Mobility Modelling using Attraction Points for Cellular Network Environments

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Abstract: Mobility modelling is a critical element in the development, dimensioning and deployment of any cellular network infrastructure. As subscribers generally move in a deterministic manner, the mobility model used should reflect these inherent user patterns. Throughout a typical day, due to work/recreational activities, users are attracted to different areas of a cellular network, i.e. outlining cells of a city experience busy hour traffic in the morning as users are entering the city centre. To capture these inherent user mobility patterns, we propose a cellular network mobility model using attraction points distributed throughout the network to influence the destination of a user depending on the time of day. A key element in the proposed model is its simplicity of implementation with minimal computational overhead making it an ideal candidate for network analysis where real user mobility data is unavailable or the computational overhead of such a model is excessive.

1. Introduction

Mobility modelling is an important consideration in any network model in which users move between points of attachment such as intra-system handover in a cellular network environment. The performance of a wireless network can be heavily influenced by the manner of user mobility, as users request/relinquish resources as they move between cells of a homogeneous/heterogeneous network environment [1].

In order to create accurate movement scenarios, e.g. movement through and around a city centre, a mobility model that accurately depicts user behaviour in such environments is required. Different mobility models characterising individual user behaviour or aggregate movement have been proposed. These proposals, outlined in the next section, are either too simplistic to fully characterise realistic user mobility or too complex to be easily implemented into a cellular network model. In this paper we propose a mobility model based on the random way point model but introduce the concept of attraction points to influence destination points of users throughout the simulated network. Users move toward the attraction points by choosing intermediate destination points, movement between these points is controlled by the random way point model.

This paper presents results for a fictitious cellular network environment in which five cell types are considered – city, town, commercial, rural, free space/highways. Results show how users can be influenced to move between different parts of the network using the proposed mobility model and thus provide the deterministic mobility patterns inherent in wireless networks.

2. Mobility Models

Much work has been done on mobility models to control the movement of users in the simulation and analysis of wireless cellular networks for network dimensioning/planning proposes. Individual subscriber motion has been modelled using simple models based on Brownian motion [2], the random waypoint [3] or Markovian models [4]. These models are characterised by uniform user distribution throughout the network environment and randomly chosen movement over the surface area. Aggregate subscriber movement has been characterised using fluid models [5].

The fluid model describes user movement as a flow of fluid, which is uniformly distributed over $[0,2\pi]$ and assumes a uniform user distribution. The above mobility models neglect the inherent mobility patterns of users throughout a typical day. More complicated models such as that proposed in [6] use transportation data gathered over a daily period from a city centre network to give a more realistic movement of subscribers. Although these models provide an accurate representation of user mobility they are inherently complex and introduce a large computational overhead to the analysis of a network model.

Therefore, there is a requirement for a mobility model that has the simplicity of models such as the random waypoint but can characterise user mobility patterns without the complexity of models based on transportation data and city maps.

3. Mobility Modelling using Attractor Points

To characterise the mobility pattern of users throughout a cellular network over a typical day we propose a simple model based on the random waypoint approach but introduce a fictitious cellular network environment and the concept of attraction points distributed across the network. The 49-cell network used in the simulation model is shown in Figure 1. We consider five cell types – City, Shopping, Town, Rural and Highway/Roads/Free Space. The cell types are arranged into ten zones, Z0 – Z9.

A cell type transition probability matrix is used by each mobile to choose a destination cell depending on the time of day. The cell type transition probability matrix is shown in Figure 2. It is an $n \times n$ matrix, where n is the number of cell types in the network. Element x_{ij} gives the probability of a user who is residing in cell type i moving to a cell of type j. The matrix is used to influence the movement pattern of users throughout the network, e.g. in the morning users positioned in the towns have a high probability of moving toward the city cells.

The movement of users throughout the network is controlled as follows.

- A destination cell type is chosen using the cell type transition probability matrix.
- If moving to a different cell type, a cell zone is chosen with equal probability.
- An attraction point is chosen uniformly within the destination zone.
- Mobiles begin to move toward a new position. The new position is chosen so that the mobile is continuously moving toward the attraction point. New intermediate destinations are chosen in this way until the mobile reaches within 100m of the attraction point. In this way, users do not move in a straight line to the attraction point, but are continuously progressing toward their destination.

- A new attraction point is chosen within the current cell zone after an exponentially distributed dwell time.
- Throughout the simulation at pre-defined intervals each mobile picks a destination cell type using different cell type probability matrices. In doing so, users are influenced to move toward particular attraction points depending on the time of day.

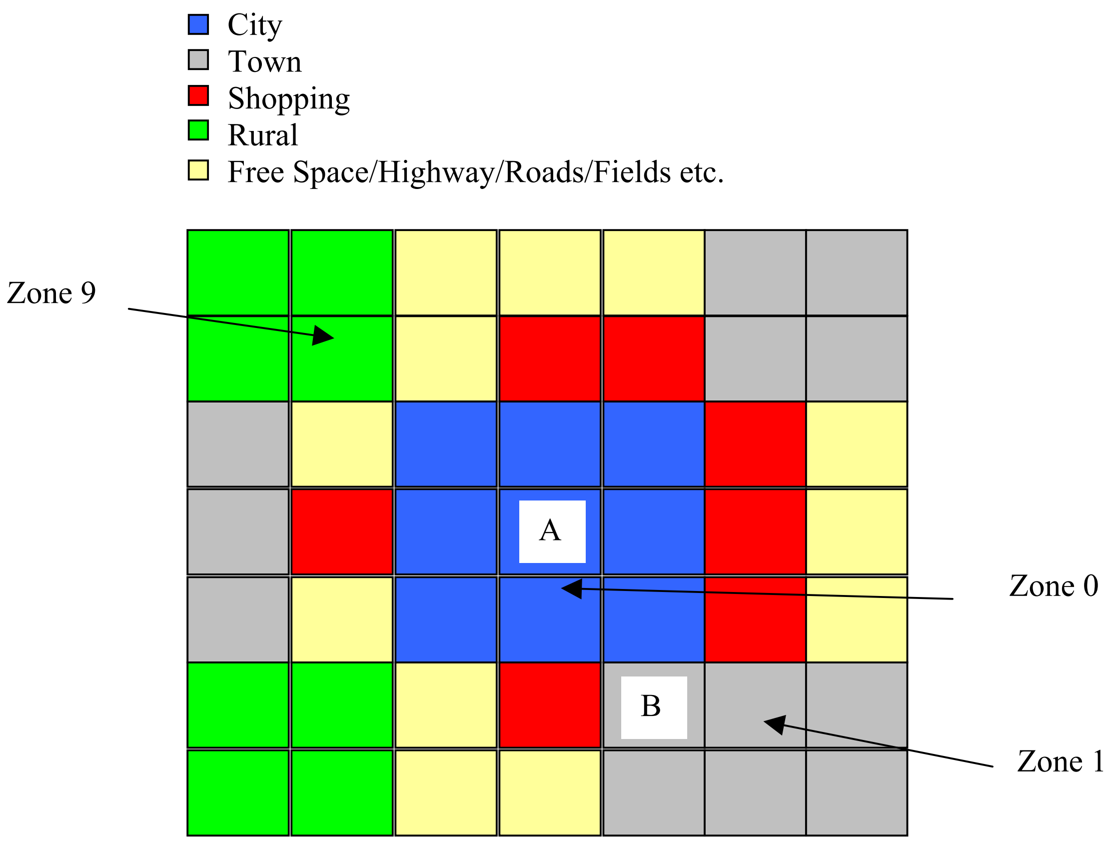

Figure 1 - Cellular Network Environment

Cell Type

$$\text{Cell Type}\quad \begin{bmatrix} x_{11} & x_{12} & x_{1n} \\ & x_{ij} & \\ x_{n1} & x_{n2} & x_{nn} \end{bmatrix}$$

Figure 2 - Cell Type Transition Probability Matrix

The proposed approach is much less complex that previous schemes [6] as it doesn't rely on detailed street maps and transportation data to characterise user mobility throughout the network and therefore will not add much computational complexity to a network dimensioning/planning process. It does however provide a means of controlling and influencing user mobility throughout a network, resulting in deterministic user mobility patterns. Figure 3 depicts the trajectory of a mobile starting from an arbitrary position *x* moving toward an attraction point, *A*.

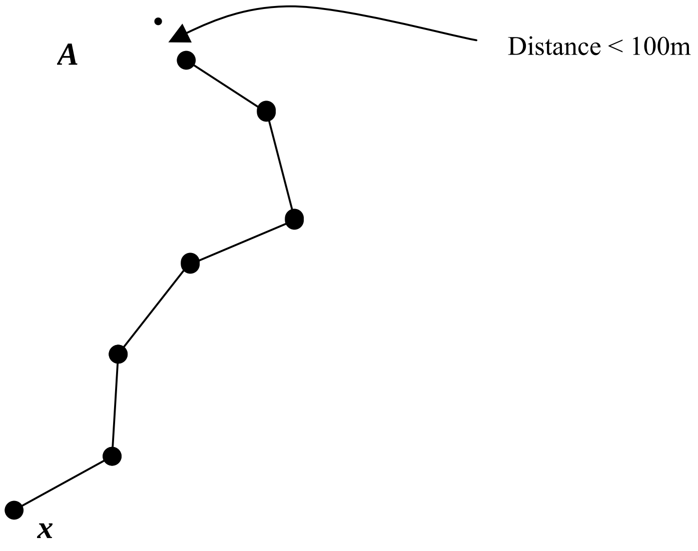

Figure 3 - Mobile trajectory toward attraction point, A

4. Simulation Results

To assess the controlled/deterministic movement of users throughout the network, results are presented here that show users been primarily attracted toward city cells in the morning and then returning to town/suburban cells in the evening. Users are attracted to the city centre at simulation time = 0mins (Figures 4 to 7) and toward towns/rural cells at simulation time = 500mins (Figures 8 to 11). The results illustrate the deterministic nature of the mobility model and by using multiple cell type transition probability matrices, users can be influenced to move to any region of the network, e.g. modelling a crowd moving toward a football stadium.

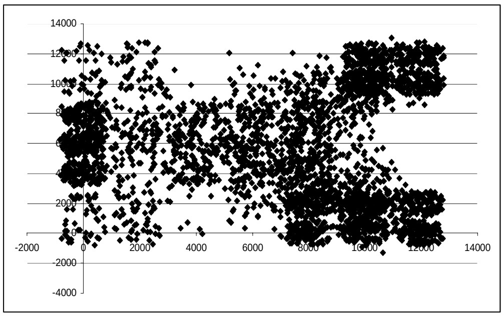

Figure 4 - City Attracted – 30mins

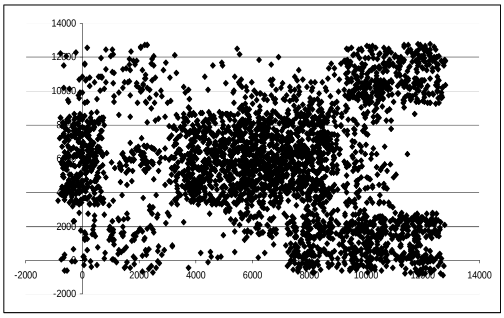

Figure 5 - City Attracted – 60mins

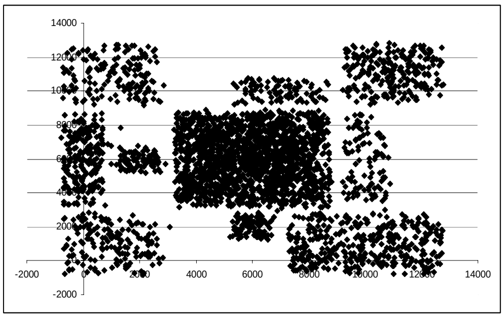

Figure 6 - City Attracted – 180mins

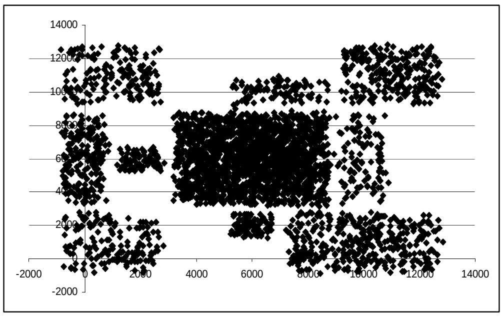

Figure 7 - City Attracted – 210mins

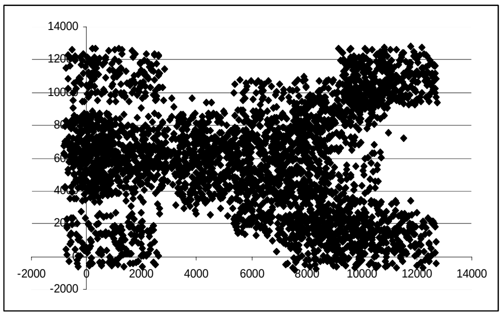

Figure 8 - City Attracted – 530mins

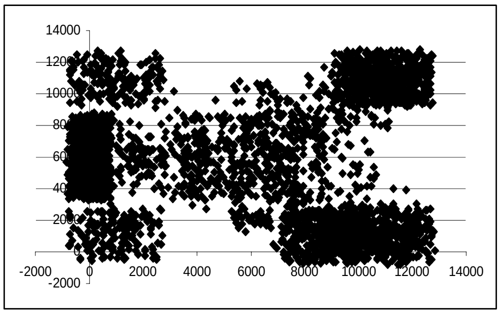

Figure 9 - City Attracted – 560mins

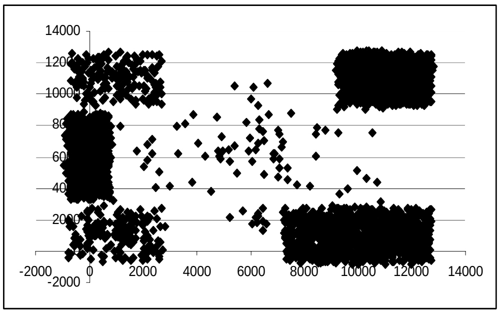

Figure 10 - City Attracted – 690mins

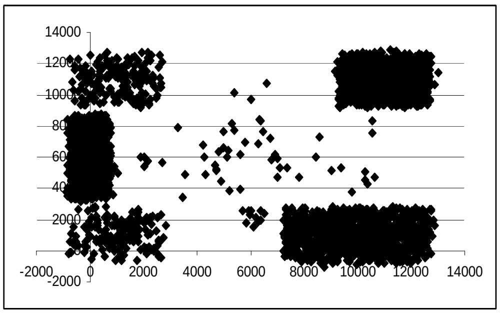

Figure 11 - City Attracted – 710mins

To further illustrate the deterministic movement pattern of users throughout the network, Figure 12 and Figure 13 depict the handover rates into cells labelled A and B respectively in Figure 1 over four simulation runs. In each simulation, the cell type transition probability matrix is designed so that users are initially attracted to city cells before migrating to town and rural cells. Using the proposed mobility model has allowed for the development of an adaptive capacity reservation scheme in a heterogeneous wireless network environment in which handover traffic rates can be predicted and the reserved capacity dynamically adjusted based on the predicted handover traffic [7].

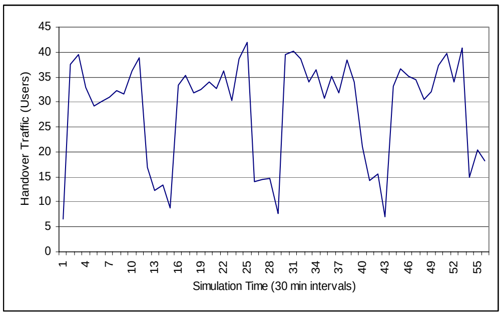

Figure 12 – Cell A Handover Traffic Rate

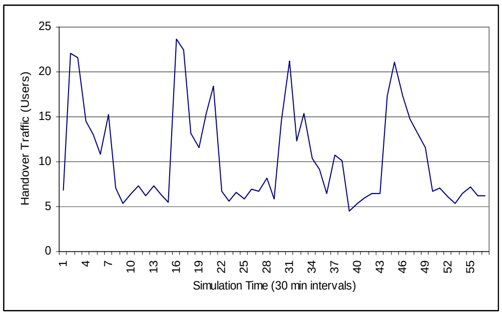

Figure 13 - Cell B Handover Traffic Rate

5. Conclusions

In this paper we have introduced a mobility model with minimal computational overhead to model the deterministic movement of users between attraction points distributed throughout a fictitious cellular network environment. A cell type transition probability matrix controls users attractiveness to a particular cell type over time. Results have shown the deterministic mobility behaviour of the model as users migrate from town to city and back to town cells over the duration of the simulation. The deterministic movement of users has been further illustrated via intra-system handover rate plots over a number of simulation runs.

The ease of implementation and lack of computational complexity makes this mobility model an ideal candidate for wireless network modelling in which realistic user behavioural patterns are critical to network performance and stability.

6. References

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