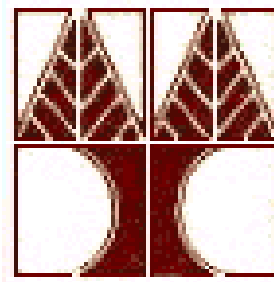**Master's Thesis**


**Coverage and Capacity Planning in Enhanced UMTS**


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**June 2004**


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# Chapter 1

## Introduction

### 1.1 From UMTS to Enhanced-UMTS

The success of $2^{nd}$ generation mobile networks (Global System for Mobile Communications (GSM)), and the rapid growth of mobile and Internet users led towards the development of the 3rd generation of mobile telecommunication systems. The 3rd generation of mobile telecommunication systems is standardized by the 3G Partnership Project (3GPP) [1], in Europe, and 3G Partnership project – 2 (3GPP2) [2] in the USA. In 3GPP, the 3rd generation of mobile communication systems is named UMTS (Universal Mobile Telecommunication System). Initially in the first release of UMTS, 3GPP R99 [3], the UMTS transport network technology was ATM-based, but in the later specification of 3GPP UMTS R5 [4] the aim is to have an "All IP" architecture, i.e. the transport technology in all the parts of the UMTS network is IP-based. An Enhanced UMTS network is an IP based network that supports additions and modifications to the UMTS network (mainly based on 3GPP R5).

The 3G Partnership Project (3GPP) proposed the UMTS all-IP architecture to integrate IP and wireless technologies. This architecture evolved from the second generation (2G)

GSM, to GPRS, UMTS Release 1999 (UMTS R99), UMTS Release 2000 (UMTS R00) and finally to UMTS Release 6. UMTS Release 2000 has split up into Releases 4 and 5. UMTS Release 4 (R4) is concerned with the core circuit switched (CS) domain, the UTRAN and the packet switched domain remain the same. Release 5 (R5) contains, but it's not limited to: an initial phase of the IP multimedia system (IMS) on top of the packet switched domain and support for real-time voice and other delay sensitive services. High Speed Downlink Packet Access (HSDPA), IP transport in the UTRAN and security enhancements. Release 6 completes and deepens the Release 5 concepts. The following features appear in Release 6: Multimedia Broadcast/Multicast Service (MBMS), priority service, wireless LAN/UMTS interworking, IMS phase 2 and Mobile IP (MIP) proposed to replace the GTP tunnels from the GGSN to the RNC [1].

Enhanced UMTS addresses mainly the 3GPP Release 5 enhancement of High Speed Downlink Packet Access (HSDPA). However, enhancements include more than that. The considered enhancements for an Enhanced UMTS network further are the all-IP architecture, several link layer enhancements, and techniques for QoS support in an all-IP UMTS. The goal of the all-IP network is, while minimizing network operation costs, to enable broadband access operators to move from being mere connectivity providers to being full-service providers, providing Internet connectivity, voice services, broadcast/multicast services and next generation broadband services to end users, all from a single network.

HSDPA is a packet-based data service in W-CDMA downlink with data transmission on the order of 10 Mbps over a 5MHz bandwidth in W-CDMA downlink. The HSDPA concept introduces new adaptation and control mechanisms to enhance downlink peak data rates, spectral efficiency, and quality of service (QoS) control for packet services. New features that are present in HSDPA are:
- Adaptive Modulation and Coding (AMC)
- Hybrid Automatic Request (HARQ)
- Fast scheduling
- Channel Quality Feedback

HSDPA has managed to establish a cost-effective high-bandwidth, low-delay packet-oriented service within UMTS. Compatibility with UMTS release was very important, so the HSDPA architects adhered to an evolutionary philosophy. It is a straight-forward enhancement of the UMTS Release '99 (R99) architecture, with the addition of a repetition/scheduling entity within the base station that resides below the R99 media-access control (MAC) layer. HSDPA User Equipments (UEs) are designed to coexist with R99 UEs [5].

Link layer enhancements include new wireless techniques required to increase the bit rate and the capacity gain. Examples of such techniques include Hybrid Space-Time coding plus Adaptive Antennas (Beam-forming) schemes as they enable capacity increase. Furthermore, the association with Multiple Input Multiple Output (MIMO) systems is investigated in Enhanced UMTS. The combination of adequate coding/modulation schemes to increase the spectral efficiency is a technique capable of handling higher than 2 Mbps bit rates given the available total bandwidth (5 MHz).

QoS support for an all-IP architecture has all the IP related difficulties in providing QoS guarantees. In order to utilize both the radio access network (RAN) and the core network part of the Enhanced UMTS efficiently, and to provide high-quality heterogeneous services to the end-user, the IP-based network layer should comprise appropriate QoS mechanisms. For the radio interface, effective per-flow QoS mechanisms need to be developed. For the RAN and the core network, resource management mechanisms for aggregate QoS, based on DiffServ need to be developed. New network protocols for the access network and TCP/IP for the core network need to be investigated.

## 1.2 W-CDMA as a radio communication technique

Several radio communication techniques exist in order for multiple users to be able to co-exist and share the same air interface simultaneously. These techniques achieve a separation of the signals that use the same spectrum at the same time. Widely used techniques in mobile networks are Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Code Division Multiple Access (CDMA). A

successor of the CDMA technique used in Enhanced-UMTS networks is the Wideband Code Division Multiple Access (W-CDMA) technique.

TDMA works by dividing a radio frequency into time slots and then allocating slots to multiple calls. In this way, a single frequency can support multiple, simultaneous data channels. This technique is used by the GSM digital cellular system. FDMA is the division of the frequency band allocated for wireless cellular communication into many channels, each of which can carry a voice conversation or, with digital service, carry digital data. FDMA is a basic technology in the analog Advanced Mobile Phone Service (AMPS), the most widely-installed cellular phone system installed in North America. With FDMA, each channel can be assigned to only one user at a time. The Digital-Advanced Mobile Phone Service (D-AMPS) also uses FDMA but adds time division multiple access (TDMA) to get three channels for each FDMA channel, tripling the number of calls that can be handled on a channel [33].

CDMA does not assign a specific frequency to each user. Instead, every channel uses the full available spectrum. Individual calls are encoded with a pseudo-random digital sequence. Likewise, in W-CDMA each user transmits a data sequence spread by a "code" (spreading code). This code is unique to the connection between the mobile station and the base station both in the uplink and the downlink direction, in such a way such that any other connections appear as noise (orthogonal to the noise). The information bandwidth in W-CDMA can vary between 8kbps and 2Mbps [36].

### 1.3 W-CDMA Coverage and Capacity Planning

W-CDMA coverage and capacity planning is a planning methodology for W-CDMA networks. In general, Radio Network Planning (RNP) includes dimensioning, detailed capacity and coverage planning, and network optimization.

Dimensioning estimates an approximate number of base station sites, base stations and their configurations, as well as other network elements, based on the operator's requirements and the radio propagation in the area (defined in the simulator by the radio propagation model. The dimensioning must fulfil certain requirements for coverage,

capacity and quality of service (QoS). In W-CDMA, capacity and coverage are closely related and therefore both must be considered simultaneously in the dimensioning of these networks. The input to the dimensioning process is hence the initial requirements for coverage, capacity and QoS as well as the area type and the radio propagation models.

During dimensioning, planning and optimisation, several required outputs may be produced such as a rough number of base stations and sites, base station configurations, site selection, cell specific parameters for RRM algorithms and hence adjustment of RRM parameters to optimal values and finally analysis on the issues of capacity, coverage and quality of service. Such analysis is based on:

> (a) coverage: the coverage regions, area type information and propagation conditions,
>
> (b) capacity: the available spectrum, the traffic density information and
>
> (c) quality of service: the coverage probability, the blocking probability and the end user throughput.

We have two main objectives in RNP: providing coverage and providing capacity, in a way as to meet the demand for acceptable QoS and maximizing throughput. Achieving both of these goals depends on a sufficient supply of potential sites as specified within a given scenario.

**1.3 Use of Simulation as an evaluation method**

Prior to the deployment of a system, such as Enhanced UMTS, performance evaluation needs to take place in order to assess the capabilities of the system and evaluate any new mechanisms the system will use. A system in this case may be defined as a collection of related parts or entities (nodes, links, data packets etc) that interact together over a time to accomplish a goal (e.g. to deliver telecommunication services that satisfy specific QoS requirements) [6].

There are mainly two ways to achieve performance evaluation of any system. The first is to experiment with the actual system, i.e. set up the system and run it to collect

measurements that will aid in the assessment of the system. This method will give exact results, but it is costly, and often the system is not available, as it may not be built yet. The second is to experiment with a model of the system. This model can be a physical model of the system (and not the actual deployed system) or it can be an abstract model. The term abstract model refers to an abstract representation of the system, usually containing structural, logical or mathematical relationships which describe a given system in terms of states, entities and their attributes, and events.

An abstract model can in turn be evaluated using two different methods, the analytical solution, which includes a mathematical analysis of the model, or simulation. A mathematical formulation of the system can also be costly to develop, and often due to the complexity of the derived model approximations are undertaken, which put into question generalization of the results. In this thesis, only the simulation method will be addressed.

There are several types of simulation models that can be created. They can be categorized according to the type of input data they accept. Deterministic simulation models accept a unique deterministic set of input data and thus after the simulation is run, a unique deterministic set of output data is produced. On the other hand, there are stochastic simulation models, which accept realizations of random variables and random processes as input data thus producing corresponding random output data.

Simulation models may also be categorized according to the factors that cause system state to change. System state is a collection of variables that contain all the information necessary to describe the system at any time. Continuous simulation or else time-based simulation models are models in which state variables of the simulated system change continuously in time. Discrete event-based simulation models are models in which state variables of the simulated system change instantaneously at separate points in time, according to events. This type of simulation requires a time-keeping mechanism to advance the simulation time from one event to another, as simulated processes advance in time.

Discrete-event based simulation is a very popular performance evaluation method in telecommunication networks evaluation. It has several advantages over other methods. The two main advantages are that it allows performance evaluation of analytically intractable mathematical models of complex systems and that it allows performance evaluation of complex systems at arbitrary level of detail and in arbitrary time scale. The design and implementation of the Enhanced UMTS system level simulator is based on this method [7].

## 1.4 Goals of this thesis

This work addresses the main issues for achieving a simulation environment that enables coverage and capacity planning for an Enhanced-UMTS mobile network, and presents relevant results obtained for different environments.

This thesis uses the Enhanced-UMTS system level simulator developed within the IST funded SEACORN project. This simulator is able to perform system level simulations for an Enhanced-UMTS network in order to collect coverage and capacity results (e.g. optimal cell radius for a specific scenario and corresponding load).

To evaluate the performance of Enhanced UMTS through this simulation environment, specific scenarios are specified, mainly based on [4]. The scenarios are in the form of sub-problems, dealing with a different environments and parameter sets. In order to build a system level simulation scenario, it is not adequate to only have implemented the simulation framework; the simulator needs to support models that will provide the traffic and mobility of the users. Therefore, for each sub-problem the simulation requirements are determined, what level of detail is desired regarding traffic and mobility models, propagation environment, what are the relevant performance measures, etc.

Models (for mobility and traffic) and simulation methods that allow assessment of system behaviour in terms of capacity and quality of service are developed, taking into consideration the constraints imposed by user mobility, interference, as well as the multi-service nature of the traffic. Mobility models account for user motion in indoor

and outdoor environments taking into account cellular structures (pico-cells, micro-cells and macro-cells). Traffic models that account for the dynamic behaviour of the traffic and the mixture of voice with data (in multiple rates) are considered.

Chapter 2 presents related work published in the area of W-CDMA network planning. Four simulators that may be used for W-CDMA coverage and capacity planning are presented. Results from these simulators are used in Chapter 4 for comparison with the results obtained from the proposed system level simulator.

Chapter 3 discusses Implementation Issues of the Enhanced UMTS System Level Simulator, addressing System Level Simulator Design, External Interfaces with the Link and Network level simulators, Radio Resource Management, Radio Propagation, Traffic Modeling and finally Mobility Modeling.

Chapter 4 focuses on coverage and capacity planning. The chapter presents the methodology for the system level simulation tests and the specific scenarios that were run. Consequently, the results obtained from the Enhanced UMTS system level simulator are presented and a comparison of these results with coverage and capacity results obtained from different simulators is shown.

Chapter 5 concludes this thesis.

# Chapter 2

## Related Work

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2.1 Related Work on Simulation of W-CDMA network planning

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### 2.1 Related Work on Simulation of W-CDMA network planning

W-CDMA networks are multi-service environments that support bit rates from 8kbps to 2Mbps. Consequently, cell coverage varies according to the different bit rates and the different QoS requirements. Coverage and capacity are thus coupled as they influence each other. Planning of a W-CDMA network should hence consider both coverage and capacity to determine the values for each that provide the best support of the objective traffic mix.

Dehghan, Lister, Owen and Jones address several W-CDMA capacity and planning issues in [36]. The paper goes through the planning steps, link budgets and uplink capacity estimation procedure. To support their arguments, the authors present an example W-CDMA network, with results for a realistic site location in central London. Estimations for capacity are supported by providing corresponding Grade of Service (GoS) measures. They aim to locate those parameters, which affect the capacity of a W-CDMA network both from a theoretical point of view as well as through simulation runs.

Hoppe, Buddendick, Wolfle and Landstorfer also address WCDMA radio network performance in [9]. They present a dynamic simulator that aims to support the planning process of a W-CDMA network by analyzing the performance results obtained through simulation. The simulator is described and its major blocks are addressed, such as initialization, propagation modeling, uplink and downlink analyses. Furthermore, the performance parameters are described. The proposal of the dynamic simulation tool is

supported by a simulation example that outputs for a specific user distribution to provide coverage maps for different bit rate data services. The topology of the scenario aims to replicate downtown Munich. The scenario concentrates in presenting the *complex* interaction of coverage and capacity in a W-CDMA network.

Hoppe, Wolfle, Buddendick and Landstorfer further presented work in Fast Planning of W-CDMA networks in [10]. The paper elaborates on a proposed simulation tool that supports the W-CDMA coverage and capacity planning by evaluating the performance of specific network configurations. The results mostly focus on the voice service and present a coverage map for the specific scenario. The simulator is dynamic and it may be utilized, according to the authors, in order for implementation of W-CDMA networks to be done more efficiently.

Wacker, Laiho-Steffens, Sipila and Jasberg [11] address similar issues concerning W-CDMA radio network planning. They propose a static simulator for studying these issues. The proposed simulator allows analyzing coverage, capacity and quality of service related issues. The structure of the simulator is presented focusing on the initialization phase, the uplink and downlink iteration and the post-processing phase. An example scenario is provided to support the work. The scenario uses tri-sectored antennas in a 19-cell topology and presents separate results for uplink and downlink analysis. The aim is again to investigate the interactions between coverage and capacity and further to study different strategies for optimal planning of W-CDMA networks.

The simulators presented in this Chapter are time-based simulators focusing on the air interface as the most probable bottleneck of the system, supporting system level results on capacity and coverage. They aim to show the dependency of W-CDMA planning on the specific scenario used (including traffic model, propagation model, topology etc) as well as the inter-dependency of coverage and capacity in W-CDMA radio network planning. Results from the above simulators will be compared with results obtained from the Enhanced-UMTS system level simulator. An extensive description of the system level simulator follows in Chapter 3.

# Chapter 3

## Enhanced UMTS System Level Simulator: Implementation Issues

### 3.1 Introduction

The developed system level simulation environment captures the dynamic end-to-end behavior of the overall network. *Dynamic end-to-end behavior* includes the dynamic user behavior (e.g. mobility and variable traffic demands), radio interface, Radio Access Network, and Core Network, at an appropriate level of abstraction. The simulator is build using a discrete event based (DES) approach.

The physical link level behaviour is captured through a separate time based link level simulator, also developed within the SEACORN project [22]. The physical link level simulator is not addressed in detail in this thesis, only as an interface to the system level simulator since link level results are inputted into the system level simulator. Furthermore, the network level behaviour is in turn addressed in a separate network level simulator. The interface to this simulator is explained as part of the implementation of the system level simulator; however, the network level simulator is not addressed on its own.

In link and network level simulators only a limited part of all the phenomena that influence the simulation process of a UMTS network is studied at a time. A general evaluation that can provide an overview of the most important aspects is then necessary.

It is worth noting that the focus of the developed simulator is not only to capture the air interface behaviour as the only probable bottleneck (a common assumption in literature on UMTS [8, 9, 10, 11], but also investigate the influence of the all IP network in the overall UMTS system behaviour. The evaluation of the end-to-end system performance needs to incorporate the desired Quality of Service (QoS) measures as influenced by both the network behaviour and the radio link. This perspective results from the all-IP network approach. In an all-IP network QoS is currently not guaranteed.

## 3.2 System Level Simulator Design

Designing a simulation tool to evaluate the performance of 3G and beyond mobile networks at system level has to include both a consideration for the link layer as well as the network design which should include interference and user mobility and traffic specification.

The simulation approach used by the system level simulator is a discrete event-based approach that uses inputs representing the link layer generated in a time-driven simulation environment. Thus, the detail of the link level captured at extremely small time intervals is used at the system level where events such as packet events and mobility events drive the simulation [13, 14].

Although the system level simulator is an event-driven simulator, certain aspects of it need to consider time steps. As mentioned previously the link level time step is abstracted by using inputs generated in a separate time-driven simulator. Another mechanism that needs to consider a time step is the Power Control mechanism, which is part of the Radio Resource Management mechanisms, addressed in subsequent section. A different approach is taken to compensate for the Power Control time step. During Fast Power Control, events are scheduled to run every 0.667 ms, which enables the

event-based simulator to run at the Power Control frequency when this is demanded by the Power Control algorithm. This method cannot be used for link level simulations because they run continuously at extremely small time steps and cannot be efficiently scheduled at system level as events.

Thus, we may consider that the system level simulator is partly based on a hybrid approach, rather than on pure event-based techniques. A hybrid approach has its difficulties. Different system components run at different levels of abstraction (use different levels of data), run at different speeds and are triggered by different sets of "events". The basic objective of simulation is to monitor the behavior and performance of a system and consequently the simulation methods need to reflect as much as possible the real network.

The credibility of the simulation is based on more than simply the approach used by the tool. Another issue that has to be considered also is the use of pseudorandom generators in the case that such generator is used in the simulation. The proposed simulator uses the ns-2 predefined random generator which takes as input a random seed and uses it to generate the randomness required by the simulation. By feeding the generator with a variety of different random seeds and checking the interval of the final results we can acquire a level of confidence on the accuracy of the results that are based on the random generation tool. The validation of this as well as several other aspects of the system level simulator (e.g. radio propagation, traffic) is considered in detail in chapter 4 and sample validation results are presented.

The simulator may be used for two purposes. Firstly, it may be used to evaluate the performance of a given network by collecting Quality of Service (QoS) measures. QoS is an important issue and can be evaluated by collecting such measures as cell throughput, end-to-end delay and jitter and packet drops. QoS is evaluated at packet level, but the tool can further provide evaluation of the system at call level, usually referred to as Grade of Service (GoS) measures. These can include call acceptance rates, call block and call drop probability etc. QoS provisioning has to be considered both for the RAN and Core network but also for the wireless interface.

Radio Resource Management is hence an issue of primary importance to support the provision of QoS, and mechanisms for Radio Resource Management need to be implemented accurately and be used as part of the tool. Section 3.4 is dedicated to describing the Radio Resource Management mechanisms used in the system level simulator, based on descriptions found in [20].

Secondly, the system level simulator may be used for Radio Network Planning (RNP) purposes, i.e. tuning of certain system parameters in order to reach an optimal configuration for the given network [21]. W-CDMA Radio Network Planning (RNP) includes dimensioning, detailed capacity and coverage planning, and network optimization.

Dimensioning estimates an approximate number of base station sites, base stations and their configurations, as well as other network elements, based on the operator's requirements and the radio propagation in the area (defined in the simulator by the radio propagation model). The dimensioning must fulfil certain requirements for coverage, capacity and quality of service (QoS). Capacity and coverage are closely related and therefore both must be considered simultaneously in the dimensioning of W-CDMA networks. The input to the dimensioning process is hence the initial requirements for coverage, capacity and QoS as well as the area type and the radio propagation models.

During dimensioning, planning and optimisation, several required outputs will be produced such as a rough number of base stations and sites, base station configurations, site selection, cell specific parameters from RRM algorithms and hence adjustment of RRM parameters to optimal values and finally analysis on the issues of capacity, coverage and quality of service. Such analysis is based on:

    (a) Coverage: the coverage regions, area type information and propagation conditions,

    (b) capacity: the available spectrum, the traffic density information and

    (c) Quality of service (QoS): the coverage probability, the blocking probability and the end user throughput.

Radio Network Planning requires the system parameters to be accessible to the user of the tool and the generation of certain results that differ from the previously discussed results but are more appropriate for RNP purposes such as coverage maps, capacity figures, comparison of coverage and capacity for a given scenario to show the tradeoff of coverage and capacity in CDMA and W-CDMA networks. This tradeoff between coverage and capacity is addressed extensively in [5]. The authors propose a set of formulas that estimate the optimal effective coverage and hence capacity of the system.

In further sections several design issues will be addressed in further detail. These issues include: System Level Simulator Interfaces, Radio Resource Management, Traffic Modeling, Mobility Modeling, and Radio Propagation.

The design process needs not only concentrate on the logical entities that the system level simulator must include but also at the implementation level, how the modules will interact, how the system level algorithm will be structured and in general design the simulator in a functional manner given the logical modules that are required.

The simulator is comprised of several modules representing network physical entities, environment characteristics and models for dynamic user behaviour such as traffic and mobility.

Figure 3.1 shows the interconnection of the simulator modules. A scenario creates an environment and runs a set of simulations on that environment. To set up an environment several modules need to interact.
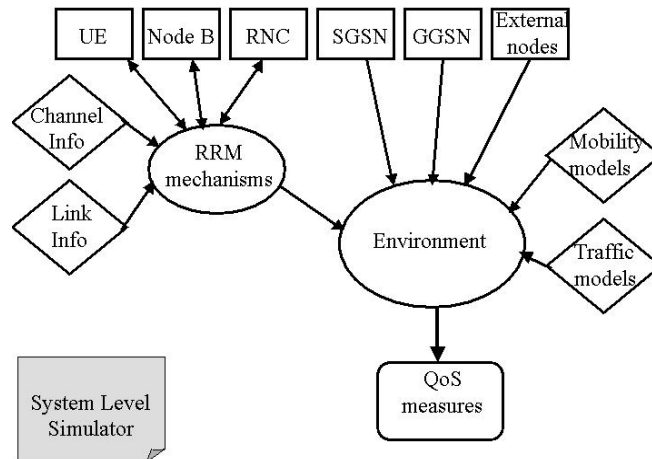
**Figure 3.1: The interactions of the modules that comprise the system level simulator**

The network topology is defined, by configuring each node to be one of the nodes indicated in the diagram (UE, Node B, RNC, SGSN, GGSN or external nodes). In the case these nodes are UMTS nodes (UE, Node B, RNC) they interact with the RRM mechanisms; else they interact directly with the environment. The RRM mechanisms take as further inputs link information (taken as inputs from separate link level simulations) and channel information (in the form of propagation models). The output from the RRM mechanisms is inputted in the environment as well. Furthermore, the environment is completed with the appropriate mobility and traffic models.

The modules comprising the simulator are categorized according to their functionality in one of three groups: Control Mechanisms, Mobile Environment Characterization and Performance Evaluation (Figure 3.2).
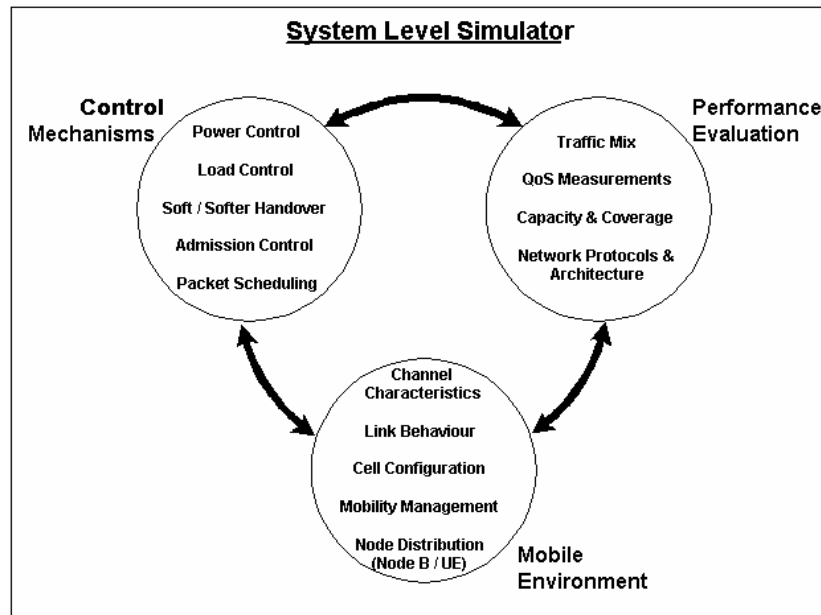
**Figure 3.2: A modular view of the system level simulator**

Control mechanisms, which include Power Control, Soft/Softer Handover, Admission Control, Load Control and Packet Scheduling, input information about the network state, the High Speed Downlink Packet Access (HSDPA) and the link level information.

The mobile environment, which includes the network layout and state, accepts user traffic characteristics and information about mobility from specified scenarios as well as physical parameters and channel behaviour information from the link level simulations. The mobile environment category contains the methods of generating a topology for a scenario as well as the initialization or redefinition of node properties. Node Bs and UEs are distributed in a predefined grid that represents the simulation area and for the basic simulator the cells are initially assumed to be circular with equal radii, but can be extended to hexagonal (or other) patterns.

Several factors influence the mobile environment such as the specific radio propagation model used, propagation delays between UE and UTRAN and between UTRAN and SGSN/GGSN, the mobility scenario defined for the UEs, the Uplink and Downlink differences and how these are modelled and the IP delay.

Performance evaluation will consider the network traffic model, the network protocols and architecture from the network and transport level simulations, and scenarios for traffic services and applications. Network performance must enable the evaluation of coverage, capacity, RRM mechanisms, protocols and architectures, and QoS/GoS (using metrics such as call blocking, call/packet dropping, and end-to-end packet delay).

The task of evaluating a network's performance demands for detailed and reliable results on the performance of the enhanced network. An additional demand is to obtain such results at acceptable simulation times. The simulator needs to be designed at an appropriate level of abstraction from a real network and simultaneously incorporate an adequate level of system detail.

Several factors influence the performance including the coverage and capacity, (such factors are mobility, QoS demands, radio environment, and radio and core network control mechanisms). For example, the distance between the UE and the Node-B, the path loss, and the power control mechanisms affect the coverage. Capacity is affected by traffic and handover mechanisms. Interference affects both coverage and capacity. QoS is affected by the different network architectures, protocols, and Radio Resource Management (RRM) mechanisms. These factors will be provided by network and transport level simulations.

The basic algorithm for the system level simulations is presented in Table 3.1.

| |
|---|
| 1. Generate network elements – network topology |
| 2. Distribute users on the simulation space |
| 3. Traffic generators start |
| 4. Calculate which of the users are active |
| 5. Update users location (simulation triggers) |
| 6. Update Handovers |

7. Estimate the interference for each specific cell

8. Determine the Signal-to-Interference Ratio (SIR)→compare against the target SIR

9. If calculated SIR < target SIR, then BLOCK

10. If it is a Real Time Service (RTS) then activate Admission Control (AC)

    a. If there are radio resources available then ADMIT

    b. Else AC send request for resources to Packet Scheduling (PS)

       i. If PS could free resources from Non Real Time (NRT) then NRTs reconfiguration, RTS admitted

       ii. Else BLOCK

11. If it is a non Real Time Service (non-RTS) → PS

    a. If there are radio resources available then ADMIT

    b. Else BLOCK

12. Perform Power Control

13. Update counters for statistics

14. If time > simulation time → Stop Simulation

15. Else process next event

**Table 3.1: System level simulator algorithm.**

The network topology is generated as a first step. Several types of nodes exist including UMTS aware nodes (e.g. UE, Node B, RNC) and non UMTS aware nodes. Most types of nodes communicate via fixed links with the exception of UEs and Node Bs that communicate via a wireless interface (characterized by inputs from link level simulations). UEs are distributed in the simulation environment at the beginning of the simulation as indicated in step 2.

The active users begin generating traffic, according to a pre-specified traffic model (step 3). The traffic model may also control the call duration for each user as well as the active users at a specific time (step 4). Step 5 uses the mobility model specified to update user positions by assigning movements and speeds to either individual users or

groups of users. Once the positions of the users have been updated, the handover mechanism handles any inter-cellular position changes (step 6). The redistribution of users due to mobility may have caused changes in the interference for each cell. Therefore, these interferences are recalculated after any handovers.

Steps 8-12 present how the RRM mechanisms operate when triggered by certain measurements. The RRM mechanisms manage the resources over the wireless interface. For each new service request there is a different sequence of events depending on whether the new service is a real time service or a non-real time service (steps 10 & 11). Finally, steps 13-15 update any traces to keep the simulation statistics and progress to the next event unless the simulation time has expired.

The design and implementation of the Enhanced UMTS system level simulator was performed within the IST funded SEACORN (Simulation of Enhanced UMTS Access and Core Networks) project [22].

## 3.3 External Interfaces

The E-UMTS system level simulator simulates the end to end behaviour of a UMTS or an Enhanced UMTS network. In order to achieve this, the simulator considers the complete network infrastructure at an appropriate level of abstraction. This includes the physical link layer, the network and transport layer and the system aspects of the network hence creating the need to develop three distinct simulators to examine in detail the different aspects and then merge them into one. The system level simulator integrates the simulation results from link level simulations and uses them as inputs to the system level simulations. Moreover, the network level simulator for E-UMTS is integrated in the system level simulation framework. Hence, a definition of the conceptual interfaces is necessary to facilitate the exchange of data and functionality between the simulations performed by each one of these simulators.

System level simulations aim at generating an overall understanding of the Enhanced UMTS network mechanisms and their effect on QoS. Since in an IP-based network QoS is not guaranteed, looking at the overall network will allow us to verify whether the

bottleneck of the communication chain is in the Core network and/or the radio (wireless interface and radio access network), or whether the network has a significant influence.

Building a system level simulator is often done by appropriately breaking the system down into subsystems according to the required element to be studied. In this case the system level simulations were abstracted into three simulators: the link level simulator, network and transport level simulator and the system level simulator.

The link level simulator was responsible to simulate the physical link level and to test combinations of different wireless techniques such as Adaptive Antennas, Space-Time Coding, Multiple Input Multiple Output (MIMO) systems, and spectrally efficient coding and modulation schemes in order to provide relevant parameters that will enable the system simulator to capture the behaviour of a population of mobile users at the link level [23].

The network level simulator is responsible for investigating the edge-to-edge IP transport network and the end-to-end IP network layers. The end-to-end IP layer extends from the mobile terminal to the remote host and it is used in the same manner as the IP layer in a typical TCP/IP model [24].

The system level simulator is responsible to evaluate through simulations the system level aspects of an E-UMTS network. Merging the system level simulator, with the network level simulator and by incorporating the appropriate measures from the link level simulator we are able to simulate, at system level, the end to end behaviour of an E-UMTS network.

To better understand the interfaces between the three simulators, let us relate them with separate aspects of the Enhanced UMTS network architecture. The network architecture of the Enhanced UMTS network simulator model includes the Radio Access Network (RAN) and the Core Network (CN). The RAN contains the User Equipment (UE) and the UMTS Terrestrial Radio Access Network (UTRAN), which includes the base station (Node-B), routers, and the Radio Network Controller (RNC). The system level

simulations will consider the overall end-to-end network behaviour, taking into account the wireless environment and the user mobility. Since the physical link level and transport and network level simulations already consider portions of the overall network, those portions will be represented at the system level by an interface to the simulations of link and network and transport simulators.

At an abstract view of the Enhanced UMTS network, (Figure 3.3) we can see the link level simulator at the radio interface, the transport simulator at the UMTS Terrestrial RAN, and the network level simulator and the system level simulator, both as end-to-end simulators but at a different level of detail.
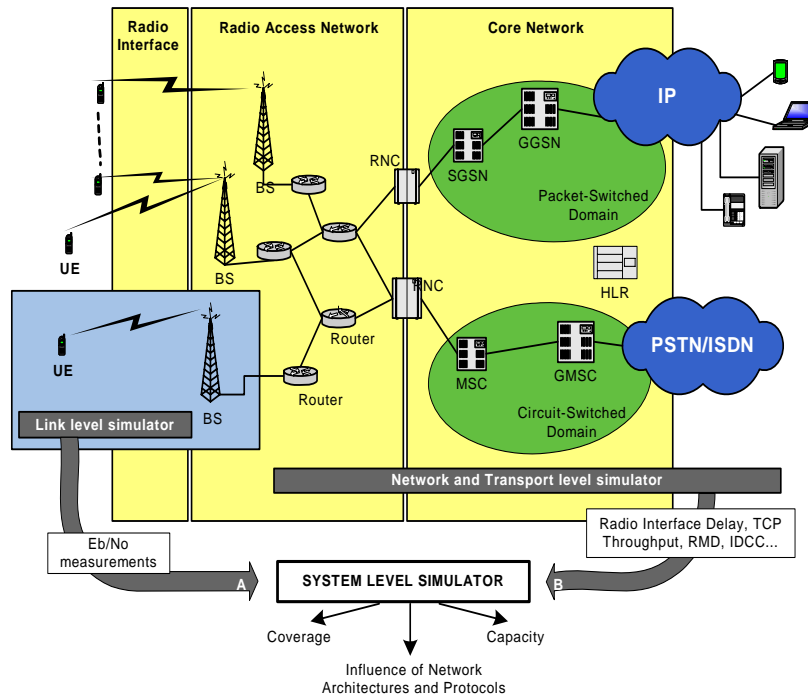


**Figure 3.3 - Visualising the interfaces**

The link level simulator provides the system level simulator its output as data (for example, packet-dropping probabilities for W-CDMA air interface may be provided as curves obtained from a set of simulations using an accurate time-based link level simulator). This Input must be identified as uplink (from the UE to the BS) or downlink (from the BS to the UE) parameters in the simulation code. For example, the Signal to

Interference Ratio (SIR), and the Block Error Rate (BLER) can take different values for the uplink and the downlink.

The system level simulator uses Eb/N0 measurements, which are measurements of signal energy per bit to noise power density per hertz. These measurements provide a predefined QoS. They are imported from the link level simulator, as shown by the arrow A in Figure 3.3.

Arrow B in Figure 3.3 indicates some of the parameters that the network level simulator is expected to provide; system measures for different traffic classes. Metrics such as radio interface delay and TCP throughput fall in this category. Investigation of certain architectures and protocols may also take place. The system level simulations are expected to test how such architectures and protocols affect the offered QoS. Software integration will allow the proposed implementations to be used

### 3.3.1 Interface between the Link and System level simulators

The link level simulation studies the effect of the radio channel on individual bits transmitted and also analyses the radio propagation. Furthermore, it includes the Enhanced UMTS physical layer features. The link level simulator aims to identify enhancements to the transceiver model to predict performance. Link level simulations address such issues as channel coding, interleaving and transmission and reception.

On the other hand, system level simulation must apply the findings of the link level simulation to a multi-cellular environment with numerous mobile users who generate traffic according to the specified traffic model. System level simulations move the users in simulation area and change transmission powers. Therefore, to achieve its results the system simulation has to consider the link level simulation results as an input.

This dichotomy between link level and system level simulations for a given network is necessary due to very different time scales used in each type of simulation: in link level simulations, the time step should be of the order of magnitude of one chip (0.26 microseconds), whereas in system level simulations, the time step is usually the power control time step (0.667 ms) [20]. The system level simulator is developed using the ns-2 simulation environment, which is event based [25]. However it considers the power control time-step when there are events in the event scheduler. Therefore, we can consider the system level simulator as using a more hybrid approach rather than a pure event-based approach.

The link level simulation output is provided as input to the system level simulator in the form of curves of Eb/No vs BER (Bit Error Rate).

Eb/No is the measure signal to noise ratio for a digital communication system. It is measured at the input to the receiver and is used as the basic measure of how strong the signal is (different forms of modulation have different curves of theoretical BER vs. Eb/No). These curves show the communications engineer the best performance that can be achieved across a digital link with a given amount of power.

The system level simulator will use the BER values for different scenarios, different number of users and varying mobility, to examine how the required services can be provided and with what capacity, in order to keep the mobile users satisfied, i.e., maintaining the required level of QoS.

### 3.3.2 Interface between the Network and System level simulators

The main purpose of an End-to-End IP network simulation is to study the performance of IP over Enhanced UMTS. In this context, IP means the network layer and above, i.e. transport and application layers.

The network level simulator studies the end-to-end behaviour, similarly to the system level simulator. However, the focus of the two simulators is different. The network level simulator concentrates on the network performance (whilst abstracting mobility and radio effects) but the focus of the system level simulator includes the user behaviour (e.g. traffic mix and mobility scenarios).

The network level simulations are expected to focus on one or a few (abstracted) users within one single cell. In contrast, the system level simulation is expected to consider many users in a multi-cellular environment. The network simulator uses noise to represent other users. Noise however is not very useful in larger scale end-to-end simulations where many users interact within each cell, and across many cells. The extended mobile user interaction necessitates the use of more representative Interference measures in a system level simulation, rather than noise measures.

The network level simulator is more static in the aspect that it does not explore user mobility in the simulations and does not consider a multi-cellular network. For an Enhanced UMTS network, a static simulation is useful only as a complementary solution to a simulation that will include the dynamic user behaviour (e.g., mobility and variable traffic demands). A static snapshot simulation would be making use of average conditions. Models such as mobility and traffic are required for achieving more accurate evaluation measures. These involve dynamic behaviour that needs to be incorporated in the system level simulator simulation

The interface between the network and system level simulations is done directly by integrating the software extensions that comprise the network level simulator in the system level simulator. Both of the simulators use the NS-2 network-modelling tool as the simulation framework. Hence, the interface involves software integration between the network level simulations provided, with the software that comprises the system simulation environment developed.

In addition, the choice of an object-oriented simulation environment for the development of both network and system level simulators helps achieve a smooth interface between the two. This is because dealing with pieces of software as abstract but at the same time distinct objects (e.g., nodes, agents etc), makes the process easily comprehensible. In addition to this, object-oriented environments provide software modularity, a feature that provides more reliable software integration, as it facilitates the design of the integration process.

## 3.4 Radio Resource Management

The study of the RRM mechanisms facilitates the assessment of the feasibility of offering a mix of services with an acceptable QoS in an IP based mobile network. Third generation (3G) wireless systems, such as the Universal Mobile Telecommunication System (UMTS) are designed to support a wide variety of services like speech, video telephony, Internet browsing, etc. This mixture of services produces a range of Quality of Service (QoS) requirements. These requirements are controlled in the radio interface, by Radio Resource Management (RRM) mechanisms.

The specific Radio Resource Management (RRM) mechanisms implemented in the system level simulator are Power Control, Packet Scheduling, Call Admission Control, Load Control and Handover.

The main goal of power control is to handle intra-cellular and inter-cellular interference. Interference arises due to the fact that all users in a CDMA system can share a common frequency. This is especially important for the uplink direction, since one UE located close to the Node B and transmitting with excessive power, can easily override mobiles that are at the cell edge (the near-far effect), block the whole cell, or even cause interference to UEs in neighbouring cells (inter-cell interference). In the downlink direction the system capacity is directly determined by the required code power for each connection. Power Control tries to keep the transmission powers at a minimum level while ensuring adequate signal quality and level at the receiving end.

Admission Control and Packet Scheduling both participate in the handling of non Real Time (NRT) radio bearers. Admission Control takes care of admission and release of radio access bearers (RABs). Radio resources are not reserved for the whole duration of the connection but only when there is actual data to transmit. Packet Scheduling allocates appropriate radio resources for the duration of a packet call, i.e., active data transmission.

Packet Scheduling is done on a cell basis. Since asymmetric traffic is supported and the load may vary a lot between uplink and downlink, capacity is allocated separately for both directions.


For Real Time traffic Admission Control is responsible and it must decide whether a UE is allowed to enter the network. If the new radio bearer would cause excessive interference to the system, access is denied. The Admission Control algorithm estimates the load increase that the establishment or modification of the bearer would cause in the Radio Access Network (RAN). Separate estimates are made for uplink and downlink. Admission Control functionality is located in the radio network controller (RNC) where all the information is available.


Under normal circumstances the Load Control ensures system stability and that the network does not enter an overload state. In order to achieve stability the Load Control works with the Admission Control and with the Packet Scheduler. This task is called preventive Load Control. Only in unusual circumstances can the system be found in a situation of overload. When this happens the Load Control is responsible for reducing the load in a relatively fast way, bringing the system back to the desired state of operation. The Load Control process is distributed between two types of network elements, the Node B and the RNC.


The Handover process is one of the essential means that guarantees user mobility in a mobile communication network. The handover concept is simple. When a subscriber moves from the coverage area of one cell to another, a new connection with the target

cell is set up and, if necessary, the connection with the previous cell released, so as to provide continuity of service. The basic reason behind a handover is that the air interface does not fulfil the desired criteria set for a connection and either the UE or the UTRAN initiates actions in order to improve the connection.

## 3.5 Radio Propagation

The estimations for the radio propagation models, for the UMTS and Enhanced UMTS environments, are based on the COST Action 231 (European Cooperation in the field of Scientific and Technical research: Digital mobile radio towards future generation systems) [26]. This project dealt more precisely with theoretical and empirical approaches and extensive measurement campaigns in European cities. The models created by the COST Action 231 are based on the already existing approaches of Walfisch, Ikegami and Hata models.

### *3.5.1 Radio Propagation for the Office Environment*

The propagation model implemented in the simulator for the Office environment scenarios is the Indoor Office path loss model. The indoor office path loss model exhibits a low increase of path loss versus distance, which is a worst case from the interference point of view and is defined as follows:

$$L = L_{FS} + L_c + \sum k_{wi} L_{wi} + n^{((n+2)(n+1)-b)} * L_f$$

where $L_{FS}$ is the path loss of free space between transmitter and receiver, $L_c$ is the constant loss, $k_{wi}$ is the number of penetrated walls of type $i$, $n$ is the number of penetrated floors, $L_{wi}$ is the loss of the wall of type i, $L_f$ is the loss between adjacent floors, and b is the empirical parameter. The average number of floors considered in office environment is usually 4. For capacity calculations in moderately pessimistic environments, the model can be modified to n=3. Another simplification is to use the weighted average for certain loss categories. For example, the path loss for typical floor structures can be averaged to 18.3 dB, for light internal walls to 3.4 dB and for internal

walls to 6.9 dB. Under such simplifying assumptions of the office environment the indoor path loss model has the following form:

$$L = 37 + 30\log_{10}(R) + 18.3n^{((n+2)(n+1)-0.46)}$$

where $R$ is the transmitter receiver separation given in metres and n is the number of floors in the path. $L$ shall in no circumstance be less than free space loss. According to [26] a log normal shadow fading standard deviation of 12dB can be expected.

### 3.5.2 Radio Propagation for the Business City Centre Environment

The propagation model used for the business city centre environment is based on a combination of the existing Walfisch and Ikegami approaches, and it is called the Walfisch-Ikegami model. The business city centre is characterized by micro cells, base station antennas located below roof top level and free line-of-sight (LoS) between antenna and mobile and these features need to be considered in the radio propagation model.

The proposed path loss model is defined below:

$$Lb = 42.6 + 26.\log(d/km) + 20.\log(f/MHz) \quad \text{for } d \geq 20\text{m}$$

Where $L_b$ is equal to free-space loss for d=20m.

The above path loss formula for LoS scenarios is simple but at the same time different from free space loss formula. To achieve this propagation loss expression, COST 231 performed several measurements in the city of Stockholm.

### 3.5.3 Radio Propagation for the Urban Environment

The propagation model used for the urban environment is the Hata model. To estimate the propagation loss by the Hata model, we have to know four important parameters: frequency f, distance d, the Node B antenna height $h_{Base}$ and UE antenna height $h_{Mobile}$.

However, this model cannot be used in all situations and is restricted to the following range of parameters:

- Frequency of 150 to 1000 MHz

- Distance of 1 to 20 km

- Node B antenna height from 30 to 200 m

- UE antenna height from 1 to 10 m (the value usually varies from 1m to 3m)

This model is applicable to test scenarios evaluating urban environments outside the high rise core where the buildings are of nearly uniform height. The Hata model proposed by COST 231 [26] must not be used for micro-cells or pico-cells and its application is restricted to macro-cells. The path loss is given by the following formula:

$$L = 40(1-4\text{x}10\text{-}3\Delta hb)Log10(R) - 18Log10(\Delta hb) + 21Log10(f) + 80 \text{ dB.}$$

Where:

- R is the Node B - UE separation in kilometers;

- f is the carrier frequency of 2000 MHz;

- $\Delta hb$ is the base station antenna height, in meters, measured from the average rooftop level.

Considering a carrier frequency of 2000 Mhz and a base station antenna height of 15 meters, the formula becomes:

$$L = 128.1 + 37.6 \, Log_{10}(R)$$

$L$ will not be less than free space loss. This model is valid for non Line-of-Sight (NLoS) case only and describes worse case propagation.

## 3.6 Traffic Modeling

One of the main goals of Enhanced UMTS is to be able to provide 8-10 Mb/s in both the uplink and downlink directions by exploring new technologies such as HSDPA (High Speed Downlink Packet Access) [5], adaptive antennas and new channel coding

techniques. Support for new applications with higher data rate, as well as increased user capacity needs to be evaluated through the Enhanced UMTS simulator.

An application is defined as a task that requires communication of one or more information streams, between one or more parties that are geographically separated, being characterized by the service attributes, and also by traffic and communication characteristics. A set of applications with a common set of characteristics or a single application may be classified as a service. Applications and services may be categorized as interactive (conversational, messaging and retrieval) and distribution (broadcast and cyclical) [27]

In interactive services there is a two-way exchange of information between any two hosts. Interactive services may be subdivided into three different subcategories: conversational, messaging and retrieval services.

Conversational services provide bi-directional dialogue communication. It is a bi-directional, real-time, end-to-end information transfer between two hosts. Such applications include: Video-telephony and Video-conferencing. Messaging services offer host-to-host communication using the store-and-forward method. Such applications are not real time. They include: Stored Video and Voice Mail. Retrieval services provide the user with the capability to retrieve information stored in information centres that, in general, is for public use. Such applications are: broadband retrieval services for film, audio information and archival information.

In distribution services information transfer is primarily one-way, from the service provider to the subscriber, including broadcast services, where the user has no control over the presentation of the information, and cyclical services, which allow the user some measure of presentation control.

Broadcast services provide a continuous flow of information, distributed from a central source to an unlimited number of authorized receivers connected to the network. Each user can access this flow of information but has no control over it. An example application is an electronic newspaper broadcast service. Cyclical services allow

distributing information from a central source to a large number of users. The information is provided as a sequence of information entities with cyclical repetition. The user can control the start and order of the presentation of this information. Examples of cyclical applications are tele-text and electronic newspaper using public networks.

In UMTS the traffic classes are differentiated according to 3GPP QoS classification of services, i.e. conversational, streaming, interactive and background. The distinguishing factor of these classes is how delay- sensitive the traffic is. While the conversational class is the most delay-sensitive the background class is the less delay-sensitive one.

Conversational class will be transmitted as a real-time connection. It is always performed between live end-users. This is the only type where the required characteristics are strictly imposed by human perception. The end-to-end delay is low (less than 400 ms) and the traffic is nearly symmetric. Some of its applications are speech service, video telephony and voice over IP.

Multimedia streaming is a technique for transferring data such that it can be processed as a steady continuous stream. In this way, the client browser can start displaying the data before the entire file has been transmitted. In this class, applications are very asymmetric, like web broadcast or video streaming on demand.

Interactive class is applied when the end-user (human or machine) is on line requesting data from remote equipment. It is characterized by the request response pattern of the end-user and the content of the packets must be transparently transferred (low bit error rate). Examples of human interaction are: Web browsing, database retrieval, and server access. And examples of machine interaction with remote equipment: polling for measurement records and automatic data base enquiries. Some of the interactive class applications are: location based services and computer games.

Background class is more or less insensitive to delivery time. That is because the destination is not expecting the data within a certain time, so the delay can be from

seconds to minutes. And applications, such as e-mail, SMS or downloading databases, can be delivered background since they do not require immediate action.

The implementation of the different services would lead to a large number of models. The goal of the present section is to present a generic model for packet data services, more suitable for implementation purposes, and that will be used as the implementation frame for all the different services. The aim is that the generic models can behave, in an aggregated way, as any of the described services by simply enabling specific distributions for the different generic model phases. For that objective, the main characteristics of previously presented services must be addressed and grouped. Due to the difficulty of finding common characteristics between the real time traffic and the non real time traffic, two generic models are developed, one for each service type.

Most of the non-real time services share the following characteristics:

- At the start of a connection, a number of small messages are exchanged to set-up the service.
- In some cases TCP is used. The slow start and the congestion avoidance algorithms rule the behaviour of the traffic offered to the network.
- At the end of the service, some small packages are often exchanged to release the connection.
- For some services, the user requires some time to analyze the received data before requesting the download of new data. This time is commonly known as the *reading time*.

It is very difficult to develop a generic real time model that describes the statistical behaviour of all the real time traffic services as Voice over IP or Video Telephony, since it is highly dependent on the service, the application, etc. However, this traffic type does not have neither large gaps in the transmission stream (as the reading time in NRT traffic), nor data request packets. Therefore, the commonly used characteristics of RT services are the packet size and the packet inter-arrival time.

In general, when modelling applications, there are many parameters to be considered. These parameters include service parameters (RT or NRT, Unidirectional or Bi-

directional, unicast or multicast), traffic parameters (generation process, distribution of the duration, average duration of connections, transmission data rate), communication parameters (burstiness, BER, Communication Protocol), session and activity parameters (BHCA and inter-arrival time, arrival distribution, average active/inactive time and its distribution, duration and its distribution), service component parameters (generation process distribution, generation rate, average duration, number of times each component is accessed) and operation parameters (environment, mobility scenario, deployment scenario) [27]. We will provide these parameters for the traffic model used for the sample scenarios presented in Chapter 5.

In the system level simulator traffic is monitored by tracing the packets sent and received. A trace is a collection of packet records that contains time-stamp information about the source and destination (of the current link), size and type of packet, and a packet unique id. Each trace file contains packets of a single flow that is packets flowing on one direction of the path (one or many links). Thus the results are obtained on a per-flow basis. A flow is defined as a set of packets with the same protocol number, destination and source IP addresses, and port numbers.


## 3.7 Mobility Modeling

The mobility is greatly dependent on the environment of each user. A natural separation of the operating environments is in outdoor environments and indoor environments. By outdoor environments we mean physical locations that are located outdoors such as: roads and railway tracks, rural areas, urban areas and downtown areas. Indoor environments include: home, office, airports, train stations, commercial zones, theatres and stadiums and parking zones. 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.

However, a more useful classification of environments is according to the cell size that characterizes the specific environment. This work considers three categories: pico-cellular environments, micro-cellular environments and macro-cellular environments.

Pico-cellular environments have small cells and low transmit powers, and both the users and the base stations are located indoors. Some examples of physical environments that correspond to the Pico-cellular category are: home, office, airport and train station, malls, theatres and covered stadiums and covered parking zones.

Micro-cellular environments are characterized by small cells and low transmit powers as well. In our scenarios, however, only outdoor users are considered. Examples of micro-cellular environments are: open stadiums, open parking lots, open commercial zones, downtown areas (Manhattan grid).

Finally, the macro-cellular environments have large cells and high transmit powers as opposed to the previous two types of environments. For the macro-cellular environment, we implement different type of antennas than the previous two environments, for increased capacity. These will be further explained in Chapter 5 Examples of such environments are: urban areas, rural areas, roads and railway tracks.

Several mobility models have been defined, such as the random walk model, the fluid flow model, the random Gauss-Markov model, the reference point group mobility model etc [29]. From existing mobility models appropriate ones need to be chosen and used in the simulations for the Enhanced UMTS network. The choice will follow from the choice of the environments that the simulation scenarios employ.

The environments chosen are a minimum representative set of environments. One pico- one micro- and one macro-cellular environment are implemented for this work, namely, the office model, the business city centre model and the urban model.

For the office model, the Random Waypoint Mobility Model is implemented. For the business city centre scenario, the Manhattan grid model is used and finally for the urban environment, the mobility model implemented is the Gauss-Markov Model.

Now that the three environments have been chosen, each environment needs to be further defined, according to how the users move, in order to advance to the implementation of mobility models that suit each environment.

In an Office environment the users are stationary most of the time. When they move the path is either along the x or the y axis. They have a specific destination, which is randomly chosen. The source and destination positions are either in an office room or a corridor. Several parameters may be specified such as the ratio of room situated mobile terminals to the corridor situated mobile terminals at any time, the average time in an office room and the corresponding average time in the corridor, the mobile speed and the average distance between source and destination.

In a Business City Centre environment, the mobiles move along streets and may turn at crossroads with a given probability. Positions are updated relatively often because the speeds considered for this environment are pedestrian. A good value for a position update is every five meters. At each position update, there could be a speed change according to a given probability. Several parameters may be specified such as the average speed and the minimum speed, the probabilities to turn or to change speed.

In an urban environment the mobiles move with higher speeds according to a pseudorandom mobility model. Position updates are not as often as in the Business City Centre due to the higher speeds. The positions may be updated every twenty meters for example. Parameters that could be specified are: average speed, probability to change direction at a position update, maximal angle for this change of direction.

# Chapter 4

## Coverage and Capacity Planning

## 4.1 Introduction

A key issue for $3^{rd}$ Generation (3G) mobile operators is radio network planning (RNP). RNP should meet current standards and demands and also comply with future requirements. It mainly depends on coverage and capacity. Its main objectives are to support the required traffic mix with sufficiently low blocking and delay (capacity) and to ensure service availability in the entire service area (coverage), while providing the required QoS.

This work concentrates on a specific aspect of radio network planning, i.e. coverage and capacity planning. Coverage and capacity are closely related and therefore both must be considered simultaneously in the planning process of W-CDMA networks.

Coverage planning consists of the selection of the location and the configuration of the antennas. The coverage area achieved by a single antenna depends mainly on the propagation conditions and is independent of all other antennas in the network. The cell range in a W-CDMA system does not only depend on propagation conditions but also on the traffic load of the cell. Increasing the cell load causes the cell coverage area to become smaller (the

well known cell breathing problem [20]). In this manner, coverage and capacity in a W-CDMA network are interconnected.

Estimating capacity involves determining how many mobile users each cell can serve with the pre-specified traffic mix. Once the cell capacity and subscriber traffic profiles are known, network area base station requirements can be calculated. The starting point for coverage estimation is to define the required data rate(s) in the network area. Usually the operator predefines these. In the case of the Enhanced UMTS system level simulations, these are based on traffic estimations and forecasts completed within the IST SEACORN project.

Simulation can be done by creating a uniform base station and mobile distribution plan with defined service profiles. A uniform distribution is chosen so that we get a homogeneous network, without any hotspots (where user concentration is too high). A homogeneous network scenario enables us to reach certain conclusions regarding the optimal coverage and capacity in an ideal situation. Another consideration when creating a topology is cell coverage. Cell coverage overlap parameter can increase the cell count dramatically. A common value used for cell overlap is 20%-30%, but it can change by the operators subject to the build cost.

This chapter presents and analyzes results on Enhanced-UMTS coverage and capacity planning obtained using the system level simulator presented in Chapter 3. Furthermore, it provides an evaluation by comparison of the obtained results.


## 4.2 Methodology

Coverage and Capacity planning is dependent on the selected scenario, i.e. the results depend on the specific scenario parameters such as site selection, antenna-specific parameters, propagation, traffic and mobility models used for the environment simulated. Therefore, the first step is to carefully select the environment parameters that will characterize the specific scenario. Planning is mainly dependent on the propagation model and the traffic model; therefore they need to be carefully defined for each scenario, so as to "closely" represent reality.

Once the specific scenario is specified, a first educated guess of a reasonable configuration of the Node Bs is done. The estimation is for the locations of the Node Bs in the predefined simulation area. The initial estimations regarding the topological configuration of the base stations is based on recommendations of the SEACORN project [22].

Consequently, two sets of simulations are run for each scenario. For the first simulation set we vary the values of the cell radii, while keeping the rest of the scenario parameters constant. The best cell radius (directly proportional to the distance between Node Bs in a homogeneous environment), and hence the best cell coverage, is given by the least number of blocked calls in a simulation run. Once the best cell radius is determined for each scenario a set of simulations with varying number of users per environment is run. This is done to determine the maximum capacity that can be supported by the specific scenario.

Once the best coverage and capacity for each scenario are determined, the results are compared with results from different simulators to evaluate their accuracy. Figure 4.1 illustrates this process.
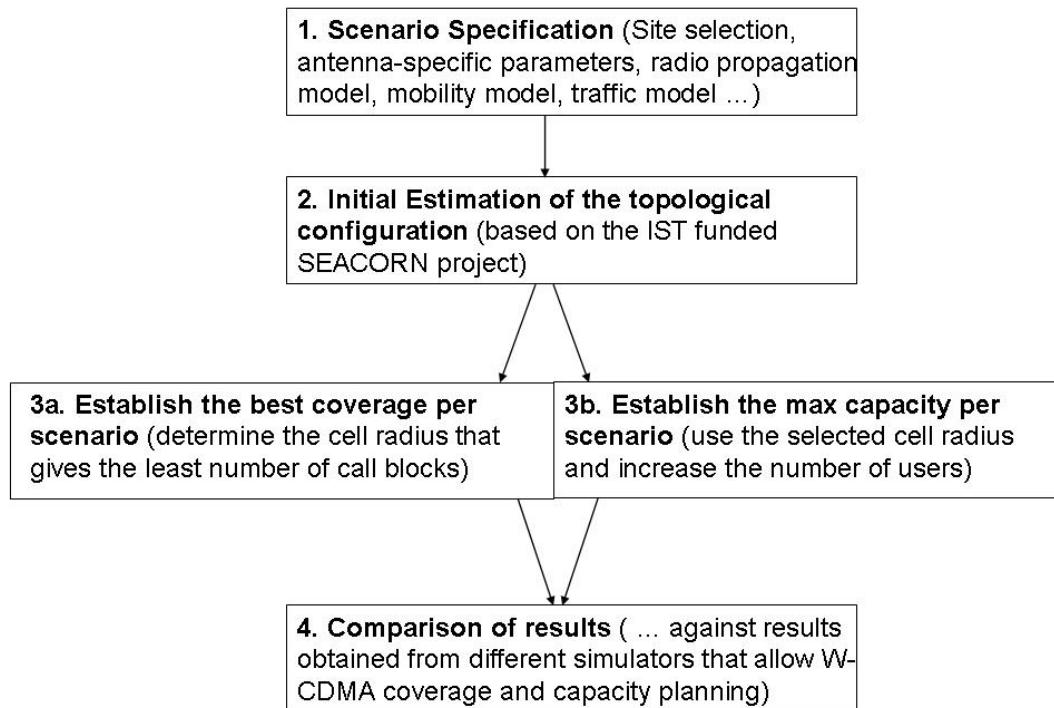
**Figure 4.1: Coverage and capacity planning methodology**

## 4.3 Scenarios

The scenarios were simulated in the event-based system level simulator developed within the IST SEACORN project using the publicly available ns-2 (Network Simulator – version 2) simulation environment. Each simulation scenario is defined by a variety of parameters, including traffic, propagation and mobility models as well as topologies and user population. Furthermore, each scenario corresponds to a specific operating environment. We simulate three such environments: an Office environment, a Business City Centre environment and an Urban environment.

The propagation models used in all scenarios are based on the COST 231 models [26]. The scenarios use the propagation models described in Section 3.4. The traffic models for each environment are based on traffic forecasts prepared within the SEACORN project, and characterize the proposed Enhanced-UMTS traffic mix per environment. The traffic model will be described separately for each environment. The mobility

models for each scenario are based on the descriptions provided in Section 3.6, and are further described below.

### 4.3.1 Office Environment scenario

The topology of the Office scenario consists of 6 pico cells. The Node Bs are situated in offices separated by a corridor 5m wide. The height of the offices is 3m. Figure 4.2 illustrates the distance between he Node Bs to be 30m but this is subject to change as we will show in the simulation results in the following section.
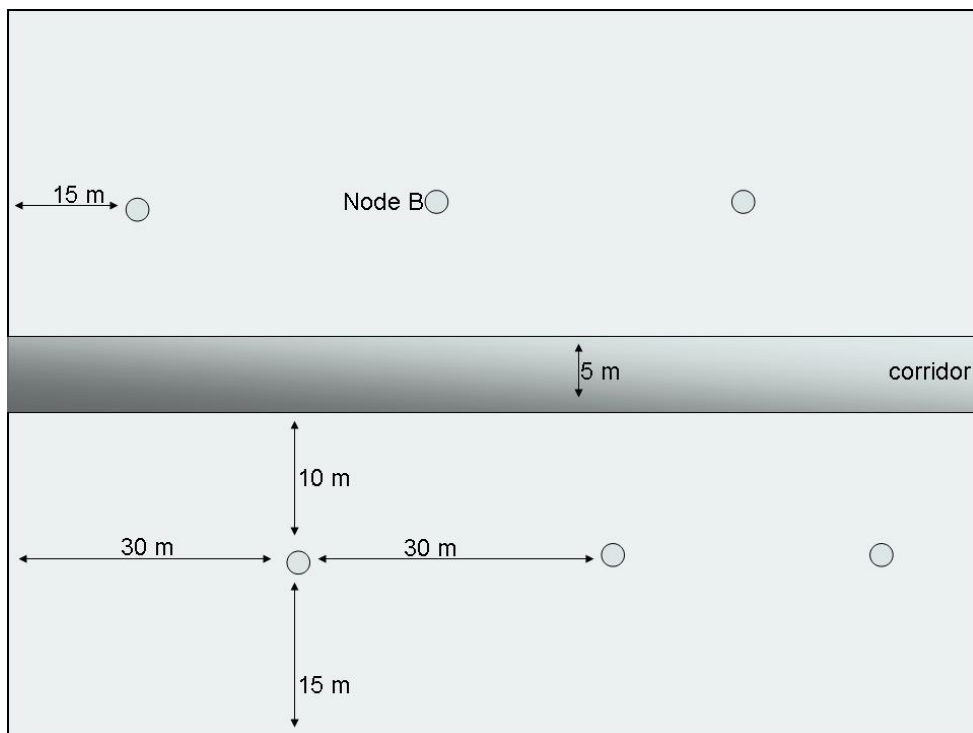


**Figure 4.2: Topology scheme for the Office Scenario.**

The mobility model used for the Office Environment scenario is the Random-Waypoint mobility model. The model defines a pattern of movements for each user individually. This pattern is confined within the predefined grid area and consists of a sequence of movements.

Each node in the model is assigned a pause time. Every node waits for the time specified as the pause time, and then chooses a random location on the map and heads

toward that location with a fixed speed of 3km/h (0.83m/s), a typical pedestrian speed. Once it arrives, it again waits for the duration of the pause time before moving again. The pause time is normally distributed between 0 and max pause time defined in this scenario to be equal to the total simulation time (200 sec). In this manner some users never move during the simulation and this is randomly assigned. Since in the Office environment we have to consider the walls of the offices and the corridor, the users are restricted to move only in the x- or the y-direction. The average ratio of room to corridor mobile terminals is 85%.

The Radio Propagation model used is the Indoor propagation model (see Section 3.4).

A traffic mix model is defined for this environment that generates traffic according to predefined usage percentages and assigns an application to each user accordingly. The traffic mix includes four types of services: voice at 12 kbps, multimedia at 144kbps, narrowband at 384kbps and wideband at 768kbps. The corresponding applications are modelled as distributions with predefined burst and idle times and are run using UDP as the transport protocol. The corresponding service usages for the Office scenario [22] are:

- Voice: 29%

- Multimedia: 18%

- Narrowband: 24%

- Wideband: 29%

The following set of graphs presents the initial user distribution for three sub-scenarios: (a) 200 total users, (b) 300 total users and (c) 400 total users. The graphs show the locations for the Node Bs, the UEs and also show which of these UEs are active at initialization.
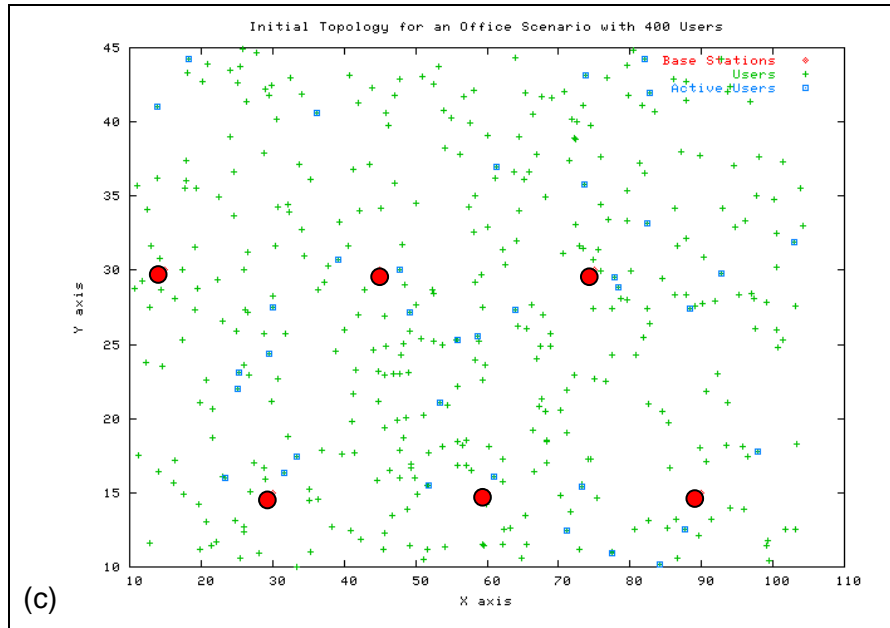
(a)



(b)
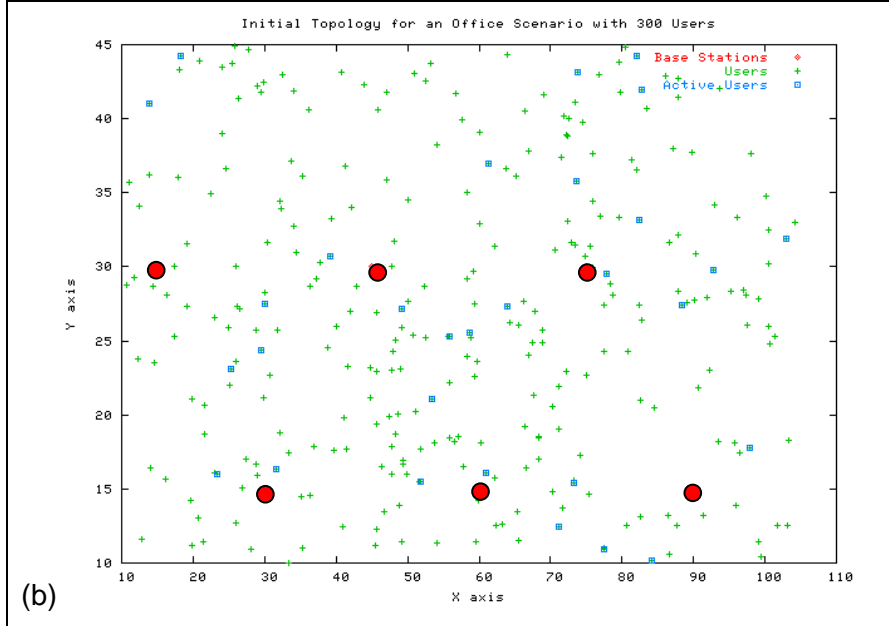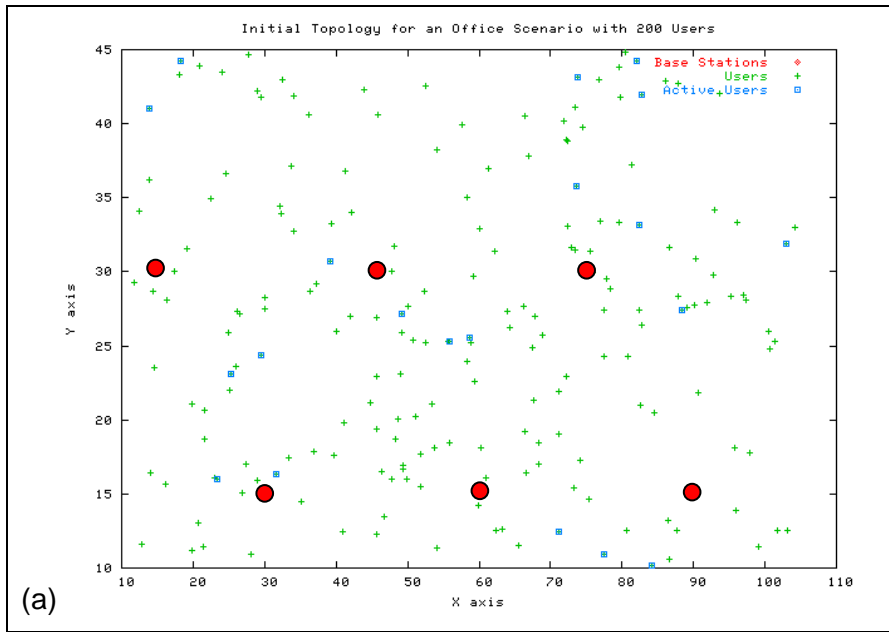
**Figure 4.3: Initial user distribution for the Office scenario (a) 200 total users (b) 300 total users (c) 400 total users.**

### 4.3.2 Business City Centre Environment scenario

The BCC topology consists of 25 micro cells, which are arranged as a grid with building blocks and crossroads. The grid size (total simulation area) for the 25-cell topology is 1350m x 1350m. This is better illustrated in Figure 4. The antennas used in this scenario are omni- antennas. An omni-antenna transmits at a 360-degree angle. The Node Bs are located outside the buildings in one of the corners. The distance between the Node Bs illustrated in Figure 4.4 is 230m.
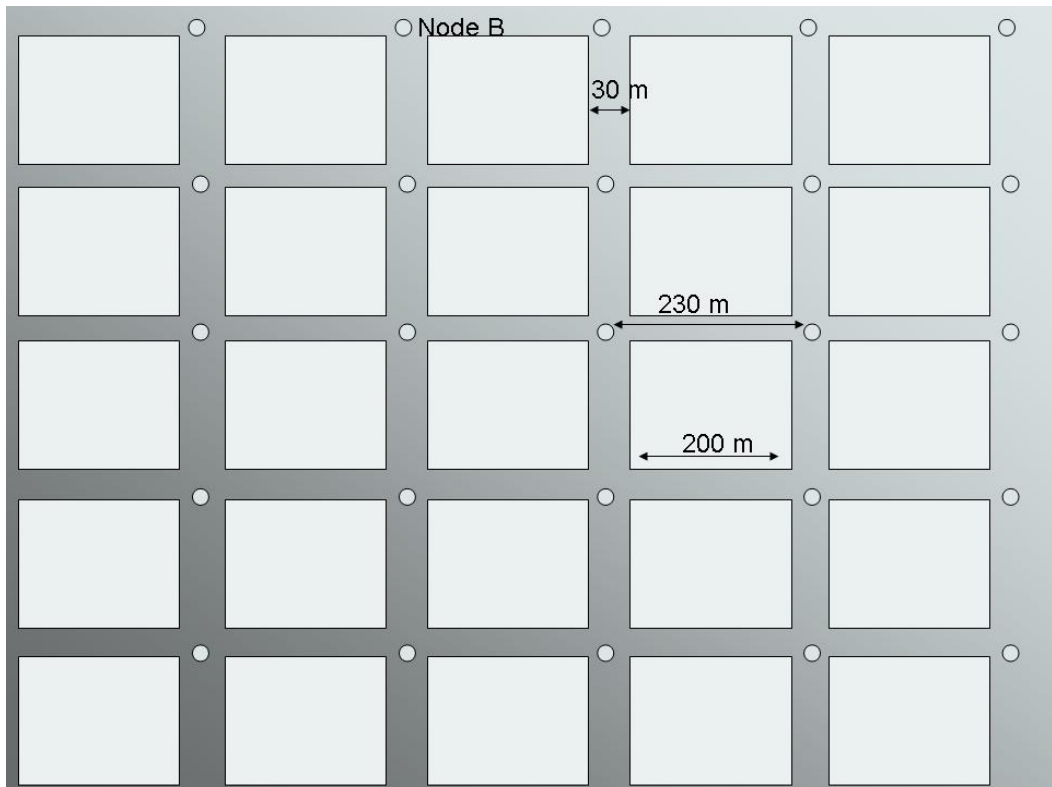
**Figure 4.4: Topology scheme for the BCC Scenario**

The mobility model used for the Business City Centre environment is the Manhattan Grid mobility model. A pattern of movements is defined separately for each user. The Manhattan Grid model specifies that the nodes move only on predefined paths along a Manhattan grid (only parallel to either the x- or the y- direction). In the model we assume a Manhattan grid, i.e. blocks along the x- and y-direction separated by paths where the mobile users move. Specifying the number of these blocks in each direction provides the topography of the business city center being simulated.

Since we consider only pedestrian users, the user speed, is set here again as in the Office environment to equal 3km/h or (as ns-2 specifications require), 0.83m/s. The users move in the roads and at each crossroad they have a 0.5 probability to turn and a 0.5 probability to keep walking straight.

The following set of graphs show the initial distribution of the users for the Business City Centre 25-cell topology in the case of 1000, 1250 and 1500 users. The red marks

indicate the positions of the base stations, the green marks indicate the positions of the users and the blue marks show the positions of the active users.
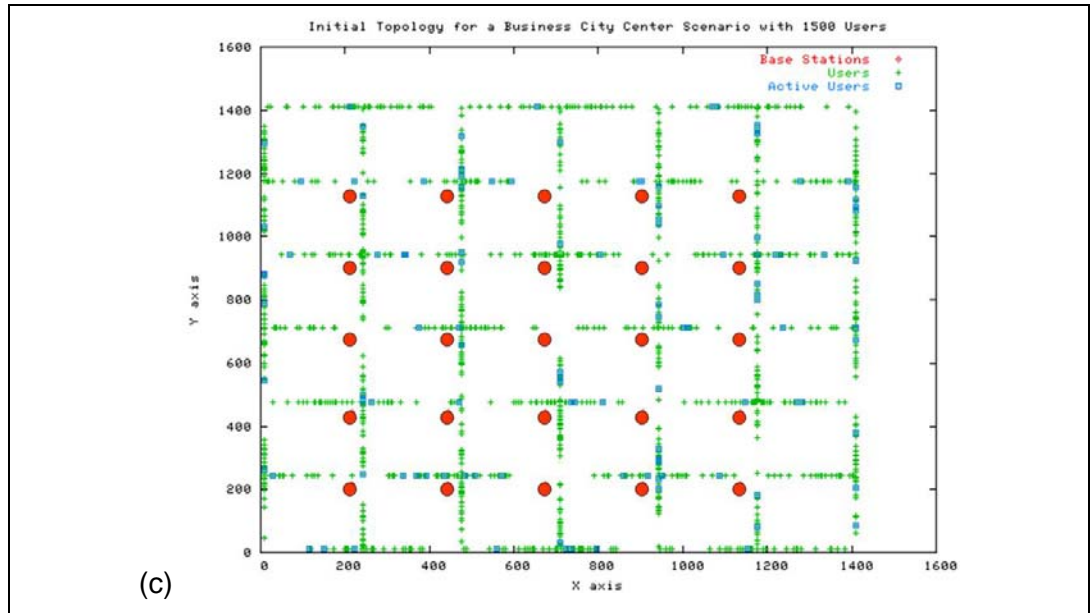


(a)

(b)

Initial Topology for a Business City Center Scenario with 1500 Users

(c)
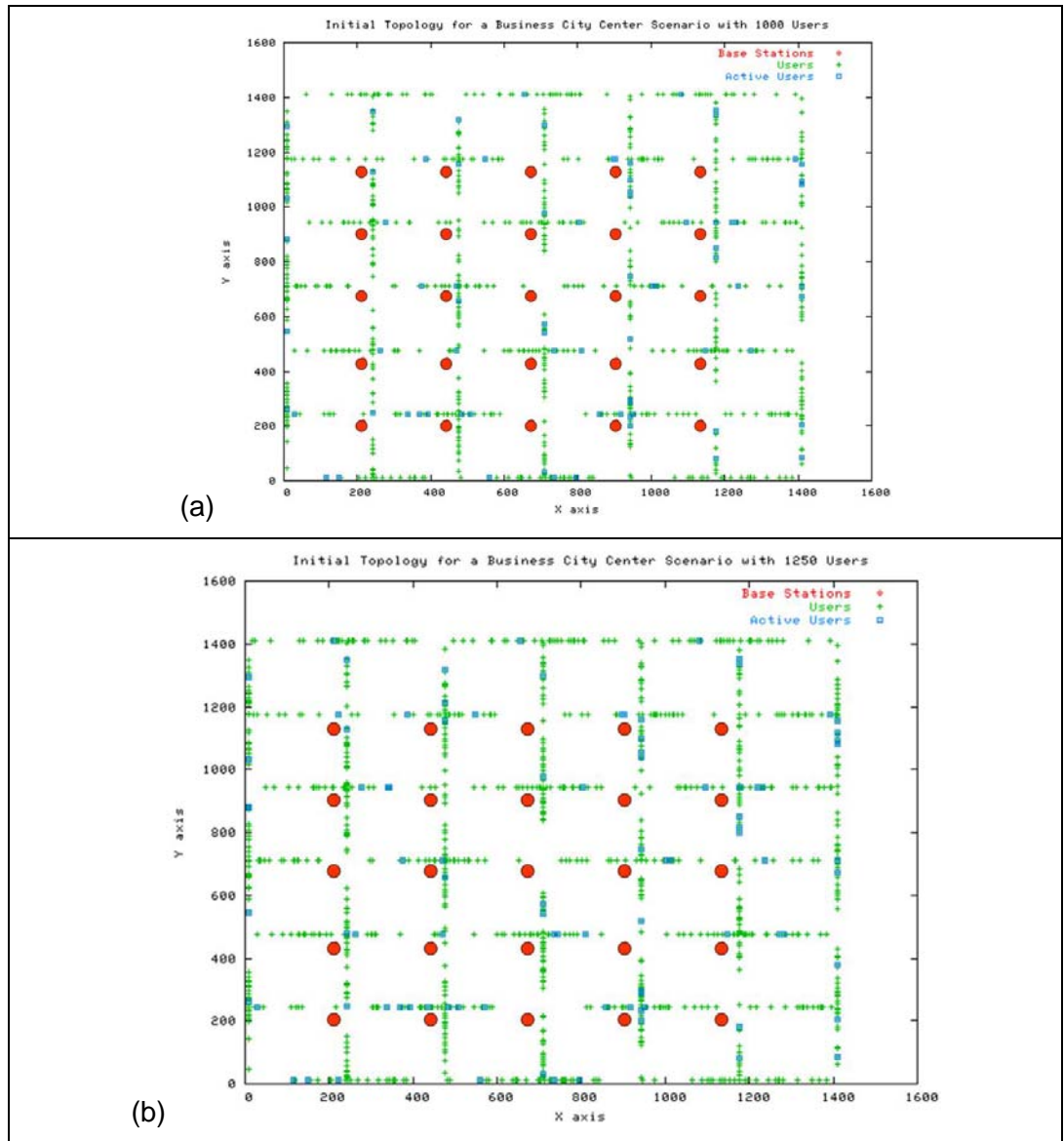
**Figure 4.5: Initial Distribution of users in the BCC scenario. (a) 1000 users, (b) 1250 users, (c) 1500 users,**

The Radio Propagation model used is the Walfisch-Ikegami-LoS propagation model (Section 3.4).

A traffic mix model is defined that generates traffic according to predefined usage percentages and assigns an application to each user accordingly, similarly to the Office scenario. The corresponding service usages for the Business City Centre scenario [22] are:

- Voice: 27%

- Multimedia: 16%

- Narrowband: 26%

- Wideband: 31%

*4.3.3 Urban Environment scenario*

The topology consists of 19 base stations, using tri-sectored antennas, thus having 57 sectors. A tri-sectored antenna transmits at a 120-degree angle (one sector). Three such antennas are located in the Node B so as to cover a 360-degree angle allowing, however, up to three times the capacity that an omni-antenna can support. The concept of tri-sectored antennas is better illustrated in Figure 4-5, which presents the topology scheme for the 19-cell topology for the Urban scenario.
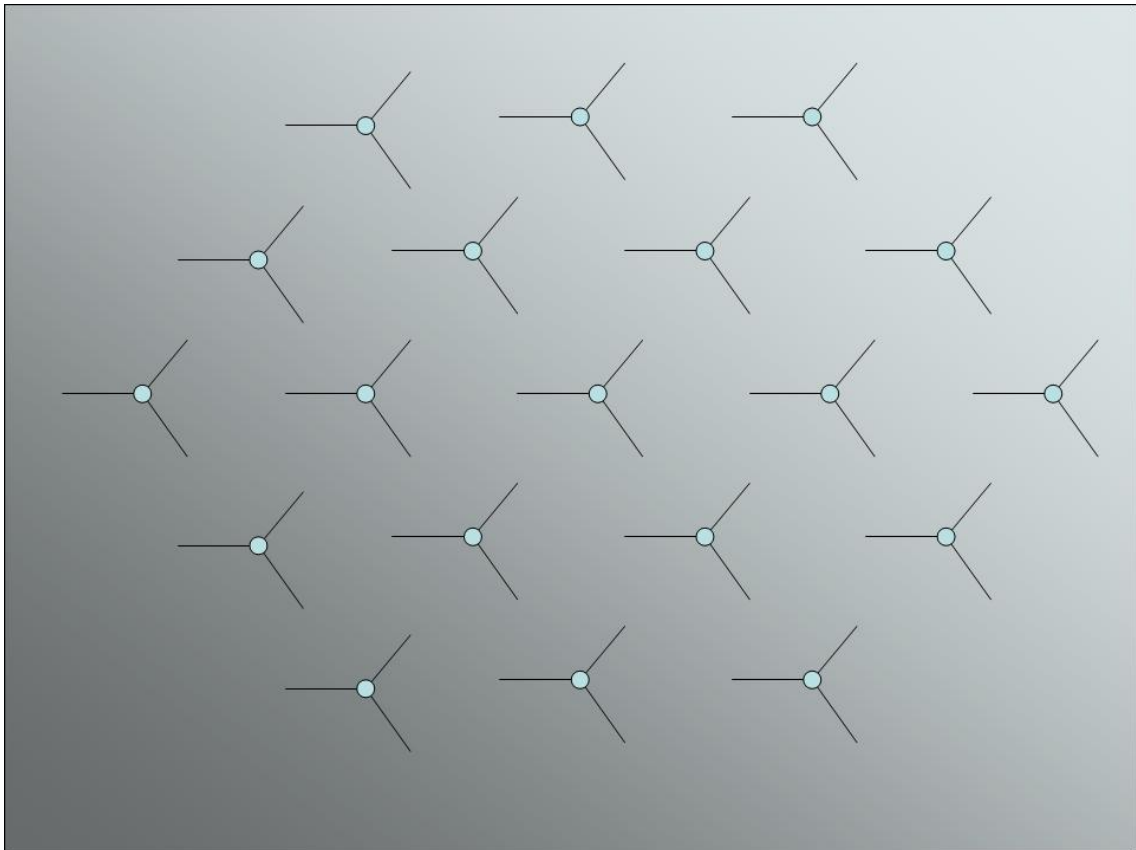


**Figure 4.5: Topology scheme for the Urban Scenario**

The mobility model used for the Urban environment is the Gauss-Markov mobility model. This is an entity mobility model, as it defines individual and not group movement patterns. The pattern is confined within the predefined grid area. As in all mobility scenarios, the users are confined within this area and return to a point inside the topology when they reach the borders.

The Gauss-Markov model implemented to model mobility in an urban vehicular environment is defined to be between the random walk (slow speeds) and the fluid flow (very high speeds) models. The two models, random walk and fluid flow are labeled as extremes. Most of the nodes move somewhere in-between those speeds. Parameters for the Gauss-Markov model include the mobile speed at 50 km/h (13.89 m/s), and a random seed, a number that is fed into a random number generator, as this model aims to assign pseudorandom paths to the mobile users.

The Radio Propagation model used is the Hata propagation model, also described in previous chapter.

The traffic mix model defined for this environment generates traffic according to predefined usage percentages and assigns an application to each user accordingly. As in the two previous scenarios, the traffic mix includes four types of services: voice at 12 kbps, multimedia at 144kbps, narrowband at 384kbps and wideband at 768kbps. What changes in the Urban scenario are the corresponding service usages [22], which are:

- Voice: 42%

- Multimedia: 16%

- Narrowband: 18.5%

- Wideband: 23.5%

The following set of graphs shows the initial user distribution for 800, 900 and 1000 users, showing also the location and the active users for the sub scenarios of the urban environments scenario.
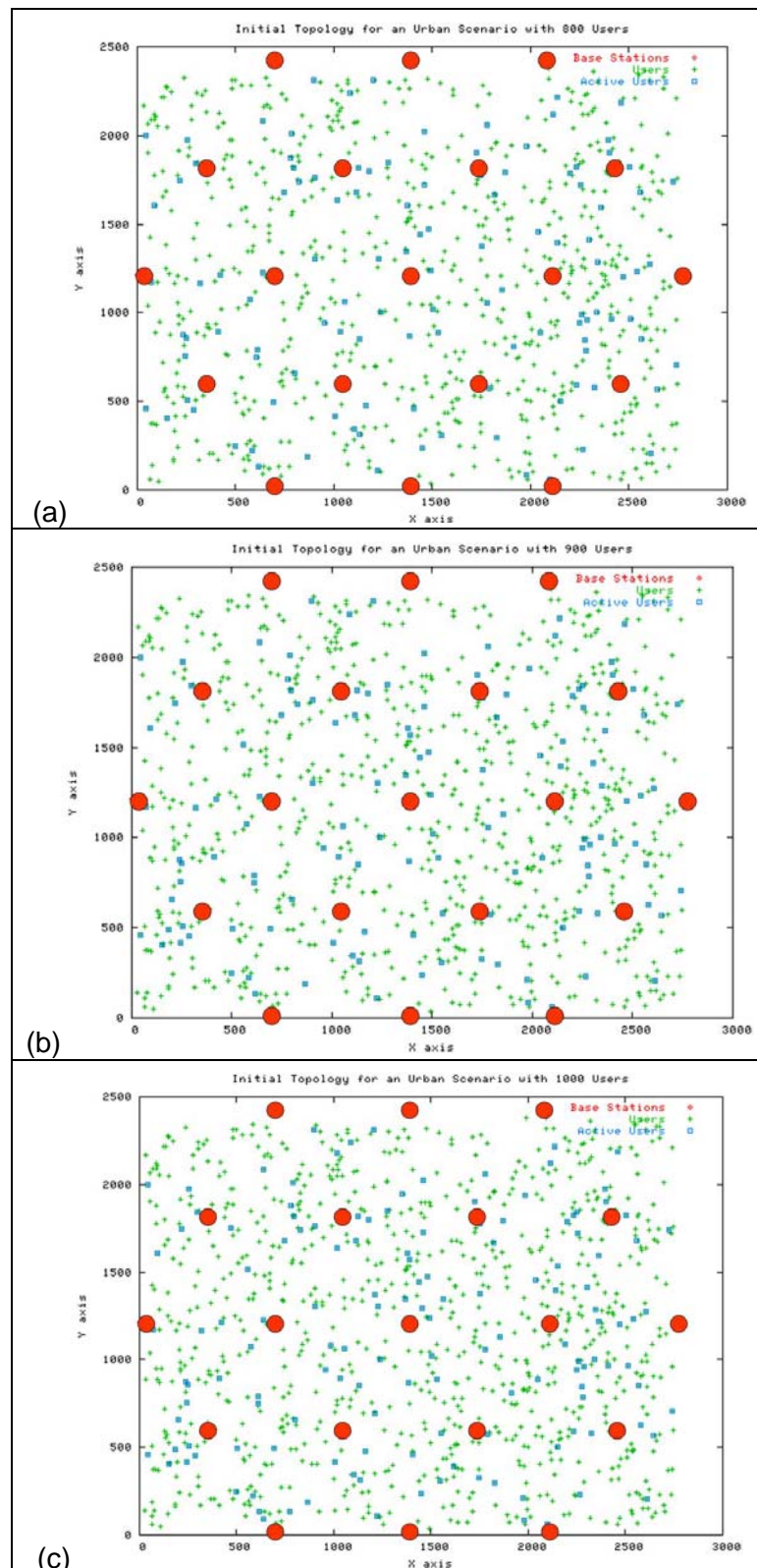
**Figure 4.6: Initial User Distribution in the Urban/Vehicular environment (a) Total 800 users (b) Total 900 users (c) Total 1000 users**

## 4.4 Simulation Results using the Enhanced UMTS system level simulator

This section presents results for coverage and capacity obtained using the Enhanced UMTS system level simulator and based on the scenarios discussed in Section 4.3.

Coverage and capacity measures are scenario specific, i.e. they depend on the specific environment and traffic model used. The three environments we study include an indoor environment (Office) and two outdoor environments (Business City Centre and Urban). Furthermore, two traffic models will be examined for each environment. The first set of results uses a traffic model with a single type of traffic for all users, namely the voice service with bit rates of 12 kbps. The second set of results uses a traffic mix model that includes the sound, multimedia, narrowband and wideband services at the corresponding bit rates of 12kbps, 144kbps, 384kbps and 768kbps. The best coverage is given by the distance that achieves the minimum acceptable number of call blocks achieving at the same time the maximum possible capacity. In our scenarios, the best coverage is found by the least number of call blocks for the distances and number of users in these scenarios. Similarly, the best capacity is the maximum number of users that give the maximum acceptable number of call blocks for the chosen best coverage.

The first set of results (voice service) are mostly for comparison purposes (Section 4.5) since most of the published results only consider voice users instead of multi-traffic users. Moreover, it is better to examine the behavior of the network in a situation where a single type of traffic is used before examining its behavior in situation where a traffic mix is applied, because it gives a more predictable behavior of the network.
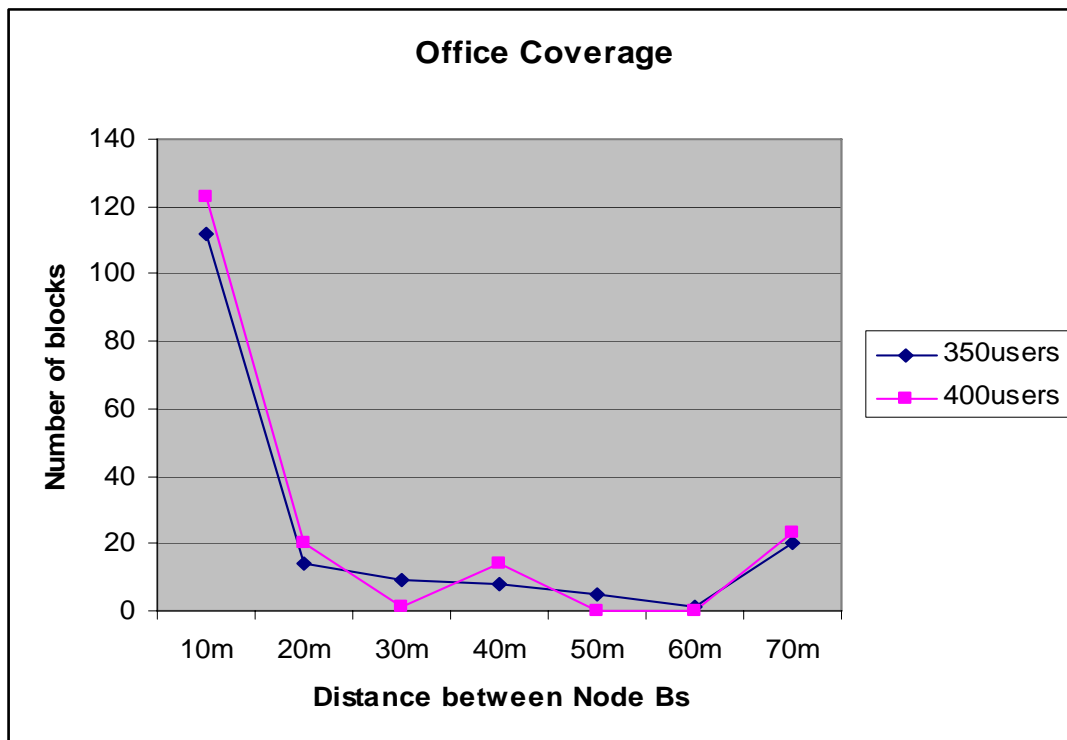
**Figure 4.7: Office Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks**

Figure 4.7 presents coverage for the Office environment (using voice users only) as a function of increasing distance between Node Bs vs. Number of call blocks for each simulation. For confidence reasons, this simulation was run twice with a different number of users (350 users and 400 users). Fewer users would not generate a large enough number of call blocks to allow us to make observations about the coverage. The two curves show similar behavior, in terms of distance that generates the least amount of blocks. In both cases the least number of blocks is generated when the distance between the Node Bs is 60m.

In the 400 user simulation, the 50m distance also generates the minimum number of blocks. Therefore, the 60m is not conclusive; it would be more accurate to set the best distance to be a choice between the two values. Furthermore, the value for the 40m distance may be considered to be an outlier as it does not follow the general trend of the rest of the results. The 350 user simulation results exhibit a smoother curve with a clearer lower value at the distance of 60m.

The first distance (10m) generates a comparatively very large number of call blocks. The reason for this is that the Node Bs are placed very close to each other causing inter-cellular interference.

There are two reasons that calls are blocked in these scenarios. The first reason is no admittance from the Admission Control mechanisms because of lack of appropriate codes for the call. For example, many high bit rate users in a cell would use up the codes available causing lower bit rate users not to be admitted. Since only low bit rate users are considered in these scenarios, namely voice at 12kbps, this does not happen. The Admission Control algorithm admits based on the available codes, more than 100 voice users per cell. The second reason is because of power, either too much detected power, i.e. interference, or not enough power to support the call (lack of sufficient coverage).

For each simulation run the individual statistics for the blocks were obtained. These statistics show that all of the blocks in the 10m simulation runs were due to interference. This is expected since due to the low bit rate of the voice users it is unlikely that they would be blocked due to lack of enough codes.
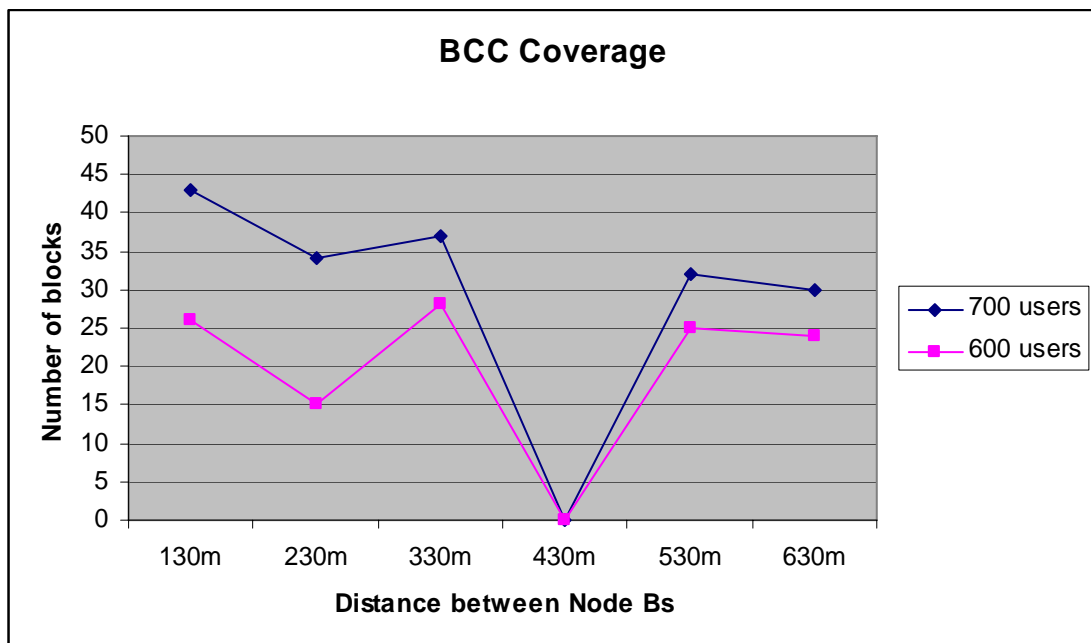


58

**Figure 4.8: BCC Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks**

Figure 4.8 presents coverage for the Business City Centre environment (using voice users only) as a function of increasing distance between Node Bs vs. Number of call blocks for each simulation. As previously, this simulation was run twice with a different number of users (600 users and 700 users). Fewer users would not generate a large enough number of call blocks to allow us to make observations about the coverage.

The choices for candidate best distances are 130m, 230m, 330m, 430m, 530m and 630m. The choice for these distances results from recommendations made within the SEACORN project for the BCC topology. The roads have a length of 30m, while the building blocks are squares with a side that varies between 100m, 200m, 300m, 400m, 500m and 600m for our simulation purposes. A distance between any two Node Bs includes a building block side and a road, hence the resulting values for candidate best distance.

The two obtained curves, similarly to the Office scenario, behave in a similar manner. It is obvious that in both simulation runs the distance 430m generates the least number of call blocks. Results for smaller or larger distances do not vary dramatically. Again, because of the use of voice traffic only, no call blocks occur due to lack of appropriate codes to support them. The reason for the observed blocks is power: as the Node Bs are located closer together signal interference causes the calls to be blocked, while as the Node Bs are located further away from each other, the signal strength is insufficient to support all the calls.

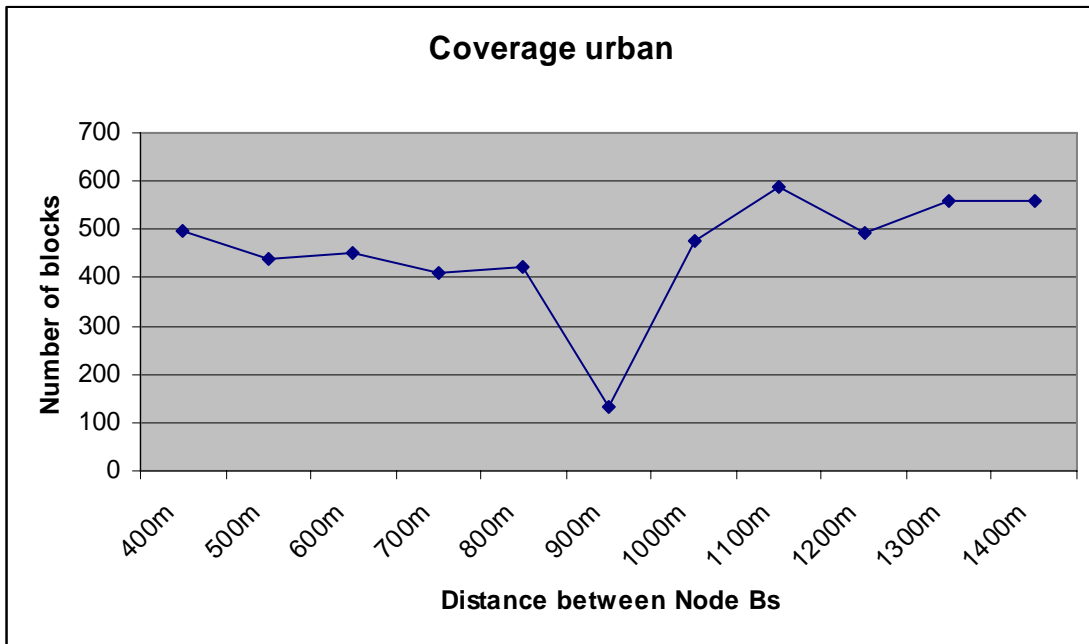**Figure 4.9 (a): Urban Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks (7-cells)**
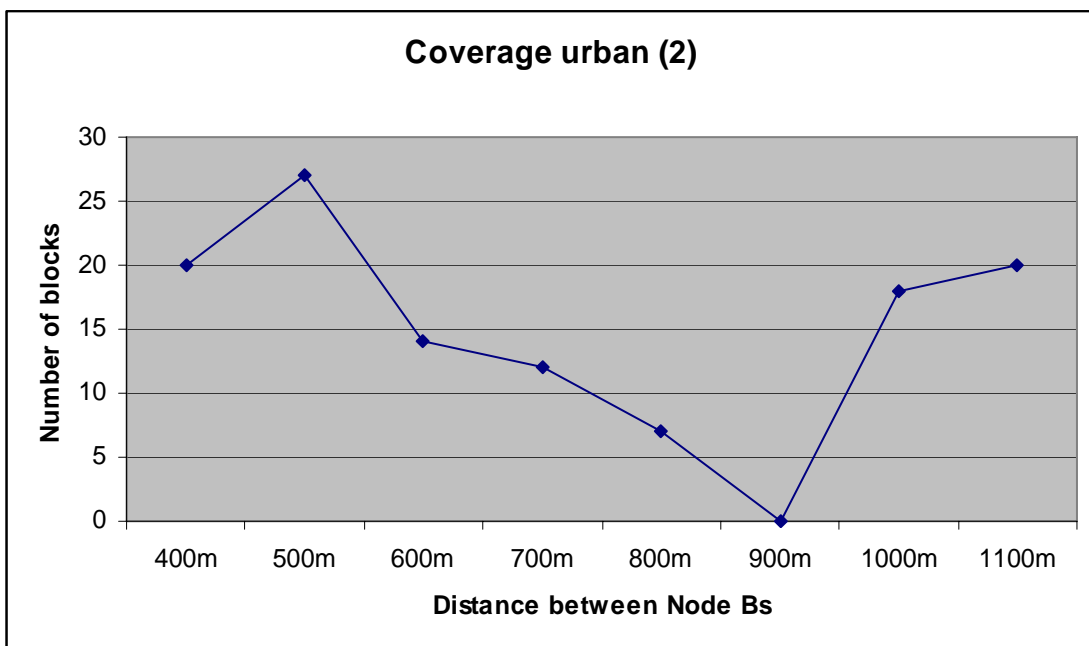


**Figure 4.9 (b): Urban Coverage (voice service) in terms of distance between Node Bs vs. number of call blocks (19-cells)**

Figure 4.9 (a) presents the coverage results for the urban environment. The results show that for the voice service, the best distance between Node Bs is 900m. The above results were obtained using a 7-cell topology and 2000 users. We observe that in all simulations we have a very large number of blocks. To improve the accuracy of the results we run the simulation again on a 19-cell topology with 4000 users (to ensure there is adequate number of blocks). The results are shown in Figure 4.9 (b).

The above results show a negligible number of blocks for the chosen coverage for the Office and Business City Centre environments. For the urban environment, the 7-cell scenario generated a large number of blocks but we use the 19-cell scenario to estimate recommended capacity, because it has a very small number of call blocks. The recommended corresponding capacity for each scenario is the number of users in the scenarios. For example, in the Office environment, distance of 60m (or 50m) between Node Bs and a population of 400 sound users (or less) in the topology appears to be supported. Moreover, a distance of 400m to 500m (430m value from our simulation results) in the Business City Centre and a population of up to 700 sound users are recommended for coverage and capacity planning of this scenario. Finally, for the urban scenario the best distance appears to be 900m and the acceptable capacity is 4000 users for the 19-cell scenario.

The following set of results presents the coverage in the three environments in terms of distance between Node Bs vs. number of call blocks for each scenario. The traffic model used for this set of results is the traffic mix described in the previous section, with different usage percentages for each environment. These simulations use a large number of users per scenario in order to ensure a relatively large number of call blocks. In this manner we manage to collect an adequate number of call drops for each simulation run and compare them to decide which distance gives the best coverage. As defined previously, the best coverage is given by the distance that achieves the least number of call blocks.

The number of users in the Office scenario is 600, in the BCC scenario is 3000 and in the Urban scenario the number is 5000. Figure 4.10 shows the results for the Office

scenario, Figure 4.11 presents the results for the BCC scenario and Figure 4.12 presents the results for the Urban scenario.
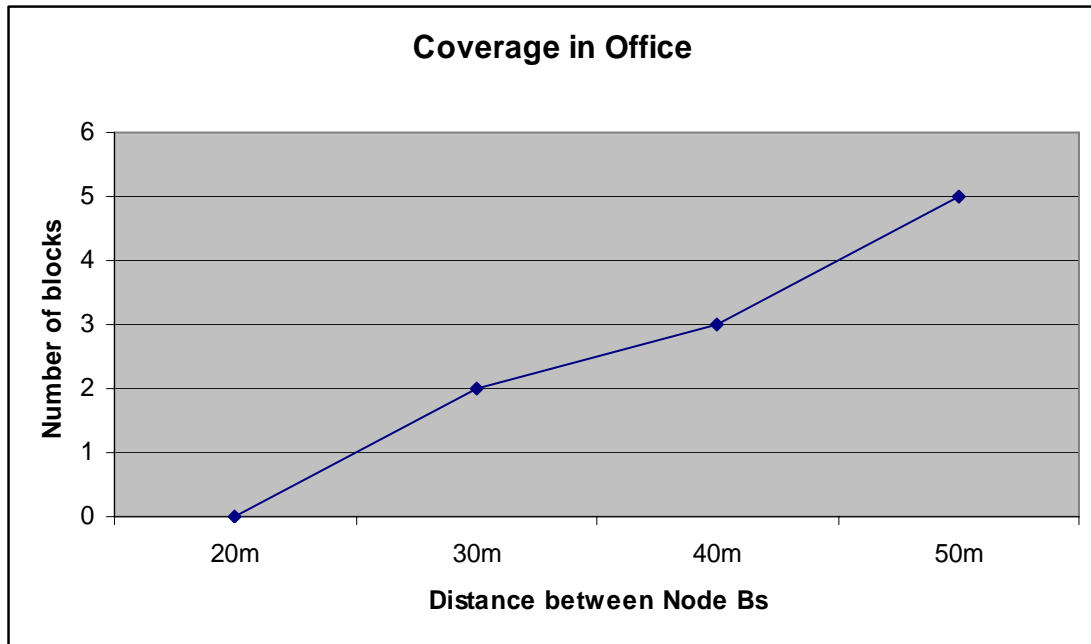
**Coverage in Office**



**Figure 4.10: Coverage in the Office scenario in terms of distance between Node Bs vs. number of call blocks.**

The results in the Office scenario show that the best coverage is provided when the distance between Node Bs equals to 20m. This is expected since in the traffic mix, higher bit rate users exist than simply voice users as seen before. Therefore in order for these users to be adequately covered by the antenna signal, the Node Bs need to be closer together than previously where all the users generated voice at 12kbps.

As shown in the previous set of results, when the distance between Node Bs was 10m too much interference was caused. For this reason the 10m distance was omitted from this set of results.
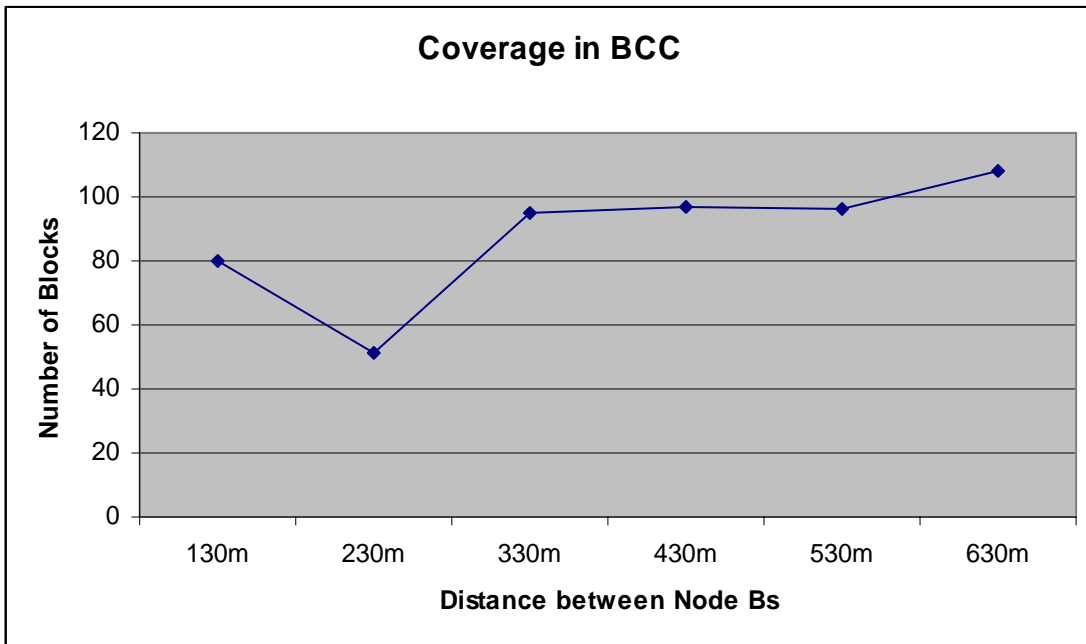
**Figure 4.11: Coverage in the BCC scenario in terms of distance between Node Bs vs. number of call blocks.**

The results for the Business City Centre scenario give 230m to be the best distance between the Node Bs. As expected, this value is less than 430m, the best distance in the voice simulations. The higher bit rates that exist in the traffic mix used in this set of scenarios require the Node Bs to be closer together to support the multi-rate users in the best possible manner.
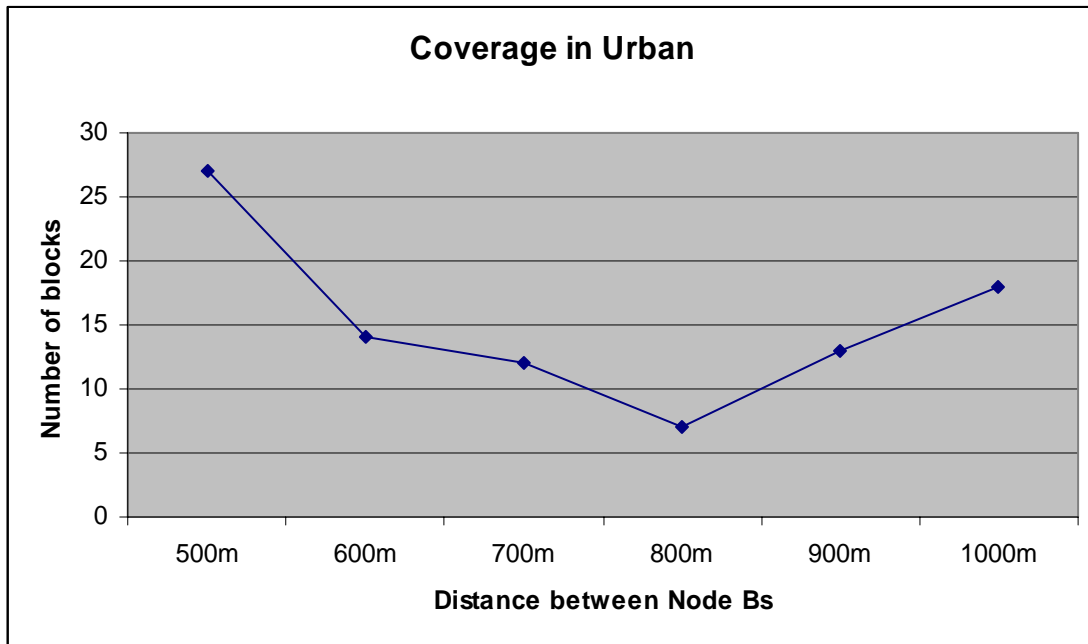
**Figure 4.12: Coverage in the Urban scenario in terms of distance between Node Bs vs. number of call blocks**

The best coverage in the Urban environment is provided when the distance between the Node Bs is 800m. This value is less than the value in the voice scenario for the Urban environments as expected, due to the change in the traffic model as discussed above.

Therefore, the best coverage is provided when the distance between the Node Bs equals to about 20m in the Office environment, 230m in the Business City Centre environment and 800m in the Urban environment. Distances that are smaller or bigger than these values result in a higher number of call blocks. These results confirm our initial assumption, that coverage and capacity planning is scenario specific, and it is influenced by the traffic mix. The results are not, however, sensitive to an increase of users of the same traffic type. This is important to operators as it can facilitate the planning process of a network in a specific environment as long as they can plan the network based on a representative traffic mix.

In order to make sure that the number of users per scenario does not alter the results for the best coverage of each scenario, the same simulations were run with a modified number of users for each scenario. The Office scenario was run with 650 users instead

of 600, the BCC scenario was run with 4000 users instead of 3000 and the Urban scenario was run with 6000 users instead of 5000. The results shown below in Figure 4.13 (Office), 4.14 (BCC) and Figure 4.15 (Urban) verify that the best coverage is given when the distance between the Node Bs is 20m in the Office environment, 230m in the BCC environment and 800m in the Urban environment.
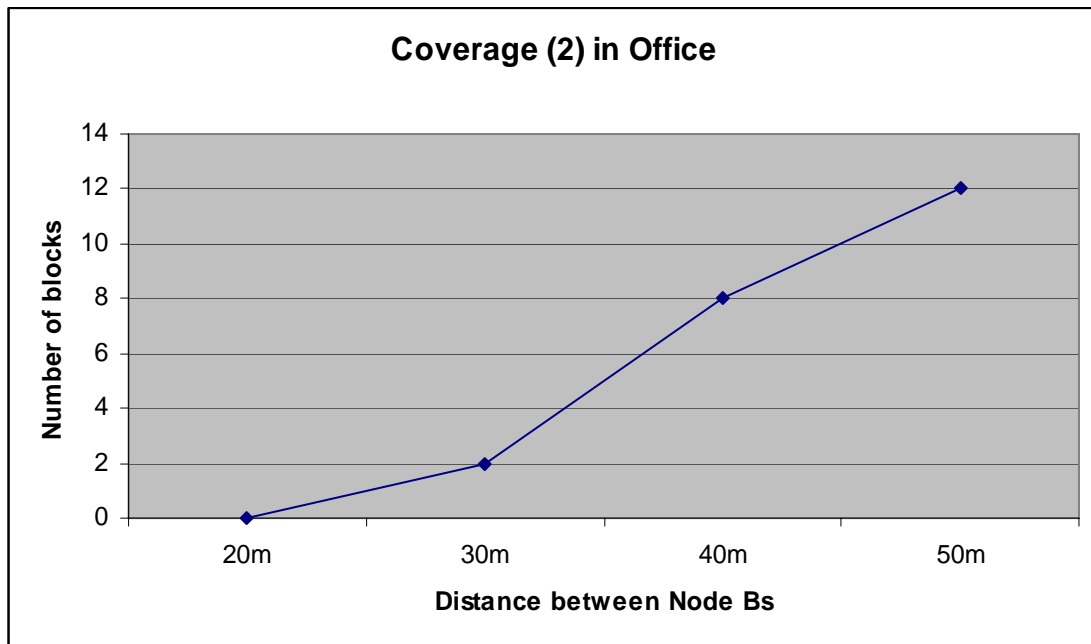


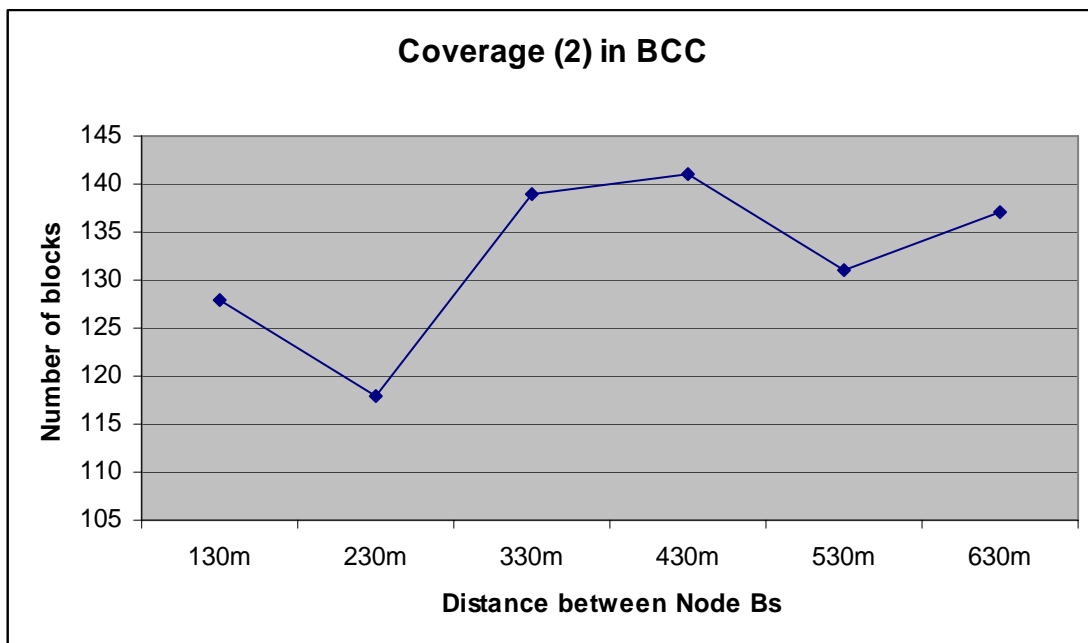**Figure 4.13: Coverage in the Office scenario with 650 users**

**Figure 4.14: Coverage in the BCC scenario with 4000 users**
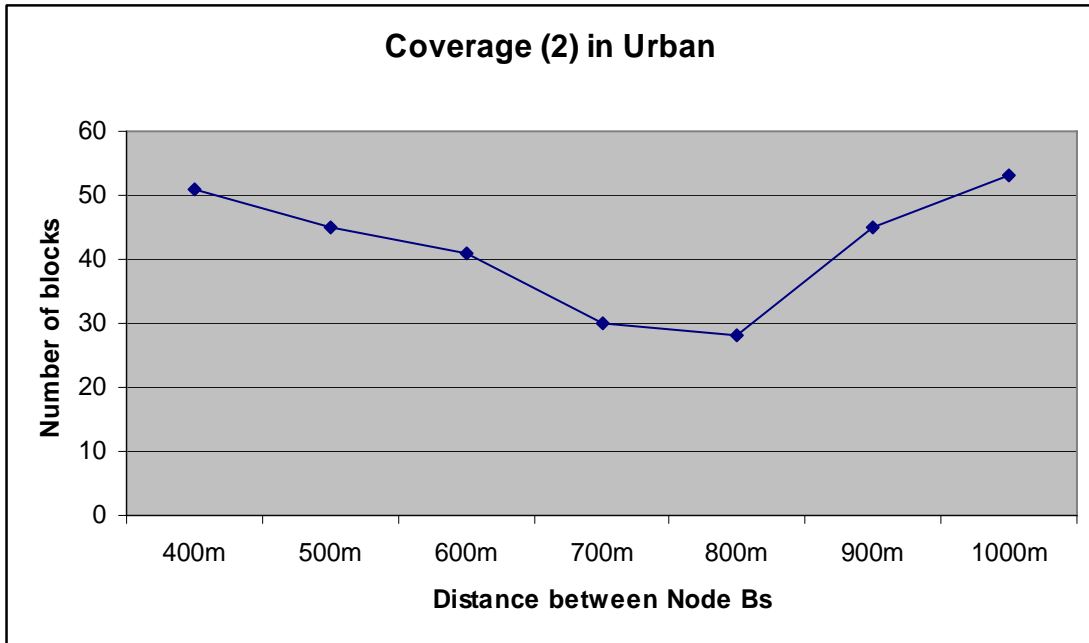
**Coverage (2) in Urban**



**Figure 4.15: Coverage in the Urban scenario with 6000 users**

From the large number of call blocks in the previous set of results, we can conclude that the number of users simulated for the coverage scenarios, combined with the defined traffic mix, is very large to be indicative of a good capacity value for each scenario. The following set of results aims to find the maximum acceptable capacity for each environment by performing simulations with different numbers of users. The same traffic mix model is used for each environment scenario.

The best distance between the Node Bs is selected and applied to the next set of results. This set of results presents the capacity for the Office, the BCC and the Urban scenarios. The variable parameter is the number of users. The same traffic model is applied here, as in the simulations for coverage, in order to determine the acceptable maximum capacity for these scenarios.

For each scenario, we present a graph of number of users vs. call blocks as well as a table that shows the number of active users and the corresponding number of active voice, multimedia, narrowband and wideband users. Furthermore, the total load for each

scenario as well as the average load per cell is determined based on these numbers and presented in each table.

Figure 4.16 and Table 4.1 apply to the Office environment scenario. Figure 4.17 and Table 4.2 apply to the BCC environment scenario. Figure 4.18 and Table 4.3 apply to the Urban environment.
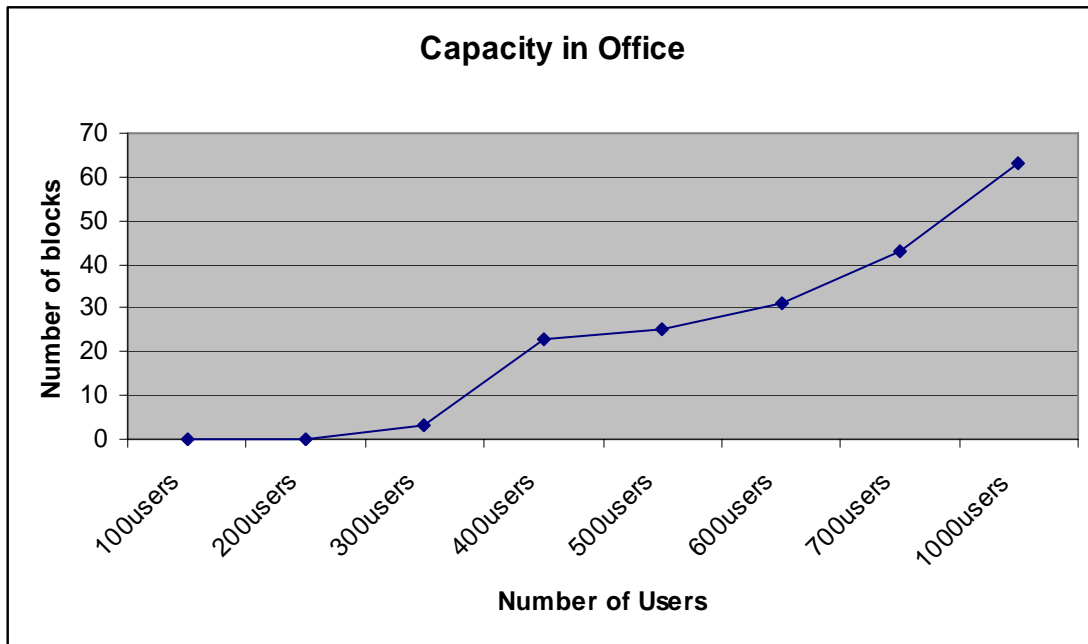


**Figure 4.16: Capacity in the Office scenario in terms of number of users vs. number of call blocks**

The first simulation that generates call blocks is the 300 users' simulation. However, the number of generated call blocks is a negligible number, as it is sensitive to other environmental simulation factors. For example, a different user distribution or mobility model could possibly eliminate these blocks. The rest of the scenarios show an increasing tendency in the number of call blocks they generate. The recommendation for capacity planning is that the maximum capacity in the Office environment is kept up to 300 users for this topology and traffic mix. An increase in this number increases the call blocks and this will results in an overloaded system, that cannot offer the users the required QoS.

Table 4.1 presents the active users and corresponding load for the simulations that generated call blocks only. Therefore, the simulations for 100 users and 200 users do not appear in this table. The increase of the average load per cell and the increase of the high bit rate users is the reason for the increasing number of blocks in the scenarios with 400 users and above.

| Total Number of Users | 300 | 400 | 500 | 600 | 700 | 1000 |
|---|---|---|---|---|---|---|
| Total Number of Active Users | 30 | 36 | 43 | 51 | 55 | 77 |
| Active Voice Users | 14 | 17 | 22 | 27 | 31 | 45 |
| Active Multimedia Users | 7 | 8 | 9 | 10 | 10 | 13 |
| Active Narrowband Users | 4 | 5 | 5 | 6 | 6 | 8 |
| Active Wideband Users | 5 | 6 | 7 | 8 | 8 | 11 |
| Corresponding Load (kbps) | 6552 | 7884 | 8856 | 10212 | 10260 | 13932 |
| Average Load per cell (kbps) | 1092 | 1314 | 1476 | 1702 | 1710 | 2322 |

**Table 4.1: Active users and Corresponding Load in the Office scenario**
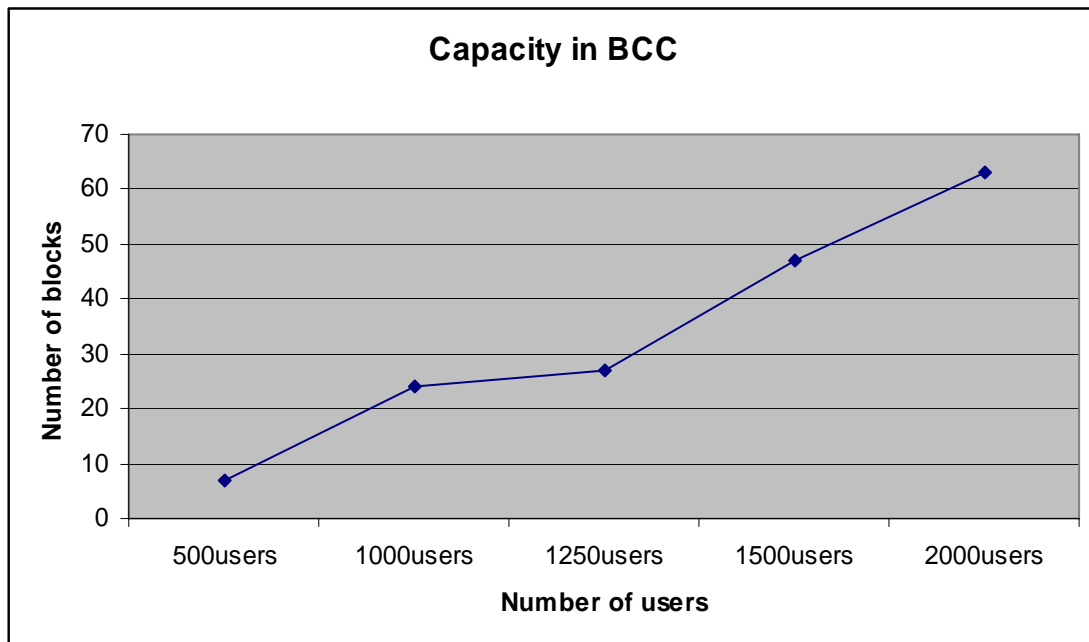


**Figure 4.17: Capacity in the BCC scenario in terms of number of users vs. number of call blocks**

Increasing the number of users increases the call blocks in a linear manner. From the 1000 user scenario and above the number of call blocks are not acceptable compared to the numbers of active users in the scenarios. Although some call blocks are generated in the 500 user scenario, it is a relatively small number when compared to the number of users and the sensitivity of other simulation factors, and therefore it can be neglected.

The recommended capacity for this scenario is thus less than 1000 users, preferably in the region of 500 users. The specific statistics on the activity of the users and the corresponding total load and average load per cell are found in Table 4.2.

| Total Number of Users | 500 | 1000 | 1250 | 1500 | 2000 |
|---|---|---|---|---|---|
| Total Number of Active Users | 40 | 77 | 92 | 114 | 153 |
| Active Voice Users | 23 | 46 | 58 | 70 | 97 |
| Active Multimedia Users | 9 | 13 | 15 | 20 | 24 |
| Active Narrowband Users | 5 | 12 | 13 | 15 | 19 |
| Active Wideband Users | 3 | 6 | 6 | 9 | 13 |
| Corresponding Load (kbps) | 5796 | 11640 | 12456 | 16392 | 21900 |
| Average Load per cell (kbps) | 644 | 1293 | 1384 | 1821 | 2433 |

**Table 4.2: Active users and corresponding Load in the BCC scenario**

For determining the capacity in the urban environment, the topology has been decreased from 19 cells to 7 cells. This was done for technical reasons since the 19-cells urban scenarios are extremely computationally demanding.

The results should focus on the system load, especially the average user per cell, rather than the number of users to estimate the effect on capacity. They show an expected increase in the average load per cell compared to the Business City Centre scenarios for the same number of users. This is due to the use of tri-sectored antennas that serve three times the number of users than omni-directional antennas used in the Business City

centre environment. In the 7-cell topology, the users are confined within the grid area and thus do not make use of the external sectors of the most outer antennas.
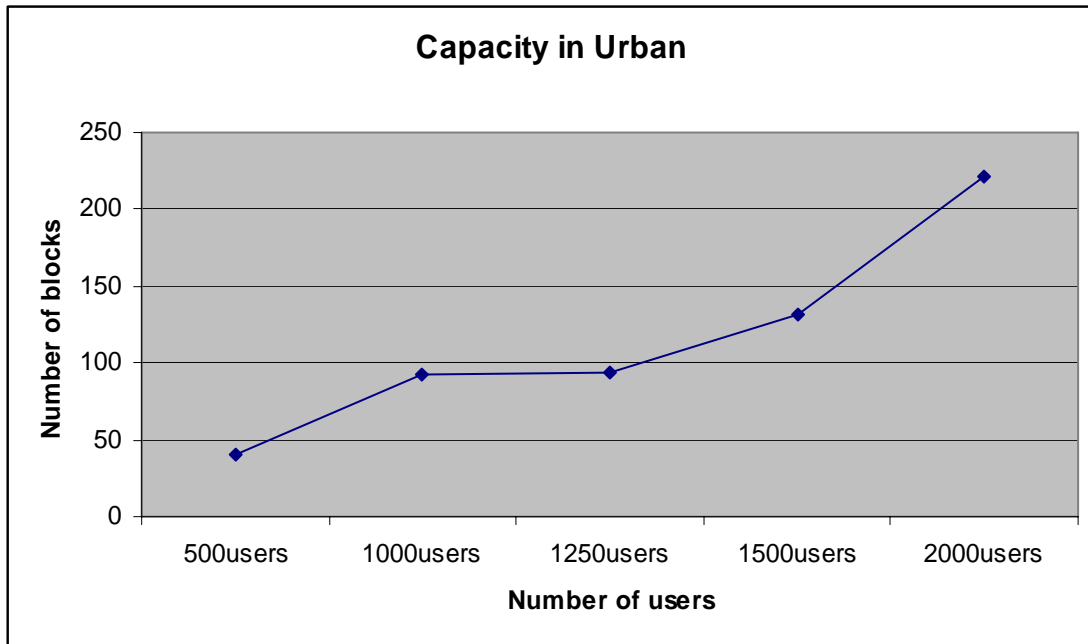


**Figure 4.18: Capacity in the Urban environment in terms of number of users vs. number of call blocks**

The number of blocks in this scenario has increased in comparison to the Business City Centre scenario. However, this is due to the confinement of a large number of users in a smaller grid area (from 19 cells to 7 cells). The average load per cell for each corresponding user population is greater than the average load per cell in the Business City Centre environment. This shows that the use of tri-sectored antennas in this environment allows for an increased cell capacity.

In the following table we observe that moving from 1000 users to 1250 users there is a noteworthy increase of active users and hence load per cell, while the number of call blocks does not increase. Therefore, a capacity of up to 1250 users can be used, but it is recommended to keep it around 500 users since for the 500 user scenario the number of call blocks is negligible.

| Total Number of Users | 500 | 1000 | 1250 | 1500 | 2000 |
|---|---|---|---|---|---|

| Total Number of Active users | 73 | 143 | 178 | 215 | 285 |
|---|---|---|---|---|---|
| Active Voice Users | 56 | 119 | 148 | 175 | 234 |
| Active Multimedia Users | 9 | 13 | 15 | 20 | 24 |
| Active Narrowband Users | 5 | 6 | 8 | 11 | 13 |
| Active Wideband Users | 3 | 5 | 7 | 9 | 14 |
| Corresponding Load (kbps) | 6192 | 9444 | 12378 | 15396 | 22008 |
| Average Load per cell (kbps) | 884 | 1349 | 1768 | 2199 | 3144 |

**Table 4.3: Active users and corresponding Load in the Urban environment**

## 4.5 Comparison with results from different simulators

In Chapter 2, four separate simulators used for W-CDMA coverage and capacity planning have been presented. In this section published results from these simulators are compared with similar results obtained from the Enhanced UMTS system level simulator, in order to increase the confidence in our results and consequently the tool itself.

The results we have for comparison are published results and thus are not extensive but sample results that are used in the corresponding papers to demonstrate the use of the proposed tools. The published results deal with scenarios where the users generate voice traffic (usually at the rate of 12 kbps). Previously, we have presented coverage and capacity results for Office, Business City Centre and Urban scenario using only voice users. These results may be used for comparison against these already published results.

All comparisons deal with scenarios that generate voice. This is done to best evaluate the accuracy of the results from the system level simulator by making direct comparisons with the results from the different simulators. Furthermore, for evaluation purposes we want to avoid the randomization in user bit rates, so as to have a predictable load in the network.

Figure 4.19 presents the proposed topology for an urban-like environment as published in [11]. It shows the network topology and the user distribution used in the scenario. As can be observed the distance between the Node Bs is 3000m. The users generate Voice at 12kbps.

The paper shows that a 144kbps user moving randomly around the above mentioned grid area with pedestrian speed of 3Km/h has a 72% coverage probability while a Voice user has 98% coverage probability [11]. This implies that a high bit rate user is not adequately supported in moving around this environment and has a probability of 28% to be blocked or dropped due to lack of coverage. A voice user is supported in this topology.
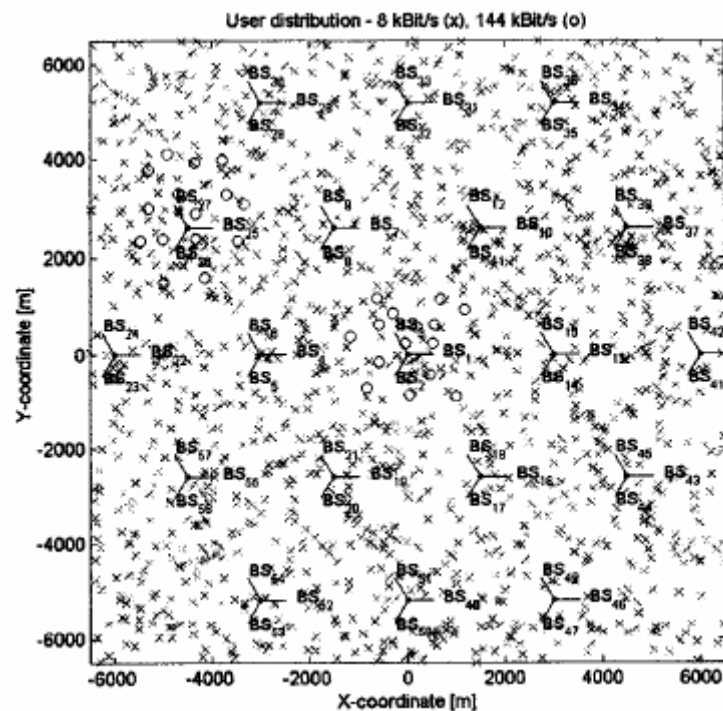


**Figure 4.19: Network topology and user distribution proposed in [11]**

Similarly to our urban scenario, the topology consists of 19 cells with tri-sectored antennas. The distance in our scenarios is shown to achieve best capacity at 900m. Bigger distances up to 1400m may also acceptable as the number of blocks in the 19-cell scenario is very low for a capacity of 4000 voice users. The number of users in the scenario evaluated in [11] is 1500. This number would not generate any blocks in our 19-cell scenario in order to determine the best distance between the Node Bs.

Figure 4.20 presents the coverage area for the voice service presented in [9]. The scenario in [9] simulates a city centre environment based on the city of Munich. The results are comparable to our Business City Centre scenario results. As can be observed from the coverage map the distance between Node Bs varies between values slightly less than 500m to values slightly more than 1000m. The average number of users in the scenario is 750.

The white color in the map marks areas with no coverage, but as mentioned in the paper these areas are mostly within buildings, therefore the coverage provided for the voice service is sufficient. Further study on coverage for the 384kbps service showed that with the current topology, coverage for the higher bit rate service is poor as some areas show no coverage.
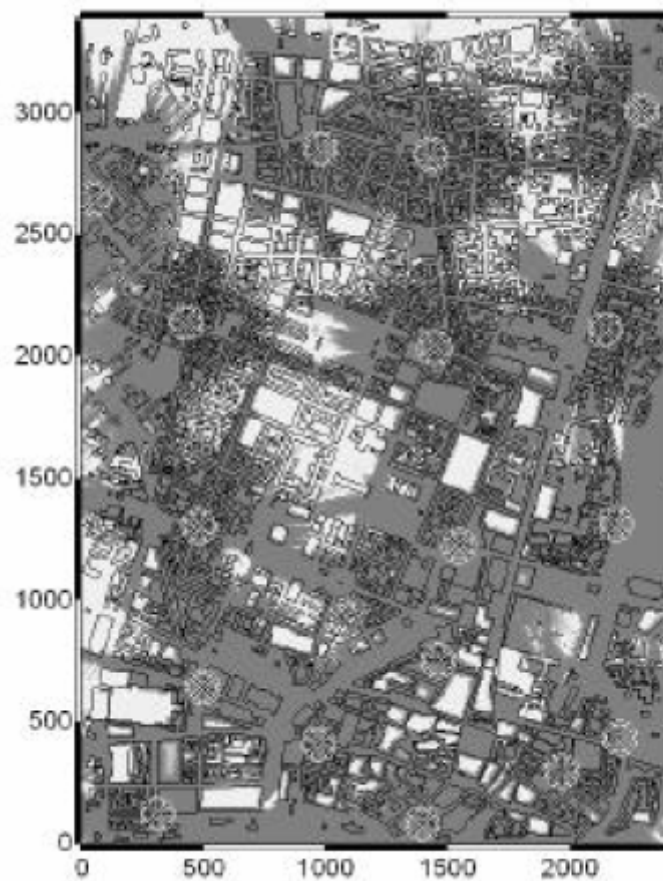


**Figure 4.20: Coverage map for the voice service in a city centre environment as presented in [9]**

The results obtained for the best coverage of the Business City Centre for the voice traffic are comparable to the results published in [9] for the scenario replicating the city of Munich. We concluded that for voice users the recommended distance between the Node Bs is about 430m. The distances here vary around 500m, very close to the value we generated. Furthermore, the published results show that some areas do not have adequate coverage; therefore a decrease in the 500m distance could possibly cover those areas as well. Furthermore, the average number of users in our simulations is 650 (600-user scenario and 700-user scenario) instead of 750 used in the published scenario. The numbers are comparable, especially when considering that the number of call blocks for the recommended 430 m distance is negligible.

The next comparison involves a similar coverage map (Figure 4.21). This result is taken from [10]. The Node B configuration appears to be the same as in [9]. However, this scenario uses a smaller number of mobile users than the scenario presented in [9]. In [10] the scenario simulates 300 users, while in [9] the scenario simulates 750 users. Since the service bit rate is the same, we may conclude that the scenario presented in [10] imposes a lighter load on the network.

The coverage for the users distributed uniformly across the simulation area is shown to be much better in this scenario than in [9]. This is mainly due to the decreased capacity, which causes the coverage area of each cell to increase. This also highlights the interlinking of coverage and capacity in WCDMA networks.
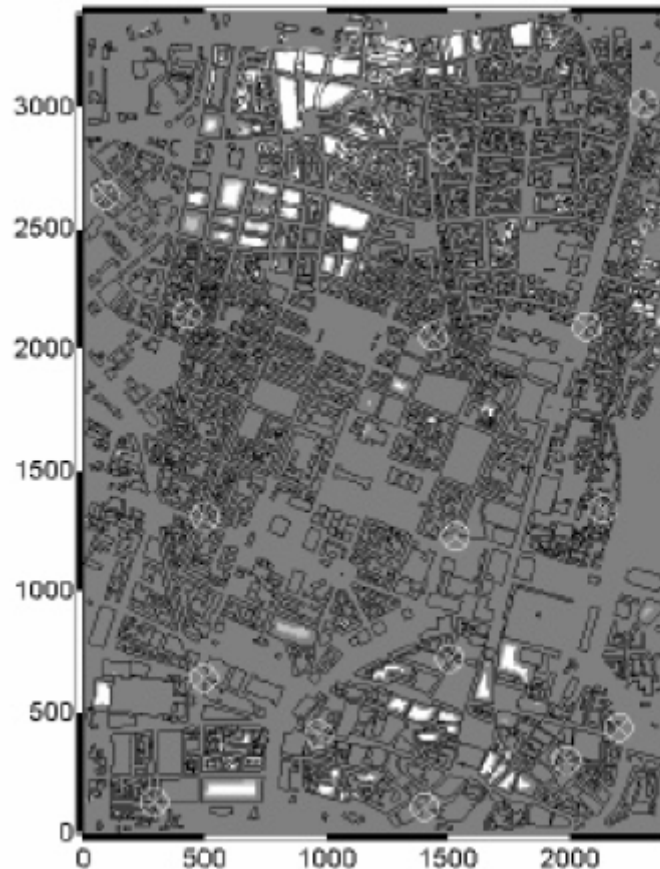
**Figure 4.21: Coverage map for the voice service in a city centre environment as presented in [10]**

The results obtained from our Business City Centre scenario support on average 650 users, a much larger number than 300 for a very similar topology. The Enhanced UMTS system level simulator can thus support such scenarios as the one presented in [10]. An explanation for the increased capacity is that UMTS enhancements included in our simulator support higher bit rate services and thus provide increased capacity, which is evident in a situation where only voce users are monitored.

The aims of the research presented in [36] are to analyze the capacity of a W-CDMA system in a macro-cellular environment. Two sets of simulations are run with two slightly different topologies. The first is a homogeneous topology with macro-cells of radius 577m. The second is a topology that best replicates a macro-cellular deployment scenario in central London. The published work uses a Vodafone internal simulator to

collect its results. The paper mentions that the results agree with independent analysis carried out using Motorola's system simulator on the same scenarios. The results are summarized in Table 4.4.

| Central London scenario | | Homogeneous network scenario | |
|---|---|---|---|
| *Network GoS* | *Mean Users/cell* | *Network GoS* | *Mean Users/cell* |
| 99% | 17 | 99% | 50 |
| 98% | 18 | 98% | 51 |

**Table 4.4: Cell capacities as presented in [36]**

Network Grade of Service (GoS) is defined as the percentage of successful calls in the cells that are traced. Therefore the capacity is given by the mean number of users per cell vs. the percentage of successful calls.

Our recommended best distance for an urban environment is 900m. For this scenario it is 1154m (577m is the cell radius). The simulated network in our urban scenario is homogeneous, therefore we compare it with the results obtained in [36] for the homogeneous topology. For a 99% of successful calls the recommended capacity in [36] is 50 users per cell. This translates into 950 users for the 19-cell topology. Our choice of distance supports adequately 4000 users in a 19-cell topology. The observed increase in capacity can be explained by the UMTS enhancements included in our simulation environment, such as link layer enhancements.

# Chapter 5

## Conclusion

In W-CDMA networks such as UMTS and Enhanced UMTS, it is not simple to determine the cell range (coverage) mainly due to the several variable parameters that need to be considered for separate environments. It has been shown that cellular planning in such networks is quite scenario dependent. It depends on cellular topology, radio propagation, traffic load, population density, mobility model etc. A system level simulator is necessary to evaluate different scenarios through numerous simulations in order to establish the best combination of values for coverage and capacity for each specific environment.

In this thesis, we present an Enhanced UMTS system level simulator, which was developed within the SEACORN project, and then evaluate its capabilities in simulating realistic scenarios for the purpose of coverage and capacity planning, a major issue faced in W-CDMA networks. Consequently, the coverage and capacity of three specific environment scenarios were evaluated. The scenarios were simulated both using voice-only users and multi-traffic users. This second set of scenarios used a pre-specified traffic mix, mainly based on recommendations and traffic forecasts completed within the IST funded SEACORN project. The Enhanced UMTS system level simulator has also been developed within the SEACORN project.

The novelty of this work is that we focus on Enhanced UMTS for coverage and capacity planning and obtain results with scenarios supporting a traffic mix that includes high bit-rate mobile users as well as voice users.

Finally, the results obtained by the system level simulator were juxtaposed against published results of several W-CDMA system level simulators. The results verify the interlinking between coverage and capacity in W-CDMA networks. More specifically, in W-CDMA networks the capacity depends on the coverage and, in turn, the coverage

is dependent on the specific environment parameters and used bit rates (traffic model) in the deployed environment.

Future work includes further refinement of the results for coverage and capacity and further results on QoS measures for the chosen coverage and capacity scenarios, such as throughput, delay, jitter, blocking/dropping probabilities etc. More scenarios with variations in the traffic models may be used to establish, if possible, the relationship between optimal coverage and capacity values for specific environments deploying Enhanced UMTS.

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