the rate of in-moving calls terminating in the pixel is given by $(?_{in\text{-}n} + ?_{in\text{-}e} + ?_{in\text{-}w} + ?_{in\text{-}s})\,P_T$. We now get the following equation for each pixel:

$$?_s\,(1 - P_{sT}) = (?_{in\text{-}n} + ?_{in\text{-}e} + ?_{in\text{-}w} + ?_{in\text{-}s})\,P_T \qquad (2)$$

Here, the quantities $?_s$, P_{sT} and P_T are considered to be known. However, the equations (1) and (2) given above are insufficient to determine all the crossing rates because there will be as twice the number of unknowns as the number of equations.

The crossing rates can be directly expressed in terms of arrival rates and transition probabilities. In case all the transition probabilities are known the crossing rates can be calculated and vice versa. A useful suggestion made in a previous study is to consider vehicular traffic rates to be proportional to the width of the road allowing traffic in a particular direction [3].

6. MEAN NUMBER IN A PIXEL

Provided that a given system satisfies all the conditions required for stationary behaviour we can apply Little's law to relate mean numbers in the system or a part of the system to corresponding arrival rates and the mean system times [2]. Let us first concentrate on an arbitrarily selected test pixel, say pixel j. We denote the mean number in this pixel by $?_j$ and observe that this comprises two parts. The first part, say $?_{j1}$, consists of the fresh users who emerge in the same pixel and the second part, denoted by $?_{j2}$, is due to all the users who enter the pixel from neighbouring pixels. Thus

$$?_j = ?_{j1} + ?_{j2}. \qquad (3)$$

In order to simplify the mathematical derivations we represent the entry and exit points to and from a pixel as shown in Figure 3. All users who enter the pixel at the top, right, bottom or left edge do so at points a, b, c and d, respectively. All users who exit the pixel from top, right, bottom and left edge do so at points A, B, C and D, respectively (please see Figure 3). It should be noted that this simplification has, however, no impact on the accuracy of the calculations.

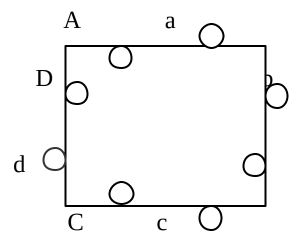

Figure 3: Entry and exit points

We start with the expression for $?_{j1.}$ Knowing the arrival rate of the fresh calls, denoted by $?_{js}$, and the average times they spend within the pixel, $?_{j1}$ can be expressed as follows:

$$?_{j1} = ?_{js}\,(P_{jsA}\,t_{jsA} + P_{jsB}\,t_{jsB} + P_{jsC}\,t_{jsC} + P_{jsD}\,t_{jsD} + P_{jsT}\,t_{jsT}) \qquad (4)$$

Here, P_{jsA}, P_{jsB}, P_{jsC} and P_{jsD} are the transition probabilities for a fresh call to leave the pixel at point A, B, C and D, respectively. Such a fresh call can also terminate before leaving the pixel with a probability denoted by P_{jsT}. These five probabilities should add up to unity. The mean sojourn times in each of the five cases are denoted by t_{jsA}, t_{jsB}, t_{jsC}, t_{jsD} and t_{jsT}.

The above relationship can be presented in vector form, for the whole set of n pixels in the grid, using the vector $\mathbf{[?_{js}]}$ and the diagonal matrix $\mathbf{D}$. The vector $\mathbf{[?_{js}]}$ contains the arrival rates at pixel level and the j^{th} row diagonal element of the matrix $\mathbf{D}$ is equal to $P_{jsA}\,t_{jsA} + P_{jsB}\,t_{jsB} + P_{jsC}\,t_{jsC} + P_{jsD}\,t_{jsD} + P_{jsT}\,t_{jsT}$. The resulting matrix equation is

$$\mathbf{[?_{j1}]^T} = \mathbf{[?_{js}]^T}\,\mathbf{D}\ . \qquad (5)$$

The expression for $?_{j2}$ becomes much more complicated as all the calls which emerge in the whole system contribute to this component. A call which pops up outside the test pixel can enter it once or even several times. Even the calls initiated within the test pixel can move out of the pixel and re-enter at a later instant. For this evaluation we need to define two matrices, **Q** and **P**, having $n \times 4n$ and $4n \times 4n$ elements, respectively.

The matrix **Q** contains the transition probabilities for a fresh call to reach the exit points A, B, C and D of the corresponding pixel. These probabilities are already identified through P_{jsA}, P_{jsB}, P_{jsC} and P_{jsD}. A call exiting at point A enters the pixel on top of the test pixel at point c. In other words the exit point A of j^{th} pixel is identified with the entry point c of $(j\text{-}m)^{th}$ pixel, where m denotes the number of pixels in a row. Similarly, the exit points B, C and D correspond to the entry points d, a and b of the corresponding neighbour. Let us number the columns of **Q** through 1a, 1b, 1c, 1d, 2a, 2b, 2c, 2d, 3a, …, na, nb, nc and nd. In j^{th} row of **Q** there will be exactly 4 non-zero elements. These four elements are P_{jsA}, P_{jsB}, P_{jsC} and P_{jsD}. They have the column numbers (j-m)c, (j+1)d, (j+m)a and (j-1)b, respectively. The entries corresponding to the bordering pixels need special attention, where the wrap-around methodology or proper setting of the relevant probabilities may be utilized. With this definition the matrix product $[?_{js}]^T$ **Q** gives a vector, whose elements represent the fresh call entry rates at the corresponding entry points of the neighbouring pixels.

The matrix **P** gives the one step transitions from one entry point to another entry point. From a given entry point there are exactly four possible transitions and thus any row in **P** contains up to four non-zero entries. In the $(ja)^{th}$ row these entries are P_{jaA}, P_{jaB}, P_{jaC} and P_{jaD} with the column numbers (j-m)c, (j+1)d, (j+m)a and (j-1)b, respectively. It is possible to obtain the k-step transition probability matrix by raising the matrix **P** to the power k. Now we get the overall entry rates at the entry points of the pixels by the vector expression $[?_{js}]^T\mathbf{Q}\{\mathbf{I} + \mathbf{P} + \mathbf{P}^2 + \mathbf{P}^3 + \ldots\ldots\}$.

This is to be multiplied by matrix **Y** to get $[?_{j2}]^T$. The matrix **Y** is the pixel aggregate time matrix and is of the order $4n \times n$. Each column in **Y** has just four non-zero entries. In the j^{th} column these entries occupy the row positions numbered ja, jb, jc and jd. The entry at position ja is $P_{jaA}\, t_{jaA} + P_{jaB}\, t_{jaB} + P_{jaC}\, t_{jaC} + P_{jaD}\, t_{jaD} + P_{jaT}\, t_{jaT}$, where P_{jaA}, P_{jaB}, P_{jaC}, P_{jaD} and P_{jaT} are the probabilities that a call entering pixel j at point a exits at point A, B, C, D or terminates. Corresponding mean sojourn times are denoted by t_{jaA}, t_{jaB}, t_{jaC}, t_{jaD} and t_{jaT}, respectively. The entries in rows jb, jc and jd are obtained similarly. Now the vector $[?_{j2}]$ can be expressed by the equation

$$[?_{j2}]^T = [?_{js}]^T\mathbf{Q}\{\mathbf{I} + \mathbf{P} + \mathbf{P}^2 + \mathbf{P}^3 + \ldots\ldots\}\,\mathbf{Y}$$

$$= [?_{js}]^T\mathbf{Q}(S_{k=0,8}\, \mathbf{P}^k)\ \mathbf{Y}$$

$$= [?_{js}]^T\mathbf{Q}(\mathbf{I} - \mathbf{P})^{-1}\ \mathbf{Y} \qquad (6)$$

The vector $[?_j]$ can be obtained by adding the two vectors $[?_{j1}]$ and $[?_{j2}]$:

$$[?_j] = [?_{j1}] + [?_{j2}]\ . \qquad (7)$$

This completes the presentation of the mean numbers in pixels in terms of arrival rates, transition probabilities and mean sojourn times.

7. CONCLUDING REMARKS

We have introduced a novel approach to model mobility in mobile communication systems. Practical methods to estimate the related parameters have been discussed. The essential mathematical relationships pertaining to this model have also been derived. This model is applicable either at pixel level or at cell level to analyse the impact of mobility on system performance.

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