

MocNet Simulation Specification

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1 Introduction

This document outlines the simulation to be developed in the MocNet project. It will be a discrete event simulation using next-event incrementing to advance time. As we're interested in cell-level data, we will simulate the movement between cells according to a probabilistic random walk. Our method is very similar to the pixel-oriented mobility model [6]. Despite this coarse discretisation of space, some underlying geographical features will be captured by the probability matrices. We note that even simulations that capture the geography more precisely will merge into our simulation when only returning cell-level data. The MocNet Simulation will also include some temporal dependencies caused by e.g. commuting. The simulation consists of two different parts: the mobility simulation and a call arrival simulation. Each part will be presented below. Also, two different geographical environments and three anomaly situations will be simulated: a road with an accident and a town centre with a flash mob and a flee situation.

2 Mobility simulation

In the mobility simulation the User Equipments (UEs) will move from their current cell to any of that cell's neighbours, following a predefined probability matrix. When a UE moves to a new cell it samples a residence time, t_R , and stays in the new cell for the duration of that time. UEs leave the simulation permanently if they exit the simulation area. Likewise, new UEs will be introduced to the simulation at the simulation area border cells. Temporal differences in the number of UEs currently roaming the cells is modelled by introducing more or less UEs to the simulation.

2.1 Motorway mobility simulation

2.1.1 Probability Matrix

In the motorway simulation there will be UEs moving in two directions. However, an individual UE will in general move along the road in one and only one direction. To accomplish this we need to keep track of what direction the UE

is currently travelling in, which is equivalent to keeping track of what cell it came from. To this aim, we number the cells, and only let the UE travel in either a positive number direction (i.e. to neighbouring cells with a number higher than the one of the current cell) or in a negative number direction (i.e. to neighbouring cells with a lower number than the current cell). See Fig. 1 for a graphical representation of the numbered cells and the road. However, more rare variations such as UEs leaving the road or turning back should also be accounted for. Therefore UEs are allowed to enter one of the side-cells, and when in a side cell either exit the simulation with a probability of 99%, or turn back on the road in either direction. This means that a car in a side-cell is allowed to break the number direction rule. As the majority of the cars move in a forward direction there's a 98% chance that the car will continue in its current (positive or negative) direction. See Fig. 2a and 2b for a graphical representation of the turn probabilities.

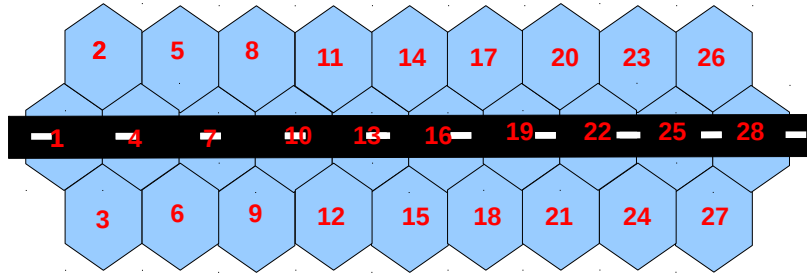
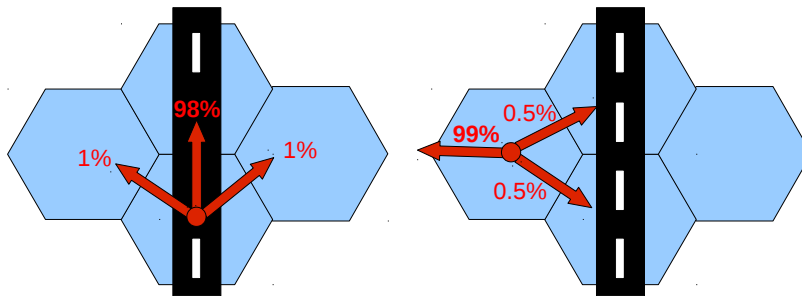


Figure 1: The road and numbered cells. In order to make sure the car don't change direction UEs are only allowed to move to cells with a higher number if the current cells number is higher than that of the past cell, and vice versa. The only exception is when the car is in one of the side cells.



(a) Probabilities for a car on the road. (b) Probabilities for a car in the side cells.

Figure 2: The probabilities for the motorway scenario.

Cars can enter the simulation either on the sides or through the leftmost or

rightmost cell of the simulation area. A car that has just entered the simulation will not leave it straight away but must take at least one step. On the sides the step can be in either direction with equal probability, while if the car enters on the road it acts as if it came from a numbered cell outside the simulation. For the side-cells this is different from the normal turn probabilities and we need to keep track of new cars during their first step.

This set of mobility rules gives the probability matrix shown below for a car travelling in a positive number direction:

$$M = \begin{matrix} & & 1 & 2 & 3 & 4 & 5 & 6 & 7 & & OUT \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ \cdot \\ \cdot \\ \cdot \end{matrix} & \left(\begin{matrix} 0 & 1\% & 1\% & 98\% & 0 & 0 & 0 & \cdot & \cdot & \cdot & 0 \\ 0.5\% & 0 & 0 & 0.5\% & 0 & 0 & 0 & \cdot & \cdot & \cdot & 99\% \\ 0.5\% & 0 & 0 & 0.5\% & 0 & 0 & 0 & \cdot & \cdot & \cdot & 99\% \\ 0 & 0 & 0 & 0 & 1\% & 1\% & 98\% & \cdot & \cdot & \cdot & 0 \\ 0 & 0 & 0 & 0.5\% & 0 & 0 & 0.5\% & \cdot & \cdot & \cdot & 99\% \\ 0 & 0 & 0 & 0.5\% & 0 & 0 & 0.5\% & \cdot & \cdot & \cdot & 99\% \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{matrix} \right) \end{matrix}$$

2.1.2 Cell dwell times

We assume that the cell dwell times are independent and equal to the time it takes for the UE to travel through the cell. However, rather than sampling the cell dwell times directly, we sample the speed of the UE and then calculate the dwell time by dividing the cell-length (here assumed to be 5km) by the sampled speed. The speed is sampled from the normal distribution with a mean of 100km/h and a standard deviation of 12km/h. This means that approximately 90% of the UEs have a speed between 80 and 120 km/h. Also, a UE will only be allowed to move on to a cell if there are less than 1000 cars travelling in the same direction as the car in it. This means that if there is a queue that takes up the entire space of the cell, a car can not enter it.

2.1.3 User Equipment arrival and exit

To include the effects of commuting the number of UEs in the simulation area is varied. In the road simulation the UE behaviour is streamlined, with most UEs entering the simulation, following the road for a certain amount of time, and then leaving the simulation. That is, the out-rate will be dependent on, and similar to, the in-rate. Therefore we can vary the number of UEs in the simulation at any given time by varying the in-rate. To this aim we model the UE arrivals according to an inhomogeneous Poisson Process, with rates as shown in table 1.

Table 1: Arrival rate

7.00-9.00 am and 4.00-6.00 pm	100 UE / min
Othertime	33 UE / min

2.2 Scenario Simulation

The scenario to be simulated is an accident where all traffic is stopped. The accident can take place anywhere in cell 13 with the exact position being sampled using a uniform distribution before the simulation is run. Two accident scenarios will be investigated; during rush hours and during normal hours. The exact time of the accident is sampled from within either rush hours or normal hours as appropriate. It is always the cars travelling in a positive number direction that are affected by the accident.

In order to know which cars are affected a fake cell border is placed at the accident position. This border is then closed at accident time and cars are no longer allowed to cross it. This means that there will be a build up of cars in beginning of cell 13 until N_{13B} , i.e. the number of cars that can fit in the area before the accident, is reached. When this happens the cell 12-13 border will be closed and the queue will start building in cell 12. This pattern of queue build up and border closure will be repeated until no cars are allowed to enter the simulation. Note that the traffic in the negative number direction is flowing as normal.

In reality cars close to a slip road could obviously choose to exit the motorway when they notice the queue. However, as this will only be an option for very few cars we will not to implement this functionality. Rather, once a car is stuck in a queue it will stay there for ever.

2.3 Town center mobility simulation

2.3.1 Probability Matrix

Our town centre is a grid as shown in Fig. 3. If the UEs were to move randomly with no spacial dependencies a uniform distribution should be used when sampling the next cell. That is, any of the neighbouring cells gets chosen with a probability of 16.7% in every step. However, as humans rarely move completely at random we include some spacial dependencies. Cell 10 represents an attraction in our model and could e.g. be the town centre. To find what influence the attraction should have on the transition probabilities we must first decide how much more attractive cell 10 should be. We decide that every UE in the simulation is 10% more likely to choose a neighbouring cell that is closest to 10 in every step of the simulation. These cells are marked with arrows in Fig. 3. When we have two cells that are closest to 10, half of the extra UEs go to one cell and the other half to the other. That is: single nearest neighbours represent a 10% extra attraction (represented by red arrows in Figure 3), while n nearest neighbours represent a $\pm \frac{10}{n}\%$ extra attraction (represented by yellow arrows). The transition probabilities with an attraction cell of $x\%$ are calculated as follows:

$$\begin{aligned} \text{Normal neighbours} &= \frac{100-x}{6} \\ \text{One neighbour closest to attraction} &= \frac{100-x}{6} + x \\ n \text{ neighbours closest to attraction} &= \frac{100-x}{6} + \frac{x}{n} \end{aligned}$$

This means that for a 10% extra attraction rate the red arrows represent a 25% transition probability, yellow arrows 20% and no arrow is 15% transition probability.

As people who have already visited the town centre are unlikely to go back again, we need a new set of probabilities for UEs that have been in cell 10. These probabilities will drive the UEs out of the simulation area. That is, the shortest path arrows will be flipped around and their probabilities recalculated. Now the UEs are $x\%$ (e.g. 10%) more attracted to leaving the simulation, and should therefore move towards the simulation area border more often. As some cells have an inflow of UEs from multiple cells (cells with yellow arrows in Figure 4), while others only have one preceding shortest path cell (cells with red arrows in 4), we will need to account for this when calculating the transition probabilities if we want the UEs to be spread spherically even over the simulation area. Also, just like before the number of succeeding neighbouring cells that are on a shortest path needs to be accounted for. In fact, the probabilities can be calculated as follows:

$$\text{Normal neighbours} = \frac{100 - x}{6} \quad (1)$$

$$\text{One inflow cell} = \frac{100 - x}{6} + \frac{x}{n_s} \quad (2)$$

$$n \text{ inflow cells} = \frac{100 - x}{6} + \frac{x}{n_s * n} \quad (3)$$

$$(4)$$

where x is the border attraction probability and n_s the sum of cell neighbours that are on a shortest path. That is, if the start cell has two half-cell succeeding neighbours (yellow arrows) and one full cell succeeding neighbour (red arrow) on a shortest path to the border $n_s = 2$.

For $x = 10$ and 3 neighbours ($n_s = 2$) on the shortest path to a border cell the probabilities are 15% for a normal cell, 20% for a one inflow cell, and 17.5% for a two inflow cell. Also, the exit probability for a UE on a border cell will be increased by 10%.

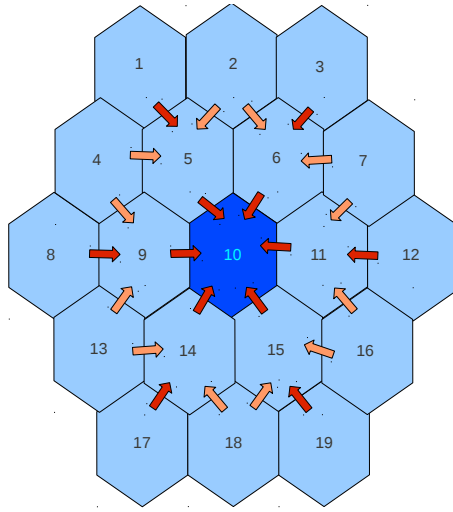


Figure 3: The grid used for the town centre scenarios. Cell 10 is considered an attraction and the arrows point towards the shortest path to the attraction. Orange arrows means there are two shortest paths and red arrows means there is one.

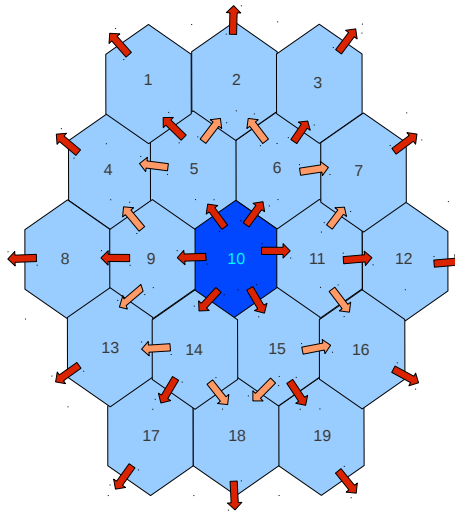


Figure 4: When the UEs have visited cell 10 they are more likely to move out from the simulation scenario. Yellow arrows means two preceding cells, red arrows one.

2.3.2 Cell dwell times

We assume that the cell dwell times are independent, and model them using a gamma distribution with $\alpha = 3$ and $\beta = 10$.

2.3.3 User Equipment arrival and exit

As opposed to the road simulation the town simulation allows for a large variety of UE behaviours, and the relationship between the in-rate and out-rate is complex. Therefore we need a more refined strategy for changing the number of UEs in the simulation area.

We assume that the number of people in an area are normally distributed, with means as shown in Figure 5. The numbers in Figure 5 have been calculated using the population density in Stockholm city in 2005, i.e. 3318 km^{-2} [3], and the assumption that the maximum number of people moving in our area is approximately 50% of the this density. Specifically, at most there are 6600 UEs in the simulation area (4 km^2). Further, we assume that this maximum is reached during lunch time (noon). The minimum number of people is set to approximately 0.5% of the population density (66 km^{-2}) and the normal high level approximately 40% (5280 km^{-2}). The change from one level to another is assumed to be linear. The total number of UEs will be drawn for each period at the beginning of each simulation day, and then be kept constant.

During normal mode, i.e. when the number of UEs in the simulation, N , is constant, a UE exit triggers a new UE entry in any of the border cells. When an increase in N is needed extra UEs enter the simulation according to a Poisson Process. The rate at which the extra UEs enter is calculated from the total increase and the time span during which this increase is to take place. To decrease N only a certain percentage (e.g. 50%) of the exists spawn new entries. This stop percentage should be calibrated once the simulation is developed to make sure enough UEs exit the simulation area.

As some border cells have three exit edges while others only have two we need to account for this when sampling what cell to put a new entry in if we wish to sustain a spherically even UE distribution.

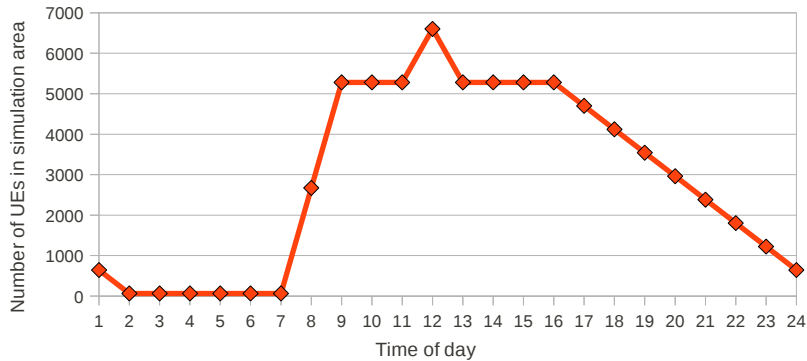


Figure 5: The number of people in the town center at different points in time

2.4 Scenario Simulation

Two scenarios will be modelled: a flash-mob scenario and a flee scenario. In the flash-mob scenario an increased number of people will move towards cell 11 while in the flee scenario most UEs will quickly move away from cell 11.

The flash-mob scenario will be modelled using the same attraction force model as described in 2.3.1, but the force will not be turned on until the time

of the scenario. The new transition probabilities are calculated as follows:

$$p_{new} = p_{old} - \frac{x}{6} \quad \text{for cells that are not on the shortest path to cell 11.} \quad (5)$$

$$p_{new} = p_{old} - \frac{x}{6} + \frac{x}{n} \quad \text{for } n \text{ neighbour cells on shortest path to cell 11.} \quad (6)$$

Also, if the time of the flash-mob is $[t_s - t_f]$ the pause time for the UE entering cell 11 because of the flash-mob during this time will be exponentially distributed with a mean of $t_f - t_c$, where t_c is the current time. Also, UEs leaving cell 11 will be pushed out of the simulation just as for cell 10.

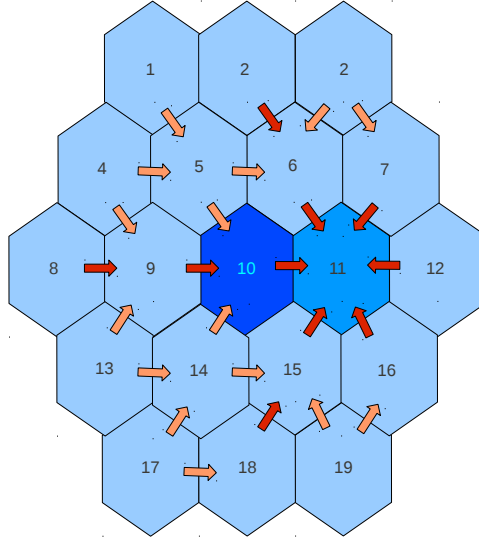


Figure 6: A graphical representation of the flash mob scenario.

The flee scenario is modelled in a similar way, although the range of the repulsion force is one cell (See Figure 7). The probability of entering cell 11 from any direction is reduced by 90% at the time of the flee event. Also, at the start of the flee scenario we sample 90% of the UEs in cell 15 to leave straight away, i.e. we reduce their pause time to a new one sampled from an exponential distribution with mean 3 minutes. As soon as the flee scenario end time is reached all transition probabilities are set to their normal value.

The total number of UEs in the simulation area will not be affected by the arrival of a flee or flash-mob scenario.

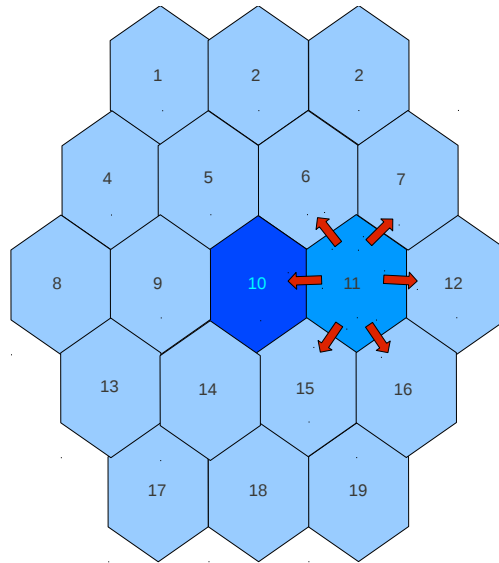


Figure 7: A graphical representation of the flee scenario.

3 Call modelling

Calls could be modelled as a Poisson Process. Burstiness could be included by using a Markov Modulates Poisson Process [1], although we will ignore burstiness in this application. However, peak periods and time dependence will be included. Many papers [7, 2, 5] report similar rate patterns, and the relative variations in our graph is based on the numbers reported in [5]. Fig. 8 shows how the arrival-rate changes over the day, and the top rate is set to 1.5 calls/hour, close to the 1.4 rate reported in [4]. The rate is also close to the 2 calls/hour (including calls and call modifications) used in [8]. As we need to model both incoming and outgoing calls, two Poisson Processes will be needed. We assume that the rate is identical for both incoming and outgoing calls.

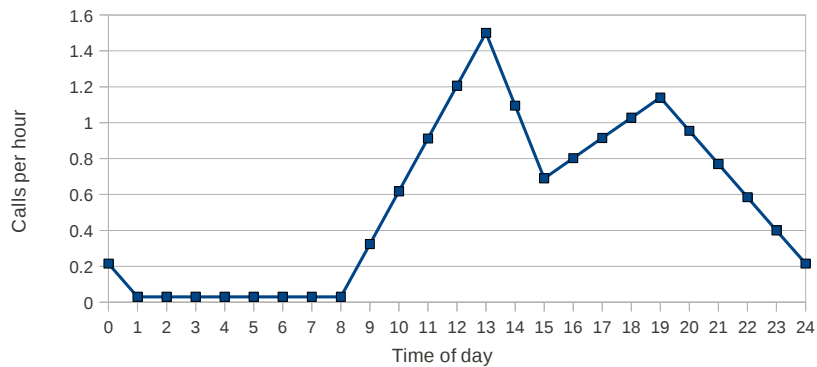


Figure 8: The call arrival rate varies over the day as shown. The shape of the function is based on the numbers reported in [5], while the top arrival rate is taken from [4].

When it comes to call-holding time we will use a gamma distribution with $\alpha = 2 \text{ min}$ and $\beta = 10 \text{ min}$.

References

- [1] Attahiru Sule Alfa and Wei Li. A homogeneous pcs network with markov call arrival process and phase type cell residence time. *Wirel. Netw.*, 8:597–605, November 2002.
- [2] Julian Candia, Marta C. Gonzalea, Pu wang, Timothy Schoenharl, Greg Madey, and Albert-Laszlo Barabasi. Uncovering individual and collective human dynamics from mobile phone records. *Journal of Physics A: Mathematical and Theoretical*, 41(22):1–11, 2008.
- [3] Statistiska Centralbyrån. Tätorternas landareal, folkmängd och invånare 2000 och 2005. http://www.scb.se/Pages/ProductTables____13001.aspx.
- [4] C.N.Lo, R.S. Wolff, and R.C. Bernhardt. An estimate of network database transaction volume to support universal personal communication services. *First International Conference on Universal Personal Communications, ICUPC'92*, 9(3):1–6, 1992.
- [5] Houda Khedher and Fabrice Valois. Traffic characterization for mobile networks. In *Vehicular Technology Conference, 2002. Proceedings. VTC 2002-Fall. 2002 IEEE 56th.*, volume 3, pages 1485–1489, 2002.
- [6] Ranjit Perera, Andreas Eisenblätter, Erik Fledderus, Carmelita Görg, Michael Scheutzow, and Stefan Vermijmeren. Pixel oriented mobility modelling for umts network simulations. In *Proc. ITS Mobile Summit*, pages 828–831, 2002.
- [7] Jonathan Reades, Francesco Calabrese, Andres Sevtsuk, and Carlo Ratti. Cellular census: Explorations in urban data collection. *IEEE Pervasive Computing*, 6:30–38, 2007.
- [8] Mikael Ronström. Database requirement analysis for a third generation mobile telecom system. In Willem Jonker, editor, *Databases in Telecommunications*, volume 1819 of *Lecture Notes in Computer Science*, pages 90–105. Springer Berlin / Heidelberg, 2000. 10.1007/10721056_7.