GSM AND UMTS MOBILITY SIMULATOR

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January 2005

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ABSTRACT

GSM AND UMTS MOBILITY SIMULATOR

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In this thesis, a mobility simulator for GSM and UMTS has been designed and implemented using Visual C#.Net. The objective has been to design and implement such a simulator that can be used to create and study different traffic load scenarios and mobility patterns that can cause congestion situations. The modular approach adopted for the GSM and UMTS simulator allow us to evaluate the performance of new services. The simulator uses propagation simulation results and terrain profile data to produce capacity and performance metrics related to GSM and UMTS networks. The capacity and the service quality of the network are assessed in a long-term system level simulation scheme. Mobility generation is the core of the simulator program. It generates random paths for the mobile users in the simulation. Then the effects of the mobility patterns of the users on the system capacity are investigated. In GSM mobility simulator, mobility, traffic generation, call-admission and handover are implemented. In UMTS, in addition to GSM modules, power control and soft handover generation is implemented.

Keywords: mobility simulation, call-admission, handover, GSM, UMTS

ÖZET

GSM VE UMTS MOBILİTE SİMÜLATÖRÜ

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Bu tezde GSM ve UMTS için hareketli bir simülatör, Visual C#.Net programlama dili kullanılarak geliştirilmiştir. Değişken trafik yükleri ve kullanıcı hareket paternlerinin GSM ve UMTS sistemleri üzerindeki etkilerini görmek amacıyla, bu simulator kulanılabilir. Modüler olarak tasarlanan bu simülatör, yeni servislerin de denenmesi için bir ortam yaratmaktadır. Bu program, yayılım simülasyonu ve arazi profillerini, GSM ve UMTS performans sonuçlarını hesaplamak için kullanır. Kapasite ve servis kalitesi sonuçları, uzun zamanlı simulasyon yoluyla hesaplanır. Kulanıcı hareketleri bu simülatörün en önemli parçasıdır. GSM veya UMTS gibi sistemlerde, kullanıcıların hareketli olmaları, kapasite ve sevis kaltesini etkilemektedir. Bu yüzden bu harket paterninin, simülatör içinde, doğru bir şekilde modellenmesi gerekmektedir. Ayrıca GSM simülatöründe, trafik modellemesi, çağrı kontrolü ve handoff modellenmiş ve kullanılmıştır. Buna ek olarak UMTS programında, trasmisyon güç kontrolü ve soft-handoff kullanılmıştır.

Anahtar kelimeler: hareketli simülasyon, çağrı kontrolü, handoff, GSM, UMTS

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To my family and friends…

Chapter 1

INTRODUCTION

As a result of the growing demand for mobile communication, wireless communication schemes became more popular recently. The intense development of the radio communication industry brought the need for careful planning of these networks. The hardware used in these wireless networks is expensive, so they must be used optimally. In the planning phase of these wireless networks, simulations are needed in order to test the planned network layout. Mobility simulation is a kind of a simulation, which has the ability of showing the network performance due to the mobile behavior of the network subscribers. Doing a mobility simulation on a planned network is an effective way of investigating the capacity and the quality of a wireless network. In this thesis, Global System for Mobile Communication (GSM) and Universal Mobile Telecommunication System (UMTS) are modeled and mobility simulators for each network are developed.

1.1 Wireless Networks

The transition from analogue to new digital systems has provided further growth in wireless communication schemes. Many countries had implemented the Global System for Mobile Communication (GSM) in 1990's. GSM is referred to as a second-generation wireless network. GSM networks support voice and low speed data traffic. Growing demand in higher data rates and expanding various services causes the European research and development work focus on third-generation systems. Universal Mobile Telecommunication System (UMTS) is a third-generation (3G) wireless network. UMTS can handle various service demands, supplying the mobile users, high bandwidth. UMTS is deployed in a small number of countries presently.

The efficiency of a wireless system is determined by the following factors:

- The bandwidth utilization of the wireless channel
- The cost of the system
- Interference in the network

The wireless channel can be described as a medium where the information is carried by electromagnetic propagation. It is the radio wave propagation environment. The bandwidth given to the wireless system must be utilized optimally, in order not to waste this resource. In wireless systems, the network equipment is highly expensive, so the design of the network layout affects the cost drastically. Interference[1] in the network influences the system performance and call quality, so low interference means high service quality. Design of the system infrastructure changes the interference level, because of this; a careful planning phase must be applied at design time.

The design objective of early mobile radio systems was to achieve a large coverage area by using a single, high-powered transmitter with an antenna mounted on a tall tower [1]. By using this approach, a high coverage area is achieved; on the other hand, the system capacity will be limited by that only one base station. All of the bandwidth is assigned to that base station, so it is impossible to use the same frequency anywhere else in the system. Frequency reuse is limited by interference. The base station antenna's power must be high enough to cover the entire service region, so the signals interfere with each other on the entire network. In second-

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[1] Interference is caused by transmitters, which are using the same frequency band. It is basically, the sum of the signals at the same frequency, other than the intended one.

generation networks, this problem is solved by applying cellular layouts to the network design. Using lower transmitter powers at the base stations, smaller cells are formed. Each cell is allocated a portion of the total bandwidth reserved for this service and the frequency sets are repeatedly used at further base stations. Using this scheme degrades the interference and boosts the capacity. It offers high capacity in a limited spectrum allocation without any major technical changes. On top of this approach, connection times are divided into different time slots, so none of the two mobiles communicate to a specific base station at the same time. This approach is called Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). FDMA and TDMA are both used in GSM technology.

Growing demand in data rates causes the network models to use all of the channel bandwidth everywhere in the service region. Third-generation (3G) wireless networks use Code Division Multiple Access (CDMA) scheme. In CDMA, every user is allocated the entire spectrum all of the time, in opposite to GSM networks that use TDMA and FDMA. Every communicator is assigned a specific code to encode the information-bearing signal. The codes used are orthogonal, so the encoded signals do not interfere with each other. 3G systems can handle various service demands such as fast web browsing, live video streaming or online gaming.

1.2 Network Simulators and Mobility

Predicting the capacity and performance of a GSM or a UMTS network enable us to estimate the infrastructure requirements that accommodate the expected offered traffic. The infrastructure requirements vary according to the wireless network structure. For example, GSM infrastructure requirements are; radio link bandwidth, number of base stations and base-station tower heights. It is known that [2], the exact estimates of system capacity and performance due to these requirements are hard to set up by analytical techniques. For example, such techniques can be useful in determining the capacity of a UMTS system that utilize only voice traffic, but they do not implicitly deal with mixed traffic cases (internet applications, file transfers or real time video streaming). Due to the inflexibility of the analytical methods, network simulators are used. There are two basic types of network simulators in the literature [2].

- Static Simulators
- Dynamic Simulators
  - Long-term dynamic simulators
  - Short-term dynamic simulators

Static simulators are based on Monte Carlo approaches [3]. They basically, work by randomly dropping mobiles in a pre-defined network layout. Then, the static simulator decides what proportion of the mobiles is successfully served by the wireless system. This process is repeated for a pre-defined number of times and in each step the mobile location distribution is randomly changed and network performance values are updated. The output metrics are averaged over the simulation time, to give a single network capacity (or performance) metric. Note that, in a static simulation there is no time concept, therefore these simulators do not handle system functionalities like handover[2]. Hence, static simulations require validation for these dynamic functions from the dynamic simulations. On the other hand, as long as there is no time correlation between the simulation steps, static simulations converge faster than dynamic ones.

Dynamic simulators can handle non-homogenous base station layouts, realistic propagation data, and non-homogenous traffic distribution. They enable us to study dynamic properties of wireless networks like handover and admission

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[2] When a mobile station is moving from the coverage area of one cell to another during an established connection, the link is transferred to the new cell. This link transfer is called handover. Handover avoids discontinuity in the conversation.

control[3]. Fundamentally, there are two different types of dynamic simulators in the literature [2, 4], long-term and short-term. They are differentiated by their time-scales of simulation, but indeed, they both include functions like admission control, handover control and call dropping[4]. If our interest is focused on system capacity or performance due to those dynamic functions, long-term simulations will satisfy our needs. On the other hand, controls like time-slot selection, packet scheduling or fast cell selection are handled in short-term dynamic simulators, because these simulators are working in micro-timescales.

The major disadvantage of short-term simulations is their complexity and long running times, because these simulators will be accessing the system with in very short time scales. One of the best-known dynamic network simulators in the literature is NS (Network Simulator) [5]. NS is a powerful network simulator that has the ability of simulating vast number of different network schemes. It is a discrete event simulator, which focuses on packet scheduling issues. There is no specific module related to GSM and UMTS wireless systems in NS. It is possible to extend NS (NS is an open source software) to simulate GSM and UMTS but NS characteristics are not appropriate for these system level simulations. In estimating the capacity of GSM like systems, long-term simulations satisfy all of the needs, because it is much computationally easier. It is possible to use realistic propagation data, environmental settings, traffic parameters and mobility generation in such a fast simulator scheme.

Long-term dynamic simulations are extended versions of static models that are based on Monte Carlo approaches. Single drop of mobile stations to the network layout, are repeated in time, where each mobile has two important time-related characteristics, mobility and call activity (can be referred as traffic properties). The call activity or traffic property of mobile stations can be handled

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[3] The receivers decide whether to accept an incoming connection by the use of admission control mechanisms.

[4] The call is dropped when there is no adequate signal level at the receiver.

by turning on and off the mobiles during the simulation time. The times when the mobile will turn on/off, is decided by an exponential traffic distribution. A long-term simulator operates in relatively large time steps, in the order of seconds (1s – 10s).

In this thesis, long-term dynamic approach is used to simulate the two wireless networks, GSM and UMTS. Instead of using the term "long-term dynamic simulator", "mobility simulator" is used, because mobility generation is explicitly modeled in order to create a realistic dynamic simulator. The mobility model will need to be designed carefully, if the intended traffic distribution is non-homogenous, since the probability of a mobile passing through any point in the service area is not uniform.

In order to generate realistic mobility patterns for the mobiles in the simulation, a fast mobility generation algorithm is developed. In order to generate random paths for mobile users, path-finding problem must be solved. This problem can be solved by several routines; one of them is a graph-based solution. This approach is accurate in finding shortest paths within a graph, but the algorithm is slow and has running time of $O(n^2)$[6]. The second approach to this problem is step-taking algorithms, which are much faster then graph-based algorithms. In this thesis, a step-taking algorithm is developed to solve the path-finding problem, which has a running time of O(n).

1.3 Thesis Overview

In Chapter 2, first a brief description of mobility simulator that is developed within this thesis study is given. Then, the input data needed for this simulator tool is described. This data's properties are explained and the effects of the changes in this data on the simulator depicted network capacity (or performance) are described. Chapter 2 also demonstrates how the mobility generation is achieved, by giving different ways of solving the path-finding problem. The algorithm that is implemented in dynamic simulator tool is depicted and the advantages and disadvantages of this scheme are explained.

Chapter 3 presents GSM simulation tool developed within this thesis by first giving a brief description of the working principles of GSM networks. Then, GSM network planning is described and the effects of this planning phase on the GSM service performance are represented. The simulation algorithm developed for the GSM simulator tool is depicted and available results obtained from the simulator is represented. Chapter 3 also provides a sample simulation of a pre-designed GSM network layout. The output metrics are discussed and the effects of the GSM system parameters on these metrics are illustrated.

Chapter 4 provides extensive coverage of UMTS. The medium access layer of UMTS is different from the traditional access techniques like TDMA and FDMA used in second-generation mobile systems, so this chapter introduces CDMA technique. The configuration parameters of UMTS are illustrated and the effects of these parameters on the performance metrics of UMTS are explained. ITU performance tables are very important in modeling the 3G networks. These tables are used to extract bit error rate requirements for different service demands, so as the transmit powers of both the base and the mobile station. A sample simulation's results are depicted and discussed in this chapter.

Chapter 5 describes the deficiencies and advantages of using a dynamic mobility simulator for predicting capacity and performance of wireless networks. It also demonstrates the future work that can be done in order to improve the mobility simulator.

Chapter 2

MOBILITY SIMULATION

The principal characteristic of mobile networks, which distinguishes them from conventional fixed networks, is that the identity of the calling and called subscriber is not associated with a fixed geographical location. The mobile subscribers establish a wireless connection with the nearest available base station[5]. In addition to this, they can make and receive call while they are moving. GSM and UMTS support these functions.

A mobility simulation is a dynamic network simulation, which focuses on the effects of the user-mobility to the network's performance and capacity. In fact, this kind of a simulator can be thought as a system, which has inputs and outputs. The inputs are the planning data and the outputs are the network performance and capacity due the mobile effect of the users. This scheme is depicted in Figure 2.1. The input data to the simulator is further explained in the next section.

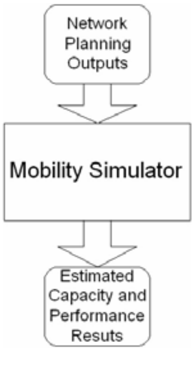

Figure 2.1: System view of the mobility simulator

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[5] Base station is the network access device, which the users connect to other users through this device.

These simulations work on planned network layouts. They replicate the real world usage of the wireless service. Actually, the simulator creates a virtual landscape, a network infrastructure and mobile users that demand service from the wireless network. A planning phase must occur to create the network layout, before starting the simulation. This phase will generate the data needed for the mobility simulator. The details of the outputs of the mobility simulator are explained in Chapters 3 and 4.

Mobility of these wireless users must be well modeled in order to make an accurate simulation of a wireless network. The model will need to handle non-homogenous traffic distribution, because the possibility of a user passing through any particular tile of the service area is non-uniform.

The mobile users are categorized into two, pedestrians and vehicles. They have an average speed of movement. These values are depicted in Table 2.1.

Mobile Users	**Speed (km/h)**
Pedestrians	3-5km/h
Vehicles	30-120km/h

Table 2.1: Mobile user speeds

As seen in the table above, the pedestrians have an average speed of 3-5km/h. In the simulation, some portion of the pedestrians is assigned 3km/h speed and the other portion is assigned 5km/h speed. This scheme is repeated for the vehicles in the simulation.

After the speeds are assigned to the users, the movement paths must be generated. At this stage, the direction of movement must be modeled. At the beginning of the simulation, the mobile units are randomly dispersed over the simulation area. Then, they choose a random destination point in the simulation grid and start to move to reach to the destination. At the destination, they choose another destination point. This procedure goes on until the simulation ends. While reaching the destination, the mobile units must choose an appropriate direction of movement. Path-finding algorithms solve the problem of choosing an appropriate way to get to the destination. These algorithms and our way of solving the problem are explained in section 2.2.

2.1 Data Needed for a Mobility Simulation

Mobility simulator simulates a planned network layout. Network layout consists of the following items:

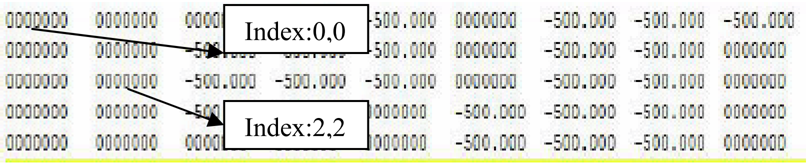
- Population in the service area
- Building data
- Places of the base stations
- Channel assignments to the base stations
- Propagation simulation results (Coverage data)
- Traffic profiles of the mobile users

The number of mobile users that are in the simulation is decided by using the population information in the service area.

The simulated environment has buildings in it so the buildings must be modeled in a way that the simulator can access. Simulator accesses the building data for generating mobility patterns for the users simulated in the network, which is explained in Section 2.2. An example of a building model is shown in Figure 2.2.

Figure 2.2: Building model

The blue painted parts in the above building model indicates buildings and the other areas are the streets passing through them. The model is then digitized with a specific metric resolution. For example, if 5m is chosen as the resolution, the building map is converted to a grid, where each grid element is 5m to 5m square. This grid is stored in a text file, in order to be used by the mobility simulator program. If a grid point coincides with a building, its value is set to –500. If it coincides with a street area, its value is set to 0. The text file, which stores the building model given in the above example, is depicted in Figure 2.3.



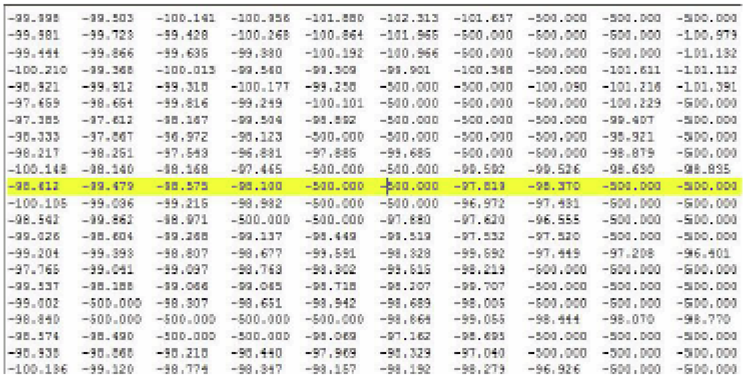
```
0000000   0000000   0000                        -500.000  0000000   -500.000  -500.000  -500.000
0000000   0000000   -5                          -500.000  0000000   -500.000  -500.000  0000000
0000000   0000000   -500.000  -500.000  -500.000  0000000   -500.000  -500.000  0000000
0000000   0000000   -50                         000000    -500.000  -500.000  -500.000  0000000
0000000   0000000   0000                        000000    -500.000  -500.000  -500.000  0000000
```

Figure 2.3: Building text file

The mobility generator reads this text file and stores in a two dimensional array. The index of the array starts from (0,0), which indicates the first value in the text file. This indexing is also depicted in Figure 2.3. The distance between two consecutive grid points is defined by the metric resolution (5m in this example).

Places of the base stations and the channel assignment to those base stations are discovered from traffic analyses. Traffic analysis uses the population information in the service region in order to calculate the number of channels to accommodate this offered traffic. Then the places of the base stations are discovered by traffic analyses. Traffic analysis is not in the scope of this thesis, because the mobility generator uses the outputs of this phase as inputs. This data is also stored in a text file.

Propagation simulation results reveal the received signal power coming from the base stations, all over the terrain. If the transmit power of the base stations is known, a propagation algorithm is used to investigate the propagation of the signal from the transmitter to the receiver. The mobility simulator needs propagation simulation results, because the received signal power determines whether a mobile user can successfully establish a connection or not. In doing a propagation simulation, the receivers must be assumed and placed everywhere in the simulation area. This procedure must be followed, because the users are mobile and the received signal power coming from every transmitter to every point in the area must be known. In this thesis, the propagation simulations are not investigated, but only used as inputs to the mobility simulator. Okumura Hata model [7] is used for propagation simulations. This data is also called coverage data. The received signal power values obtained from this analysis is stored in text files, which has the same template and size with the building file. There are multiple files each corresponds to a specific base station coverage data. An example of a coverage file is depicted in Figure 2.4. The thematic view of the coverage file is shown in Figure 2.5.



```
-99.898   -99.503   -100.141  -100.956  -101.880  -102.313  -101.657  -500.000  -500.000  -500.000
-99.981   -99.723   -99.428   -100.268  -100.864  -101.965  -500.000  -500.000  -500.000  -100.979
-99.444   -99.866   -99.636   -99.980   -100.192  -100.966  -500.000  -500.000  -500.000  -101.132
-100.210  -99.368   -100.013  -99.540   -99.309   -99.901   -100.348  -500.000  -101.611  -101.112
-98.921   -99.912   -99.318   -100.177  -99.258   -500.000  -500.000  -100.090  -101.216  -101.391
-97.659   -98.654   -99.816   -99.249   -100.101  -500.000  -500.000  -500.000  -100.229  -500.000
-97.385   -97.612   -98.167   -99.504   -98.882   -500.000  -500.000  -500.000  -99.407   -500.000
-98.333   -97.867   -96.972   -98.123   -500.000  -500.000  -500.000  -500.000  -98.921   -500.000
-98.217   -98.261   -97.543   -96.881   -97.886   -99.686   -500.000  -500.000  -98.879   -500.000
-100.148  -98.140   -98.168   -97.465   -500.000  -500.000  -99.592   -99.526   -98.690   -98.835
-98.612   -99.479   -98.575   -98.100   -500.000  -500.000  -97.818   -98.370   -500.000  -500.000
-100.105  -99.036   -99.216   -98.982   -500.000  -500.000  -96.972   -97.431   -500.000  -500.000
-98.542   -99.862   -98.971   -500.000  -500.000  -97.880   -97.620   -96.555   -500.000  -500.000
-99.026   -98.604   -99.268   -99.137   -98.449   -98.519   -97.532   -97.520   -500.000  -500.000
-99.204   -99.393   -98.807   -98.677   -99.591   -98.828   -99.692   -97.449   -97.208   -96.401
-97.765   -99.041   -99.097   -98.763   -98.802   -99.616   -98.219   -500.000  -500.000  -500.000
-99.537   -98.188   -99.066   -99.065   -98.718   -98.207   -99.707   -500.000  -500.000  -500.000
-99.002   -500.000  -98.307   -98.651   -98.942   -98.689   -98.005   -500.000  -500.000  -500.000
-98.840   -500.000  -500.000  -500.000  -500.000  -98.864   -99.055   -98.444   -98.070   -98.770
-98.574   -98.490   -500.000  -500.000  -98.069   -97.162   -98.695   -500.000  -500.000  -500.000
-98.938   -98.868   -98.218   -98.440   -97.969   -98.329   -97.040   -500.000  -500.000  -500.000
-100.186  -99.120   -98.774   -98.947   -98.157   -98.192   -98.279   -96.926   -500.000  -500.000
```

Figure 2.4: Coverage file

Figure 2.5: Coverage view

The values are in dBm scale. The –500 values shown in the figure above, are the building locations. Only outdoor propagation simulation is used, because the mobiles are assumed to travel around the buildings, not entering them.

Traffic profiles of the mobile users reveal the probability of a mobile to attempt a connection. In other words, when the mobile user's radios are set to on or off, are decided by these parameters. These parameters are average on time and average off time. On time and off time is the time duration, which a mobile is having an on-going connection and which a mobile's radio is off, respectively. The mobility simulator has a specific module, which generates this traffic. Traffic generation is explained in Chapter 3.

2.2 Mobility Generation

The core functionality of a mobility simulator is mobility generation. At the beginning of the simulation, the mobile units are randomly dispersed over the simulation area. Then, they choose a random destination point in the simulation grid and start to move to reach to the destination. While reaching the destination, the mobile units must choose an appropriate direction of movement. This problem of choosing an appropriate path to the destination is called path finding. The mobility generator uses the stored building data to create paths on top of it. The simulation area is converted to a grid so, the geographical locations map to grid points. If there are no buildings in the simulation area, then the path-finding problem is easy to solve. A straight line between the start and the destination point will constitute the generated path. On the other hand, if there are buildings in the simulation area, the path must travel around those buildings while reaching the destination. These two cases of path finding are depicted in Figure 2.6.

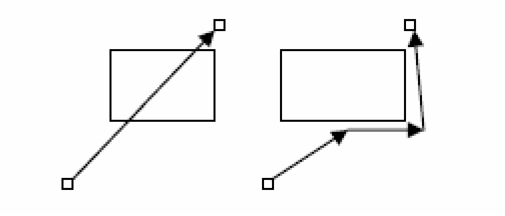


Figure 2.6: Simple path finding vs. path finding with buildings

When trying to write movement for mobile units, the biggest choice is probably between the graph-based and step-taking approaches [6].

2.2.1 Graph-based and Step-taking Path Finding

As the virtual environment becomes larger and more complex, the ability of mobiles to consciously find their way around the terrain plays an important role in their mobile behavior. Path finding is the process, which is used to route the mobile through the simulation grid. There are buildings in the simulation area, so the mobile must be routed around the buildings. If there are complex building structures in the area, simple algorithms of path finding can cause looping routes. Those routes do not reach the destination points of the mobiles, so they are ineffective. These simple algorithms result in undesired crowded spots. The undesired effects of simplistic path finding algorithms are degraded by graph-based and step-taking path finding algorithms [8].

As seen from Figure 2.4, the simulation area is converted to a grid. There are two types of grid points, free and building grid points. The building points correspond to places containing buildings. The mobile cannot pass through this type of points, but can move through free grid points. In graph-based approaches to path finding, the grid points correspond to graph nodes. If there are no buildings in the area, all the nodes will be connected to each other. Consequently, if there are buildings there is no path between a free node and a building node. Pathfinders look at the whole map and find a path for the unit to take. After that, the unit takes each step prescribed by the pathfinder. Some graph bases path finding algorithms are A* and Dijkstra [6]. These algorithms are complex and needs lots of pre-processing. Also, graph based approaches are computationally complex and has a running time of O[n^2] where n is the number of nodes in the graph. The whole grid must be first converted to a connected graph and then the algorithm must investigate this entire graph to find a possible path between two nodes. These algorithms are used to find the shortest path and some of them are very accurate [6, 8].

In this mobility simulator, there is no need for a shortest path for the mobile units, because their movement is modeled as random motion. The only criterion for the path-finding problem in the mobility simulation is that the algorithm must find a path between any two points in the simulation grid.

Alternatively, step-taking algorithms look only for the next step for the motion and leave the remainder of the path to the goal for later. The step-taking algorithm developed within this thesis is as follows:

```
1.  While (not at the goal)
    {
2.     Pick a direction to move toward the goal
3.     If (that direction is clear for movement) move there
4.     Else (pick another direction according to an avoidance strategy)
    }
```

With this approach all that needs to be known are the relative positions of the entity and its goal, and whether the immediate area is blocked. In picking another direction depicted in step 4 of the algorithm, choosing an appropriate avoidance strategy is crucial. An incorrect avoidance strategy can cause serious loops in the path, thus degrades the mobility behavior. In our implementation, the mobile user saves the movement it made during the previous steps and uses this information to avoid loops at simulation instance. If the mobile encounters a building, it just moves around it staying besides the building. This behavior is supplied by the history information of the path of that mobile.

First, all the mobile units are randomly dispersed over the simulation area (uniformly). Then, for every mobile unit, a random destination point is chosen. The algorithms duty is to move the mobile unit (with the specified speed) in a path such that the destination point is reached. When a mobile user reaches its specific destination point, another random destination is chosen, and this process continues within the specified simulation duration. Choosing destination points for every user in the simulation, supplies the ability of making more and less crowded areas in the simulation area. A random variable chooses the coordinates of the destination points. By adjusting the probability of the random variable to choose more or less in a specific region, some places can be more crowded (visited by the mobiles more), on the average. The C# code of the algorithm is depicted in the appendix.

Chapter 3

GSM SIMULATION

GSM simulator models the system with realistic mobile user traffic distribution, an accurate propagation data on top of a real building data and generated user mobility. The propagation simulation is done with the usage of a real building and terrain data before the actual GSM mobility simulation is established. Then, the received power values are written to a simple file and read by the GSM mobility simulator in order to determine whether a mobile user can connect to the system or not. The RLC (Radio Link Control) layer in the GSM structure is modeled in the simulator that simply determines whether the user can access to the system. The simulator is written in C# in .Net environment.

With the intention of analyzing the performance of a GSM cellular network design, GSM mobility simulator is developed. Simulation models the GSM system and the cellular environment with precise models of signal propagation, user mobility and traffic distribution. This application works as fallows. First, a simulation model of the network is created, and then a user population is virtually generated. With these virtual mobile users and traffic characteristics, the planned network model is simulated. The users are mobile so, the mobility generator produces their routes. In addition, the data rate demands of the users are controlled by these simulation parameters. The simulation, at the end, generates graphs and reports that inform GSM network performance related metrics.

The GSM mobility simulator described in this thesis can be applied to many areas such as, design of physical network layout, assessing the impact of network adjustments and configuration changes, analyzing the effect of new network components such as base stations, handsets and demonstrating the outcome of service profiles [25]. The simulator described in this thesis is a dynamic network level simulator for the performance evaluation of GSM. Dynamic simulator models the time correlation between the events, which is useful in determining the overall performance of these types of wireless networks. In each simulation step, mobiles move along their paths and this mobility behavior leads to handovers, which play an important role in service quality and capacity of the GSM network [9].

3.1 GSM Overview

GSM denotes Global System for Mobile Communications. It is referred as a second-generation wireless network. It serves voice only traffic with a data rate of 9.6 kbps. GSM uses combination of TDMA (Time Division Multiple access) and FDD (Frequency Division Duplex) as a medium access protocol. A channel gets a certain frequency band for a certain amount of time. Spectrum for GSM is 890 to 915 MHz and 935 to 960 MHz. GSM uses different channels for uplink for downlink. The length of a GSM time frame in a single frequency channel is 4.615 msec. A time frame is divided into 8 time slots of duration 0.577 msec. GSM uses different time slots for an uplink and a downlink connection, so this arrangement avoids transmitting and receiving at the same time, degrading interference [2, 4]. Time-frequency correlation of GSM channel is illustrated in Figure 3.1.

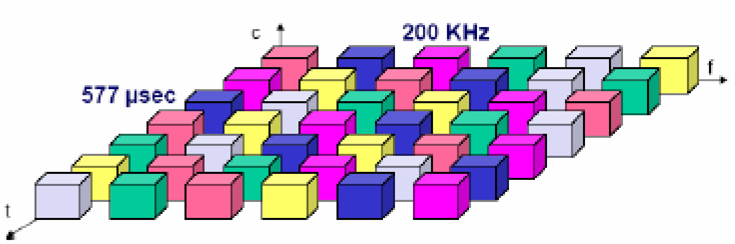


Figure 3.1: TDMA-FDMA property of GSM

Spectrum is limited but demand is high, so in GSM, a cellular structure is used. Every cell has a base station and assigned frequency set. Therefore, every additional cell can accommodate more users. The same frequency channel can be used in two or more cells, so this frequency reuse causes interference of signals. As the interference level increases, the receivers are not able to demodulate the signal. This interference limits large frequency reuse ratios in GSM.

3.2 GSM Network Planning

Network planning is the first step while establishing a wireless network. Electromagnetic spectrum is a unique resource across a vast range from 3 kHz to 300 GHz. Unlike other physical resources, it cannot be depleted. However, as radio signals overlay each other in an additive way, there exist interdependencies and thus rivalry among users. In an extreme case, interference can damage the radio signals of all participants to the point where they become unrecognizable and therefore useless. Planning in these networks is crucial because good network planning means minimum interference on the system. Planning the network beforehand increases the service quality and capacity. The other necessity of planning is economy of investment [10, 11]. The resources are expensive so they must be optimally used.

Network planning data is the input to the mobility simulator. Therefore, a planned network is needed in order to make a mobility simulation. The planning data is obtained from two analyses:

- Traffic Planning
- Coverage Analysis

Traffic planning data is places of the base stations and the channel assignments to those base stations. Coverage analysis reveals the received signal power values that are coming from the base stations, all over the service area. In order to make a coverage analysis the building data and terrain profile are used. At the beginning of the simulation, these data are fed to the simulator.

3.3 Configuration Parameters and Performance Metrics

The configuration parameters can be classified into three main parts.

- Mobile user's parameters
    - Speed
    - Traffic profile
- System configuration parameters
    - Base station locations
    - Number of voice channels assigned to each base station
    - Received signal power over the simulation area, for each base station (dBm)
    - Handover Threshold (dBm)
    - Minimum received signal power for communication (dBm)
    - SINAD threshold (dB)
    - Hysteris Value (dB)
- Simulation parameters
    - Physical dimensions of the simulation area
    - Duration of simulation
    - Number of mobile users to be simulated

Speed of the mobiles is used when generating the movement of the users in the simulation area. Traffic profile parameters are used in producing the random traffic for the mobiles. There are two traffic related parameters, on time and off time. On time is the time duration, when the mobile is established a link to a base station. Off time is the period, when the mobile's radio is off. These both time intervals are modeled as negative exponential random distribution, which the formula for the random number is given in (3.1).

$$E = -\mu * \log_{10}(U) \tag{3.1}$$

where,

μ: Mean of the exponential random number

E: Exponential random number

U: Uniform random number between 0 and 1

On time and off time random numbers have a mean of average on time and average off time respectively. The typical values used in the simulator are tabulated in Table 3.1.

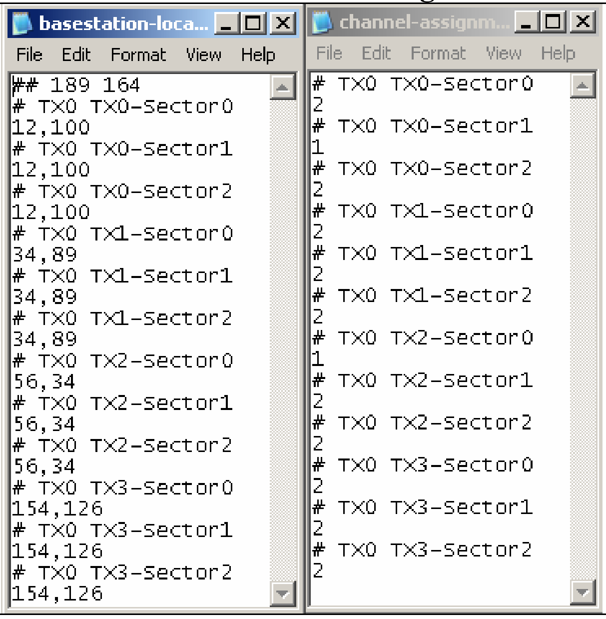
Average on time	Average off time
60 sec.	10 min.

Table 3.1: Average on and off time values

With the given mean values, the simulator generates the time instances when the mobile will attempt a connection and when the mobile closes the connection.

System configuration parameters consist of network planning outputs and GSM related parameters. Network planning outputs are; base station locations, number of channels allocated to each base station and received signal strength data for each base station. These data are stored in text files and read by the simulator at the beginning of the simulation. Examples of these text files are shown in Figure 3.2.

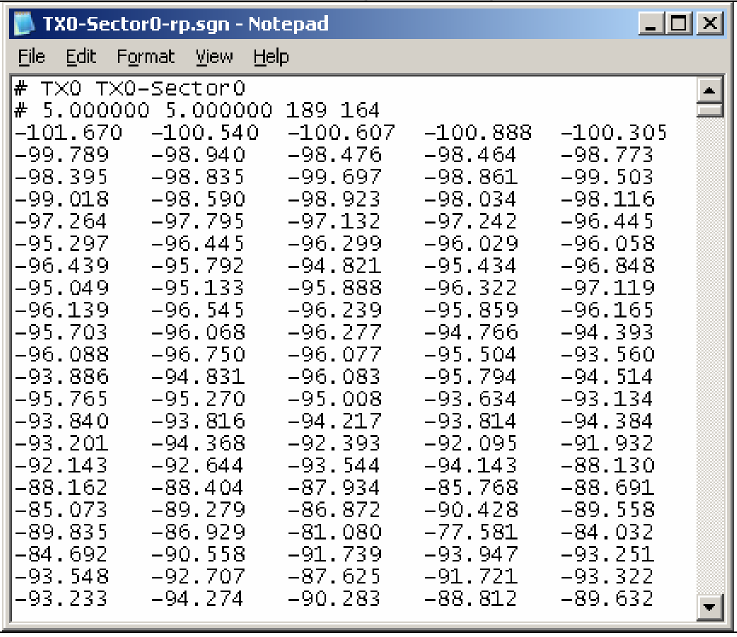
Base station locations **Channel assignments**



```
## 189 164
# TX0 TX0-Sector0
12,100
# TX0 TX0-Sector1
12,100
# TX0 TX0-Sector2
12,100
# TX0 TX1-Sector0
34,89
# TX0 TX1-Sector1
34,89
# TX0 TX1-Sector2
34,89
# TX0 TX2-Sector0
56,34
# TX0 TX2-Sector1
56,34
# TX0 TX2-Sector2
56,34
# TX0 TX3-Sector0
154,126
# TX0 TX3-Sector1
154,126
# TX0 TX3-Sector2
154,126
```

```
# TX0 TX0-Sector0
2
# TX0 TX0-Sector1
1
# TX0 TX0-Sector2
2
# TX0 TX1-Sector0
2
# TX0 TX1-Sector1
2
# TX0 TX1-Sector2
2
# TX0 TX2-Sector0
1
# TX0 TX2-Sector1
2
# TX0 TX2-Sector2
2
# TX0 TX3-Sector0
2
# TX0 TX3-Sector1
2
# TX0 TX3-Sector2
2
```

Received signal strength



```
# TX0 TX0-Sector0
# 5.000000 5.000000 189 164
-101.670  -100.540  -100.607  -100.888  -100.305
-99.789   -98.940   -98.476   -98.464   -98.773
-98.395   -98.835   -99.697   -98.861   -99.503
-99.018   -98.590   -98.923   -98.034   -98.116
-97.264   -97.795   -97.132   -97.242   -96.445
-95.297   -96.445   -96.299   -96.029   -96.058
-96.439   -95.792   -94.821   -95.434   -96.848
-95.049   -95.133   -95.888   -96.322   -97.119
-96.139   -96.545   -96.239   -95.859   -96.165
-95.703   -96.068   -96.277   -94.766   -94.393
-96.088   -96.750   -96.077   -95.504   -93.560
-93.886   -94.831   -96.083   -95.794   -94.514
-95.765   -95.270   -95.008   -93.634   -93.134
-93.840   -93.816   -94.217   -93.814   -94.384
-93.201   -94.368   -92.393   -92.095   -91.932
-92.143   -92.644   -93.544   -94.143   -88.130
-88.162   -88.404   -87.934   -85.768   -88.691
-85.073   -89.279   -86.872   -90.428   -89.558
-89.835   -86.929   -81.080   -77.581   -84.032
-84.692   -90.558   -91.739   -93.947   -93.251
-93.548   -92.707   -87.625   -91.721   -93.322
-93.233   -94.274   -90.283   -88.812   -89.632
```

Figure 3.2: Base station location, frequency allocation and received signal power text files

First line in base station locations file starts with '##'. The two numbers indicate the size of the simulation grid. In this example, there are 189 * 164 grid points in the simulation area. The metric resolution is 5 m. so; the physical dimension of the region is 189*5=945m to 164*5=820m. The lines starting with '#' indicates the id's of the base stations and the followings lines denotes the location that base station in the grid. For example, the 'TX-0 Sector 0' base station is located at (12,100) in the grid. Note that, there are three sectors for each cell, because 120° sectored base stations are used. Three sectors of a site[6] are located at the same spot in the grid.

Channel assignment file consists of the number of channels allocated to each base station. The lines starting with '#' denotes the id's of the base stations and the following lines denotes the number of frequency channel allocated to that base station. For example, the site with id 'TX-1 Sector2' has 2 frequency channels. Every frequency channel has 8 time slots, 1 reserved for control issues. Therefore, there exists 2*8 – 1 = 15 traffic channels in that base station. This means, 15 mobiles can connect to that base station at the same time. TDMA synchronizes the time slots, so there is no interference between mobiles that are using the same frequency band in a single cell. On the other hand, in GSM the same frequency band can be assigned to two or more different base stations. This causes interference and limits the usage of large frequency reuse ratios[7].

Received signal strength files consist of the powers of the signal transmitted (in dBm) from each base station all over the terrain. The first line that is starting with '#' denotes the base station id. The second line has the metric resolution and the corresponding grid size of the simulation area. For example, Figure 3.2 shows a signal power file for base station 'TX-0 Sector0'. The file has a metric resolution of 5m to 5m and has a grid size of 189 to 164. If a mobile is located at 0,0 location in

---

[6] Site corresponds to a cell in GSM

[7] Frequency reuse: The ability of specific channels assigned to a single cell to be used again in another cell, when there is enough distance between the two cells to prevent co-channel interference from affecting service quality. The technique enables a cellular system to increase capacity with a limited number of channels.

the simulation grid and connected to base station ‘TX-0 Sector0’, the received signal strength coming from the base station is –101.67 dBm.

The other system configuration parameters are handover threshold, minimum received signal power, SINAD threshold and hysteris value. Handover threshold and hysteris are used in determining a handover. Minimum received signal strength is the threshold, which a mobile must obtain in order to connect successfully to a base station [24]. SINAD threshold is also used in determining a successful connection. The usage of these parameters is explained in the Section 3.4. The default values are tabulated in Table 3.2.

Handover Threshold (dBm)	Minimum received signal power (dBm)	SINAD threshold (dB)	Hysterisis (dB)
-85	-105	19	3

Table 3.2: Default GSM configuration parameters

The simulation parameters are physical dimensions of the simulation area, duration of simulation and number of mobile users in the simulation. Example values of simulation parameters are given in Table 3.3.

Physical dimensions	Duration of simulation	Number of mobiles
800m * 1000m	10000 sec	350

Table 3.3: Sample simulation parameters

3.4 GSM Mobility Simulator Algorithm

The simulator is written in C# software language and the algorithm is as follows:

Simulator Algorithm

```
While the simulation ends
{
    For all mobile users
    {
        If radio of the mobile is ON (1)
        {
            Update Active Set (2)
            If the user is not connected to any base station
            {
                Attempt to connect
                Calculate SINAD (3)
                If (SINAD > SINAD threshold) AND (there is a free channel)
                {
                    Successful Connection
                }
                Else
                {
                    Unsuccessful Connection
                }
            }
            Else
            {
                Check for handover (4)
                If handover is not needed
                {
                    If (SINAD < SINAD threshold)
                    {
                        Unsuccessful Connection
                    }
                }
            }
        }
        Move the mobile unit (5)
    }
}
```

Statement ***(1)*** is decided by the exponential on/off traffic generation procedure. Active set stated in ***(2)*** is defined as eight base stations with maximum received power at the recent position of the mobile user. When the mobile's radio is on, the mobile will attempt to connect to the first base station in the active set (which have the highest received signal power). SINAD stated in ***(3)*** is the signal to interference + noise ratio. SINAD formulation is depicted in (3.2).

$$SINAD = \frac{S}{I+N} \tag{3.2}$$

where,

S: Signal power received from the serving base station
I: Total interfering signal power received from the other base station
N: Thermal Noise (N=k*T*B)
k: Boltzman's constant
T: Effective temperature
B: Channel bandwidth
(SINAD is due to frequency reuse and thermal noise in the GSM network)

The calculated SINAD value is compared with the SINAD threshold depicted in the system parameters. If the calculated value is lower than the threshold, connection cannot be established with that base station. Handover decision is taken by the handover algorithm, which is depicted in statement ***(4)***. The algorithm is as follows:

Handover Algorithm

```
If RPServingBS < Handover threshold (6)
{
    If (RPServingBS + Hysterisis) < RPAnyActiveSetBS (7)
    {
        If channel is available from that BS
        {
            Handover
        }
        Else
        {
            Handover is unsuccessful
        }
    }
}
```

RPServingBS stated in ***(6)*** is the received signal strength value from the serving (connected) base station. *RPAnyActiveSetBS* expressed in ***(7)*** is the received signal power value of base stations in the active set. If any of these values is smaller than the serving base station's received power plus hysterisis value, handover can occur. Hysterisis is defined in the system parameters. Statement ***(5)*** of the simulator algorithm assesses the mobility generator. In this step, the mobiles are re-located by using the step-taking algorithm.

3.5 Results Obtained from the Simulator

After the simulation ends successfully, the results are taken and visualized to the end-user. The outputs of the simulator show the simulation history and the GSM network performance. Obtained results are tabulated in Table 3.4.

3.5.1	Coverage Analysis
3.5.2	Localization
3.5.3	Successful / Unsuccessful Connections
3.5.4	Successful / Unsuccessful Handovers
3.5.5	Channel Utilization
3.5.6	Test Mobile Signal Profile

Table 3.4: Results obtained from the GSM mobility simulator

In each sub-chapter tabulated in Table 3.4, the methodology of obtaining the corresponding results is explained and sample snapshots of the results are given.

3.5.1 Coverage Analysis

This analysis can be done for each of the base station. It shows a colored map to represent the received power values of the interested base station all over the simulation area. The received signal power values that are read from the coverage files are drawn on the screen. By examining this map, the user can see the base stations coverage area. These maps are interactive to the end-user, so when the mouse is hovered around the map, the received signal strength in dBm and the position of the mouse in the grid is written to a text field. An example snapshot of a coverage analysis map is shown in Figure 3.3.

Intended base station can be selected

Mouse position and the received power value coming from the selected base station is shown

Figure 3.3: Coverage map snapshot

The red parts in this graph show the high coverage regions. These regions consist of points, which have higher received power values than the blue parts of the graph.

3.5.2 Localization

The color map show where the mobile users localized mostly in a thematic map fashion. The crowded areas can be seen and by overlaying the unsuccessful connection map on top of it, the end-user is able to see the network response to this crowdedness. The underlying data in this visual drawing can be referred as “probability of a mobile user located at a specific point”. The probability function is shown in (3.3).

$$p(x,y) = \frac{\sum_{t=0}^{Ts} Tstep(x,y,t)}{\max(\sum_{t=0}^{Ts} Tstep(x,y,t))} \tag{3.3}$$

where,

p(x,y): Probability that there is a user located at point x, y in the simulation environment.

Tstep(x,y,t): Total number of users located at point x, y at time t, during the simulation.

A probability of 1 is drawn with red. As the probability decreases to 0, the colors change to blue. An example snapshot of localization map is shown in Figure 3.4. The red parts indicate the crowded regions in the simulation. This is an example of a city center simulation. As long as the center of the city is more crowded then the other parts, by choosing more destination points in the center region, we can make the center parts of the city more crowded.

Figure 3.4: Localization map snapshot

3.5.3 Successful/Unsuccessful Connections

The connection statuses, which are monitored by the simulator, are stored and visualized to the end user. When a user attempts a call, the status of that call is stored. If that user is able to connect to the network, this call becomes a successful connection and shown in green spots on the simulation grid. On the other hand, unsuccessful attempts are shown in red spots. The more crowded locations in the simulation area, creates more unsuccessful connections because the number of available channels on these regions decreases due to high traffic demand as shown in Figure 3.5. In addition, less covered regions, which can be visualized by the coverage analysis map, generates red spots. In these areas, the received signal powers are low so active set becomes smaller and the user's call attempts turns out to be unsuccessful.

Figure 3.5: Successful/Unsuccessful Connections snapshot

3.5.4 Successful/Unsuccessful Handovers

Handover handling is an import role of the GSM network infrastructure and it directly affects the system service quality. In its nature, GSM networks must handle mobility. Communication must be continued while the user is moving through different cells. The mobile units are using different voice channels in different cells so, when moving out of a cell and getting in the coverage region of another cell, the previous cell's voice channel must be de-allocated and the new cell's voice channel must be allocated. Handovers are used to satisfy continuous traffic of the mobile units. If this procedure is successful from start to finish, it becomes a successful handover, on the other hand if the mobile user cannot find an available channel from the new base station or the received signal power drops below the minimum acceptable threshold, it becomes an unsuccessful handover. Similar with the Successful / Unsuccessful connections map, successful handover are drawn with green on the simulation grid and the unsuccessful ones with red as shown in Figure 3.6.

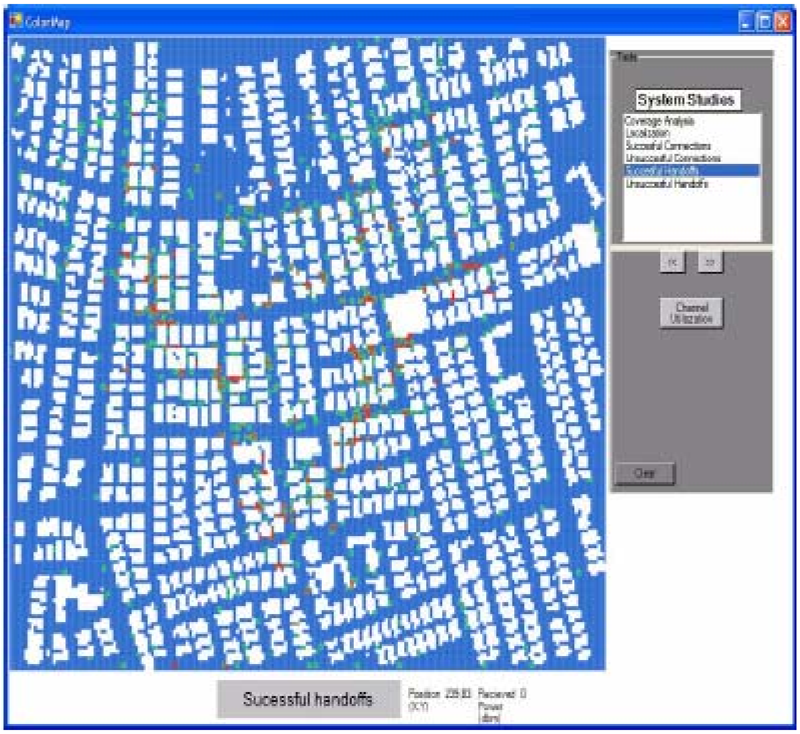


Figure 3.6: Successful/Unsuccessful Handovers snapshot

Monitoring handovers are the main interest of dynamic simulators and they must be well modeled. Handovers cause traffic overhead on the GSM network and bad handling of handovers degrades system quality. If there are unsuccessful handovers in the simulation, more channels must be assigned to the base station in order to serve this offered traffic.

3.5.5 Channel Utilization Graphs

After the planning phase, an appropriate amount of frequency channels is assigned to each base station. GSM uses TDMA as a medium access protocol, and from one frequency channel, eight voice channels are formed. Therefore, from one frequency, the base station can serve eight users at the same time. Channel utilization graphs for each base station can be seen at the end of the simulation. These graphs show the total available number of voice channels with respect to simulation time. The maximum value of the total available number of voice channels is set in the parameters part of the simulation model. By investigating these graphs, how well the GSM network utilizes its spectrum to the given service can be measured. An example channel-utilization graph is shown in Figure 3.7.

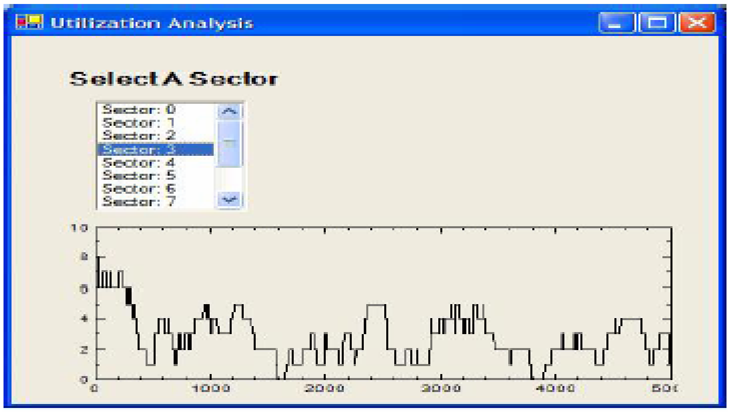


Figure 3.7: Channel Utilization Graph snapshot

Figure 3.7 shows a channel utilization graph for a base station, which has 1 frequency channel. There are 8 TDMA slots for this one frequency channel, but one slot is reserved for control issues. The maximum available channel in this graph is 7 (1*8-1).

3.5.6 Test Mobile Signal Profile

By the help of the test mobile module, the end-user can create a test mobile and define a specific route for this test unit, as shown in Figure 3.8. In addition, end-user can see the received signal strength for this specified path. The received signal for the path specified in Figure 3.8, is shown in Figure 3.9. If this test unit encounters handovers at this route, this tool shows the locations of handovers. It also shows the connected base stations during this process. After a simulation run, if there are suspicious places in the grid that causes unsuccessful connections and handovers, they can be investigated by using this tool. For example, in Figure 3.9, there is a sudden decrease in signal strength at the end of the graph, so this point can be interpreted as a possible connection loss (unsuccessful handover) point.

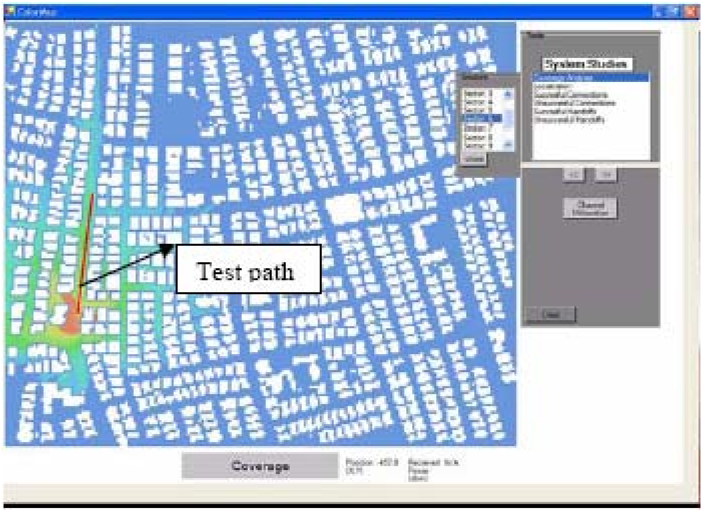


Figure 3.8: Test mobile illustration

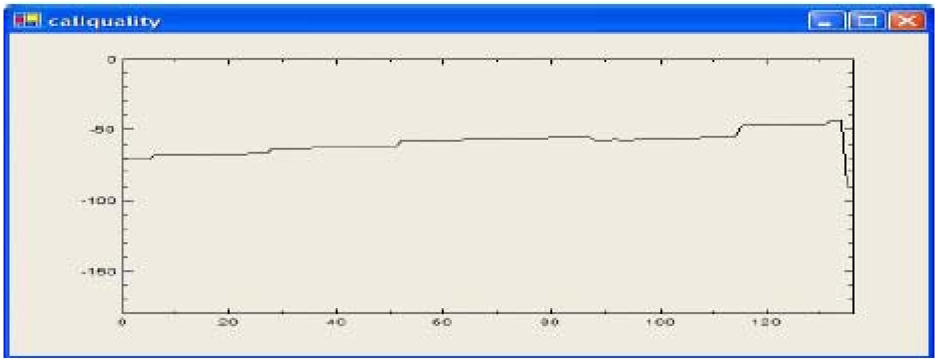


Figure 3.9: Test mobile signal profile

3.6 Sample Simulations

The simulation area is 950m to 830m in size and underneath has building profile as illustrated in Figure 3.10.

Figure 3.10: Sample Simulation area (950m*830m)

There are four installed base station towers in the simulation area and each base station tower contains three 120^{o} sectored base stations, so totally there exist 12 sectors (cells) in the region. This planned network infrastructure and propagation simulation results are shown in Figure 3.11. There are 12 sectors, so there are 12 plots in Figure 3.11, which represent the coverage regions of each sector.

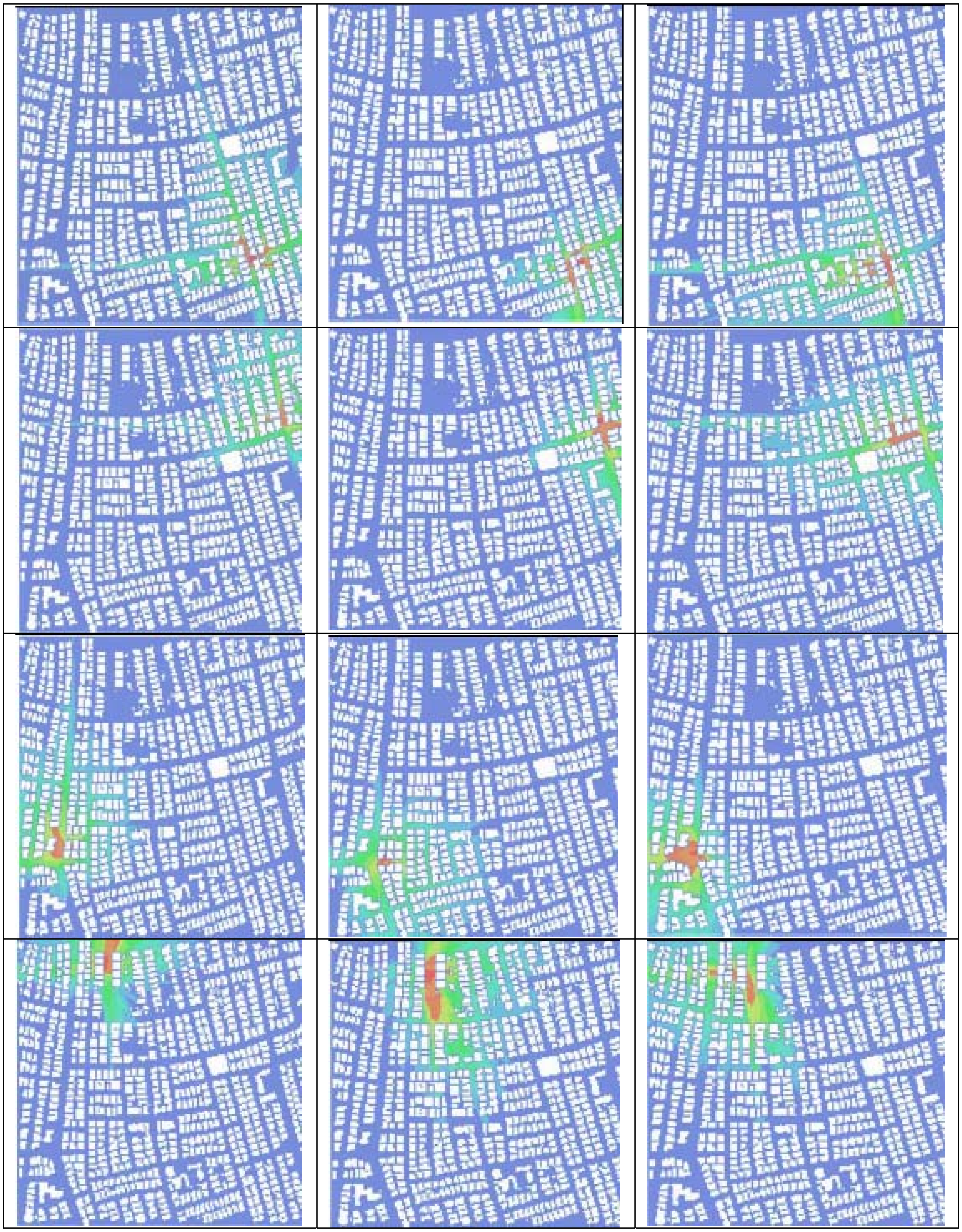


Figure 3.11: Coverage plots for sample simulation

In all of the sectors, 2 frequency channels are assigned as a result of traffic planning phase. Therefore, totally there are 12 * 2 = 24 frequency channels in the network. Each frequency channel has 8 time slots, 1 reserved for control issues, so there exist 24 * (8-1) = 168 traffic channels in the whole GSM network. Consequently, at a specific instance, maximum 168 mobile users can connect to this GSM network. On the other hand, mobility brings capacity degradations to the system, because, the user population changes dynamically resulting in crowded locations (hot spots). By using this mobility simulation, these regions will be determined. Using this scenario, two different simulations are done. First one is a less crowded (relatively less crowded) city simulation containing 100 mobile users. On the other hand, second simulation is a crowded city simulation containing 300 mobile users on the area.

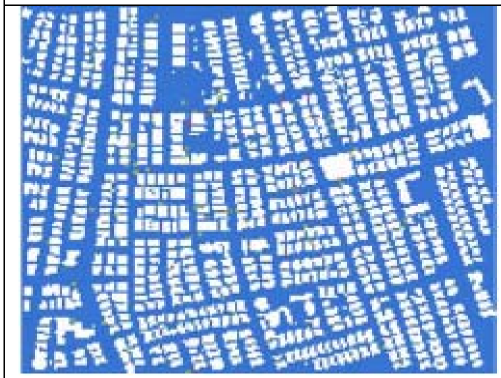
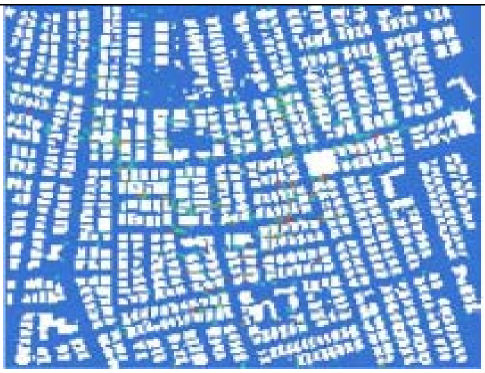
Mobility behaviors are the same for the two simulations, the mobile users travel at a speed of 5 km/h. In addition, traffic behaviors are similar; the mobiles have average on time 60sec and average off time 600sec in both of the simulations. These parameters are tabulated in Table 3.5.

	Simulation1	Simulation2
Number of mobiles	100	300
Mobile Speed (km/h)	5	5
Average on time (sec)	60	60
Average off time (sec)	600	600
Total simulation time (sec)	10000	10000

Table 3.5: Sample simulation parameters

3.6.1 Results And Discussion

Figures 3.12 and 3.13 shows the localization maps for simulation 1 and 2, respectively. The successful and unsuccessful connections are depicted in Figures 3.14 and 3.15. In addition, successful/unsuccessful handovers for simulation 1 and 2 are shown in Figures 3.16 and 3.17, respectively. Figure 3.18 and 3.19 shows a snapshot of channel utilization for a lightly loaded and a highly loaded base station, respectively. Table 3.6 gives some numerical results obtained from these simulations.

 Figure 3.12: Localization for Simulation 1	 Figure 3.13: Localization for Simulation 2
 Figure 3.14: Connections for Simulation 1	 Figure 3.15: Connections for Simulation 5
 Figure 3.16: Handovers for Simulation 1	 Figure 3.17: Handovers for Simulation 2

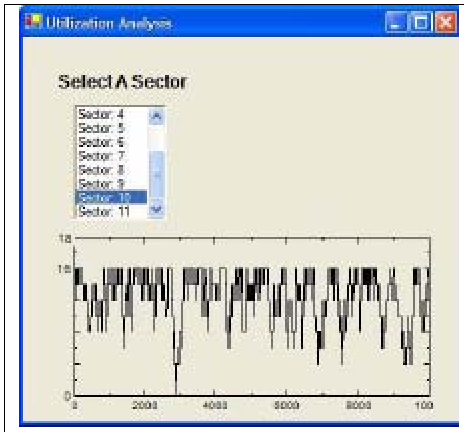


Figure 3.18: Lightly loaded base station’s channel utilization

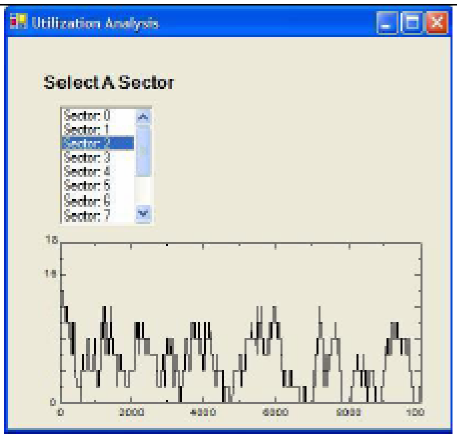


Figure 3.19: Highly loaded base station’s channel utilization

	Number of users	Unsuccessful connection rate	Unsuccessful handover rate
Simulation 1	100	~7%	~0.8%
Simulation 2	300	~12%	~1.5%

Table 3.6: Numerical results of sample simulation

As seen from the localization maps for both of the simulations (Figure 3.12, 3.13), the center area of the simulation grid is more congested than the other parts. This is because the destination points chosen by the mobility generator are more in the center parts, imitating a busy hour city center. Although there are 168 voice channels available, 7% of the calls are dropped in simulation 1 containing 100 mobile users. This is because, during the simulation, the mobiles are packed to the city center causing high traffic demand in those regions. A static simulator cannot create this effect, because it cannot reflect the dynamic behavior of the mobiles in a crowded city. The dynamic simulator also says that, approximately 1% of the handovers are resulted in connection losses. By imitating the dynamicity of the users in the service area, handovers can be investigated and a service provider can take into account the handover capacity. The base stations that encounter more handover losses must be given more channels that are reserved only for handover (Figures 3.16, 3.17). If the base stations’ traffic loads are also known by the results

(Figures 3.18, 3.19) of a dynamic simulation (using channel utilization graphs), more frequency channels can be assigned to those that have high traffic load. As expected, in simulation 2, there are more losses of connection than simulation 1, because, the number of users in the second simulation is three folds compared to the first simulation (Figures 3.14, 3.15 and Table 3.6). 90% of the unsuccessful connections are in the central locations of the simulation area; this is because central parts demand more traffic from the GSM network.

3.6.2 The effects of "simulation time"

6 simulations are done for different simulations durations, in order to see the effects of the simulation time on the unsuccessful connection rates. In Table 3.7 the results of these 6 simulations are given.

	Number of users	Simulation duration (sec)	Unsuccessful Connection Rate
Simulation 1	100	2000	15.2%
Simulation 2	100	3000	14.1%
Simulation 3	100	4000	13.6%
Simulation 4	100	8000	9.5%
Simulation 5	100	10000	7%
Simulation 6	100	15000	6.9%

Table 3.7: The effect of simulation time on unsuccessful connection rate

As seen from Table 3.7, when the simulation time is short, the unsuccessful connection rate is overshot and when simulation time increases, unsuccessful connection rates converge. This is because of the random variable used in the mobility generator. When used for a long duration, it converges to a true value and reflects the correct capacity utilization of the network.

3.6.3 The effects of “average on time” of the mobile users

6 simulations are done for different “average on time” parameter, in order to see the effects of this parameter on the unsuccessful connection rates. In Table 3.8 the results of these 6 simulations are given.

	Number of users	Simulation duration (sec)	Average on time (sec)	Unsuccessful Connection Rate
Simulation 1	300	10000	15	10.7%
Simulation 2	300	10000	25	10.9%
Simulation 3	300	10000	40	11.1%
Simulation 4	300	10000	60	12.0%
Simulation 5	300	10000	100	13.1%
Simulation 6	300	10000	150	13.8%

Table 3.8: The effect of average on time on unsuccessful connection rate

As the mobile user’s conversation duration increases, network service quality degrades. Mobile users start to allocate the voice channels long, and the available voice channels at any instance in the whole network decreases.

Chapter 4

UMTS SIMULATION

In this chapter, a dynamic UMTS network simulator tool is explained. A static simulator does not model the time-depending characteristics of UMTS system, dynamic power control, mobile motions and dynamic call statistics of mobile users. Therefore a dynamic simulation tool is needed to see the performance of this wireless network accurately [12]. The tool is similar to the GSM network simulator. Both of them are mobility simulators that imitate the mobile behavior of the users and reflect the responses of these wireless networks due to this dynamic changing in conditions. On the other hand, the main difference between UMTS and GSM simulator is the importance of modeling and calculation of the interference in the network. In addition to this, in UMTS there exist different data rate demands that cause different signal-to-noise ratio requirements at the base and mobile stations. Uplink[8] and downlink[9] conditions can be thought as in balance, so in this UMTS network simulator, only uplink is modeled. Propagation simulations are done similarly in both GSM and UMTS networks explained in the previous sections. Uplink only modeling is an assumption, which omits the downlink conditions in the UMTS system.

In fact, this simulator can be referred as a long-term dynamic simulator, because it is an extended version of a static simulator. Static simulation's snapshots are linked together in the time scale. Each mobile has two important time-related

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[8] Uplink is the connection from mobile to base station

[9] Downlink is the connection from base to mobile station

characteristics, movement and call activity. Mobility behavior is designed carefully, because the intended traffic distribution is non-homogenous. The probability of mobile passing through any particular simulation space is non-homogenous. This kind of a model can support variation of the mobile's data rates during a call. Call activity can be modeled by exponential traffic, that, every mobile is set to on or off modes during the simulation time. On the average, each mobile on/off periods fits to an exponential distribution. The traffic model is the same as the GSM simulator case, explained in Chapter 3.

A long-term dynamic model is expected to operate in large time steps (1s – 20s) [12]. In the simulation model, there is no-explicit signal level fading and therefore no explicit power control. However, at every time step, the system power balancing is triggered, accounting for changes in path loss between mobile and the base stations as well as initiation or termination of calls. During the power-balancing algorithm, changes in soft handover status are also calculated and taken into account. The status of the base station's average transmitted power can be utilized to admit or reject new calls.

4.1 UMTS Overview

In response to the growing demand, Universal Mobile Telecommunications System signals to move into third generation (3G) of mobile networks. UMTS uses Code Division Multiple Access (CDMA) as medium access layer. In CDMA, every user will be allocated the entire spectrum all of the time, in opposite to GSM networks that use TDMA and FDMA.

CDMA uses unique spreading code signal to spread the base-band data. In order to spread the data, the spreading code signal must have larger rate. The rate of this signal is called chip rate and denoted by W[10]. At the receiver, there is a

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[10] W is the chip rate, which is equal to 3.84MHz in UMTS

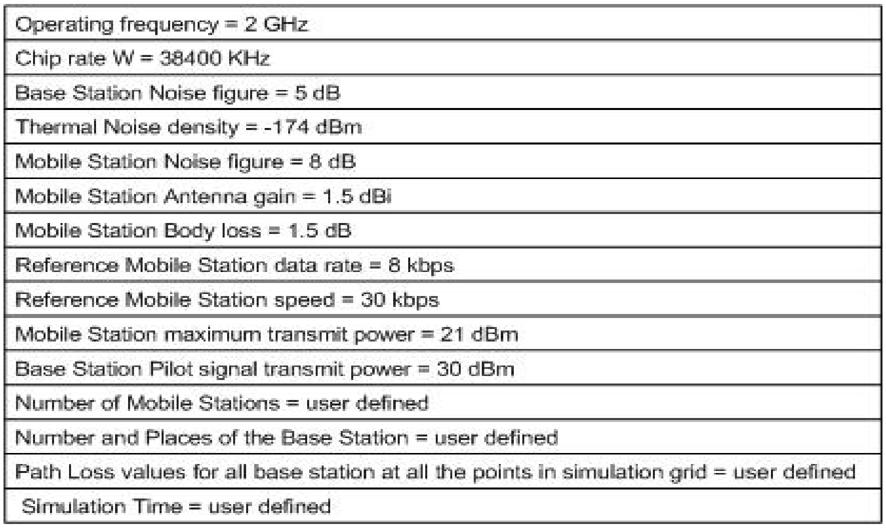
signal, which consists of different coded signals overlapped at the same frequency band [13].

The channel consists of same frequency band signals overlapped in time. Using unique codes at the transmitter, the receiver can de-correlate the wanted signal.

The interference acts as noise at the receiver. Optimally, the codes are 100% orthogonal, but in a real case, they are not. In order to have a large number of these orthogonal coding signals, the length of the code must be very large and it is not practical. The interference is due to this problem of coding signals. The receiver cannot de-correlate the wanted signal when interference is high. System capacity and call quality is very much dependent on the interference level. Power control process is deployed in UMTS to struggle the effects of the interference. It is used to limit the transmit powers of both the mobile and the base station, while maintaining the required level for good call quality.

4.2 Configuration Parameters and Performance Metrics

In the initialization part of the program, the UMTS network related parameters, base and mobile station parameters, propagation simulation results and the parameters needed for the mobility simulator are loaded to the dynamic UMTS simulator tool. The parameters are tabulated in Table 4.1.



Operating frequency = 2 GHz
Chip rate W = 38400 KHz
Base Station Noise figure = 5 dB
Thermal Noise density = -174 dBm
Mobile Station Noise figure = 8 dB
Mobile Station Antenna gain = 1.5 dBi
Mobile Station Body loss = 1.5 dB
Reference Mobile Station data rate = 8 kbps
Reference Mobile Station speed = 30 kbps
Mobile Station maximum transmit power = 21 dBm
Base Station Pilot signal transmit power = 30 dBm
Number of Mobile Stations = user defined
Number and Places of the Base Station = user defined
Path Loss values for all base station at all the points in simulation grid = user defined
Simulation Time = user defined

Table 4.1: Configuration parameters of UMTS simulator

After, loading the parameters, the link level simulation results are inserted to the tool structure. In this thesis, 'ITU's Pedestrian A' link model [14] for UMTS is used. The model is used to extract Eb/No[11] requirements for different service demands. Service demand in UMTS changes with different data rate and user speed. Link level simulation results also consists of average transmit power rise with respect to different mobile speeds, SHO gain with respect to user speeds and the signal power difference between the best server link and the second best server link. In addition, activity factors for different data rates and orthogonality factor for different mobile speeds are implemented in ITU's recommendation [14].

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[11] Eb/No is bit energy per noise density

Eb/No value is an important parameter in CDMA networks. It represents the average bit energy to noise-density ratio requirement. This requirement varies with different data rates of the mobile users. UMTS, which uses CDMA as medium access layer, inference can be modeled as noise (No) because all of the users use the same frequency channel but with different codes. The codes must be 100% orthogonal otherwise, interference happens. As the data rate demand and the speed of the mobile increases, the Eb/No requirement for a successful connection increases. This property is depicted in Figure 4.1.

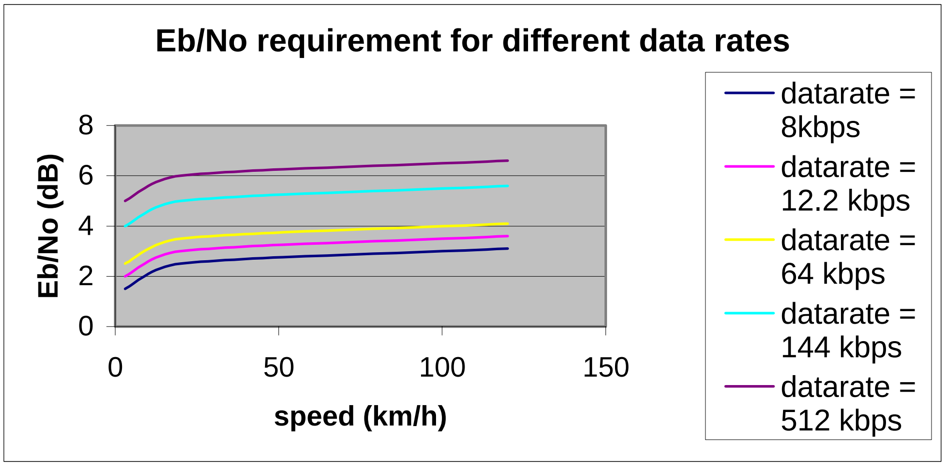

Figure 4.1: Eb/No requirement versus data rate and speed.

In Figure 4.2, orthogonality and activity factor is changing with speed and data rate demand of the mobile. At higher speeds, orthogonality degrades. Activity factor increases with data rate demand of the mobile. After ~150kbps, activity factor is 1, because at these higher rates, the demand is modeled as a “file transfer” or “high speed video conferencing”.

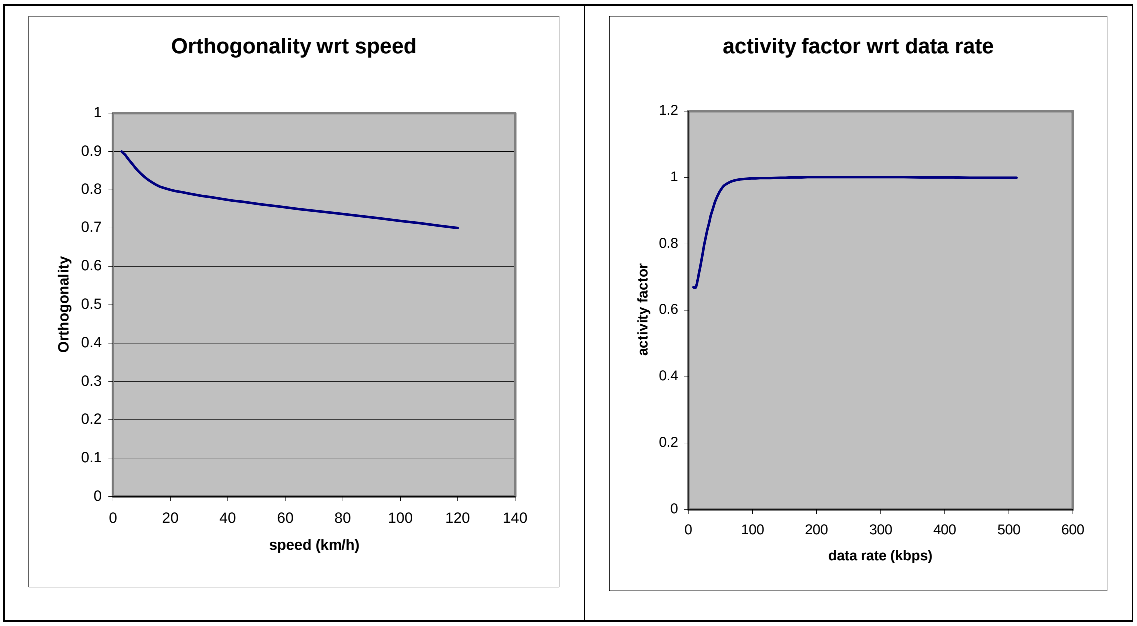

Figure 4.2: Orthogonality and activity factor versus speed and data rate, respectively.

One of the main parameters in determining the capacity of a CDMA system is the ratio of energy per information bit to noise power spectrum density (Eb/No) required to achieve certain quality of service requirements such as frame or bit error rate. The required Eb/No value depends on frame structure, coding and modulation characteristics, diversity techniques and channel model. It is a measure of signal to noise ratio for a digital communication system. It is computed at the input to the receiver and is used as the basic measure of how strong the signal is. In this respect, it is the fundamental prediction tool for determining a digital link's performance.

Another, more easily measured predictor of performance is the signal-to-noise ratio or S/N. In CDMA type systems, generally Eb/No is used. In GSM S/N is used, as a signal quality metric. Eb/No can be converted to S/N by the fallowing formulas (4.1) and (4.2):

$$\frac{S}{N} = \frac{Eb}{No} * \frac{d}{B} \tag{4.1}$$

$$N = k * T * B \tag{4.2}$$

where,

d: Data rate

B: Bandwidth

N: Noise

k: Boltzmann's constant = $1.380650\text{x}10^{-23}$ J/K,

T: Effective temperature in Kelvin, and = 290K,

B: Receiver bandwidth = 1MHz.

N= ($1.380650\text{x}10^{-23}$ J/K) * (290K) *(1MHz) = $4\text{x}10^{-15}$ W = $4\text{x}10^{-12}$mW = -114dBm

By using this conversion, the required signal power can be calculated. This is how much power the receiver must have at its input. To determine the real transmitter power, the path loss must be added. The receivers are designed taking into account this noise, in a CDMA network. This noise has a frequency spectrum that is continuous and uniform over a specified frequency band. White noise has equal power per hertz over the specified frequency band. In addition to this noise, there exists interference due to imperfect orthogonal codes. This power value is added to the noise, degrading call quality at the receiver.

In GSM simulation, minimum required received signal power for a mobile user to access the network is constant because all the users use the same data rate. On the other hand, in UMTS the minimum required signal power for a successful connection is determined by the Eb/No requirement and interference at the terminal depending on the data rate, speed and othagonality of the codes. Code Division Multiple Access (CDMA) systems are well known to be interference limited and to require power control to counteract the effects of the near-far problem and slow shadow fading. In addition, third generation mobile radio systems based on CDMA, such us UMTS, use fast power control which is able to increase capacity by compensating radio channel variations due to multi-path fading for users moving at a low, even moderate speed [15, 23].

Fast power control mechanism is deployed in UMTS because the adjustment of the transmit powers of both the base and the mobile stations is crucial. Unnecessary amount of transmit power of mobile or the base stations degrades the capacity and the performance of the CDMA networks. In UMTS, the interference is modeled as noise and the receivers can distinguish the same frequency signals using orthogonal codes if the received powers are nearly the same at the terminal. However if a signal dominates the receiver with vast power, receiver cannot demodulate the data needed from the signals that have the same frequency. In this scheme, so many variations of the transmit powers cause an average increase in noise at the terminals. An average amount power must be added to the transmit powers of the mobile units. The value is obtained from the "ITU's pedestrian A" tables. Orthogonality must also be modeled in calculating the interference coming from the other terminals that are also communicating. The othogonality factor depends on the mobile terminal speed and it is obtained from the link level simulation results.

Handover occurs when a call has to be passed from one cell to another as the user moves between cells. In a traditional "hard" handover, the connection to the current cell is broken, and then the connection to the new cell is made. This is known as a "break-before-make" handover. Since all cells in CDMA use the same frequency, it is possible to make the connection to the new cell before leaving the current cell. This is known as a "make-before-break" or "soft" handover. Soft handovers require less power, which reduces interference and increases capacity. Mobile can be connected to more than two BTS [13].

When a mobile terminal is in soft handover, it is actually communicating with more than one base station. The received signals at the multiple base stations are compared and the best of those signals is used. By this way, UMTS networks advantages the performance in the uplink. In addition to this, if there are more than one used links for only one communication, at the receiver the Eb/No requirement decreases. The SHO[12] gain is subtracted from the normal Eb/No requirement. In GSM there is an active set that is determined by the received signal strengths and the mobile user handovers between the base stations that are in the active set. Conversely, in UMTS the mobile terminal setups links to all off the base stations in the active set. These values calculated from the link level simulation results, obtained by ITU pedestrian A, are different for each mobile station that communicates in uplink. Different mobiles can demand different services with varying physical speeds.

4.3 UMTS Mobility Simulator Algorithm

The UMTS simulator program tries to assign appropriate mobile station transmit powers. Program uses a convergence loop and iterates a number of times, reaching the convergence criteria. The time resolution of the simulator is similar to the GSM network simulator and is in the order of seconds, which is user adjustable. At every iteration step, the base station sensitivities are calculated and compared with the previous iteration's sensitivity value. If there is a small difference, the convergence criterion is satisfied and simulator advances to the next simulation instance. At every simulation instance, the mobiles are moved. Base station sensitivity is the required signal power that the base station needs for a successful uplink connection. The simulator's block diagram is shown in Figure 4.3.

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[12] SHO is Soft Handover

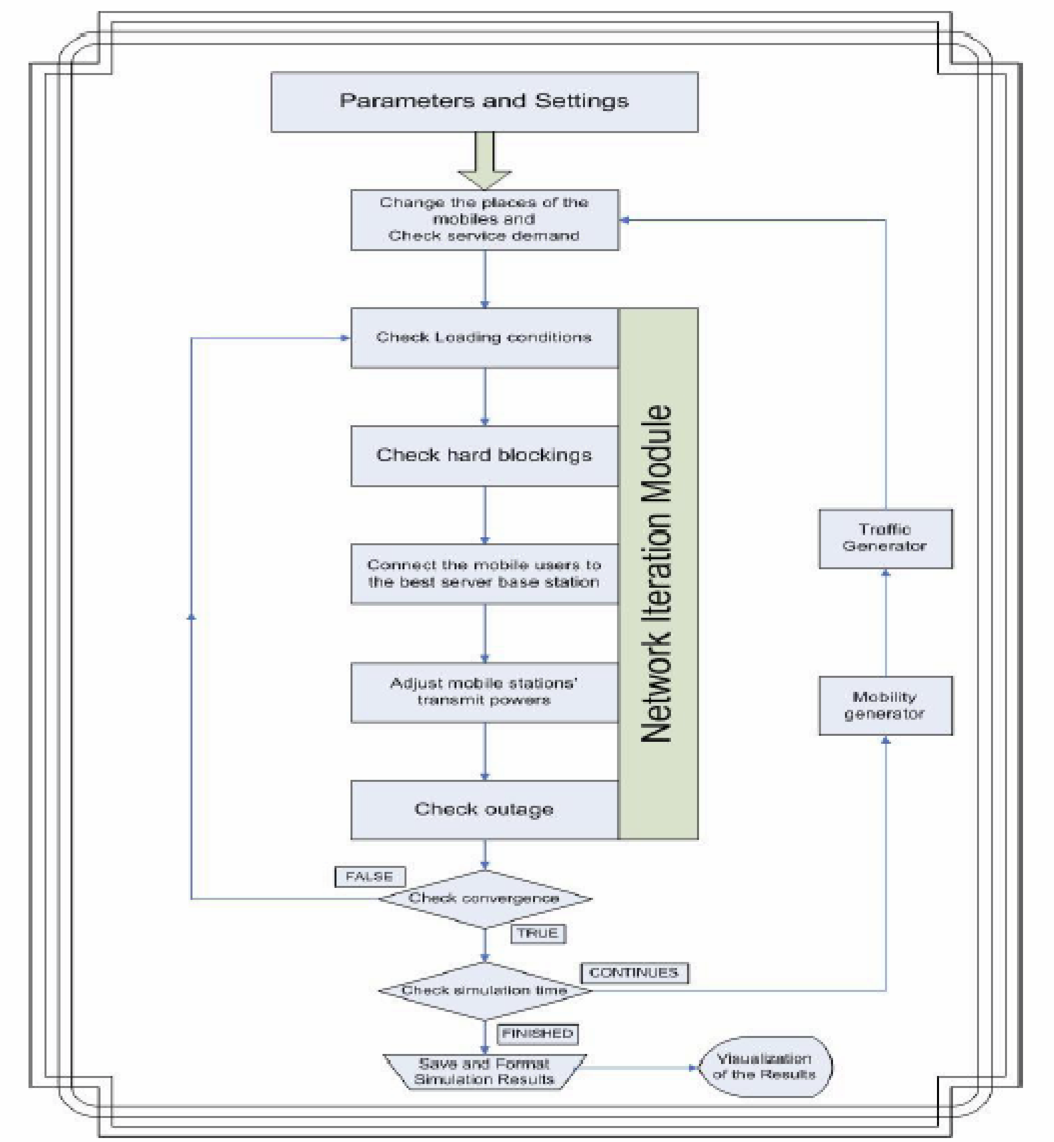
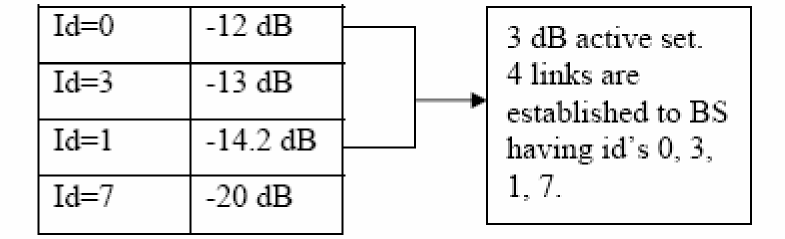


Figure 4.3: UMTS simulator block diagram

At the beginning of the simulation the initial mobile stations transmit powers are assigned. Then, the initial connections of the mobiles are established to the best servers. The loading is calculated and checked whether it is larger than the threshold. Consequently, hard blocking is checked for all mobile units. Next, the mobile unit's transmit powers are calculated and assigned. Finally, the convergence criterion is checked. If the convergence criterion is met, the simulator stops iterating.

The initial transmit powers are default values that depend on the path loss value in the uplink direction (depending on the positions of the base and the mobile station in the simulation grid) and the default sensitivity value of the base station. Default value is normally half of the maximum value (half of 21 dBm). As long as the transmit powers of mobiles will be adjusted at every simulation instance, using half power values initially, is logical.

The mobile stations' best server is determined purely by the path loss values in the uplink between the mobile terminal and all of the base stations. All of the path loss values are read from the path loss files and sorted in the ascending order. The base station that is at the top in the sorted list is chosen as the best server and an uplink connection is established between these stations. Also soft handover connections are established in this phase. In the sorted list, a window that is determined by the active set threshold value (3dB) is chosen and the base stations that are in the active list of the mobile are selected as soft handovered base stations. Therefore, numerous links can be allocated for a single user in the uplink by using soft handover property of UMTS networks. SHO connections are illustrated in Figure 4.4.



Id=0	-12 dB
Id=3	-13 dB
Id=1	-14.2 dB
Id=7	-20 dB

3 dB active set.
4 links are established to BS having id's 0, 3, 1, 7.

Figure 4.4: Active set of a sample mobile station (SHO connections).

"Loading" is a parameter that is calculated for all of the base stations in the network. It reflects the traffic load on that base station by using both own-cell and other cell interference values. Own-cell interference denotes the interference coming from the mobile users that are using the links of that base station as best server connection. Consequently, other cell interference is interpreted as the total interfering signal power coming from other cells except the best server. Interference is calculated as the total signal power, each multiplied with the orthogonality factor. Interfering signal depends on the orthogonality, which varies with the speed of the mobile terminal. Speed-orthogonality relation is obtained from ITU's pedestrian A tables as illustrated in Figure 4.2. Cell loading can be calculated by (4.3).

$$cell-loading(bs_k) = \frac{(Int_{oth} + Int_{own})}{(Int_{oth} + Int_{own} + N)} \tag{4.3}$$

where,

Int_{oth} (Other cell interference): Signal power interference that is coming from cells except the one that the base station k is in.

Int_{own} (Own cell interference): Signal power interference that is coming from the cell; the base station k is in.

$N = (thermal\_noise + basestation\_noisefigure) * W$

W : Chip Rate = 3.84 MHz

Cell-loading value is always smaller than 1, because there always exist noise N. If at any instance of the simulation, cell loading value exceeds the threshold assigned in the parameters part, those mobile stations that uses the maximum transmit power to reach the current base station is disconnected from the network. This connection is saved as an unsuccessful connection. Default value for cell-loading threshold is 0.9.

At every instance in the network iteration module, hard blocking can occur. Hard blockings in UMTS networks are due to the insufficient physical channels. By default, there are 6 channels for a single base station and 32 codes for a single channel. By using sectored cells, capacity can be increased. Similar to GSM, 32 codes are like 8 TDMA slots for one frequency channel. On the other hand, UMTS channels use the same frequency band with different codes assigned. In GSM, sectors in a site use different channels but in UMTS a sector can share its codes with other sectors in that site. The default amount of channels per site is 192. If a mobile user encounters this type of blocking during the simulation, the connection is disposed. It becomes an unsuccessful connection. This disconnection event is saved to a log and displayed to the end-user at the end of the simulation run.

Sensitivity is basically, the minimum received power at the base station terminal for a successful link establishment. It is used to vary the mobile station transmit powers in the convergence loop [16]. Sensitivity formulation is depicted in (4.5).

$$Sensitivity = \frac{1}{AF * \left(\frac{W}{(AF * Eb / No_{req} * R)}\right) * (1 - CL)} + N_{bs} \tag{4.5}$$

where,

AF : Activity Factor of the mobile station (0-1)

W : Chip Rate of UMTS

Eb / No_{req} : Bit energy to noise ratio requirement of the link between the mobile station and the corresponding base station, which is calculated from the link level simulations (ITU’s Pedesterian A link model) [14].

R : Data rate used by the mobile station

CL : Cell loading value of the base station, which the related mobile station is connected to

N_{bs} : Noise power value at the base station (best server)

A power control algorithm is used to allocate sufficient power to each mobile user. Once the convergence criterion is met, performance statistics are calculated. If, on the other hand, convergence is not met, the power levels allocated to each mobile are suitably adjusted and iteration continues [12]. Iteratively, mobile station powers are adjusted imitating the real-time behavior of the fast power control process in UMTS networks that is used to degrade interference so as the capacity and performance [17], [18], [19]. The general formulas for the adjustment are depicted in (4.6) and (4.7).

$$MSTXPower(k) = MSTXPower(k-1) + sensitivitydifference - SHOgain \tag{4.6}$$

where,

k: Iteration counter and

$$sensitivy\_difference = \frac{1 + \frac{W}{EbNoref * Rref}}{AF * (1 + \frac{W}{AF * EbNo * R})} \tag{4.7}$$

EbNo_ref (1.5 dB) and R_ref (8 kbps) are default Eb/No requirement and data rate of nominal reference user, respectively. SHO gain is calculated using link level simulation results explained previously. SHO gain depends directly on mobile speed and used data rate and it slightly drops the mobile station transmit power, because soft handover drops the Eb/No requirement at the base station. By this way, UMTS can degrade interference and increases capacity. Sensitivity difference factor adjust the mobile station transmit power due to real Eb/No corrected from the default Eb/No requirement, which is calculated both from the same link level simulation results. Using corrected Eb/No value admits to define mobile stations demanding different services [20]. SHO gain graph is depicted in Figure 4.5.

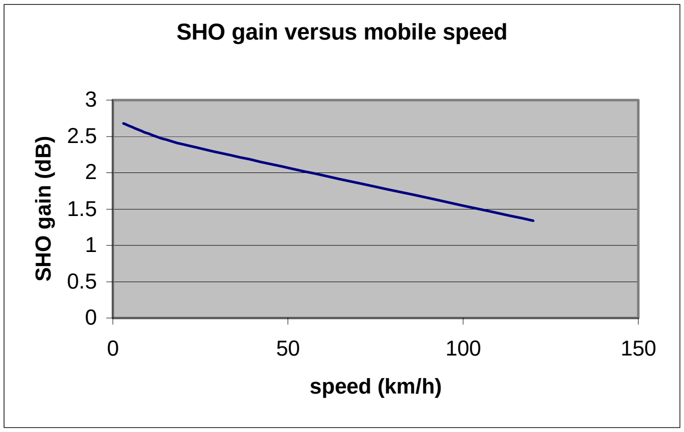


Figure 4.5: SHO gain versus mobile speed

At this instance, also blocking is investigated by checking the calculated transmit power. If the transmit power is higher then the maximum allowable value (default value is set in the parameters part), the mobile's current established links are de-allocated and the mobile's connection attempts become unsuccessful. Consequently, interference is calculated, because the mobile station transmit powers are set to a new value.

Convergence check is used to confirm convergence of a single simulation instance. If the sensitivities of the base stations become stable, iteration loop breaks and the final mobile station powers are validated. Afterwards, mobility generator moves all of the mobile stations and network iteration module once more starts its convergence loop for adjusting mobile station powers. The convergence check algorithm is shown below. (Convergence threshold is 10^{-2}).

```
While (simulation ends)
        If (base station sensitivity at iteration k - base station
        sensitivity at iteration k-1 < convergence threshold)
Convergence OK
        Else
Go on iterating
k = k + 1
where, k is the iteration counter
```

The mobility is greatly dependent on the environment of each user. In general, low speeds and well-defined mobility paths characterize indoor environments, while variable speeds and mobility paths that depend on each environment separately, characterize outdoor environments [21]. In this simulator, mobility generator produces outdoor motion characteristics.

The duty of the traffic generator module implemented in UMTS dynamic simulation is to make the mobile stations on and off. On/Off periods fit to an exponential traffic distribution. For all the mobiles during the simulation and at every initialization of the iteration process, traffic module assesses the simulator. Traffic and mobility generator modules are similar to the ones deployed in the GSM simulator, except the traffic generator now generates different data rates for the mobile stations. In GSM it only generates a constant data rate for voice only communication, however UMTS serves a vide variety of services that demand different data rates. GSM uses 8kbps for voice only communication, on the contrary, in this UMTS simulator 8, 12.2, 64, 144, 512 kbps data rate demands that emulate voice only communication, web browsing, file transfer, etc. are implemented [22]. Mobility generator module used in UMTS simulator is exactly same as the one in the GSM simulator.

4.4 Results Obtained from UMTS Simulator

The results obtained from the UMTS simulator are listed in Table 4.2 below.

1.	Localization
2.	Traffic Distribution
3.	Best Server Map
4.	Soft Handover Areas
5.	Soft Handover Overhead
6.	Cell Loading
7.	Mobile Station Transmit Power History
8.	Received Pilot Power
9.	Active Set Size Map
10.	Successful/Unsuccessful Connection

Table 4.2: Results obtained from UMTS simulator

Localization shows the mobile user distribution within the service area. There are two different types of localization plots. The first one is a snapshot of localization at a given instance of the simulation. The second one is average user distribution during all over the simulation time interval. The map in Figure 4.6 shows a static snapshot of the simulation at a specified instance; on the other hand, Figure 4.7 is taken after a dynamic simulation. It shows the average localization of the mobile users during the simulation duration. Average localization map is created by summing up all of the points that the mobile users step into during the simulation. By this way, the crowded and deserted places of the simulation area can be seen.

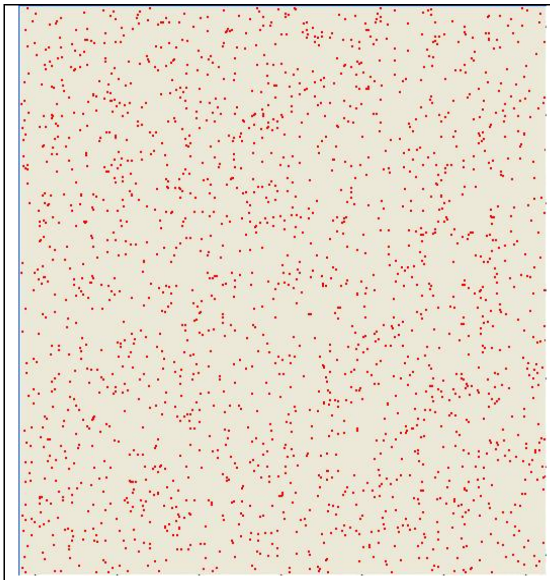


Figure 4.6: A static localization example

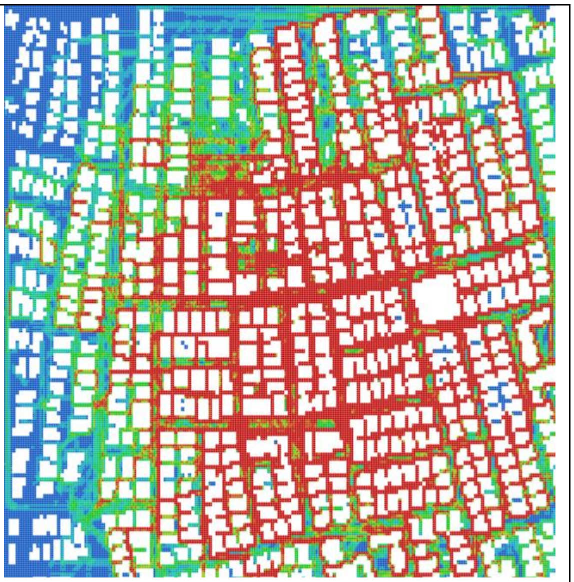


Figure 4.7: A dynamic localization example

The successful and the unsuccessful connections' reasons during the simulation time can then be investigated by using these plots. A crowded location space is a place that unsuccessful connection's occurrence rate is high. The red areas show crowded places and the blue ones are the places that the mobile users locate rarely. It is random and this randomness produces different simulation result's divergence.

Traffic distribution map shows the data rate values in the simulation grid averaged over the simulation interval. Two types of traffic distribution maps are available; one is the total traffic distribution in each cell. The second one is the data rate values shown at every point in the simulation environment. These traffic densities are for every cell in the grid and calculated by the formulas (4.8) and (4.9).

$$traffic(cell_k) : \frac{\sum_{0}^{Ts} \sum Dr(t, cell_k)}{Ts} \tag{4.8}$$

$$traffic(x, y) : \frac{\sum_{0}^{Ts} \sum Dr(t, x, y)}{Ts} \tag{4.9}$$

where,

$traffic(cell_k)$: Total traffic encountered in cell k during the simulation time

$traffic(x, y)$: Total traffic encountered at point x, y in the simulation (if any) grid during the simulation time

(x, y denotes a specific location in the simulation grid)

Ts : Total simulation time

t : Specific instance at the simulation interval

$Dr(t, cell_k)$: Total data rate usage of the mobile users that are using cell k at time t

$Dr(t, x, y)$: Total data rate usage of the mobile users that are at point x, y at time instance t.

In Figure 4.8, one can see the successful and unsuccessful connections and the places they occur. Red points denote unsuccessful connections, green ones the successful connections. The blue shapes are the base stations' locations. It can be seen that, the unsuccessful connections are done in places that are further than the base stations (4 corners of the simulation grid). As the mobile stations located further from the base stations, the received powers degrade. The received signal strengths do not satisfy the minimum required Eb/No value calculated at every simulation instance. These link losses shows that UMTS is a system, which has noise limited capacity. The data rate map is shown in Figure 4.9.

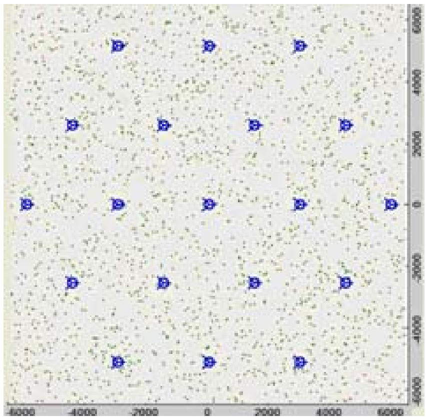


Figure 4.8: Successful-Unsuccessful connections map

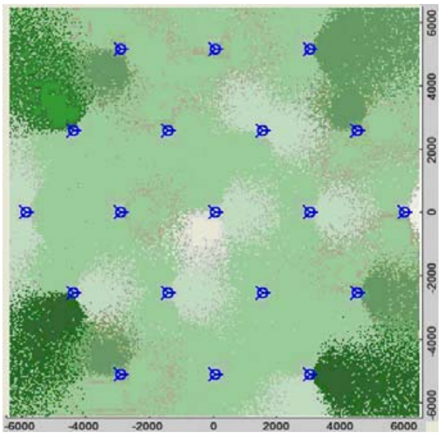
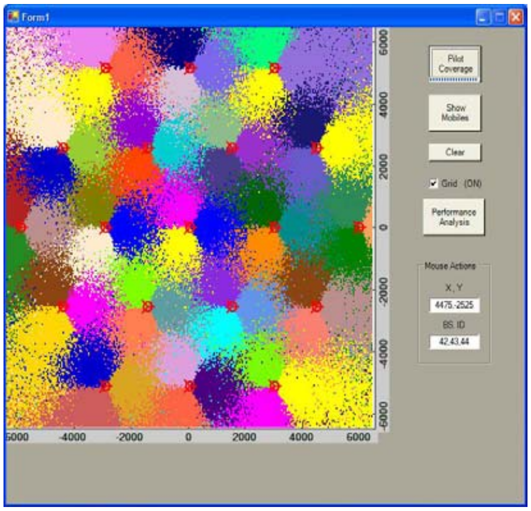


Figure 4.9: Data rate map

In order to see, which base station is the best server at any location in the grid best server map is used. Each color in Figure 4.10 represents a specific base station and best server is defined as the highest received pilot signal strength at that location. The best server plot is static for all instances of the simulation period because, the base station locations and the topology do not change during the simulation. By these plots, the planned network is shown clearly and the cell radii can be calculated.



X, Y: 4475,-2525

BS ID: 42,43,44

Figure 4.10: Best server map (each color represents different cells)

Soft handover areas are the locations that, the mobile user at that location can perform soft handover to at least one different base station other than the best server. Soft handover can be performed at a specific location, where it is served by at least two base stations within Window_add (3dB) of the best server received pilot signal strength. In Figure 4.11, soft handover areas in the simulation grid are shown. The red point denotes soft handover areas. At these points, a mobile user can connect to multiple base stations at the same time. UMTS has the ability to perform “soft handoff” or “make-before-break” call switching in which a mobile is actually in communication with more than one base station at a time. The system in essence selects the best version of the received signal at any given time, resulting in a kind of space diversity system. The blank parts of the map, are the places that are dominated by the nearest base station signal power. At these parts, the other base stations are far away so that the mobile station at these points cannot connect to base stations other than their best server.

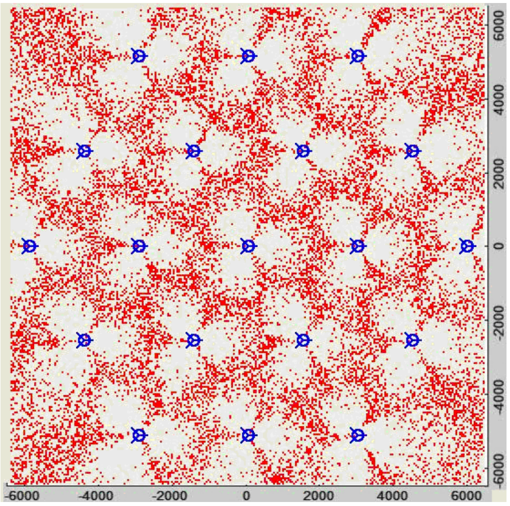


Figure 4.11: Soft Handover areas map

This value is calculated for every base station in the simulation area and drawn in the best server area of that base station. Soft handover value indicates the extra traffic load of the soft handover connections to that base station. It is calculated by the following formula (4.10):

$$SHOoverhead(cell_k) = \frac{N_{SHO}(cell_k)}{N_{users}(cell_k)} \tag{4.10}$$

where,

$SHOoverhead(cell_k)$: Soft Handover overhead at cell k

$N_{SHO}(cell_k)$: Number of Soft Handover connections in cell k

$N_{users}(cell_k)$: Total number of users connected at cell k

(SHO is performed within WindowADD(3 dB))

Handover deals with the mobility of the end users in a mobile network. It guarantees the continuity of the wireless services when the mobile user moves across the cellular boundaries. However, in UMTS, soft handovers produce overhead in terms of traffic to the system and this overhead is measured by a metric called soft handover overhead. It is simply a ratio of soft handover users to total users, which are connected to a specific base station. In Figure 4.12, soft handovers are shown in green color spectrum. Light green drawn cells, are struggling less soft handover overhead traffic. On the other hand, dark green cells have more, soft handover links established between the mobile and the base station.

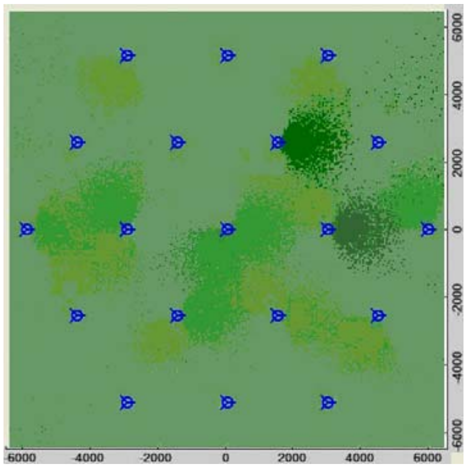


Figure 4.12: Soft Handover overhead map

Cell loading value specifies the total traffic load in a base station calculated by using the interference values for own cell and other cell. Cell-loading formula is depicted in (4.11).

$$CL(cell_k) = \frac{(Iown + Ioth)}{(Iown + Ioth + N)} \tag{4.11}$$

where,

$CL(cell_k)$: Cell loading value at cell k

Iown: total own cell interference

Ioth: total other cell interference

N: base station noise (Nf*k*T*W)

Nf: base station noise figure

W: chip rate

Cell loading value denotes the traffic load on that cell. There is a default threshold (0.9) for this metric. If a specific cell has higher cell loading than this default threshold, that cell is assumed to be fully utilized. By investigating cell-loading maps, the capacity of a pre-planned UMTS network can be simulated. This kind of simulations are called loading simulations. By increasing the number of mobile users in the simulation gradually, and by checking cell-loading values, capacity can be estimated. In Figure 4.13, cell-loading values exceed the threshold in the 4-corner cells. There are 2000 mobiles in that simulation, so the capacity of the UMTS network is approximately 2000.

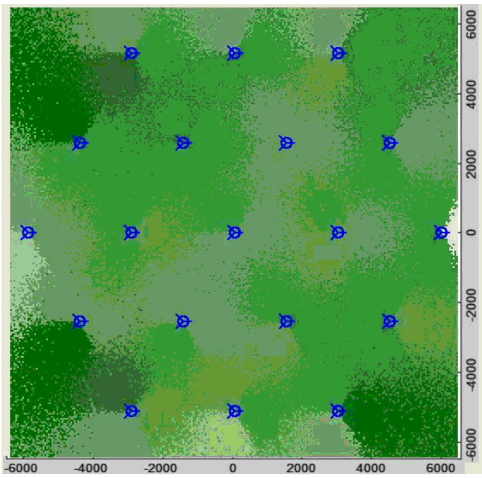


Figure 4.13: Cell loading map

Iteration after iteration, mobile user transmit power varies and it is an important parameter for overall UMTS network performance. The end-user can see, how the mobile's transmit power varies with respect to simulation time. By this way, an unsuccessful connection's reason can be investigated. An unsuccessful connection occurs when the mobile stations transmitted power cannot be increased further in the power control iterations. This occurs when the mobile station is far away from the base station or the interference coming from other link due to imperfect othogonality of the CDMA codes.

Received pilot signal power coming from the base stations plays an important role for the mobile stations to determine the base station to connect or perform soft handover. In this graph, at every location, only the best server base stations received pilot level is plotted.

In CDMA type systems, active set determines the soft handover connections to the base station in the active set of that mobile user. The active set size map shows how many SHO connections a mobile station performs at a specific instance of the simulations at a definite location. The legend on the left hand side in the Figure 4.14 shows how many base stations there are in the active set at that point in the simulation grid. The yellow parts have an active set size of 1 meaning that, the mobile station at these places can only establish a link to their best server. At the intersection of the cells, the active set size increases. The mobile station has the ability to perform soft handover with multiple base stations at these intersection regions.

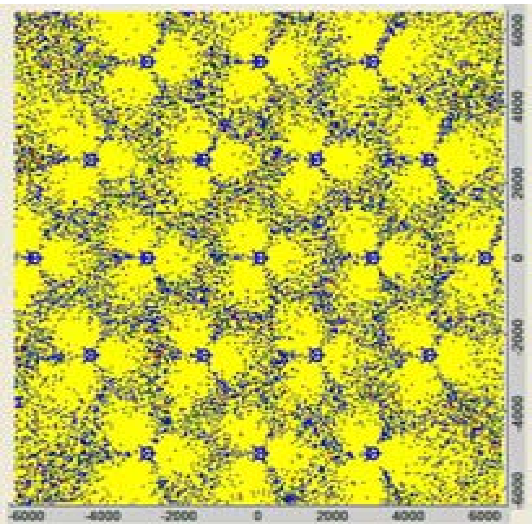


Figure 4.14: Active set size map

4.5 Sample Simulations and Discussion

Two simulations are done in order to compare and investigate the use of this kind of simulations for a UMTS network. Two of the simulations are done on the same planned network structure and have the same environmental parameters. The simulations are snapshots of the dynamic simulator. However, the mobile station speeds are needed, because the link level simulations require these values to calculate required Eb/No values. The environmental parameters are as follows:

- Simulation grid size: 6000m – 6000m
- Center point coordinate: (x, y) = (0, 0)
- Number of base station towers: 19
- Number of sectors (cells) in the grid: 57 (120^o sectoring is used) (3 sectors are deployed in 1 base station tower)

These parameters are illustrated in Figure 4.15.

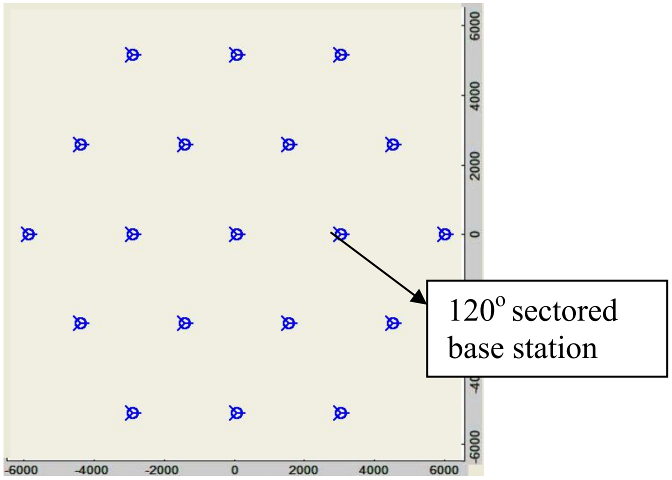


Figure 4.15: Network architecture for a sample simulation

The input data needed for the simulation is as follows:

Base station Data

The data consists of the following fields:

- x-y coordinates of the base stations: Stored in text files (19 BS - 57 sectors).
- Maximum transmit power for all traffic channels: 43 dBm
- Maximum transmit power per traffic link: 30 dBm
- Pilot power strength: 30 dBm
- Window ADD: -3 dB

Mobile station Data

- x-y coordinates of the base stations: Stored in text files
- Maximum and minimum transmit powers: 21 dBm, -50dBm
- Data Rates used by the mobile stations: Vary from one MS to another (8 kbps, 64 kbps, and 14.4 kbps). Stored in text files
- Ground speed: (5 km/h, 30 km/h, 50 km/h and 120 km/h)

Building Data and Propagation Simulation

This data is needed to make propagation simulations over the terrain and give information to the mobility generator (Mobile users cannot enter buildings). In this thesis, the propagation simulations are not investigated, but only used as inputs to the mobility simulator. Okumura Hata model [7] is used for propagation simulations with some random variation (deviation) around the calculated value.

Simulation I and II

Simulation I and II has nearly the same environment parameters. The differences are the number, speed and the service demand (data rate) of mobile stations, which are distributed in the simulation grid. The user distribution and their properties are shown below:

Mobile stations	Number	Speed	Service Demand
Simulation I	1200	10%: 120 km/h 20%: 50 km/h 30%: 30 km/h 40%: 5 km/h	50%: 8 kbps 30%: 64 kbps 20%: 14.4 kbps
Simulation II	3000	10%: 120 km/h 20%: 50 km/h 30%: 30 km/h 40%: 5 km/h	50%: 8 kbps 30%: 64 kbps 20%: 14.4 kbps

In both of the simulations the mobile stations are randomly (uniformly) distributed over the simulation grid. 120 km/h mobile users refer to high-speed vehicles, on the other hand 5 km/h users are pedestrians. Service demand varies between 8 kbps to 14.4 kbps referring to a variation between only-voice calls to high-speed file transfers. Simulation I is in a less crowded environment, because number of mobile stations is less than simulation II. The reason for the difference of the mobile station quantity is, by making these kinds of simulations, one can estimate the effects of the traffic in a planned network. The variation of the speeds and the service demands is because, the effects of these parameters are important for a network supplier. A network provider should plan and re-plan the UMTS network as the demands of the mobile users' change, so using these kinds of simulation tools is feasible and easy for a network administrator.

In simulation II, a crowded environment is simulated so, as long as UMTS capacity is limited by noise (interference), more unsuccessful connections are explainable. On the other hand, if the CDMA codes are perfectly orthogonal, the system capacity will be thermal noise and physical channel quantity (number of codes) limited. The available sectors are exactly the same for simulation I and II, so as the total number of mobile users increase, the unsuccessful connection rate increases. The total number of users in simulation II is more than two folds than the users in simulation I, but the successful connections in case I are two folds than case II. This makes the UMTS capacity non-linearly dependent on the traffic demand, because when the users are more in the network, there exist additional noise between the links and link losses occur. The sensitivity equation explained previously satisfies this phenomenon. Sensitivity is the required Eb/No (analogous to signal to noise ratio) value and it is directly proportional with CL (Cell loading) [15]. Cell loading depends on the number connected users so, if there are more users making communications in the network, the required Eb/No value is more. The mobile users and the base stations have limited transmit powers, so the mobiles that could not satisfy these criteria of required Eb/No struggles link losses. There is no explicit limit to soft handover connections [17] in the network except from required Eb/No threshold. The number of soft handover connections increased linearly when going from simulation I to simulation II.

It can be seen from the numerical results (Figure 4.24) that large percentage of the link losses occur when the mobile user is using high data rate or traveling with high speeds. This phenomenon can be explained by the link level simulations and by ITU's pedestrian A table. As speed and data rate increases, the required clean signal strength also increases. UMTS can support high data rates, so while planning the CDMA network; this incident must be investigated carefully.

Figures 4.16 and 4.17 show that, the unsuccessful connections occur more in simulation II (red points show unsuccessful connections). Figures 4.18, 4.19, 4.20 and 4.21 are the throughput and cell loading maps and the dark green parts represent highly loaded cells. In simulation II, the traffic demand is high because it is more crowded, so there are more dark green painted cells. As there are more users in the network demanding more traffic, the number of soft handover connections increases so there is high soft handover overhead on the network. This is illustrated in Figures 4.22 and 4.23 for simulation I and II, respectively. By looking at Figures 4.11, 4.16 and 4.17 together, it can be seen that whether the link losses occurs at the soft handover regions. These regions are the physical intersections of the cells, so the received signal power qualities degrade at these regions, so unsuccessful connections are more probable to occur there.

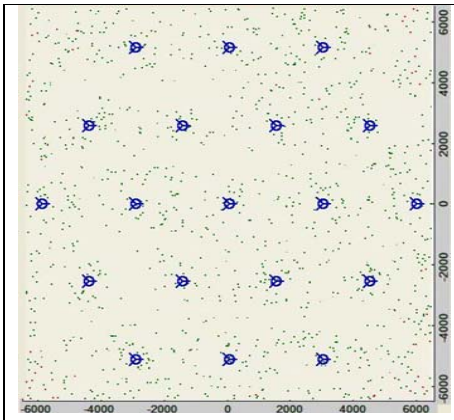


Figure 4.16: Successful-Unsuccessful connections for simulation 1

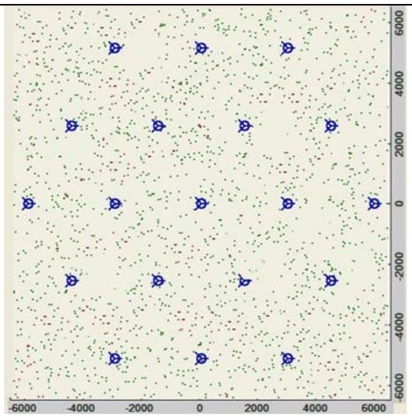


Figure 4.17: Successful-Unsuccessful connections for simulation 2

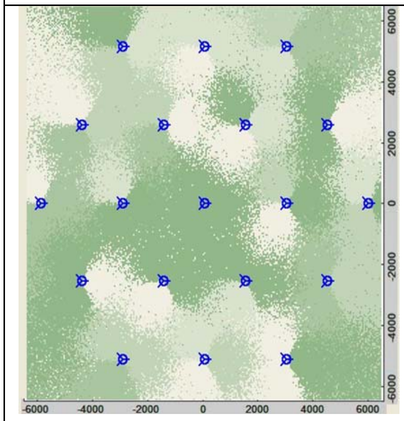


Figure 4.18: Throughput for simulation I

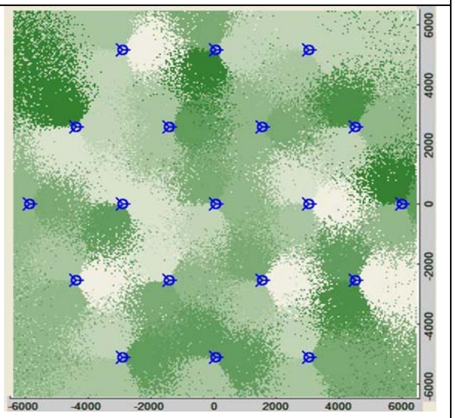


Figure 4.19: Throughput for simulation II

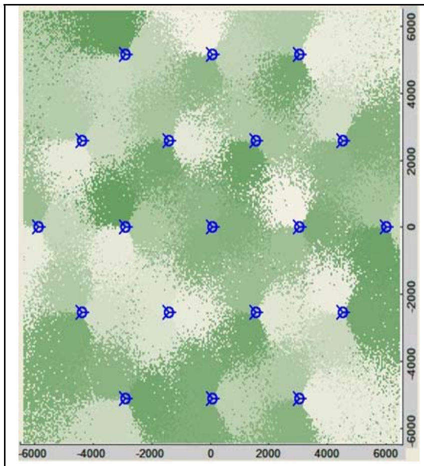


Figure 4.20: Cell Loading for simulation 1

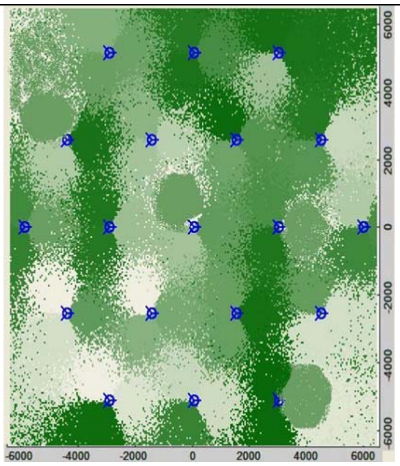


Figure 4.21: Cell Loading for simulation II

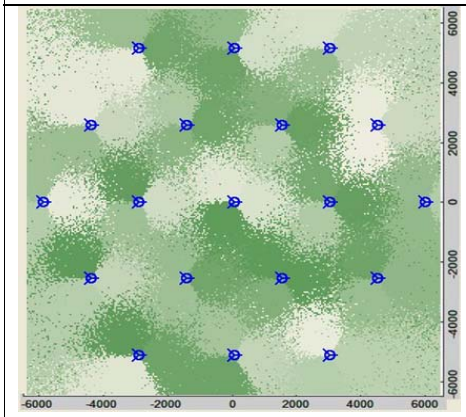


Figure 4.22: Soft Handover Overhead for simulation I

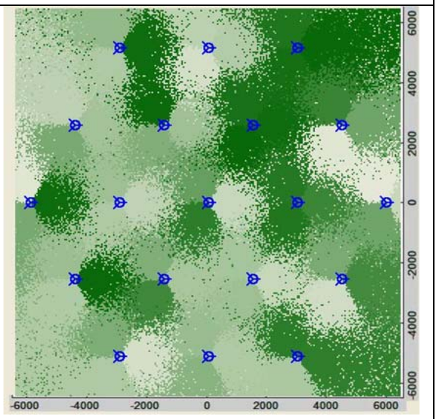


Figure 4.23: Soft Handover Overhead for simulation II

	Number of users	Successful-Unsuccessful connections		Number of Soft Handover Connections	Connection Losses due to high ground speed (120 km/h)	Connection Losses due to high data rates (14.4 kbps)
Simulation I	1200	1108	92	154	~20%	~17%
Simulation II	3000	2461	539	368	~24%	~19%

Figure 4.24: Numerical results for sample simulation

4.5.1 Effects of power control on system capacity

Power control standard deviation is an important parameter in planning a UMTS network. In adjusting the mobile-station transmit-powers, the standard deviation of the received signal strength at the base station coming from multiple mobiles, is a metric to define capacity. If the standard deviation becomes stable, that cell is fully capacitated. Standard deviation is formulated as follows (6.12):

$$\sigma_{pc}(t_m)_i = \frac{\sqrt{E(P_{ri}(t_m) - < P_{ri}(t_m) >)^2}}{< P_{ri}(t_m) >} \tag{6.12}$$

where,

$\sigma_{pc}(t_m)_i$: Standard deviation of power controlled received power at the base station coming from the i’th mobile station.

$P_{ri}(t_m)$: Received power value coming from the i’th mobile station at the base station

$< P_{ri}(t_m) >$: Time average of received power value coming from the i’th mobile station at the base station during time interval t_m.

t_m: small time interval (0.01% of simulation time)

Figure 4.25 represents the standard deviation of transmit-powers of 20 mobile stations, simulated. At the end of the simulation, the standard deviation value becomes stable, saying that, the cell is fully loaded.

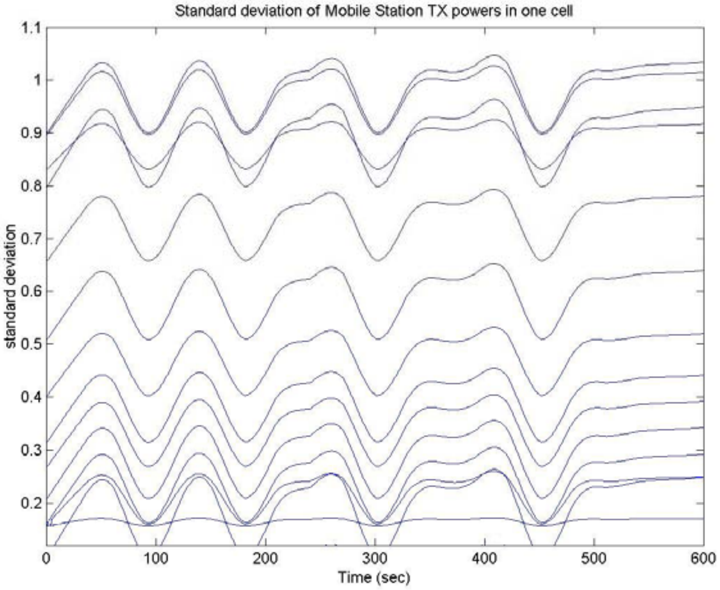


Figure 4.25: Standard deviation of 20 mobile stations TX powers connected to one cell as best server.

Chapter 5

CONCLUSION AND FUTURE WORK

The aim of this thesis is to investigate the capacity and performance of two wireless networks, GSM and UMTS. For this investigation to be accurate, mobility simulations are needed. These simulators reflect the true performance and quality of the network due to dynamic behavior of the mobile users. Mobile behavior of the users must be well modeled to simulate the network realistically. For the mobility modeling, a step-taking algorithm is used. The routes are not pre-processed, so the algorithm is computationally efficient.

In simulating the GSM network handovers must be implemented in the simulator, because disconnections during handovers crucially affect system quality. GSM simulator models the network with a reasonable user traffic distribution and an accurate signal propagation data on top of a real building map. The simulator generates capacity and performance metrics due to different traffic loads and subscriber mobility pattern.

The difference between GSM and UMTS simulators is the importance of modeling and calculation of the interference in the network. In UMTS there are different data rate demands. This divergence causes different signal-to-noise ratio requirements at the base and mobile stations. The simulator can handle various data rate demands. UMTS mobility simulator models dynamic power control, call statistics and mobile movements. In addition soft handover capability of UMTS is modeled and deployed to the simulator. In fact, UMTS simulator can be referred as a long-term dynamic simulator. It is a continuous version of a static simulator, because there is no explicit signal fading and power control. However, at every instance of the simulation, the system power balancing is triggered due to changes in mobile station locations and call statistics.

For the future work, the mobility generation algorithm may be extended to calculate paths more realistically and efficient. This would make the program to consider shortest paths to destination. Consequently, the simulating time would decrease, resulting in the ability to perform longer simulations. In addition to this, in the implantation of the UMTS simulator, the modeling of downlink characteristics of this network is neglected. Only downlink is considered and uplink is assumed to be in balance with downlink conditions. For the future work, downlink simulations may be added to the program to consider uplink conditions.

APPENDIX

Exponential traffic generation code

```
public class ExponentialTraffic
        {

                public double ontime;
                public double offtime;
                public double rate;
                public int size;
                public double interval;
                public int rem;
                public bool started;

                ExponentialRandomVariable burstlen_;
                ExponentialRandomVariable Offtime_;

                public int next_start(int seed)
                {
                        double t = interval;
                        started = false;

                        if(rem==0)
                        {
                                rem = (int)(burstlen_.get_val(seed) + 0.5);
                                if(rem == 0)
                                        rem = 1;
                                t += Offtime_.get_val(seed);
                                started = true;
                        }

                        rem--;
                        return((int)t);

                }

                public ExponentialTraffic()
                {
```

```
		}
		public ExponentialTraffic(double _ontime,double _offtime,double
_rate,int _size)
		{
			ontime = _ontime;
			offtime = _offtime;
			rate = _rate;
			size = _size;

			interval = (double)(size * 8)/(double)rate;
			Offtime_ = new ExponentialRandomVariable(offtime);
			burstlen_ = new
ExponentialRandomVariable(ontime/interval);
			rem = 0;
		}

	}
}
```

GSM simulator code

```
private void simulate()
		{


			dlg1.Show();
			draw_map();
			//dlg1.prog_reset();
			DateTime now = DateTime.Now;
			Random rand  = new Random((int) now.Millisecond);

			T_hand=Double.Parse(textBox1.Text);
			T_min=Double.Parse(textBox2.Text);
			trials=int.Parse(textBox5.Text);
			label9.Visible=false;
			hyst=6;

			progressBar1.Visible=true;
			progressBar1.Minimum = 1;
			progressBar1.Maximum = trials;
			progressBar1.Value = 1;
```

```
                progressBar1.Step =   1;


                if(checkBox1.Checked)
                {
                        fix_mobs=int.Parse(textBox3.Text);

                }
                if(checkBox2.Checked)
                        uni=true;

                grids = new     int[fix_mobs,2];
                dest = new int[fix_mobs,2];
                destbuf = new int[fix_mobs];
                mstat =new      double[fix_mobs,3];
                mbuf = new int[fix_mobs,2];
                mbufdir = new int[fix_mobs];
                mbufdir2 = new bool[fix_mobs];
                mbufdir3 = new int[fix_mobs,2];
                mbufdir4 = new int[fix_mobs];
                mbufdir5= new int[fix_mobs];

                newly = new bool[fix_mobs];
                startbuf = new int[fix_mobs];
                channel_util = new int[txs.Length/3,trials];


                for(int  i=0;i<fix_mobs;i++)
                {
                        mstat[i,0]=0;//Initially the radios       are       off.
                        int       xd=rand.Next(0,size_x);
                        int       yd=rand.Next(0,size_y);
                        while(true)
                        {
                                if(grid[yd,xd]!=-99999 && yd<size_y
        && yd>0         && xd<size_x &&     xd>0)
                                {
                                        dest[i,0]=xd;
                                        dest[i,1]=yd;
                                        mbuf[i,0]=-1;
                                        mbuf[i,1]=-1;
                                        mbufdir[i]=-1;
```

```
                                        mbufdir2[i]=false;
                                        mbufdir3[i,0]=-1;
                                        mbufdir3[i,1]=-1;
                                        mbufdir5[i]=-1;
                                        destbuf[i]=-1;
                                        newly[i]=true;
                                        break;
                                }
                                else
                                {
                                        xd=rand.Next(0,size_x);
                                        yd=rand.Next(0,size_y);
                                }
                        }

                }


                int     mob_count=0;
                while(mob_count<fix_mobs)
                {
                        int     x=rand.Next(0,size_x);
                        int     y=rand.Next(0,size_y);

                        if(grid[y,x]!=-99999)
                        {
                                grids[mob_count,0]=x;
                                grids[mob_count,1]=y;
                                mob_count++;
                        }

                }
                for(int i=0;i<fix_mobs;i++)
                {
                        mstat[i,2]=-1;
                }

                connected=0;
                handoffs=0;
                dropped=0;
                started=0;
```

```
                    init_traffic();

                    for(int  t=0;t<trials;t++)
                    {
                            dlg1.textBox1.Text=(t+1).ToString();
                            DateTime nows = DateTime.Now;

            dlg1.textBox2.Text=nows.ToLongTimeString().ToString();
                            for(int  i=0;i<fix_mobs;i++)
                            {
                                    contour();
                                    if(mstat[i,0]==1)
                                    {
                                            setup(i,t);
                                            mstat[i,1]--;
                                            if(mstat[i,1]==0 &&   mstat[i,2]!=-1)
                                            {
                                                    mstat[i,0]=0;
                                                    //dlg1.deprog(mstat[i,2]);

            chan_dealloc(int.Parse(mstat[i,2].ToString()),t);
                                                    mstat[i,2]=-1;
                                            }
                                    }
                                    else
                                    {
                                            if(will_on(t,i))
                                            {
                                                    mstat[i,0]=1;
                                                    //mstat[i,1]=calc_left(t,i);
                                                    started++;
                                            }
                                    }

                                    move(grids[i,1],grids[i,0],i,t);
                                    location[grids[i,1],grids[i,0]]++;

                            }
                            for(int j=0;j<txs.Length/3;j++)
                            {
                                    channel_util[j,t] = firsttxs[j] - txs[j,2];//kac
        tanesi dolu
```

```
                                        }
                                        progressBar1.PerformStep();


                                }


                                //dlg1.prog_reset();
                                MessageBox.Show("Simulation has ended. Now you can see
the results.","GSM
Analysis",MessageBoxButtons.OK,MessageBoxIcon.Information);
                                dlg1.Hide();
                                write_report();



                        }


private void setup(int im,int time)
                        {
                                int      x=grids[im,0];
                                int      y=grids[im,1];
                                int      check=0;
                                double src=0;
                                if(mstat[im,2]==-1)//means very        first beginning(Not
        Connected yet)
                                {
                                        for(int  i=0;i<7;i++)
                                        {
                                                if(search(x,y)[i,1]>T_min &&
txs[int.Parse((search(x,y)[i,0]).ToString()),2]>0)
                                                {
                                                        src=search(x,y)[i,0];
                                                        mstat[im,2]=src;
                                                        //dlg1.prog(mstat[im,2]);

        chan_alloc(int.Parse(src.ToString()),time);
                                                        check=1;
                                                        connected++;

        sector_info2[int.Parse(src.ToString()),1]++;
                                                        suc_connection_map[y,x]++;
```

```
                        break;
                    }
                }
                if(check==0)
                {
                    //means          not       connected to any server
                    dropped++;
                    sector_info3[0,1]++;
                    unsuc_connection_map[y,x]++;
                    mstat[im,0]=0;
                    mstat[im,1]=0;
                    mstat[im,2]=-1;
                }
            }
            else//Already connected
            {
                int     con=int.Parse(mstat[im,2].ToString());
                int     newcon=-1;
                if(rp[con,y,x]<T_hand)//recent base   station's rp is
    below T-handoff
                {
                    for(int  i=0;i<7;i++)
                    {
                        if(search(x,y)[i,0]!=con)
                        {
                            if(search(x,y)[i,1]-
rp[con,y,x]>=hyst && txs[int.Parse((search(x,y)[i,0]).ToString()),2]>0 &&
search(x,y)[i,1]>T_min)
                            {

    newcon=int.Parse(search(x,y)[i,0].ToString());
                                break;
                            }
                        }

                    }
                    if(newcon!=-1)//handoff!!!
                    {
                        //dlg1.deprog(mstat[im,2]);
                        chan_dealloc(con,time);//break before
connecting to the new b.s.
                        mstat[im,2]=newcon;
```

```
                                        //dlg1.prog(mstat[im,2]);
                                        chan_alloc(newcon,time);
                                        handoffs++;
                                        sector_info2[newcon,0]++;
                                   suc_handoff_map[y,x]++;
                                }

                                if(newcon==-1 && rp[con,y,x]<T_min)
                                {
                                        dropped++;
                                        sector_info3[0,0]++;
                                        unsuc_handoff_map[y,x]++;
                                        //dlg1.deprog(mstat[im,2]);
                                        chan_dealloc(con,time);
                                        mstat[im,0]=0;
                                        mstat[im,1]=0;
                                        mstat[im,2]=-1;
                                }
                        }

                }

        }
```

UMTS simulator code

```
System.Random rnd = new Random();

                for(int i = 0;i<number_of_bs;i++)
                        for(int j = 0;j<number_of_ms;j++)
                        {

    linklossULM[i,j]=/*160;*/105+13*rnd.NextDouble();

    //linklossDLM[i,j]=/*165;*/160+10*rnd.NextDouble();
                        }
                for(int i=0;i<number_of_bs;i++)
                        for(int j=0;j<size_y;j++)
                                for(int k=0;k<size_x;k++)
                                {
```

```
        pathlossUL[i,j,k]=/*145;*/100+13*rnd.NextDouble();

        //pathlossDL[i,j,k]=/*150;*/135+10*rnd.NextDouble();
                                        }

                        IoM = new double[number_of_bs,number_of_ms];
                        CPICHM = new double[number_of_bs,number_of_ms];
                        CPICHEcIoM = new double[number_of_bs,number_of_ms];

                        reference_ms_EbNo =
/*calc_ms_EbNoUL(reference_mobile_speed,reference_mobile_datarate)*/6.18;
                        reference_ms_AFUL =
calc_AF_UL(reference_mobile_datarate);
                        reference_ms_AFDL =
calc_AF_DL(reference_mobile_datarate);

                        for(int i = 0;i<number_of_ms;i++)
                                mobiles[i] = new Mobile();
                        for(int i = 0;i<number_of_bs;i++)
                                bss[i] = new BaseStation();

                        //*****set MS and BS parameters*****
                        //                              UNUTMA
                        for(int i = 0;i<number_of_bs;i++)
                        {
                                bss[i].TxPower = new double[number_of_ms];
                                for(int j = 0;j<number_of_ms;j++)
                                        bss[i].TxPower[j] = -280;
                        }
                        UpdateChannel();
                        //*********************************

                        //Create system performance parameters and its defaults
                        defsysperf = new DefSystemPerf();
                        sysperf = new SystemPerf[number_of_bs];
                        for(int i=0;i<number_of_bs;i++)
                        {
                                sysperf[i] = new SystemPerf();
                                //Set system performance parameters to defaults
                                sysperf[i].covth = defsysperf.covth;
                                sysperf[i].inter = defsysperf.inter;
```

```
                sysperf[i].mUL = defsysperf.mUL;
                sysperf[i].RUL = defsysperf.RUL;
                sysperf[i].SHO = defsysperf.SHO;
            }
            Initialize();
            for(int i=0;i<number_of_ms;i++)
            {
                msTxPowerV[i]=mobiles[i].TxPower;
            }
            Itterate();

public static void Itterate()
        {
            while(true)
            {
                for(int i=0;i<number_of_bs;i++)
                    oldThreshold[i] = sysperf[i].covth;
                iteration++;
                indexHL.Clear();
                RlbUL();
                for(int i=0;i<number_of_bs;i++)
                {
                    newThreshold[i] = sysperf[i].covth;
                    deltaCTnew[i] = Math.Abs(oldThreshold[i]-
newThreshold[i]);
                }
                BestServerUL();
                outageULold = (double[,])outageUL.Clone();
                CalcMStx();
                CalcIntUL();

                //downlink starts
                CalcIntDL();

            }


        }
```

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