SMMT - Scalable Mobility Modeling Tool

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***Abstract*— In this paper, we present a novel mobility model, called the Scalable Mobility Modeling Tool (SMMT), which is based around a scaleable algorithmic mobility model that can be applied to a large number of possible horizontal environments, from wide area networks (WAN) to local areas networks (LAN), to analyze the issues related to mobility management and radio resource management. The SMMT introduces the new concept of poles of gravity (PG) to characterize the spatial and temporal behavior of mobile users in a scaleable way. This technique has been applied to a cellular communications system superimposed on different geographical frameworks consisting of the City Area Model and City Center of Bristol, UK, to investigate the performance issues related to location and paging area and teletraffic issues respectively.**

Keywords*— *Mobility model, location and paging areas, teletraffic models

I. INTRODUCTION

Mobile services have been experiencing an accelerated penetration which has culminated in the exponential growth of mobile users with outlooks for continued growth in the future. Accordingly, the increase of both mobile related traffic and mobility related signaling load together with the extremely limited number of radio resources and increasing competition in service provision has meant that mobile operators are continuously designing and refining their planning tools to provide optimal and economic network configurations. The aim is not area coverage, but to supply as many mobile users and their traffic demand as possible with a minimum of infrastructure. To allow efficient resource allocation, good models of the underlying movement of mobile users are necessary. As mobile systems develop, the requirements on mobility models become more demanding. As cell sizes decrease, local accuracy becomes more important, but the requirement to model wide scale behavior remains.

A considerable amount of research efforts has been used to characterise user density and mobility, and calling behavior and their performance impacts on wireless networks. In this context, different mobility models have been used to tackle specific issues, fluid and gravity models [1] describe aggregate population movement while the Markovian and Brownian models characterize mobile user displacement on a per mobile basis. The need for different mobility models arise due to the fact that no single model provides sufficient accuracy over all topologies for both Mobility Management and Radio Resource Management scenarios. In order to refine those models, variations have been made by exploiting transport traffic data so that they can be applied to the specific topological area under investigation. While these enhanced models [2, 3] are rich and expressive within the context of transportation modeling, they are unnecessarily over-detailed at a topographical level as a basis for creating event patterns that allow teletraffic analysis of a mobile network for the purposes outlined above. Furthermore, users with mobile terminals are less constrained by the transport network, which, in fact, is absent in many short-range built-environment scenarios. What is required is a scaleable algorithmic mobility model that can be applied to a large number of possible multi-layer network configurations. Bearing this in mind, we have designed a mathematical framework which can be scaled to any demographic topology while retaining its corresponding ability and simplicity to track mobile user on a per mobile basis.

The paper is organized as follows. Section 2 introduces the novel concept of Pole of Gravity which is a stochastic node used to characterise the spatial and temporal behavior of mobile users. Section 3 presents our system model. Section 4 discusses the applications of SMMT to tackle issues related to mobility management and radio resource management when applied to the City Area Model and City Center. Finally, Section 5 concludes the paper.

II. POLE OF GRAVITY

Conventional mobile network planning tools such as PLANET [4] are driven by area coverage considerations rather than customer demand which has been the planning approach used in first and second generation of wireless networks. However, the success of future wireless systems will largely depend on the Quality of Service (QoS) that they will provide. As such the main aim of future wireless planning is no longer area coverage, but to supply as many mobile users with their traffic demand as possible with a minimum of infrastructure. The key concept to achieve this is the introduction of *Pole of Gravity* (PG).

A PG is a discrete stochastic node describing the spatial and temporal distribution of mobile users in a predefined topological area under consideration. This stochastic system exploits the results of open multiclass queuing networks and

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extract the key features of the family of the head-of-the-line proportional processor sharing (HLPPS) fluid models [5] to populate mobile users in different classes of mobility based on their mobility behavior. As such it provides a mathematical framework for predicting and tracking mobile user behavior [6]. This stochastic node conceptualizes the following aspects:

- **Classes of Mobility –** Mobile users having the same mobility behavior are grouped into specific classes of mobility (CM). The corresponding CM also reflects mobile users' calling behavior and use of services. For our model, three CM have been considered: *Business*, *Residential* and *Others*.
- **Area Zones** – The scalability of the PG allows the investigation of mobile user movements at different granularity in space. The horizontal environments under consideration have been categorised into different geographical areas ranging from City Area Model to the City Center. For the City Area Model, the topological area has been divided into four area types: *City Center*, *Urban*, *Sub-Urban* and *Rural*. Focusing to only one area type, user movement and it corresponding calling behaviour has been investigated for the City Center where this specific area type is divided into four environments consisting of *Working*, *Residential*, *Shopping* and *Streets.*
- **Attractivity Points** (APs) – These represent locations that attract users with a specific CM and at which mobiles spend a certain amount of time. The attractivity of an AP is a function of time and varies for each CM based on the environment in which the mobile user is located. Each CM is assigned one of the following attraction weights, $w \in [0, 1]$: for example, dominant (0.9), normal (0.5), or null (0.1) based on zone's attractivity during a specific time of the day.
- **Time Periods** – In the context of a wireless network, the *rush hour* (RH) and the *busy* hour (BH) can be identified. Both of these times periods are taken into account in the SMMT allowing the analysis of mobility-related signaling and proper planning and dimensioning issues.

III. System Model

Using the concept of the poles as the core technique for the spatial and temporal characterization of mobile users, the scalability of the SMMT resides in the interdependency of the three sub-models: *Physical Sub-Model*, *Gravity Sub-Model* and *Fluid Sub-Model* which characterizes our system model. These sub-models are interconnected through the coefficients of *elasticity* (α), *entropy* (γ) and *viscosity* (λ) as shown in Fig. 1.

The coefficient of elasticity is defined as the model's reactivity to restore equilibrium when a change in attraction occurs among the PGs. Entropy is a measure of introducing a degree of friction between two different PGs when a change of attraction occurs. The coefficient of viscosity gives a perception of distance between two zones of the originating mobile to its destination. A brief overview of those three sub-models is detailed in the next sub-sections.

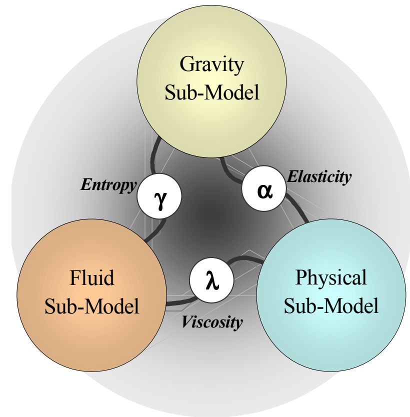

Figure 1: System Model

A. *Physical Sub-Model*

The physical sub-model specifies the geographical area under investigation and identifies the logical placement of the poles in a corresponding area zone. Based on the area type, the environments in which the PGs are located are defined. This sub-model also specifies the population density for each CM, the spatial spreading of the MUs over the predefined region and the logical connectivities among the PGs in the geographical topology under consideration. PGs are interconnected together through the minimum distance criteria based on the *angular connectivity*, *R*. These paths represent the most probable paths that mobiles will use during the simulation process.

B. *Gravity Sub-Model*

While the physical sub-model is responsible for the spatial distribution of MUs in the predefined area, the stability and temporal behavior of the model is controlled through the gravity sub-model. When a variation in the strength of the attraction weights at any PG according to its corresponding class occurs, the gravity sub-model re-calculates the steady state value of each CM and based on this process determines the amount of time a mobile spends in a PG. This process is an enhancement of the HLPPS algorithm and the main aim of this sub-model is to achieve convergence towards a stochastic equilibrium [6].

C. *Fluid Sub-Model*

Fluid models are continuous and conceptualize individual movement behavior as movement mass rather than individual movement patterns [4] on a macroscopic level. Our movement model exploits the features of the fluid model to characterize mobile user displacement at a microscopic level characterized by the *Brownian Movement Model* through a diffusion process. Individual MU movement is initiated at the end of its inter-departure time which can result in a change in the current location of the MU and class of mobility independent of its class history. This is characterized through the *transitional probability matrix* defined by the *fluid law* which is governed by the attractivity factor from the originating PG and possible destination PG and their distance of separation.

IV. SIGNALING & TRAFFIC LOAD ANALYSIS

Using the generic modeling approach presented in Section 3 and the concept of PGs detailed in Section 2, an illustration of the use of SMMT related to the aspects of signaling and traffic load analysis is shown when the scalable algorithmic mobility model is applied to the City Area Model and City Center of Bristol, UK. The mobility traces generated from those topologies are then coupled with 3G EDGE systems to derive two main traffic load parameters: rate of location updates (LUs) and channel utilization which will be used as key input parameters to dimension the packet network and meet specified Grade and Quality of Service at a later stage.

A. Location & Paging Area Analysis

Location and paging area dimensioning aims at providing an optimized system configuration for a geographical area where a given location management scheme is used.

Location updating takes place every time a MU crosses a location area (LA) updating so that the larger the coverage of a LA, the less the signaling traffic generated by location updating. When there is a need to set up a call to a mobile terminal, the cell where the terminal currently resides has to be identified in order to establish the base station through which a wireless signaling connection between the terminal and the network can be established. This is achieved by paging where a paging message is broadcast via all base stations, which are in the LA. As such, LUs and paging procedures impose a significant signaling load on the system also transferred over the radio interface (a scarce resource) and the latter is put to severe test when the mobility related conditions are maximum i.e. during *rush hours* period.

Minimization of this signaling load transaction requires the optimal partitioning of the wireless networks into contiguous location areas (LAs) for proper planning of location and paging areas (PAs) in order to avoid useless location updating. This strategy is therefore very much dependent on the underlying user movement and their associated calling behavior [7].

B. Investigation

SMMT has been applied to the City Area Zone model of Bristol which has an extension of 40 km × 40 km as shown in Fig 2. The *physical sub-model* sketches the logical placements of the PGs in the different environments (*working*, *residential*, *shopping* and *streets*) and this area has been divided into four area types (*city center*, *urban*, *suburban* and *rural*). The city center is surrounded by urban, suburban and rural areas with the rural area being the furthest from the city center. The gravitational points are defined by the 'attractivity points' while the fluid law dictates the movement of the mobiles.

The aim of the LA planning problem is a partition of cells into LAs, so that a quality criterion is satisfied. The quality criterion is associated with the signaling load of the location update (LU) and paging operations that are imposed by the allocation of cells to LAs. In our investigation, the geographical region depicted in Fig. 2 has been overlaid by a cellular structure system in which the cells are grouped in LAs. Each LA has an 8 km × 8 km extension giving a 25 contiguous LAs configuration. The crossings among cells that belong to different LAs result in LUs. The objective of this paper is not to provide a new scheme for LA/PA but to highlight the effectiveness of SMMT in generating the necessary set of output parameters to tackle LA/PA problem as shown by the simulation results in the next section.

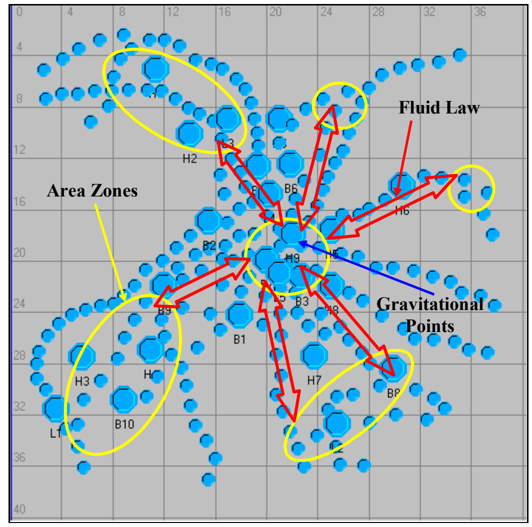

Figure 2: SMMT applied to City Area Model

C. Simulation Results

We have simulated a 3-hour period (7.00 am – 10.00 am) which includes the RH for a population of 10,000 MUs. Population movement is initiated by the fluid law which takes into account the CM of the MU, 'attractivity' weight of that CM at a specific location specified by the gravity sub-model and the distance of the MU from the desired PG.

Fig. 3 shows the distribution of MUs for the four area zones and their corresponding CM for the 3 hour period. During the start of the simulation, most of the MUs are assumed to be in the residential environment and located in the suburban area zone and as time proceeds MUs move towards the working environment which are located in the urban area zone. This figure illustrates the terminal mobility traffic of user density in both space and time and also suggests that

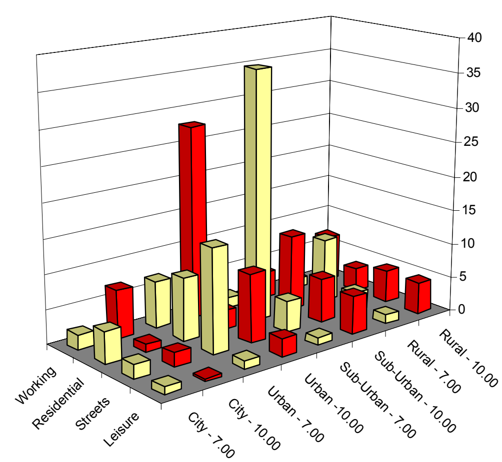

Figure 3: Mobile User Distribution over City Area Model

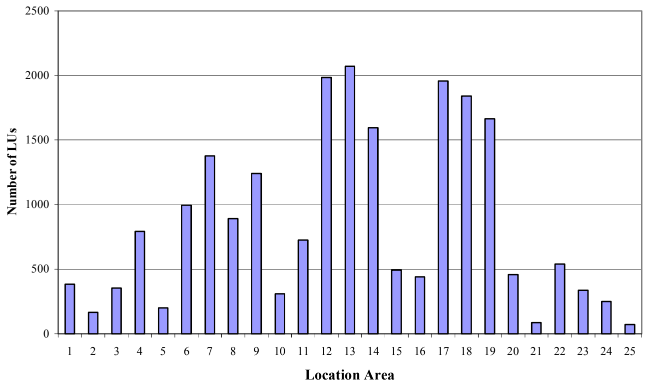

Figure 4: Number of LUs v/s LA for the 3 hour period

SMMT can be used as a planning tool in order to deploy the fixed infrastructure to meet MUs traffic demand by mapping it over a traffic model.

Optimum design of LA can be solved using either an analytical or heuristic approach [7]. Both these methods require the following input information: (1) cell topology, (2) amount of paging messages generated by cells found in the same LA (rate of incoming calls) and (3) number of LUs per LA (cell crossing rate). Applying SMMT to the cellular configuration superimposed on the City Area Model, we have measured the number of LUs per LA border for the 25 LAs configuration. The resulting amount of LUs versus the number of LAs is illustrated in Fig. 4, which forms the basis for the formulation of LA dimensioning problem.

D. *Teletraffic Issues*

A particular advantage of the SMMT is its ability to model mobility on a number of different scales. This allows the SMMT to model traffic in individual cells and areas within cells, allowing the examination of teletraffic issues and the channel utilization on specific sites.

Channel utilization is affected by a number of factors, of which user location is only one, albeit one of great importance. The particular service the user is accessing, the radio environment, and the resource scheduling policies of the MAC will also have an impact. For example, at a high level, the cell a particular user will access depends not just on their location, but also on the other traffic in the cell, the handover margin (which may also be adaptive with such factors as the user's speed), the propagation environment, and the admission control algorithm. Within a cell, for an adaptive air interface used for 2.5G or 3G systems, the channel utilization will also depend on the channel quality and interference level, which will result in different coding and retransmission strategies. This means that for teletraffic analysis, the model of user mobility has to be integrated with modeling of the air interface.

To examine the use of the SMMT in such scenarios, it has been integrated with a system level cellular simulator. The simulator is a discrete event object orientated simulator coded in Java. Users may have one of a number of different services - voice, web, ftp, WAP or H263 video, and the radio environment is modeled using a series of LUTs giving estimated packet dropping or loss probabilities for each service under

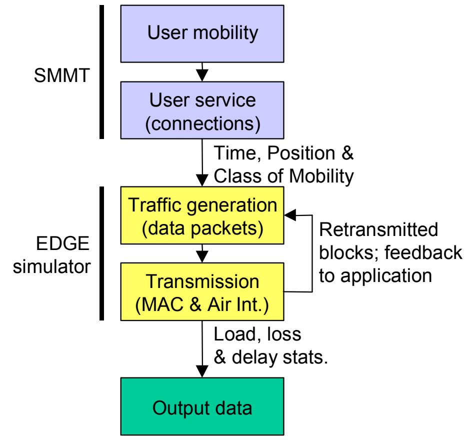

Figure 5 : Relationship between the SMMT and the system simulator

the specific signal to interference conditions experienced by that user. The system used was the 3G EDGE system, since for a TDMA system the resource management problems are somewhat more complex than for a CMDA system. However, the simulator is currently being extended to investigate TD-CDMA using modified air interface components, which does not require any modification on the part of the SMMT.

The coupling required between the system simulator and the SMMT presents a number of challenges, since feedback is required from the model of the air interface to record radio resource allocation, blocked or dropped packets, retransmissions and so on. Fully integrating the two tools to run on the same platform would have presented a number of difficulties for operation and maintenance, so the SMMT is run separately from the system simulator, reporting the location of mobiles at particular times and their class of mobility. An interface within the system simulator retrieves this information, using the location information directly and the class of mobility and timing information to control service models within the system simulator. The relationship between the simulators is shown in Fig. 5.

For different users with different CM, different service profiles are defined depending on the time of day. As an example, Table 1 gives the service profiles for the results given here. Within the data service type, traffic is distributed between web, ftp, e-mail and WAP with a distribution which also changes between different CM. The exact values are unimportant but simply show the flexibility of the approach.

TABLE I. EXAMPLE SERVICE PROFILES FOR DIFFERENT CLASSES OF MOBILITY

Class of Mobility	**Service Arrival Rate (calls/MU/hr)**			**Service Type**	
	7-8 am	***8-9 am***	***9-10 am***	***Voice***	***Data***
Business	3.5	4.5	5.5	0.3	0.7
Residence	5.5	4.0	3.0	0.8	0.2
Other	3.0	4.0	5.0	0.5	0.5

The scenario for teletraffic analysis is an 8 km × 8 km area in central Bristol. To show the effect of mobility on modeling the system, a simple grid of microcells is laid over the area. The area and the relevant PG are shown in Fig. 6. For com-

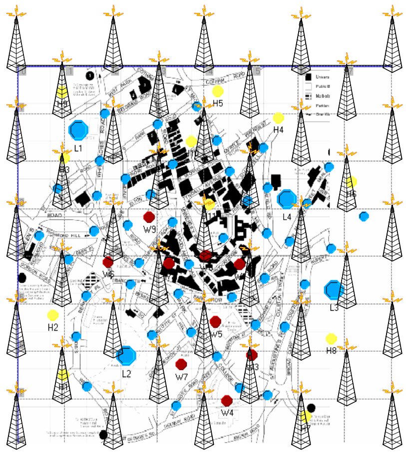

Figure 6 : SMMT model of the city center with overlaid cellular network

parison, the area in Fig 6 is equal to 4 of the squares in Fig. 2, showing how more detailed movement can be modeled by PGs in the same way.

Figure 7 shows the user traffic for 1700 active voice services users moving through the city centre scenario. The plot shows the average active users per cell. While the base stations are laid out in a regular grid with a cluster size of 4, the effect of shadowing means that the cells themselves vary slightly in coverage and therefore size. The occurence of hot spots of traffic can clearly be seen.

Fig. 8 shows cumulative distribution functions of the mean offered and carried traffic for the system taken over hourly periods. For comparison, a system with random directed mobility (where mobiles move within the area with a chosen direction but with random direction changes away from this) is also shown. The aggregate traffic per cell is normally distributed in the random case, compared to a log normal distribution in the SMMT modeled case. While almost all the offered traffic is carried in the random case, the increased variability in the case with mobility modeling causes traffic to be lost, although the average load is the same. In the SMMT case, the traffic load exceeds the available slots about 20% of the time.

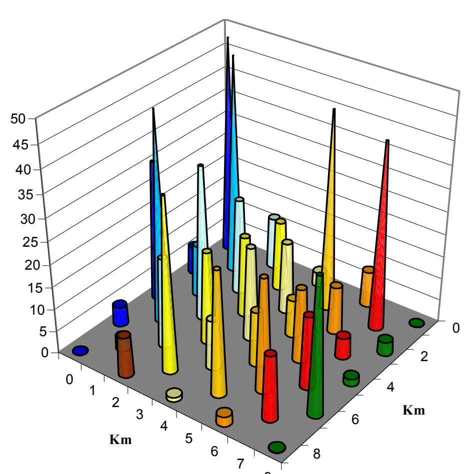

Figure 7: Spatial Distribution of Connections by Base Station Area

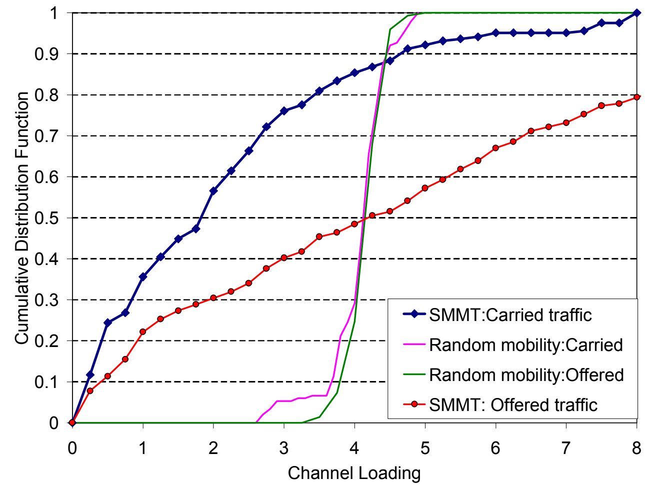

Figure 8: CDF of traffic load under modeled & random mobility

V. CONCLUSIONS

This paper presented a new mobility model for the characterization of mobile users over different geographical scales. The proposed method introduces the novel concept of Poles of Gravity to efficiently characterize the spatial and temporal behavior of mobile users in a scalable way. We applied this technique showing that the scalable algorithmic mobility modeling tool, SMMT, can be efficiently applied to both City Area and City Center of Bristol, UK to investigate the important issues pertaining to mobility management and radio resource management for a wireless communication network.

ACKNOWLEDGEMENT

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