

# OpenBTS – Network Design & System Analysis

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## Table of Symbols and Abbreviations

<b>Symbol</b>	<b>Abbreviation</b>
SDR	Software defined Radio
RF	Radio Frequency
IF	Intermediate Frequency
TX	Transmitter
RX	Receiver
TRX	Transceiver
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
FPGA	Field Programmable Gate Array
DUC	Digital up Converter
DDC	Digital down Converter
USRP	Universal Software Radio Peripheral
UHD	USRP Hardware Driver
USB	Universal Serial Bus
GSM	Global System for Mobile Communication
PBX	Private Branch exchange
VOIP	Voice over Internet Protocol
GPRS	General Packet Radio Service
EDGE	Enhanced Data rates for GSM Evolution
MS	Mobile Station
SIM	Subscriber Identity Module
IMEI	International Mobile Equipment Identity
BTS	Base Transceiver Station
BSC	Base Station Controller
BSS	Base Station Subsystem
MSC	Mobile Switching Center
NSS	Network Station Subsystem
VLR	Visitor Location Register
HLR	Home Location Register
SIP	Session Initiation Protocol
TDM	Time Division Multiplexing
LAPDm	Link Access Procedures on the D channel
ETSI	The European Telecommunications Standards Institute
RR	Radio Resources
MM	Mobile Management
CC	Call Control
TCH	Traffic Channel
RACH	Random Access Channel

SDCCH	Standalone Dedicated Control Channel
TS	Time Slot
HT	Holding Time
CPH	Calls per Hour
GUI	Graphical User Interface
BP	Blocking Probability
BCH	Broadcast Channel
CCCH	Common Control Channel
ACCH	Associated Control Channel
BCCH	Broadcast Control Channel
LAC	Location Update Center
MNC	Mobile Network Code
FCCH	Frequency Correction Channel
SCH	Synchronization Channel
BSIC	Base Station Identity Code
CBCH	Cell Broadcast Channel
PCH	Paging Channel
AGCH	Access Grant Channel
DCCH	Dedicated Control Channel
FACCH	Fast Associated Control Channel
SACCH	Slow Associated Control Channel
MOC	Mobile Originating Call
MTC	Mobile Terminating Call

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## Abstract

In this book we are going to propose OpenBTS-based mobile network design for rural areas and oasis road.

The problem here is that these 2 cases suffer from very low capacity, so there is no motive for mobile operators to cover these areas as there is no efficient cost-benefit relationship (very high cost to build a tower vs. very low benefit due to low capacity).

OpenBTS provides the solution to this issue. OpenBTS is considered as the minimum cost as we can install the network at about 1/10 of the cost of current technologies, so by dividing the large area required to be covered by a single tower to smaller areas (each covered by an OpenBTS node) and connecting these nodes so that we can cover the whole area with a much lower cost. Another problem was how we can connect these nodes without internet connection (it's expected that there is no good internet connection in the rural areas nor the oasis road).

Here comes our main contribution to solve the intra-cell connection problem. Simply we suggest making use of the low expected capacity of the system to make RF-links between the serving nodes.

Our job is divided into 2 parts:

1. Network design and system modeling (this topic is covered by chapter two) including:
  - a. Detailed Modeling of the system.
  - b. System simulation.
  - c. Calculating Pathloss due to antenna heights.
  - d. Calculating blocking probability of calls.
2. Required Modifications in the signaling messages to implement the suggested system (this topic is covered by chapter 3).



## Chapter 1 - Introduction to OpenBTS

### 1.1 Software Defined Radio (SDR)

#### 1.1.1 What is SDR?

Over the last decade as semiconductor technology has improved both in terms of performance, capability and cost, new radio technologies have emerged from military and research and development labs and become mainstream technologies. One of these technologies is software defined radio.

Although much has been discussed in recent years, a good definition of software radio is difficult to generate. This is largely due to the flexibility that software defined radios offer, allowing them to take on many different forms that can be changed to suite the need at hand, but we can say that software defined radio is:

**"Radio in which some or all of the physical layer functions are software defined"**

In other words, Software Defined Radio (SDR) is a radio communication technology that is based on Software defined wireless communication protocols instead of hardwired implementations. Frequency band, air interface protocol and functionality can be upgraded with software download and update instead of a complete hardware replacement.

Traditional hardware based radio devices limit cross-functionality and can only be modified through physical intervention. This physical intervention results in higher production costs and minimal flexibility in supporting multiple standards. By contrast, SDR technology provides an efficient and comparatively inexpensive solution to this problem, allowing multi-mode, multi-band and/or multi-functional wireless devices that can be enhanced using software upgrades.

#### 1.1.2 History of SDR

The term "Software Defined Radio" was coined in 1991 by Joseph Mitola, who published the first paper on the topic in 1992. Though the concept was first proposed in 1991, software-defined radios have their origins in the defense sector since the late 1970s in both the U.S. and Europe. One of the first public software radio initiatives was a U.S. military project named SpeakEasy. The primary goal of the SpeakEasy project was to use programmable processing to emulate more than 10 existing military radios, operating in frequency bands between 2 MHz and 2 GHz. Further, another design goal was to be able to easily incorporate new coding and modulation standards in the future.

### 1.1.3 Architecture

The software defined radio (SDR) contains a number of basic functional blocks. The radio can be split into basic blocks, namely the front end, the IF section and the base band section as shown below. Each of the sections undertakes different types of functions.

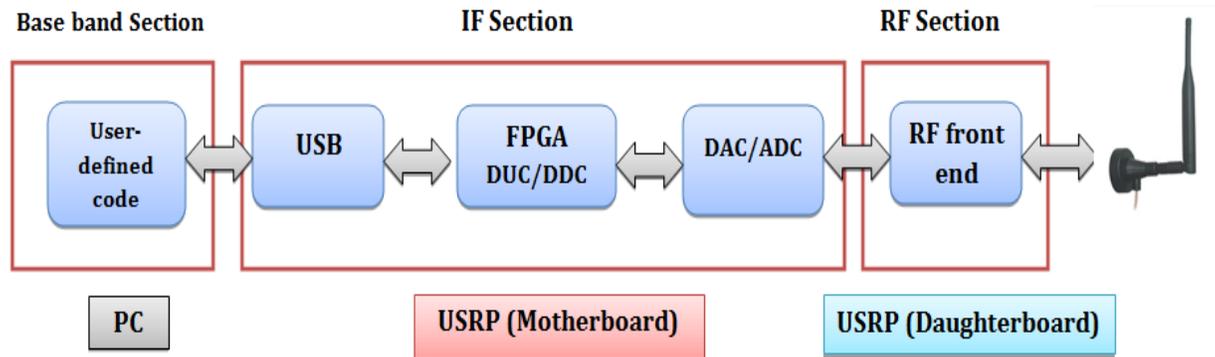


Figure 1 - USRP TX & RX Path

The front end section uses analog RF circuit (Daughterboard) and it is responsible for receiving and transmitting the signal at the operational frequency. It also changes the signal to or from the intermediate frequency through up or down conversion.

The IF section performs the digital to and from analog conversions through (ADC/DAC). It also contains the processing (FPGA) that undertakes what may be thought of as the traditional radio processing elements, including filtering, modulation and demodulation and any other signal processing that may be required.

The Digital Up Converter (DUC), where the received signal from base band processor is modulated and conditioned as required.

The Digital Down Converter (DDC), where the signal is processed and demodulated to provide the baseband signal for the baseband processor.

The final stage of the radio is the baseband processor (PC Processor).

It is so obvious that the complexity level has been transferred to the PC part where the code is written to perform baseband processing.

#### 1.1.4 Operation Concept

The ideal receiver scheme would be to attach an analog-to-digital converter to an antenna. A digital signal processor would read the converter, and then its software would transform the stream of data from the converter to any other form the application requires.

An ideal transmitter would be similar. A digital signal processor would generate a stream of numbers. These would be sent to a digital-to-analog converter connected to a radio antenna.

The ideal scheme is not completely realizable due to the actual limits of the technology. The main problem in both directions is the difficulty of conversion between the digital and the analog domains at a high enough rate and a high enough accuracy at the same time.

#### 1.1.5 Advantages of SDR

SDR has expanded the idea of open-source and enabled amateur radio users and students to try and join the world of communications with very reasonable costs and without the need of complicated hardware, all what is needed is a Computer, a single transceiver and a software code that can be easily implemented or can be obtained from the internet, All this Software enabled the prototyping to be faster and cheaper than hardware prototyping.

SDR has the ability to receive and transmit various modulation methods using the same set of hardware. The ability to alter functionality by downloading and running new software as well as the possibility of adaptively choosing an operating frequency and a mode best suited for prevailing conditions.

In other word SDR solves the two main challenges for a wireless system, which are compatibility and spectrum usage.

From the Vendors point of view,

SDR enables the implementation of a family of radio products using a common platform architecture allowing the prototyping and so faster introduction of new products and the development costs will be dramatically low.

Also the use of SDR would allow bug fixing over the air or other remote reprogramming thus reducing both time and cost associated with operation and maintenance.

While for Operators,

New features and capabilities could be added without requiring major modifications to the hardware as the old hardware could be used with simple modifications to the software to upgrade the whole system to work with the new features and services significantly reducing logistical support and operating expenditures.

A Software Defined Radio can easily be many different kinds of radio, often several different types at once. SDR has the potential to be a revolutionary technology that will dramatically impact the wireless technology industry.

### 1.1.6 SDR Application

Through the last two decades of open source developing, the SDR has about several hundreds of applications such as Cognitive Radio, RF-ID and OpenBTS which is our project subject and we will talk about it in details later.

## 1.2 USRP

### 1.2.1 What is USRP?

The Universal Software Radio Peripheral (USRP) is a computer-hosted software radios, developed by Matt Ettus and his team at the Ettus Research LLC.

The USRP product family is intended to be a comparatively inexpensive hardware platform for software radio, and is commonly used by research labs, universities, and hobbyists.

The USRP family was designed for accessibility, all USRP products are controlled with the open source UHD driver.

The USRP is designed to allow general purpose computers to function as high bandwidth software radios. In essence, it serves as a digital baseband and IF section of a radio communication system.

In addition, it has a well-defined electrical and mechanical interface to RF front-ends (daughterboards) which can translate between that IF or baseband and the RF bands of interest.

The USRP does all of the waveform specific processing on the host CPU like

- Modulation and Demodulation

All of the high speed general purpose operations are done on the FPGA like

- Digital Up Conversion (DUC).
- Digital Down Conversion (DDC).
- Decimation.



Figure 2 - USRP B100

### 1.2.2 UHD

UHD is the "Universal Software Radio Peripheral" (USRP) Hardware Driver is the device driver provided by Ettus Research for use with the USRP product family. It works on all major platforms Linux, Windows, and Mac

The goal of UHD is to provide a host driver and API for current and future Ettus Research products. Users will be able to use the UHD driver standalone or with third-party applications such as:

- GNU Radio.
- LabVIEW.
- MATLAB.
- OpenBTS.

The UHD installation and build steps are included in Appendix A.

### 1.2.3 USRP Component

The USRP is made up of the motherboard which has USB 2.0 interface for connection to the computer and the power connector and contains a FPGA section for high speed signal processing, and interchangeable daughterboards that cover different frequency ranges. In addition to ADC, DAC and one or more antennas.

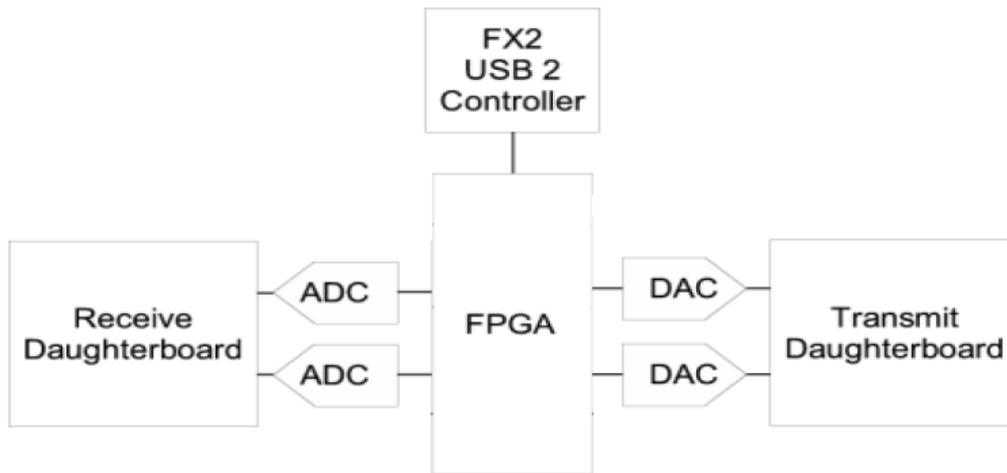


Figure 3 - USRP Component



Figure 4 - USRP B100 Motherboard

## Motherboard

The motherboard provides the following subsystems:

- FPGA,
- ADCs, DACs,
- Host processor interface,
- power regulation.
- Clock generation and synchronization

These are the basic components that are required for baseband processing of signals.

## Doughterboard

Daughterboards turn USRP motherboard into a complete RF transceiver system. Just add an antenna, and you are ready for two-way, high bandwidth communications in many popular frequency bands, it is used for analog operations such as up/down-conversion, filtering, and other signal conditioning. This modularity permits the USRP to serve applications that operate between DC and 6 GHz.

## Xilinx Spartan 3A-1400 FPGA

FPGA plays a key role in the USRP system. Basically what it does is to perform high bandwidth math, and to reduce the data rates to something you can handle with USB2.0. The FPGA connects to a USB2 interface chip, the Cypress FX2.

## Cypress FX2

The Cypress FX2 interfaces between the FPGA and a USB 2.0 port. The USRP connects to a USB port on the host computer where modulation and demodulation is performed.

### 1.2.4 USRP B100

In our project we use B100 USRP and the following section introduces its features. The B100 USRP, introduced in October 2011, replaces the USRP as the basic Software Defined Radio offering from Ettus Research.

The letter B is for Bus as the B100 USRP belongs to the Bus Series which use a USB 2.0 interface to transfer samples to and from the host computer. These are recommended for applications that do not require the higher bandwidth and dynamic range.

The features of the B100 are:

- USB 2.0 interface.
- Xilinx Spartan 3A-1400 FPGA.
- Fully supported by UHD drivers.
- Dual 64 MS/s 12-bit ADCs.
- Dual 128 MS/s 14-bit DACs.
- Onboard TCXO for precise frequency control.
- 10 MHz and 1 PPS inputs for external references.
- Flexible clocking from 10 MHz to 64 MHz
- WBX, 50 MHz–2.2 GHz Transceiver, 200 mW (23 dBm) output power.

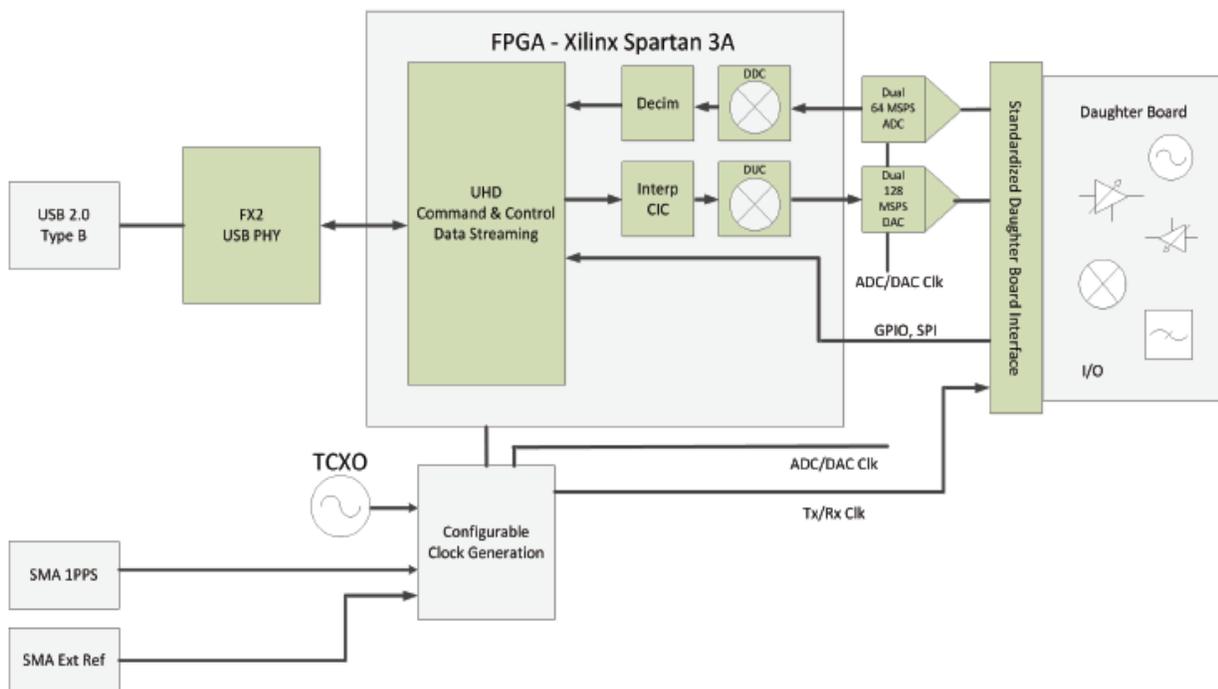


Figure 5 - USRP B100 Block Diagram

## 1.3 OpenBTS

### 1.3.1 Introduction and History

#### What is OpenBTS?

OpenBTS is a software-based GSM access point, allowing standard GSM-compatible mobile phones to make telephone calls without using existing telecommunication providers' networks. OpenBTS is notable for being the first free software implementation of the industry-standard GSM protocol stack.

OpenBTS is an open-source UNIX application that uses the Universal Software Radio Peripheral (USRP) to present a GSM air interface ("Um") to standard GSM handset and uses the Asterisk® software PBX to connect calls. The combination of the ubiquitous GSM air interface with VoIP backhaul could form the basis of a new type of cellular network that could be deployed and operated at substantially lower cost than existing technologies in Greenfields in the developing world.

In other word OpenBTS = GSM + VOIP.

#### History

David Burgess and HarvindSamra the founders of Kestrel Signal Processing are the ones who developed the code its very beginning in August of 2007, they believe that they could re-use the GSM handsets and its basic infrastructure to address the last remaining market, which is the three billion poorest people on Earth, who will not get telephone service otherwise. They will not get telephone service at \$6 a month because they simply cannot afford it and so they would like to offer it in the range of \$1 a month. The end product of this application is a complete network that supports a full GSM network enabling complete telephone calls, sending and receiving text messages, having a mailbox, transferring data (on upgrading to GPRS or EDGE) and it could even be connected to the local phone network and so could make external calls using the local phone network.

### 1.3.2 Traditional GSM networks

GSM, or Global System for Mobile Communications, is an European standard for the Mobile telecommunications and it is considered as one of the most popular standard worldwide, it is known as the second generation mobile telecommunications system “2G system”.

GSM operate in the 900MHz band, Uplink band from 890 to 915 MHz and downlink band from 935 to 960 MHz, the two bands are generally separated by 45MHz.

GSM uses GMSK “Gaussian Minimum Shift Key” with a 270.833 kHz symbol rate.

The channel is time-domain multiplexed into 8 timeslots, each with a duration of 156.25 symbol periods.

The principle component groups of a GSM network are as follows:

- The Mobile Station (MS).
- The Base Station System (BSS).
- The Network Switching System(NSS).

The diagram below shows the GSM network Architecture:

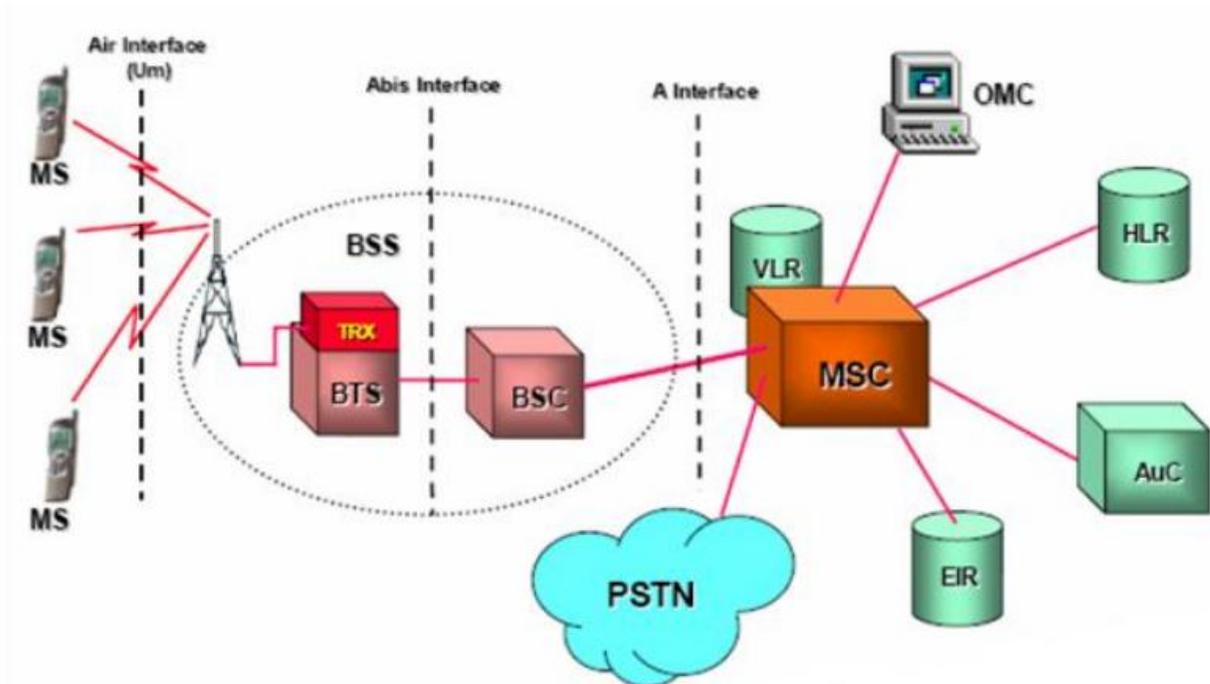


Figure 6 - GSM Network Architecture

## Mobile Station (MS)

The MS consists of two parts, the Mobile Equipment (ME) and an electronic smart card called a Subscriber Identity module (SIM).

The ME is the hardware used by the subscriber to access the network. The hardware has an identity number associated with it, which is unique for that particular device and permanently stored in it. This identity number is called the International Mobile Equipment Identity (IMEI) and enables the network operator to identify mobile equipment which may be causing problems on the system.

The SIM is a card which plugs into the ME. This card identifies the MS subscriber and also provides other information regarding the service that subscriber should receive.

The subscriber is identified by five identity numbers as follows:

## Base Station System (BSS)

The GSM Base Station System is the equipment located at a cell site. It comprises a combination of digital and RF equipment. The BSS provides the link between the MS and the MSC.

The BSS communicates with the MS over the digital air interface and with the MSC via 2 Mbit/s links.

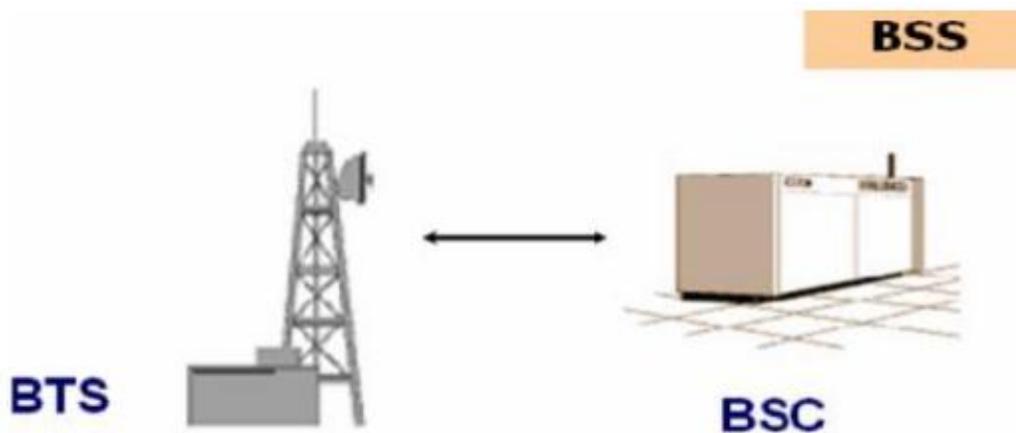


Figure 7 - Base Station Subsystem

The BSS consists mainly of:

1. The Base Transceiver Station – BTS

The BTS contains the RF components that provide the air interface for a particular cell. This is the part of the GSM network which communicates with the MS. The antenna is included as part of the BTS.

2. The Base Station Controller – BSC

The BSC as its name implies provides the control for the BSS. The BSC communicates directly with the MSC. The BSC may control single or multiple BTSs.

Network Switching System (NSS)

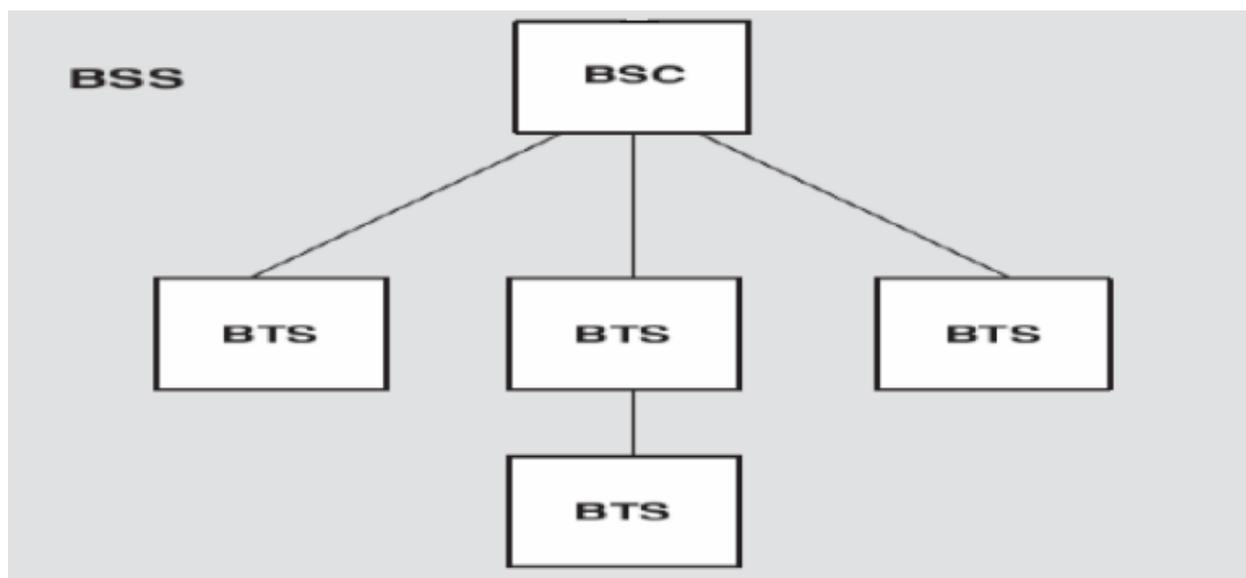


Figure 8 - BSS Component

The Network Switching System includes the main switching functions of the GSM network. It also contains the databases required for subscriber data and mobility management. Its main function is to manage communications between the GSM network and other telecommunications networks.

The components of the Network Switching System are listed below:

- Mobile Services Switching Centre – MSC.
- Home Location Register – HLR.
- Visitor Location Register – VLR.
- Equipment Identity Register – EIR.

- Authentication Centre – AUC.
- Interworking Function – IWF.
- Echo Cancellor – EC.

We will focus on MSC, HLR and VLR.

### Mobile Services Switching Centre (MSC)

The MSC is included in the GSM system for call-switching. Its overall purpose is the same as that of any telephone exchange.

However, because of the additional complications involved in the control and security aspects of the GSM cellular system and the wide range of subscriber facilities that it offers, the MSC has to be capable of fulfilling many additional functions.

The MSC will carry out several different functions depending upon its position in the network. When the MSC provides the interface between the PSTN and the BSSs in the GSM network it will be known as a Gateway MSC. In this position it will provide the switching required for all MS originated or terminated traffic.

Each MSC provides service to MSs located within a defined geographic coverage area, the network typically contains more than one MSC. One MSC is capable of supporting a regional capital with approximately one million inhabitants. An MSC of this size will be contained in about half a dozen racks.

The functions carried out by the MSC are listed below:

- Call Processing
- Operations and Maintenance Support
- Internetwork Interworking
- Billing

### Home Location Register (HLR)

The HLR is the reference database for subscriber parameters. Various identification numbers and addresses are stored, as well as authentication parameters. This information is entered into the database by the network provider when a new subscriber is added to the system.

The parameters stored in the HLR are listed opposite: The HLR database contains the master database of all the subscribers to a GSM PLMN.

The data it contains is remotely accessed by all the MSCs and the VLRs in the network and, although the network may contain more than one HLR, there is only one database record per subscriber – each HLR is therefore handling a portion of the total subscriber database. The subscriber data may be accessed by either the IMSI or the MSISDN number. The data can also be accessed by an MSC or a VLR in a different PLMN, to allow inter-system and inter-country roaming.

#### Visitor Location Register (VLR)

The VLR contains a copy of most of the data stored at the HLR. It is, however, temporary data which exists for only as long as the subscriber is “active” in the particular area covered by the VLR. The VLR database will therefore contain some duplicate data as well as more precise data relevant to the subscriber remaining within the VLR coverage.

The VLR provides a local database for the subscribers wherever they are physically located within a PLMN, this may or may not be the “home” system. This function eliminates the need for excessive and time-consuming references to the “home” HLR database.

### 1.3.3 OpenBTS and Traditional GSM

In this section we know how OpenBTS replaced the GSM Network Component which we have mentioned previously

1. A USRP (Universal Software Radio Peripheral) as hardware. USRP can be readily adapted as a GSM transceiver(BTS) (i.e.: it transmits and receives the GSM signal to and from the mobile phone).

2. OpenBTS software code which generates with UHD an air interface that to a cell phone, looks just like any other GSM cellular network.

On the network side, it's an Asterisk server (VoIP), used to connect calls.

OpenBTS software code plays the role of MSC/VLR in processing all the calls incoming to, or originating from subscribers visiting the given switch area.

Using openBTS source code only creates a beacon signal such that openBTS network is created and a phone can register to this network But, cannot make a phone call with another registered phone except when asterisk is installed and configured in this system as Asterisk plays the role of HLR in the traditional GSM network which is the main database of permanent subscriber information for a mobile network (i.e.: it stores an IMSI for each subscriber, authentication key ,subscriber status and the current location).

### 1.3.4 OpenBTS Future

Future versions of the OpenBTS may well support GPRS and EDGE. GPRS, when available, should be a software-only upgrade for any installed OpenBTS system. EDGE support may require additional computational resources but the additional software is not complex, at least when compared to the rest of the BTS.

### 1.3.5 OpenBTS Advantages

The main advantage of the OpenBTS is the minimum cost as we can install the network at about 1/10 of the cost of current technologies, and still be compatible with most of the handsets that are already in the market. By replacing the GSM core network with commodity Hardware and open source Software.

Also, OpenBTS allow bug fixing over the air or other remote reprogramming thus reducing both time and cost associated with operation and maintenance.

OpenBTS solves one of the toughest challenges for the Mobile Communication systems, which is the compatibility, as now it's about upgrading the software which is not comparable with Hardware replacement cost.

### 1.3.6 Hardware requirement for OpenBTS

For a small OpenBTS network with, the minimal hardware requirements are:

- 1) Unix computer (Ubuntu).
- 2) USRP (B100).
- 3) WBX daughterboard (as a Transceiver).
- 4) Two antennas covering GSM range (one for TX and one for RX).

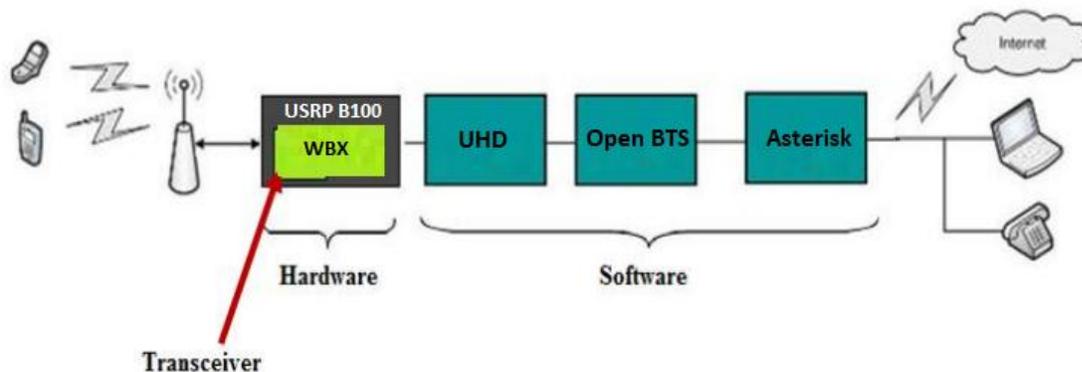


Figure 9 - OpenBTS System

### 1.3.7 OpenBTS P2.8 Release

OpenBTS P2.8 is the latest version of public OpenBTS software, it includes 4 main modules which is:

- Transceiver.
- GSM Stack .
- Control.
- SIP Switch.

### 1.3.8 OpenBTS Modules

#### **Transceiver Module**

The Transceiver is responsible for transmitting and receiving samples to and from the USRP, also it passes these samples in the form of raw bits to the GSM stack in case of reception or receives them from the GSM stack in case of transmission.

It interfaces with the GSM stack through UDP socket, and with the USRP through USB 2.0.

It performs the basic operations such as modulation, interleaving, correlation, etc.

#### **GSM Module**

The GSM module implements the GSM stack above the radio modem, it implements the three layers found in the ETSI standards.

The interface between the control and the GSM layers is the L3 messages sent between them.

#### **Control Module**

Perform the signaling and connection management

L3 radio resource management functions

L3 GSM-SIP gateway for mobility management

L3 GSM-SIP gateway for call control

#### **SIP Module**

OpenBTS uses a SIP switch or PBX to perform the call control functions that would normally be performed by the mobile switching center in a conventional GSM network, although in most network configurations. This switching function is distributed over multiple switches. These switches also provide transcoding services.

In OpenBTS P2.8 the standard SIP switch is Asterisk 1.8.

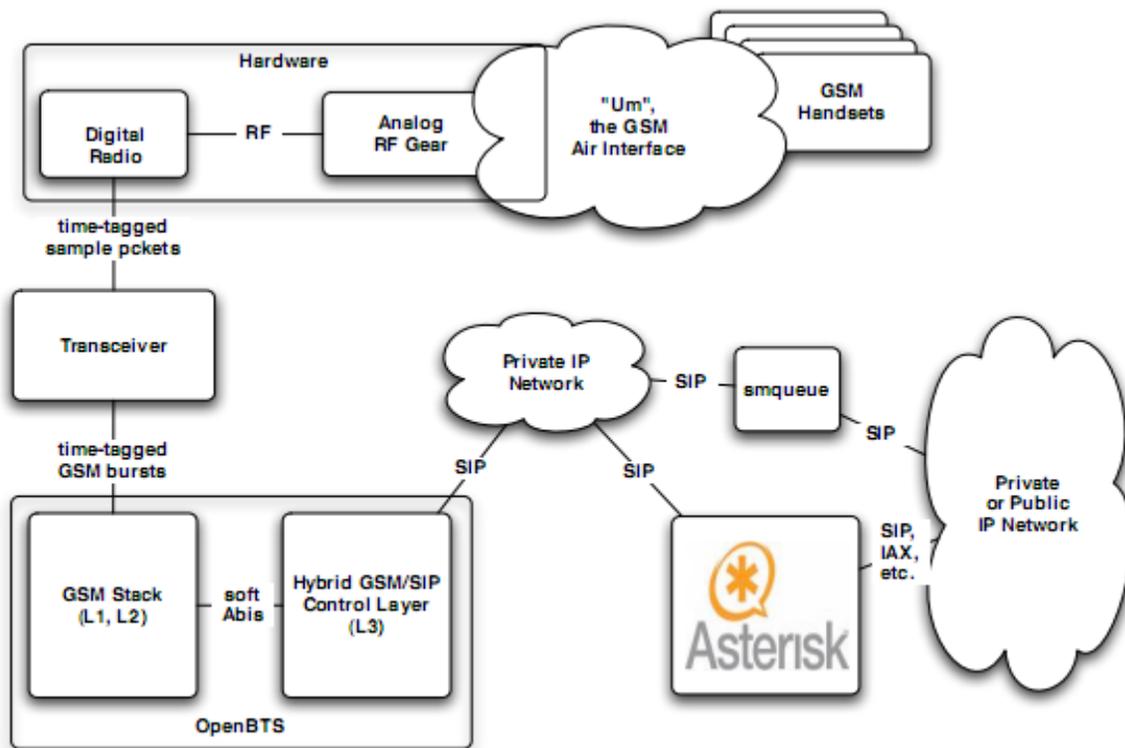


Figure 10 - OpenBTS Modules

### UP Stream data flow (Reception path)

1. Radio bursts arrive at the USRP and are digitized. The resulting samples are transferred to the transceiver software in the host CPU in time-tagged USB packets, using the standard USRP interface.
2. The transceiver syncs the USRP timetags with the GSM master clock, isolates each radioburst and demodulates it into a vector of symbol likelihoods ("soft symbols").
3. The soft symbol vector for each radio burst is timetagged with the GSM frame clock and transferred to the GSM stack via a datagram interface.
4. In the GSM stack, the TDM sublayer (of L1) demultiplexes each burst according to its timetag and sends it to the appropriate logical channel.
5. The logical channel passes each burst into its L1 FEC processor which provides bit-error concealment and recovery

6. The L1 FEC processor performs the FEC decoding. The output is a sequence of L2 frames taken by the logical channel and sent up to an L2 processor.
7. The L2 processor runs the LAPDm state machine that performs acknowledgments, retransmissions and segmentation. When an incoming L3 frame has been verified and assembled, it is placed into a queue for consumption by L3.
8. In L3, a dispatch function determines the message protocol and type and calls the appropriate control function to deserialize the message and act on its content, generally producing an L3 response on the downlink. These control functions also interact with the outside world via SIP and other protocols.

#### **Down stream data flow (Transmission Path)**

1. In L3, a control function generates an L3 message, serializes the message into an L3 frame and sends it into the logical channel, which in turn passes it down to L2.
2. The L2 processor breaks the L2 frame into segments, wraps each segment in an L2 frame. Each L2 frame is sent down to L1 according to the LAPDm state machine. LAPDm may also generate additional L2 frames on its own according to its acknowledgment and retransmission rules.
3. The L1 FEC processor encodes each L2 frame, generating four outgoing radio bursts. Each radio burst is timetagged with its intended transmission time. These bursts are passed on to the TDM interface.
4. The downstream TDM sublayer is just a mutex-controlled socket interface where the radio bursts from L1 are reformatted into messages on the transceiver's datagram interface.
5. Upon arriving in the transceiver, the outgoing radio bursts are sorted into a priority queue according to transmission time. Bursts are pulled from the queue as they become ready for transmission and the modulated. The modulated waveform samples are sent to the USRP over the standard timetagged USB interface. If no burst is ready for transmission at a given time the transceiver generates an appropriate filling sequence.
6. In the USRP the samples are converted to an analog waveform for transmission over the radio channel.

## Chapter 2 - Network design & System modeling

### 2.1 Introduction

In the following chapter we will propose high level system design for rural area and Oasis road where it is required to be covered with mobile network using OpenBTS.

The system design includes:

1. System modeling for both cases
2. Propagation models
3. Simulation results

### 2.2 OpenBTS in rural area

#### 2.2.1 System Modeling

- Assuming 4 cells each one has one frequency
- The master cell has an EXTRA frequency to pass signaling and traffic between the master and the other 3 cells.
- This can be described by the following figure.

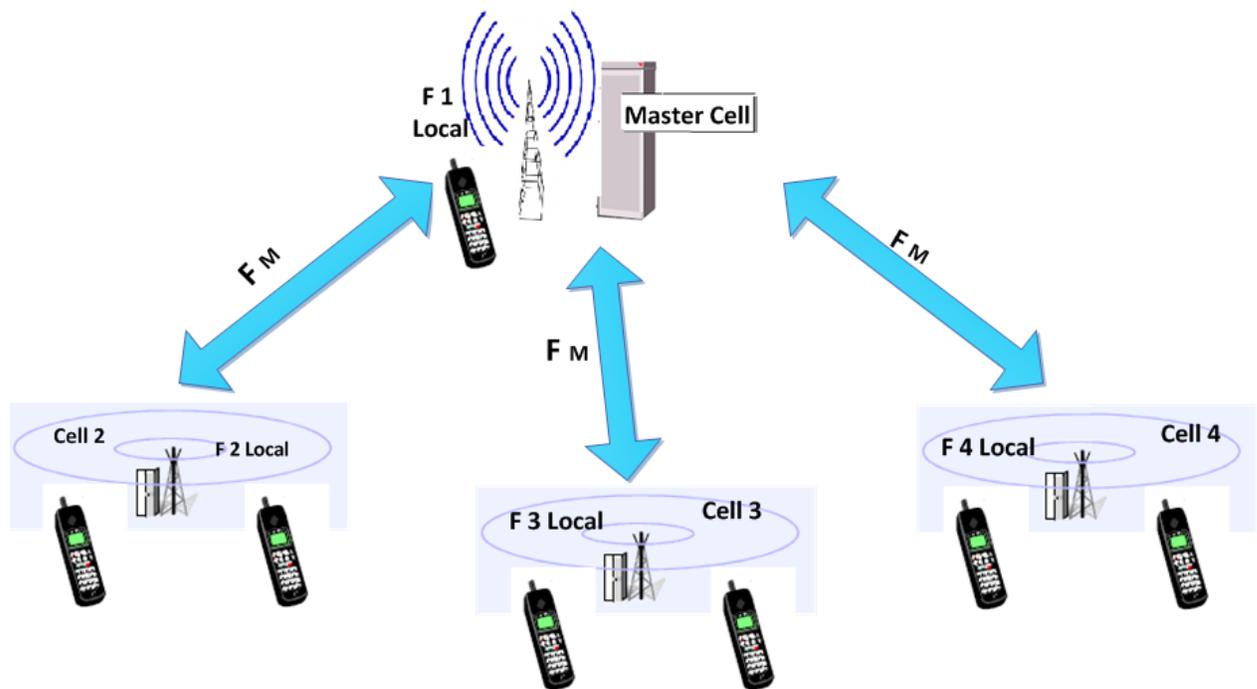


Figure 11- Rural General System Model

- The master cell which has 2 frequencies:
  - One to serve the calls under its coverage.
  - An extra frequency to pass signaling and traffic between the master and the other 3 cells
- Calls under the coverage of the master cell will not use the extra frequency to deal with the master, but this communication should be done using cables to make use of the advantage of being in the same place.
- Calls from other cells should be passed to the master using the Extra frequency.
- We can classify call according to their type as follows:

Call Type	Source	Destination
Type 1	n	n
Type 2	1	n
Type 3	n	1
Type 4	n	m

Figure 12 – Calls Types

- And to serve a call we have to make sure that the required resources are available:

Call Type	Required Channels		
	Source	Destination	Extra
Type 1	1	1	-
Type 2	1	1	1
Type 3	1	1	1
Type 4	1	1	2

Figure 13 – Required resources for each call

- Then set of flags represents either the required resources are available or not

Flag No.	Description
1	=1, indicates availability of TCH at the source cell, =0, Otherwise
2	=1, indicates availability of TCH at the destination cell, =0, Otherwise
3	=1, indicates availability of extra TCH at the source side, =0, Otherwise
4	=1, indicates availability of extra TCH at the destination side, =0, Otherwise

Figure 14 – Flags Description

- Finally for each call the set of flags should be as in the following table to be served otherwise it will be blocked

Call Type	Flags				
	1	2	3	4	5
Type 1	1	1	x	x	1
Type 2	1	1	1	x	1
Type 3	1	1	x	1	1
Type 4	1	1	1	1	1

Figure 15 – Served call flags

From the previous analysis it's clear that we have 3 sources of blocking

- 1- Lack of traffic channels at the source or the destination cell.
- 2- Lack of traffic channels needed from the extra frequency by calls of types 2,3 and 4
- 3- Lack of signaling channels needed for call setup (SDCCH).

**Notes:-**

- 1- Combination V is assumed, so TS\_0 has 4 groups of SDCCH's which means the availability of each cell to make 4 simultaneous call setups.

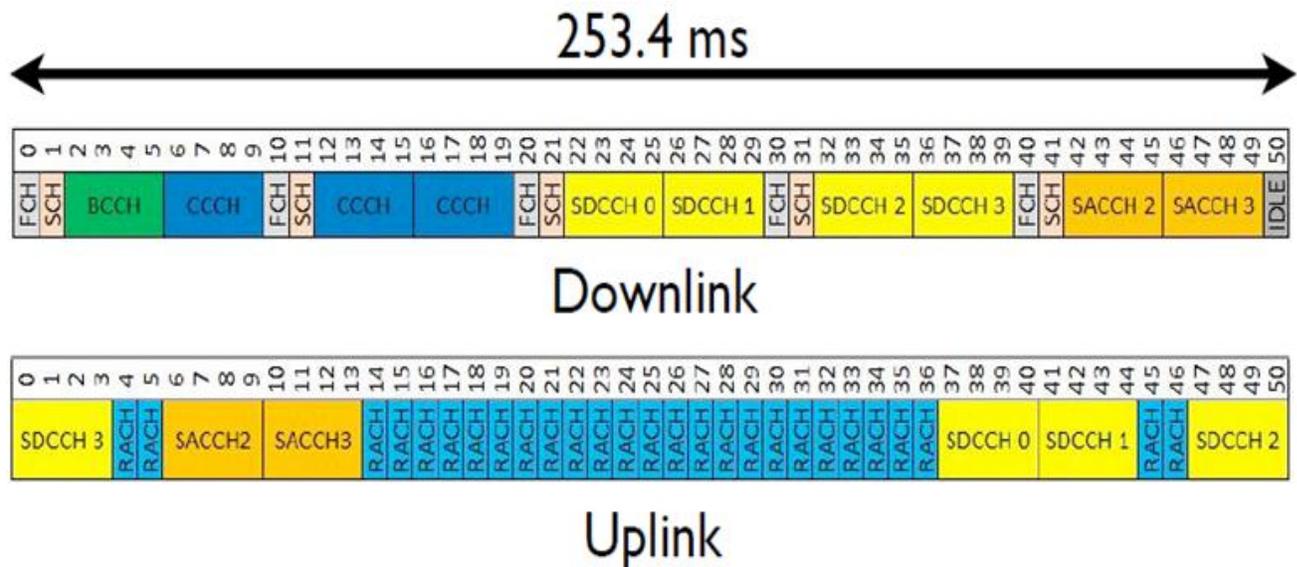


Figure 16 – Beacon V C0 T0

- 2- There is no need to include all signaling done during call setup and different msg.'s exchanged between the MS and BTS in the simulation due to 2 reasons:
  - i- We are interested only with the sources of blocking which could be due to
    - a) Lack of SDCCH
    - b) Collision at the same RACH (source is negligible compared to the 1<sup>st</sup> one).
  - ii- To simulate the call setup in detailed it's a very hard job in the code and as illustrated in point (1), it's not helpful. So, the point of interest here is SDCCH and how long it is occupied during the call setup and after searching we found that average holding time for SDCCH during call setup is 3 sec.
- 3- The first 3 channels of the master frequency are reserved to pass signaling of the 3-cells in both ways (uplink and downlink).
  - For the master frequency we have 3 signaling channels and N-3 traffic channels.
  - For the rest 3-cells we have 1-signalling channel and N-1 traffic channels.

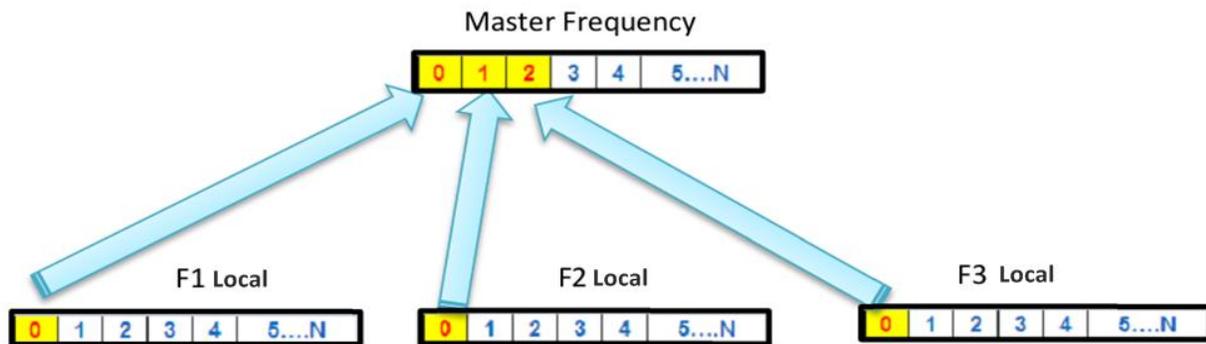


Figure 17 - Signaling between local and Master

### 2.2.2 Simulation results

We developed a GUI-based MATLAB program which simulates the above models and get the output (blocking probability) for different input parameters.

#### Example:

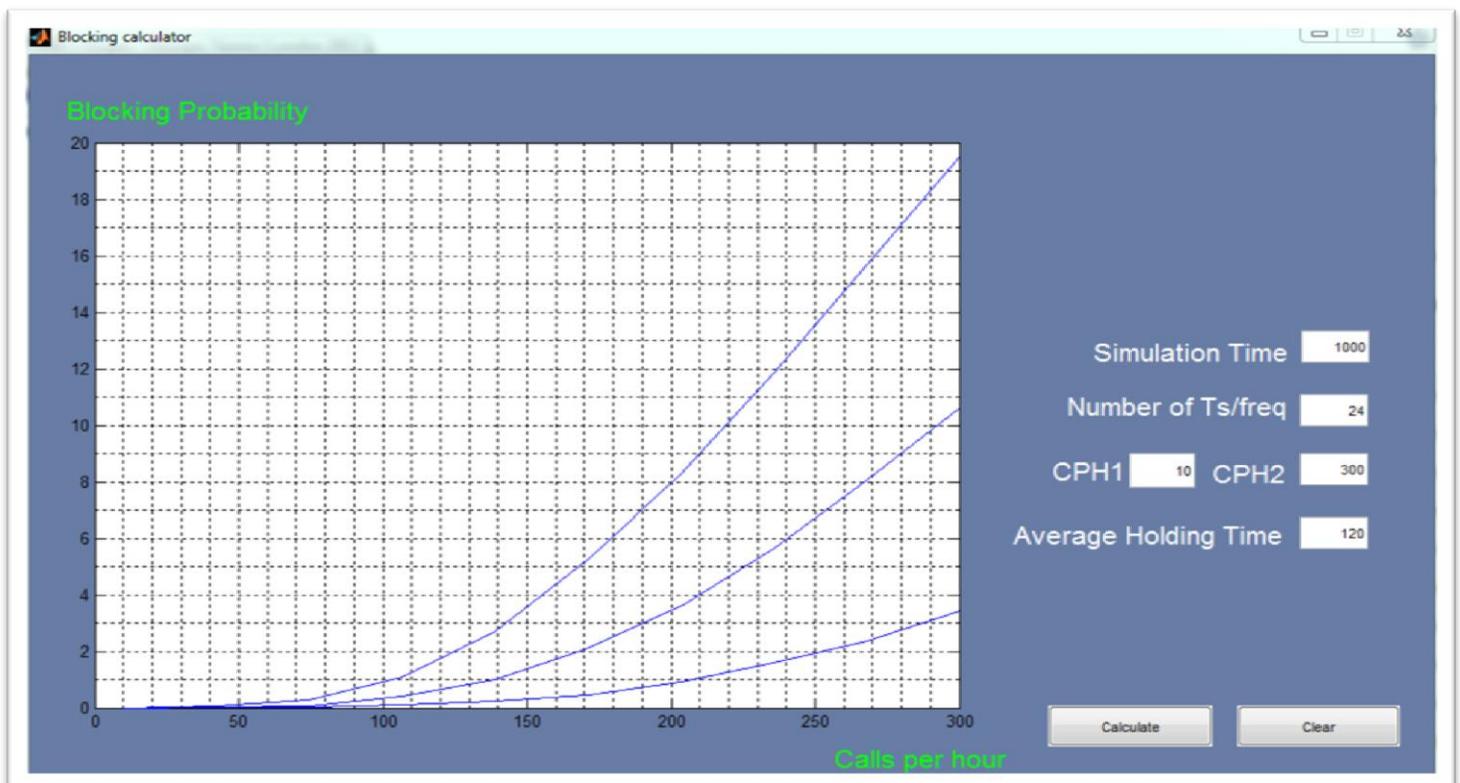


Figure 18 – Rural Simulation Result

### 2.2.3 Propagation model

Rural model 1:

- For repeating cells

$$d = 10 \text{ Km.}$$

$$H_b = 10\text{m.}$$

$$H_m = 10\text{m.}$$

$$F=900 \text{ Mhz.}$$

**From the Modified Hata model used at “ERC REPORT 68”**

Sub-case 2: Rural (Quasi-open)

$$L_{rqo} \text{ (dB)} = L_u - 4.78 \cdot [\log(f)]^2 + 18.33 \cdot \log(f) - 35.94$$

$$L_{rqo} \text{ (dB)} = 118.436 - 4.78 \{ \log(900) \}^2 + 18.33 \{ \log(900) \} - 35.94 = 94.93 \text{ dB}$$

&

- For  $150 \text{ MHz} < f \leq 1500 \text{ MHz}$

$$L(\text{urban}) = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) \\ + [44.9 - 6.55 \log(\max\{30, H_b\})] (\log(d))^\alpha - a(H_m) - b(H_b)$$

$$L(\text{urban}) = 69.6 + 26.2 \log(900) - 13.82 \log(30) \\ + [44.9 - 6.55 \log(30)] (\log(10))^1 - 21.688 - 21.688 = 118.436 \text{ dB}$$

&

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m/10)\}$$

$$a(H_m) = (1.1 \log(900) - 0.7) * 10 - (1.56 \log(900) - 0.8) + 0 = 21.688$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b/10)\}$$

$$b(H_b) = 21.688$$

$$\alpha = 1, d \leq 20 \text{ Km}$$

Rural model 2& 3:

- For repeating cells

$$d = 5 \text{ Km.}$$

$$H_b = 10\text{m.}$$

$$H_m = 10\text{m.}$$

$$F=900 \text{ Mhz.}$$

**From the Modified Hata model used at “ERC REPORT 68”**

Sub-case 2: Rural (Quasi-open)

$$L_{rqo} \text{ (dB)} = L_u - 4.78 * [\log(f)]^2 + 18.33 * \log(f) - 35.94$$

$$L_{rqo} \text{ (dB)} = 107.88 - 4.78 \{ \log(900) \}^2 + 18.33 \{ \log(900) \} - 35.94 = 105.482 \text{ dB}$$

&

- For  $150 \text{ MHz} < f \leq 1500 \text{ MHz}$

$$L(\text{urban}) = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) \\ + [44.9 - 6.55 \log(\max\{30, H_b\})] (\log(d))^\alpha - a(H_m) - b(H_b)$$

$$L(\text{urban}) = 69.6 + 26.2 \log(900) - 13.82 \log(30) \\ + [44.9 - 6.55 \log(30)] * (\log(5))^1 - 21.688 - 21.688 = 107.88 \text{ dB}$$

&

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m/10)\}$$

$$a(H_m) = (1.1 \log(900) - 0.7) * 10 - (1.56 \log(900) - 0.8) + 0 = 21.688$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b/10)\}$$

$$b(H_b) = 21.688$$

$$\alpha = 1, d \leq 20 \text{ Km}$$

Rural model 1,2 & 3:

- For serving cells

$$d = 5 \text{ Km.}$$

$$H_b = 10\text{m.}$$

$$H_m = 1.5\text{m.}$$

$$F=900 \text{ Mhz.}$$

**From the Modified Hata model used at “ERC REPORT 68”**

Sub-case 2: Rural (Quasi-open)

$$L_{rQO} \text{ (dB)} = L_u - 4.78 * [\log(f)]^2 + 18.33 * \log(f) - 35.94$$

$$L_{rQO} \text{ (dB)} = 129.5 - 4.78 \{ \log(900) \}^2 + 18.33 \{ \log(900) \} - 35.94 = 106 \text{ dB}$$

&

- For  $150 \text{ MHz} < f \leq 1500 \text{ MHz}$

$$L_u = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) + [44.9 - 6.55 \log(\max\{30, H_b\})](\log(d))^\alpha - a(H_m) - b(H_b)$$

$$L_u = 69.6 + 26.2 \log(900) - 13.82 \log(30) + [44.9 - 6.55 \log(30)] * (\log(5))^1 - 0.01588 - 21.688 = 129.5 \text{ dB}$$

&

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m/10)\}$$

$$a(H_m) = (1.1 \log(900) - 0.7) * 1.5 - (1.56 \log(900) - 0.8) + 0 = 0.01588$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b/10)\}$$

$$b(H_b) = 21.688$$

$$\alpha = 1, d \leq 20 \text{ Km}$$

Summary for all rural models:

Model Number	Cell type	Coverage distance	Mobile station height	Path loss value Lr <sub>q0</sub> (dB)
Model 1	Repeating	10 Km	10m	94.93 dB
	Serving	5 Km	1.5m	106 dB
Model 2	Repeating	5 Km	10m	105.482 dB
	Serving	5 Km	1.5m	106 dB
Model 3	Repeating	5 Km	10m	105.482 dB
	Serving	5 Km	1.5m	106 dB

Table 1 - Rural Models Pathloss

## 2.3 OpenBTS in Oasis road

### 2.3.1 System Modeling

There are about 70 kilometers uncovered by mobile networks at the Oasis road. Covering this road is considered important for the emergency calls.

#### -- Oasis Model 1:-

Assuming:

- 1- There are 7 cells, each of radius 5Km, with 7 serving frequencies and there are 6 interconnecting frequencies between 7 cells that used by repeaters.
- 2- There are 6 interconnecting frequencies between the 7 cells that used by repeaters.
- 3- Master cell in the middle of the road which is connected to the gateway.

Notes:

- 1- For simplicity we assumed that the position of the originating mobile on the road is fixed along the call (No Hand-Off in this model).

The terminating mobile is outside the coverage of 70 km in this model.

Figure that describes the system: -

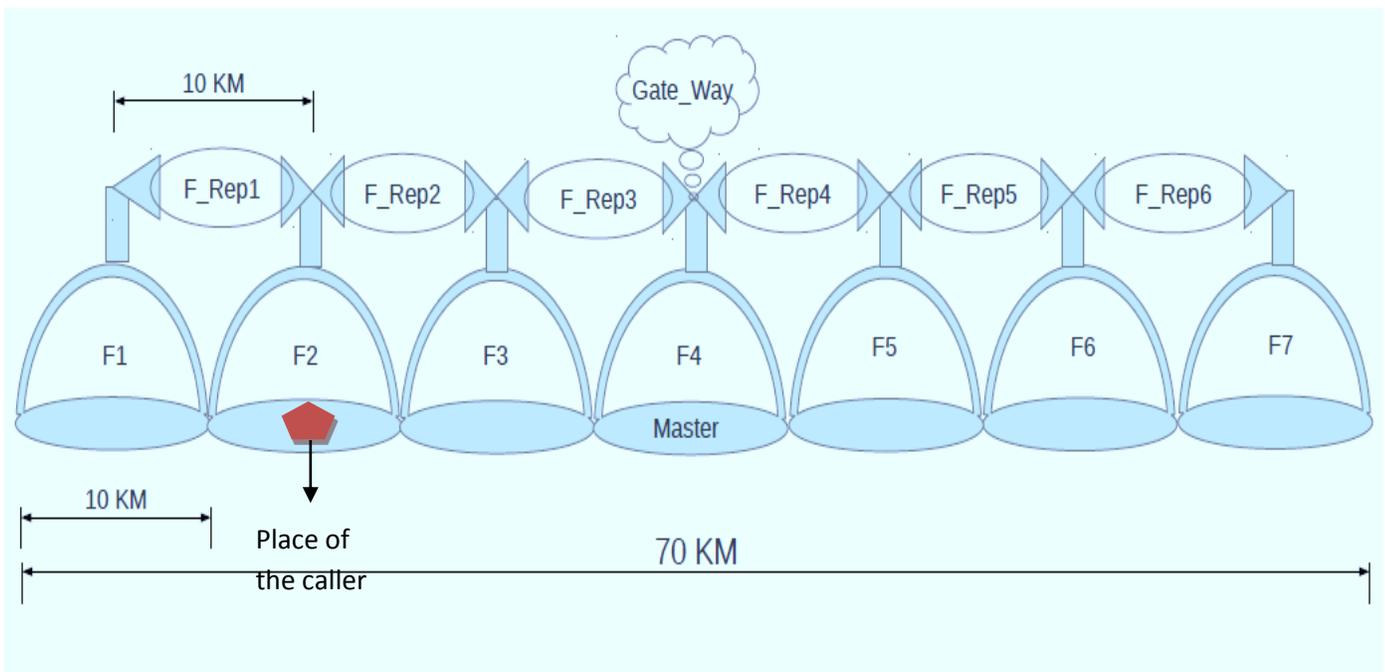


Figure 19 – Oasis Road Model 1

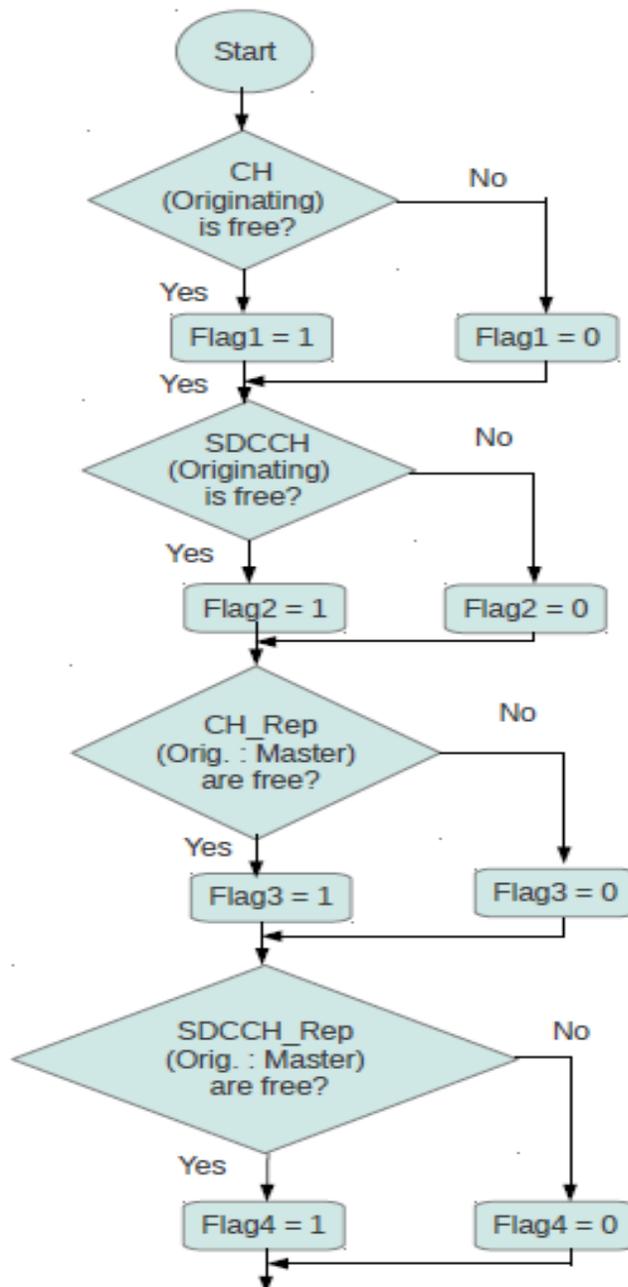
Scenario Explanation:-

Let's assume that the originating hand set in cell no. "2" and the terminating hand set outside this system:-

So,

- 1- At the Serving cell one time slot from frequency "F2" should be reserved for the holding time of the call.
- 2- The call should go out this system through the gate-way.
- 3- For the Repeating USRPs one time slot should be reserved from "F\_Rep.2 & F\_Rep.3" during the call.
- 4- After finishing the call, the system should release all reserved resources.

→Note: The Flow chart that describes the algorithm:



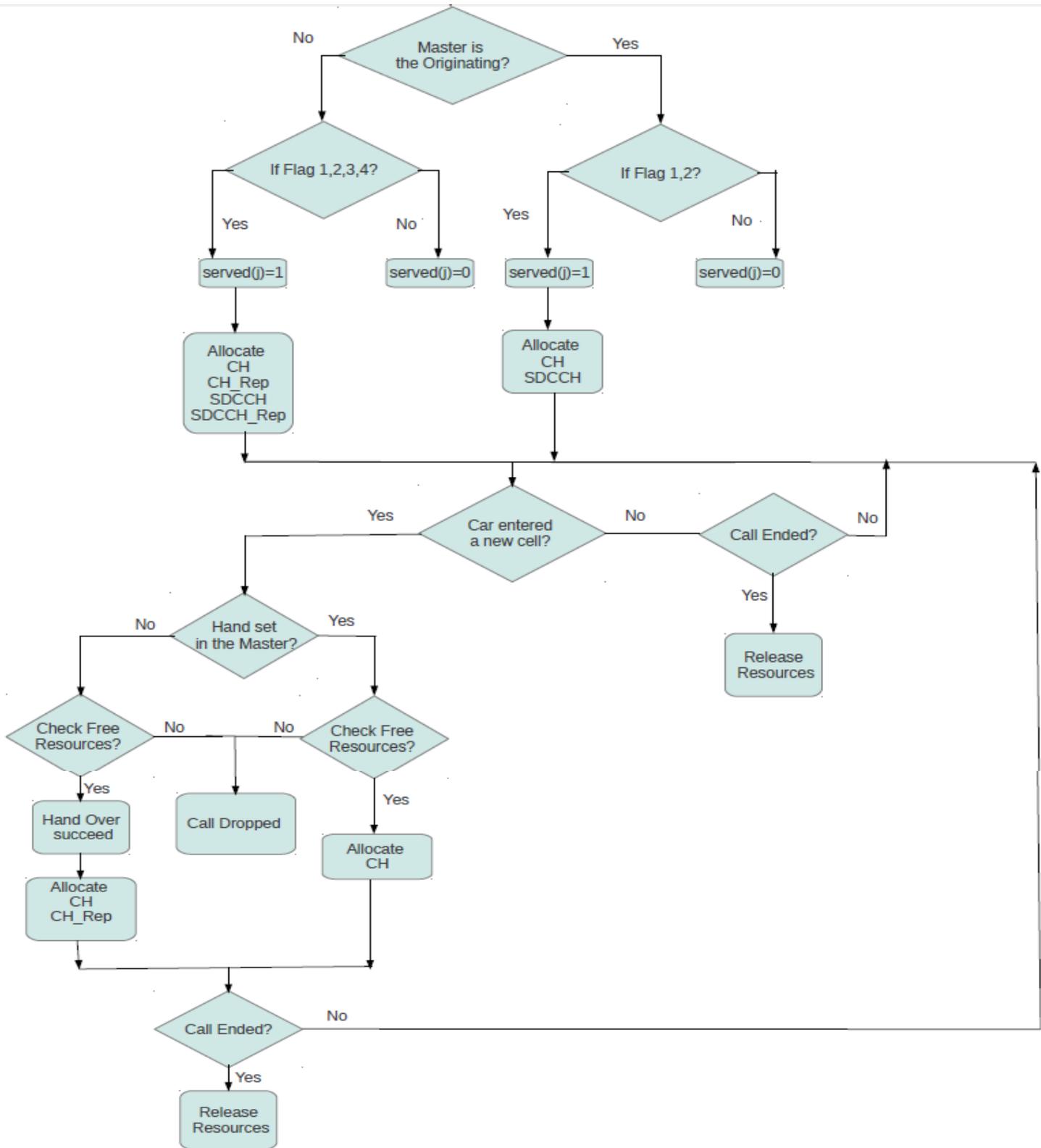


Figure 20- Simulation Flow Graph (Model 1)

-- Oasis Model 2:-

Assuming that the originating handset is moving with a certain speed so, hand over will be presented in this model.

→ Modifications on the previous simulation:

- 1- The originating handset is assumed to be moving (in a car).
- 2- The system handles channel assignment at the beginning of the call and during hand-offs.

This can be described by the following figure:-

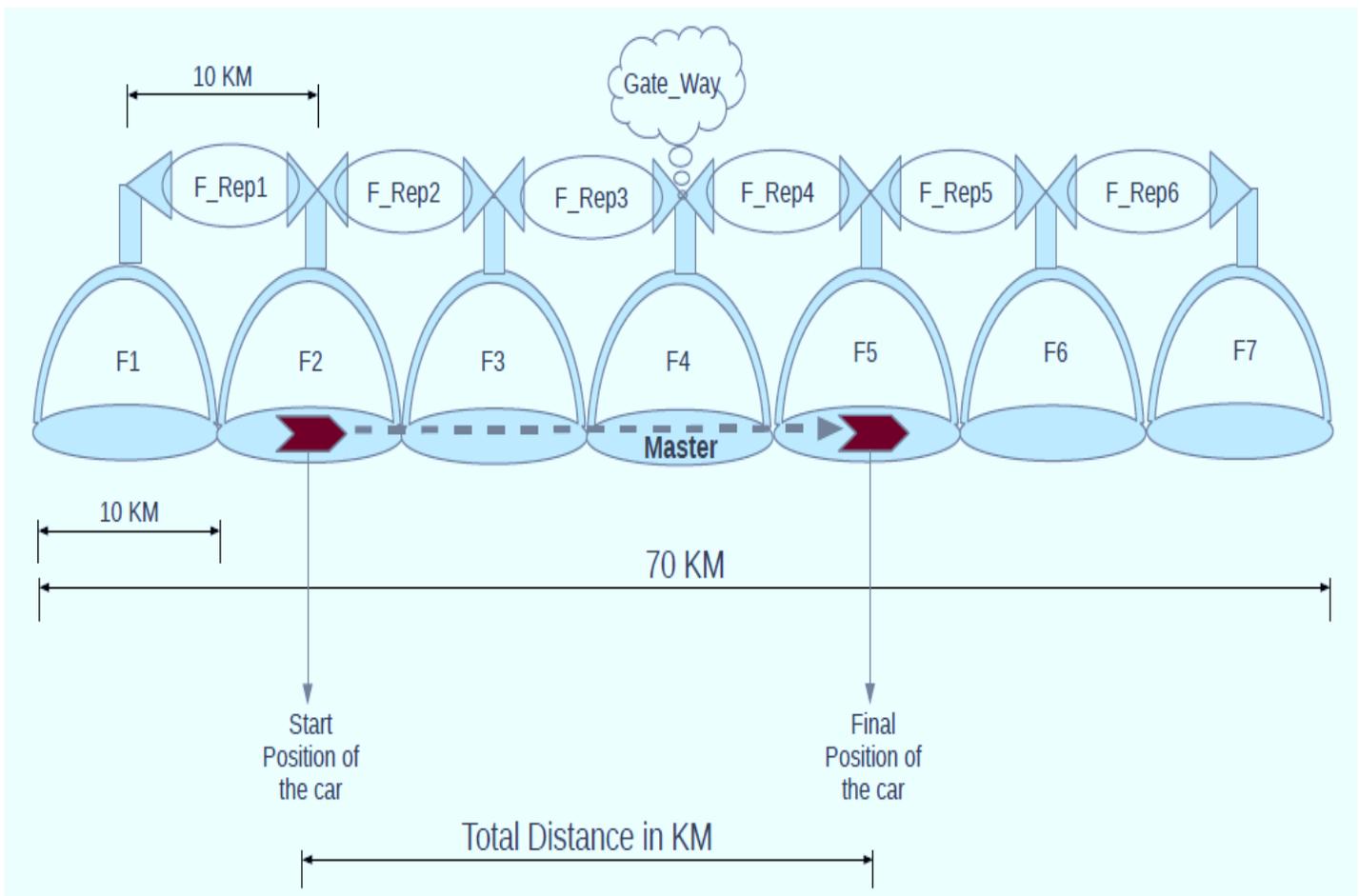


Figure 21- Oasis Road Model 1

Note: - There are no additional resources used.

Scenario Explanation:-

Let's assume that the originating vehicular handset in cell no. "2", the hold time for the call is 130 sec. and the terminating hand set outside this system.

So,

- 1- The position of the car is in cell no. "2" so, the Serving cell should allocate one time slot from "F2".
- 2- For the Repeating USRPs one time slot should be reserved from "F\_Rep.2 & F\_Rep.3".
- 3- If the car moved from cell 2 to cell 3 the network should search for a free time slot at "F3" then reserve it and release the reserved time slots from "F2 & F\_Rep.2" then the Hand over was succeeded otherwise the call would be dropped.
- 4- If the car moved from cell 3 to cell 4 the network should search for a free time slot at "F4" then reserve it and release the reserved time slots from "F3 & F\_Rep.3" then the Hand over was succeeded otherwise the call would be dropped.
- 5- If the car moved from cell 4 to cell 5 the network should search for a free time slot at "F5 & F\_Rep.4" then reserve them and release "F4" then the Hand over was succeeded otherwise the call would be dropped.
- 6- After finishing the call, the system should release all reserved resources.

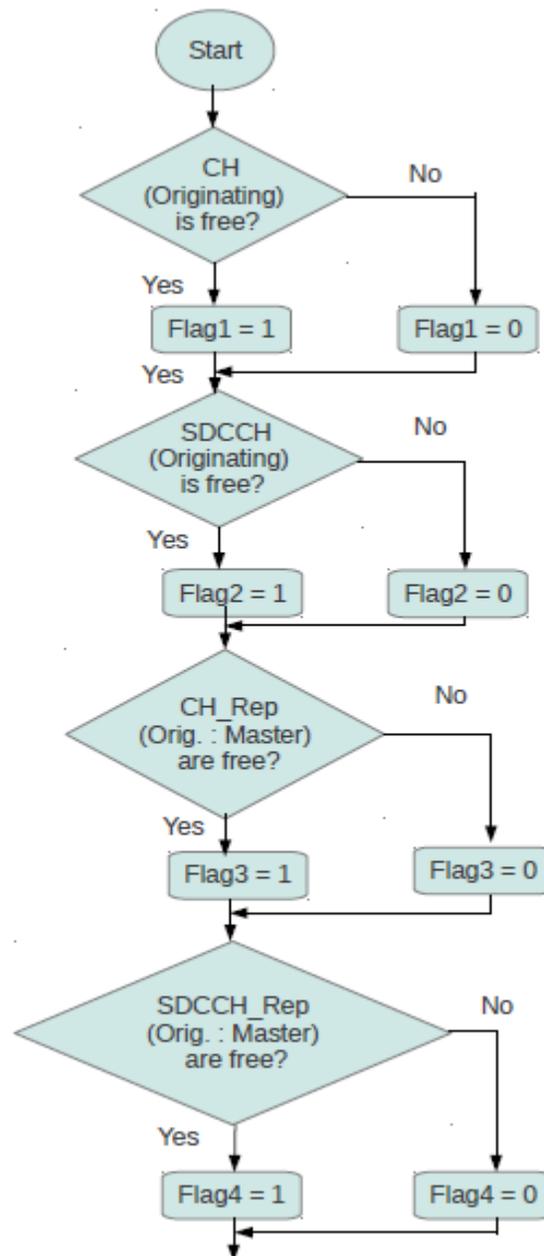
Notes:

...If the car is approaching master it releases repeating resources allocated for it.

... If the car is leaving master it acquires more repeating resources to be allocated.

... If the car is served directly by master it doesn't need any repeating resources.

→Note: The Flow chart that describes the algorithm:



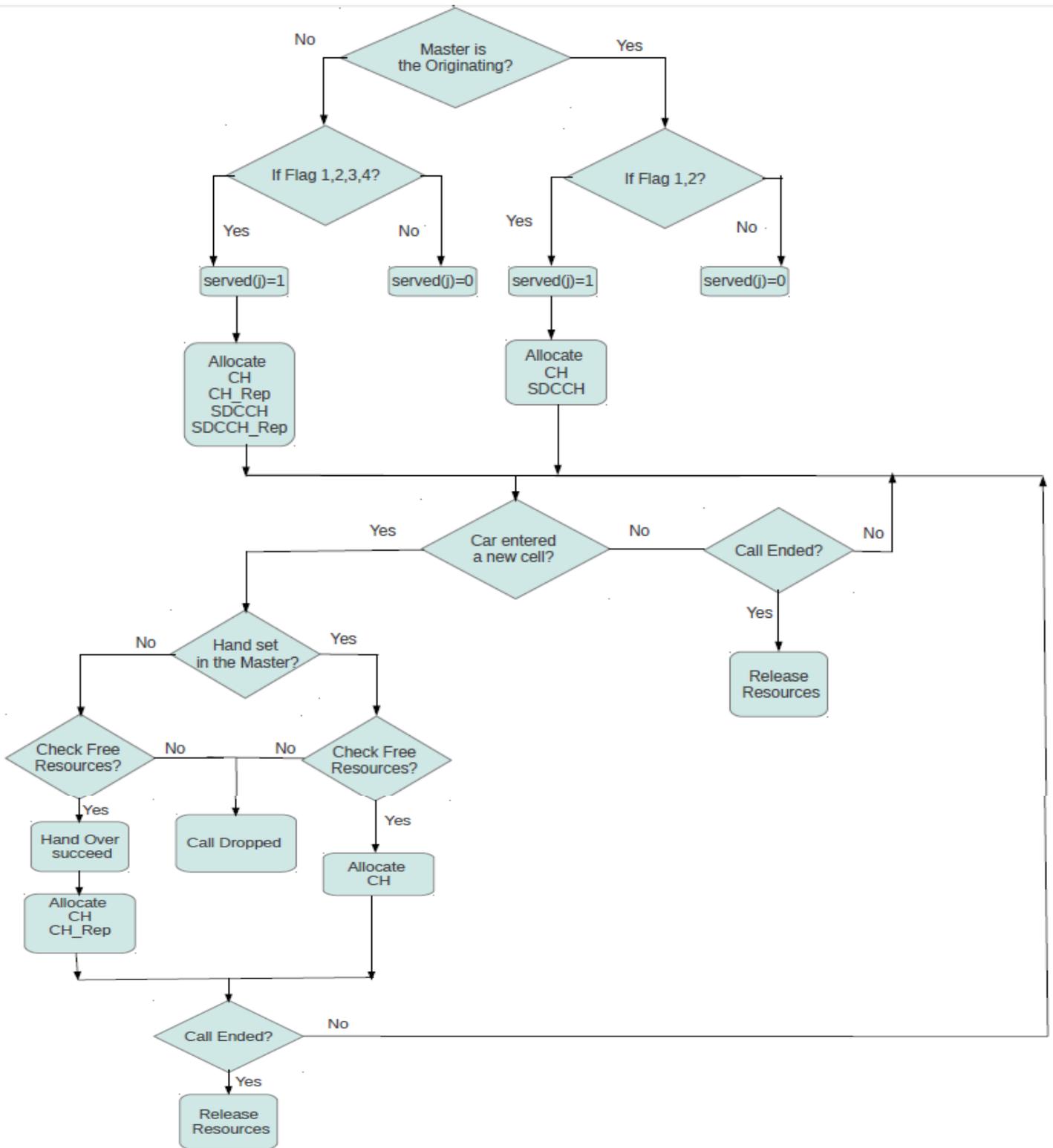


Figure 22 - Simulation flow Graph (Model 2)

If we assumed that the Originating vehicular handset in cell no. “1” and it will finish the call at cell no. “7”:-

The following figure shows the assignment of the available resources between the cells in the system.

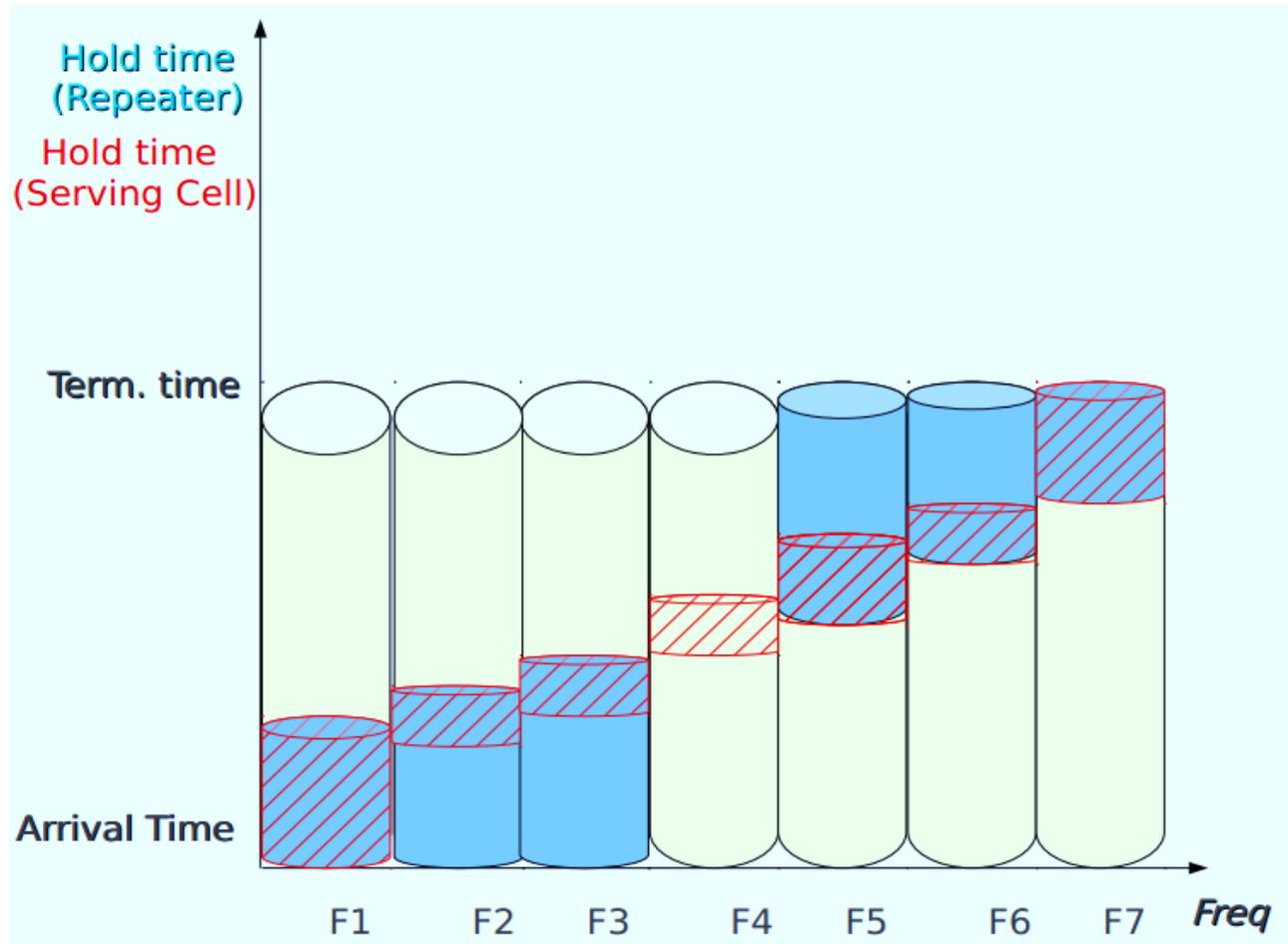


Figure 23 - Assignment of the available resources

Oasis Model 3:-

Assuming that each cell has only one USRP to serve calls under its coverage as well as repeating traffic and signaling to the next cell

→ Modifications on the previous simulation:

- 1- There will not be dedicated USRPs for repetition only.
- 2- There will be an Omni directional antenna at each cell to serve calls under its coverage as well as repeating traffic and signaling to the next cell.

This can be described by the following figure: -

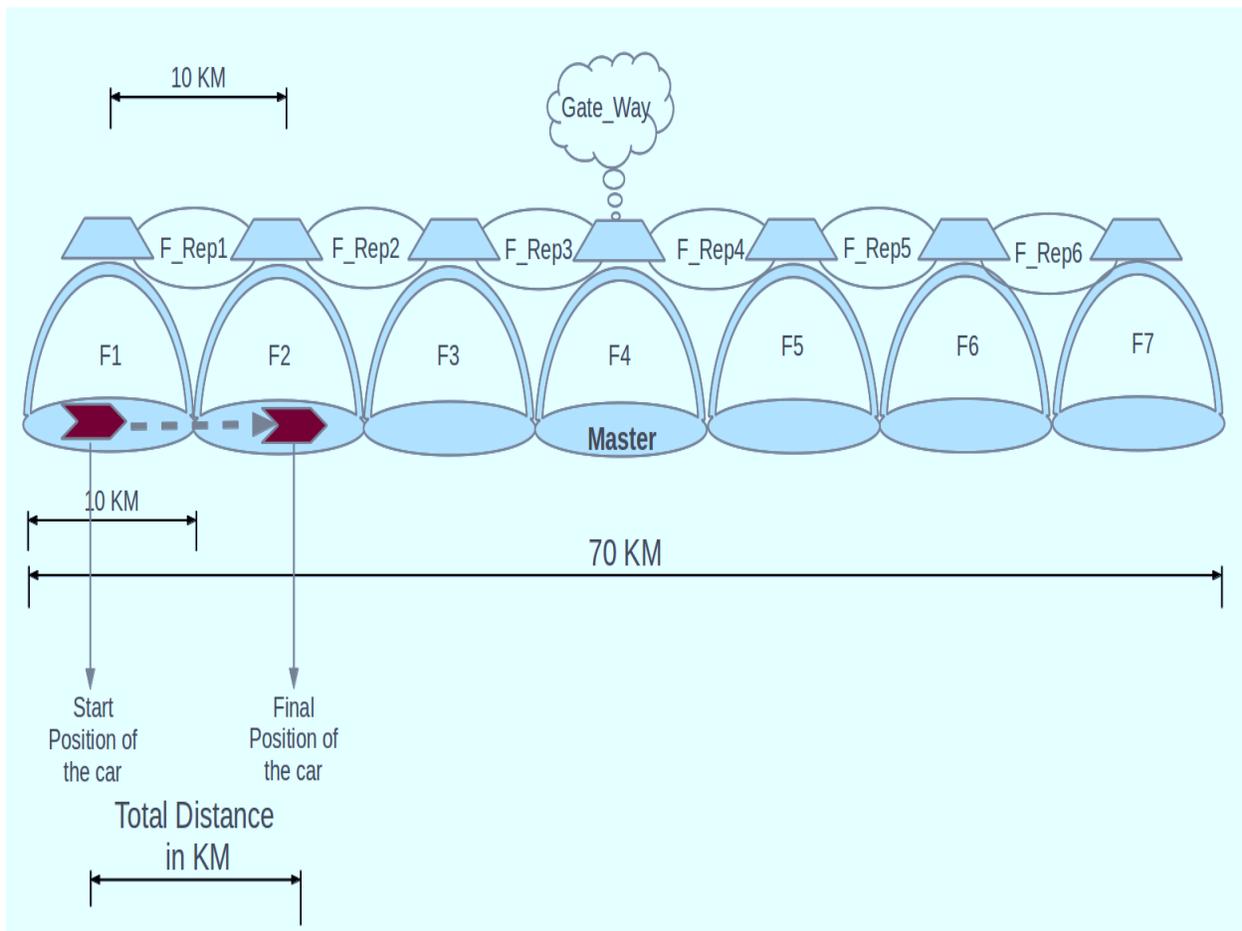


Figure 24 - Oasis Road Model 3

Scenario Explanation: -

If the system dedicates 3 time slots for serving calls in each cell/frequency and another 4 time slots for repeating calls to the master cell and the first time slot is reserved for signaling:

S: Serving.

R: Repeating.



Figure 25 - Up/Down Timming offset

Also, if the originating vehicular hand set passes through cell no. 1 and 2 during the call, so:

- 1- The hand set will make the signaling with the network at “TS 0” of freq. 1 assuming combination V is used.
- 2- The USRP at the originating cell will repeat the signaling to reach the master cell.
- 3- The USRP at the originating cell will be in serving mode and a time slot should be reserved at “F1” until hand over will occur.
- 4- Then the USRP will switch to repeating mode and a time slot should be reserved at “F1\_Rep” taking into consideration that having 3 Time slots offset between the serving TS and the repeating TS “Uplink & Downlink “until hand over will occur.
- 5- After hand over between 1<sup>st</sup> cell and the 2<sup>nd</sup> cell, the system should release the reserved time slots at “F1 & F1\_Rep” and the same procedure will be followed.
- 6- After finishing the call, the system should release all reserved resources.

Notes:

As this system uses combination V, so it has 4 groups of SDCCH at each frame.

This can be described by the following figure: -

There are 4 groups of SDCCH specified for serving and 4 groups of SDCCH specified for repeating.

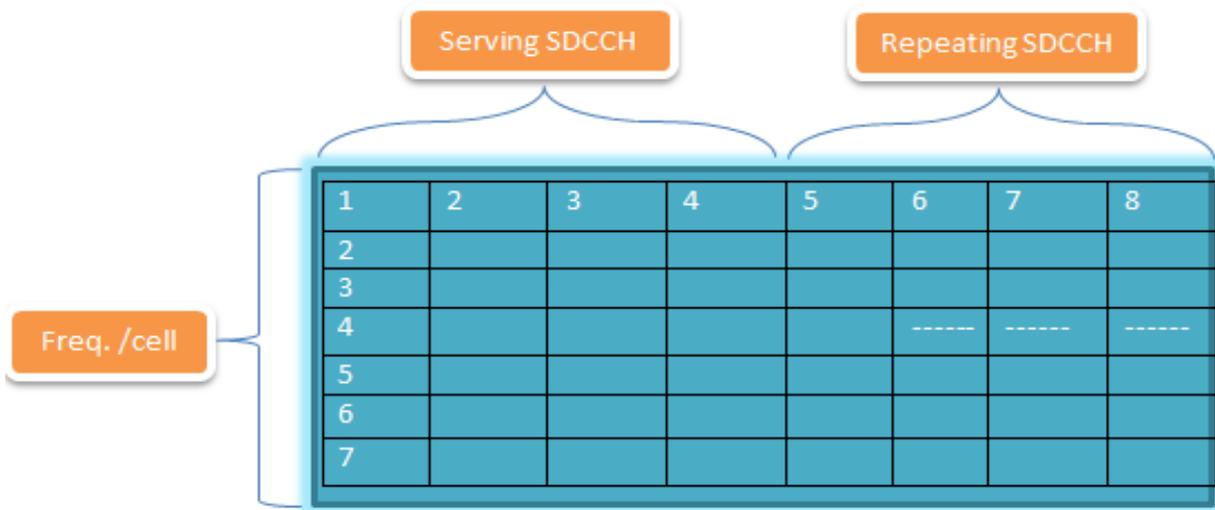


Figure 26 - SDCCH Scheme

The required Hardware and frequencies in each model:

Model Number	No. of USRPs	No. of Frequencies	No. of Gate-ways
Model 1	19 USRPs	13 frequencies	1 gate-way
Model 2	19 USRPs	13 frequencies	1 gate-way
Model 3	7 USRPs	13 frequencies	1 gate-way

Table 2- Required Hardware

### 2.3.2 Simulation results

#### Oasis Model (1) results

The following figure shows the Blocking probability calculated from the simulation for 3 different values of HT which are (600, 800 and 1000 sec), assuming traditional GSM time slots and Calls per Hour varies from 1 to 50 calls.

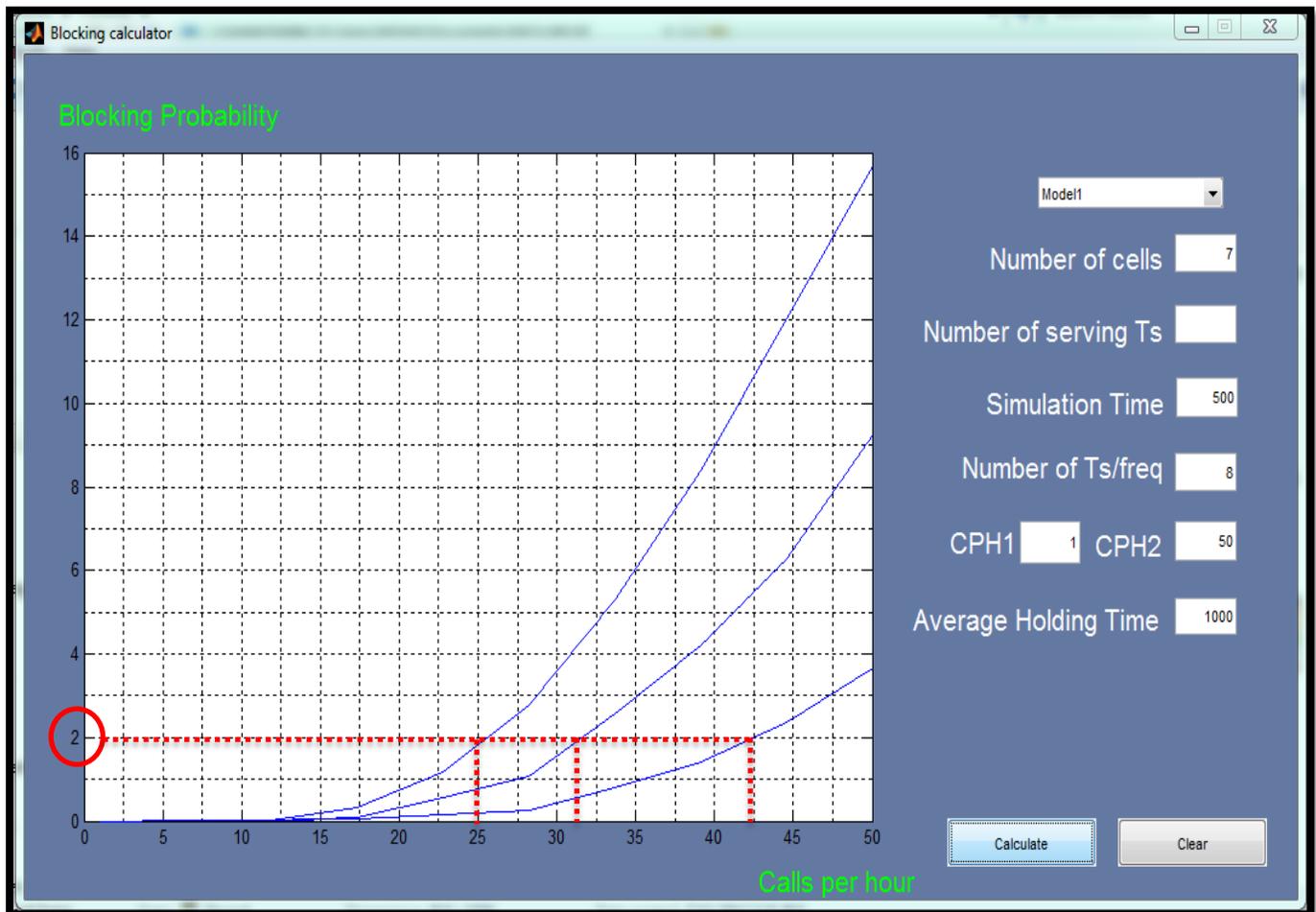


Figure 27 - Model 1 Simulation Results

Here the inputs are:

- Number of cells = 7 calls.
- Simulation Time = 500hours.
- Number of Ts/freq. = 8 time slots.
- CPH1 = 1, CPH2 = 50.
- HT = 600, 800 and 1000sec.

The resulting graph shows a blocking probability for each HT that has a limit of Calls/Hour:

Blocking Probability	Holding Time	No. of Calls/Hour
2% Blockage	600 sec.	25
2% Blockage	800 sec.	32
2% Blockage	1000 sec.	42

Table 3 - Model 1 Results

Note: The Blocking probability calculated from the simulation under low values of HT was approximately equal to 0% so, we used high values of HT to have proper values of blockage.

### Oasis Model (2) results

The following figure shows the Blocking probability calculated from the simulation for 3 different values of HT which are (500, 1000 and 1200 sec), assuming traditional GSM time slots and Calls per Hour varies from 1 to 50 calls.

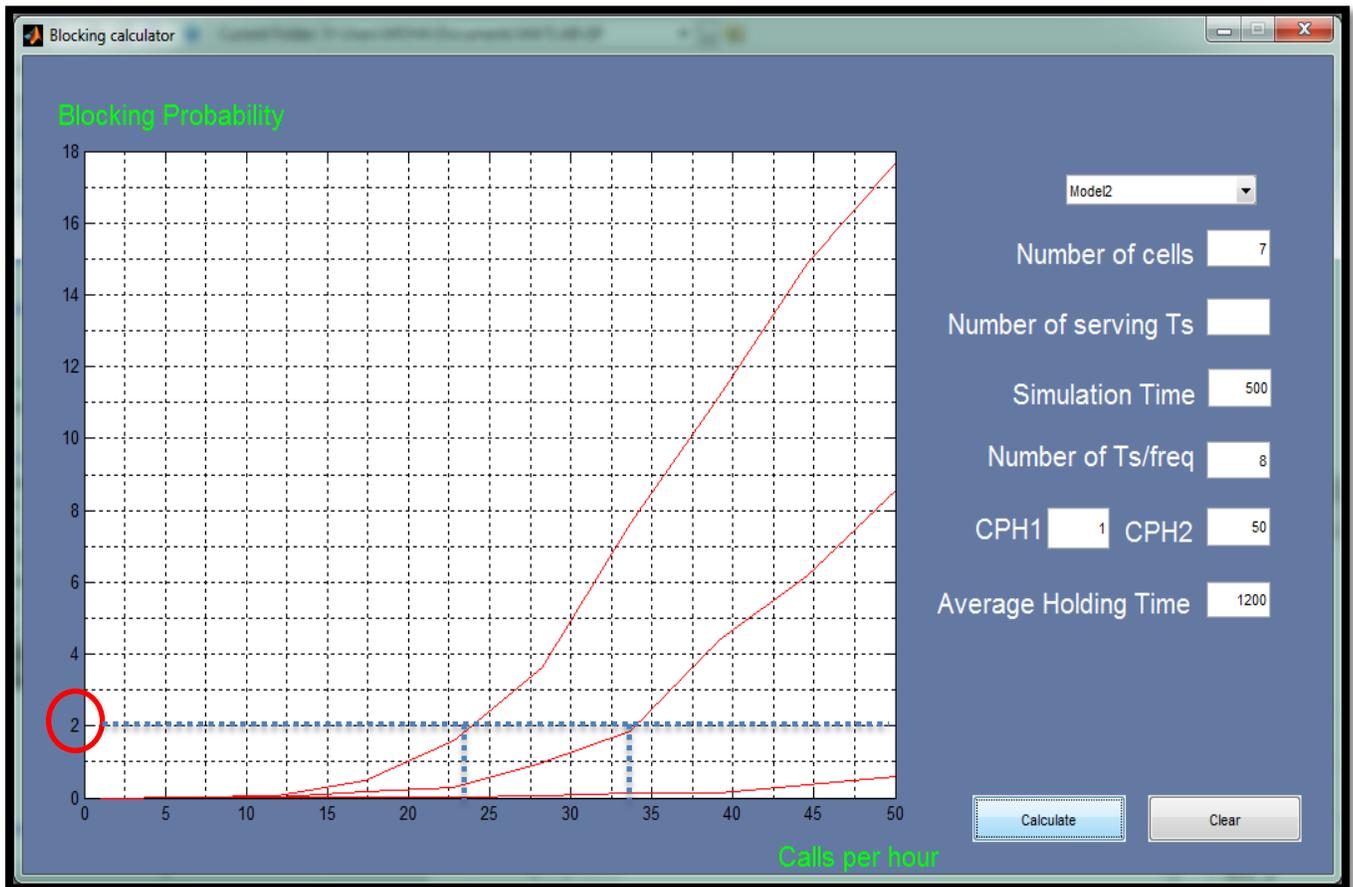


Figure 28 - Model 2 Simulation Results

Here the inputs are:

- Number of cells = 7 calls.
- Simulation Time = 500 hours.
- Number of Ts/freq. = 8 time slots.
- CPH1 = 1, CPH2 = 50.
- HT = 500, 1000 and 1200sec.

The resulting graph shows a blocking probability for each HT that has a limit of Calls/Hour:

Blocking Probability	Holding Time	No. of Calls/Hour
2% Blockage	500 sec.	26
2% Blockage	1000 sec.	34
2% Blockage	1200 sec.	+50

Table 4 - Model 2 Results

Note: The Blocking probability calculated from the simulation under low values of HT was approximately equal to 0% so, we used high values of HT to have proper values of blockage.

### Oasis Model (3) results

The following figure shows the Blocking probability calculated from the simulation for 3 different values of dedicated time slot for serving which are (1, 2 and 3TSs), assuming traditional GSM time slots, 500 sec. Holding time and Calls per Hour varies from 1 to 50 calls.

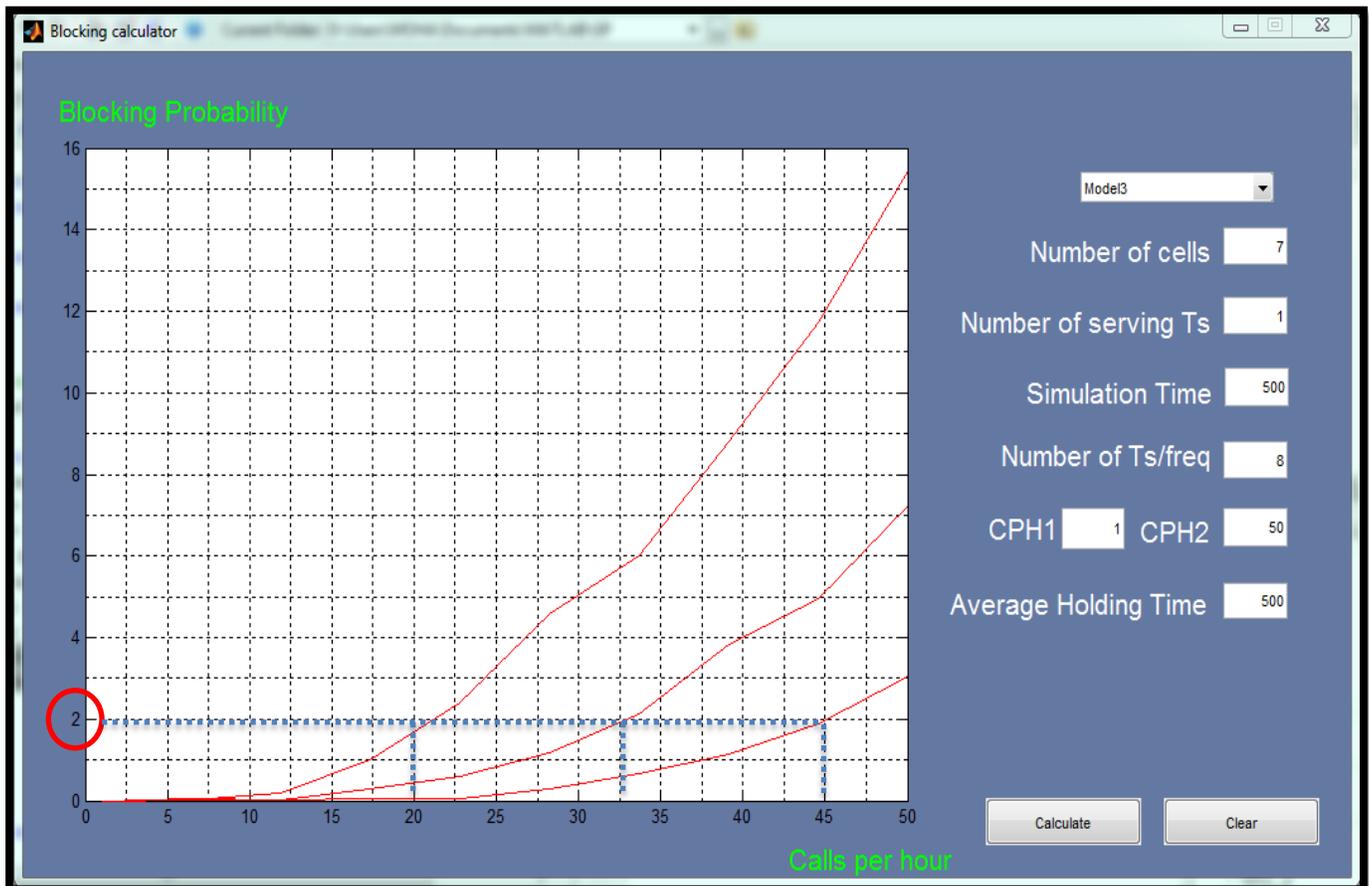


Figure 29 - Model 3 Simulation Results

Here the inputs are:

- Number of cells = 7 calls.
- Number of serving Ts = 1, 2 and 3 TSs.
- Simulation Time = 500 hours.
- Number of Ts/freq. = 8 time slots.
- CPH1 = 1, CPH2 = 50.
- HT = 500sec.

The resulting graph shows a blocking probability for each HT that has a limit of Calls/Hour:

Blocking Probability	No. of serving TSs	No. of Calls/Hour
2% Blockage	1 TS	45
2% Blockage	2 TSs	33
2% Blockage	3 TSs	20

Table 5 - Model 3 Results

Note: the largest number of served calls per hour at 1 TS dedicated for serving and 6 TSs dedicated for repeating traffic to the master cell, as there is a low probability to have many calls in the same cell at the same time.

### 2.3.3 Propagation model

**For Oasis system:**

**Oasis model 1,2 & 3:**

■ **For repeating cells**

$$d = 10 \text{ Km.}$$

$$H_b = 10\text{m.}$$

$$H_m = 10\text{m.}$$

$$F=900 \text{ Mhz.}$$

**From the Modified Hata model used at “ERC REPORT 68”**

Sub-case 3: Rural (Open Area)

$$L_{ro} = L_u - 4.78 \{ \log [(\min\{\max\{150, f\}, 2000\})]\}^2 \\ + 18.33 \{ \log [(\min\{\max\{150, f\}, 2000\})]\} - 40.94$$

$$L_{ro} = 118.436 - 4.78 \{ \log (900) \}^2 + 18.33 \{ \log (900) \} - 40.94 = 89.93 \text{ dB}$$

&

- For  $150 \text{ MHz} < f \leq 1500 \text{ MHz}$

$$L_u = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) \\ + [44.9 - 6.55 \log(\max\{30, H_b\})] (\log(d))^\alpha - a(H_m) - b(H_b)$$

$$L_u = 69.6 + 26.2 \log(900) - 13.82 \log(30) \\ + [44.9 - 6.55 \log(30)] * (\log(10))^1 - 21.688 - 21.688 = 118.436 \text{ dB}$$

&

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m/10)\}$$

$$a(H_m) = (1.1 \log(900) - 0.7) * 10 - (1.56 \log(900) - 0.8) + 0 = 21.688$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b/10)\}$$

$$b(H_b) = 21.688$$

$$\alpha = 1, d \leq 20 \text{ Km}$$

**Oasis model 1,2:**■ **For serving cells**

$$d = 5 \text{ Km.}$$

$$H_b = 10\text{m.}$$

$$H_m = 1.5\text{m.}$$

$$F=900 \text{ Mhz.}$$

**From the Modified Hata model used at “ERC REPORT 68”**

Sub-case 3: Rural(Open Area)

$$L_{ro} = L_u - 4.78 \{ \log [(\min\{\max\{150, f\}, 2000\})]^2 \\ + 18.33 \{ \log [(\min\{\max\{150, f\}, 2000\})] \} - 40.94$$

$$L_{ro} = 129.5 - 4.78 \{ \log (900) \}^2 + 18.33 \{ \log (900) \} - 40.94 = 101 \text{ dB}$$

&

- For  $150 \text{ MHz} < f \leq 1500 \text{ MHz}$

$$L_u = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) \\ + [44.9 - 6.55 \log(\max\{30, H_b\})] (\log(d))^\alpha - a(H_m) - b(H_b)$$

$$L_u = 69.6 + 26.2 \log(900) - 13.82 \log(30) \\ + [44.9 - 6.55 \log(30)] * (\log(5))^1 - 0.01588 - 21.688 = 129.5 \text{ dB}$$

&

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m/10)\}$$

$$a(H_m) = (1.1 \log(900) - 0.7) * 1.5 - (1.56 \log(900) - 0.8) + 0 = 0.01588$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b/10)\}$$

$$b(H_b) = 21.688$$

$$\alpha = 1, d \leq 20 \text{ Km}$$

**Oasis model 3**■ **For serving cells**

$$d = 10 \text{ Km.}$$

$$H_b = 10\text{m.}$$

$$H_m = 1.5\text{m.}$$

$$F=900 \text{ Mhz.}$$

**From the Modified Hata model used at “ERC REPORT 68”**

Sub-case 3: Rural (Open Area)

$$L_{ro} = L_u - 4.78 \{ \log [(\min\{\max\{150, f\}, 2000\})]^2 \\ + 18.33 \{ \log [(\min\{\max\{150, f\}, 2000\})] \} - 40.94$$

$$L_{ro} = 140.108 - 4.78 \{ \log (900) \}^2 + 18.33 \{ \log (900) \} - 40.94 = 111.602 \text{ dB}$$

&

- For  $150 \text{ MHz} < f \leq 1500 \text{ MHz}$

$$L_u = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) \\ + [44.9 - 6.55 \log(\max\{30, H_b\})] (\log(d))^\alpha - a(H_m) - b(H_b)$$

$$L_u = 69.6 + 26.2 \log(900) - 13.82 \log(30) \\ + [44.9 - 6.55 \log(30)] * (\log(10))^1 - 0.01588 - 21.688 = 140.108 \text{ dB}$$

&

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m/10)\}$$

$$a(H_m) = (1.1 \log(900) - 0.7) * 1.5 - (1.56 \log(900) - 0.8) + 0 = 0.01588$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b/10)\}$$

$$b(H_b) = 21.688$$

$$\alpha = 1, d \leq 20 \text{ Km}$$

Summary for all Oasis models:

Model Number	Cell type	Coverage distance	Mobile station height	Path loss value Lr <sub>qo</sub> (dB)
Model 1	Repeating	10 Km	10m	89.93 dB
	Serving	5 Km	1.5m	101 dB
Model 2	Repeating	10 Km	10m	89.93 dB
	Serving	5 Km	1.5m	101 dB
Model 3	Repeating	10 Km	10m	89.93 dB
	Serving	10 Km	1.5m	111.602 dB

Table 6 - Oasis Models Path loss

## 2.4 Network's components specifications and prices:

### 2.4.1 Typical RF chain figure:-

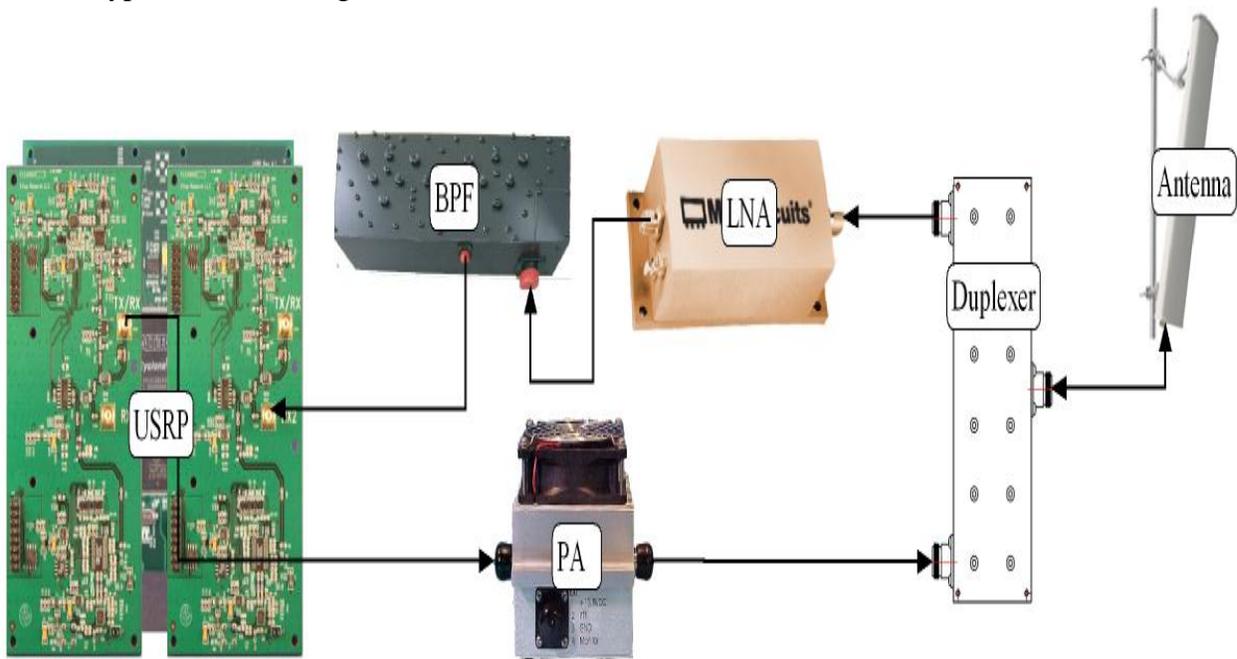


Figure 30 - Typical RF chain

### 2.4.2 Telephone pole “Network tower”:

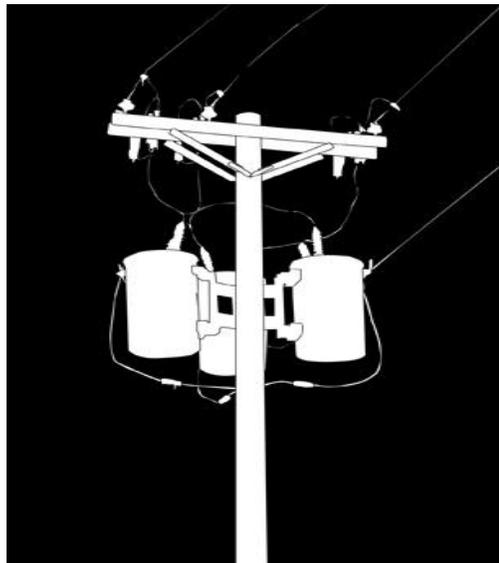


Figure 31 - Telephone Pole

### 2.4.3 Component Specifications: -

#### LNA

Using the Mini-Circuits ZRL-1150LN. It is readily available and is very reasonably priced, given its specifications:

- 685-1000 MHz
- 31 dB gain
- 1 dB compression at 24 dBm
- <1 dB noise figure
- +10 - +17 VDC supply
- \$120

#### PA

The Downeast Microwave [3340PA](#) is a good candidate:

- 30 dB gain
- 46 dB IP1 output
- 13.5 VDC supply
- \$235

The 3340PA will require a 15 VDC Zener diode on its power supply terminals to protect from over-voltage damage.

#### Duplexer

The candidate duplexer is the Anatech Microwave [AD836-881D200](#):

- 824-849 MHz, 869-894 MHz
- 70 dB isolation
- <1 dB insertion loss
- \$360

#### Bandpass Filter (BPF)

The candidate BPF is the Aantech Microwave [AB832B477](#):

- passband 824-840 MHz
- 95 dB suppression at 869 MHz
- <1 dB insertion loss
- \$325

With the 70 dB duplexer, this BPF will give a total tx-rx isolation of 165 dB.

#### Antenna

The candidate antenna is the Hyperlink [HG913P-120](#):

- 860-960 MHz (should work well enough at 825 MHz, though)
- 13 dBi (de-rate to 10 dBi for 825 MHz, worst case)
- 120-deg x 15-deg beam
- \$200

The additional 3 dB of antenna gain may add 40% to the coverage range.

#### “900 MHz Sectorized Antenna Array with three 120° Sectorial Antennas”

- Tri-Antenna Array with 360° coverage
- High performance sectorial antennas
- Single fed models feature 3-Way signal splitter and jumper cables
- 0-16° mechanical up/down tilt
- DC short lightning protection
- \$924.99

#### The tower will be a telephone pole

- \$500 for a 40 foot (12 meters) pole

#### The Gateway “VSAT”

- Antenna reflector
- Feed/OMT (Orthomode Transducer)
- LNB
- SSPA Block Upconverter
- L-Band Satellite Modem
- Cables and Accessories Package
- \$3650

Network Model	No. of serving cells	No. of RF chains	No. of Antennas		No. of towers	No. of VSATs	Total cost \$
			repeaters	serving			
Rural Model 1	4	8	4	4*3	4	0	23,520\$
Rural Model 2	3	11	8	3*3	4	0	26,840\$
Rural Model 3	3	8	5	3*3	4	0	23,120\$
Oasis Model 1	7	19	12	7*3	7	1	51,010\$
Oasis Model 2	7	19	12	7*3	7	1	51,010\$
Oasis Model 3	7	7	7	7*3	7	1	37,530\$

Table 7 - Rural & Oasis Network Cost

## Chapter 3- Signaling between GSM and OpenBTS

In the following chapter we will discuss the traditional GSM signaling messages for call setup and the modifications added to setup a call in case of using an intermediate USRP as a repeater between the MS and the master cell to repeat signaling messages as well as traffic (voice).

### 3.1 GSM Signaling

#### 3.1.1 Logical Channels

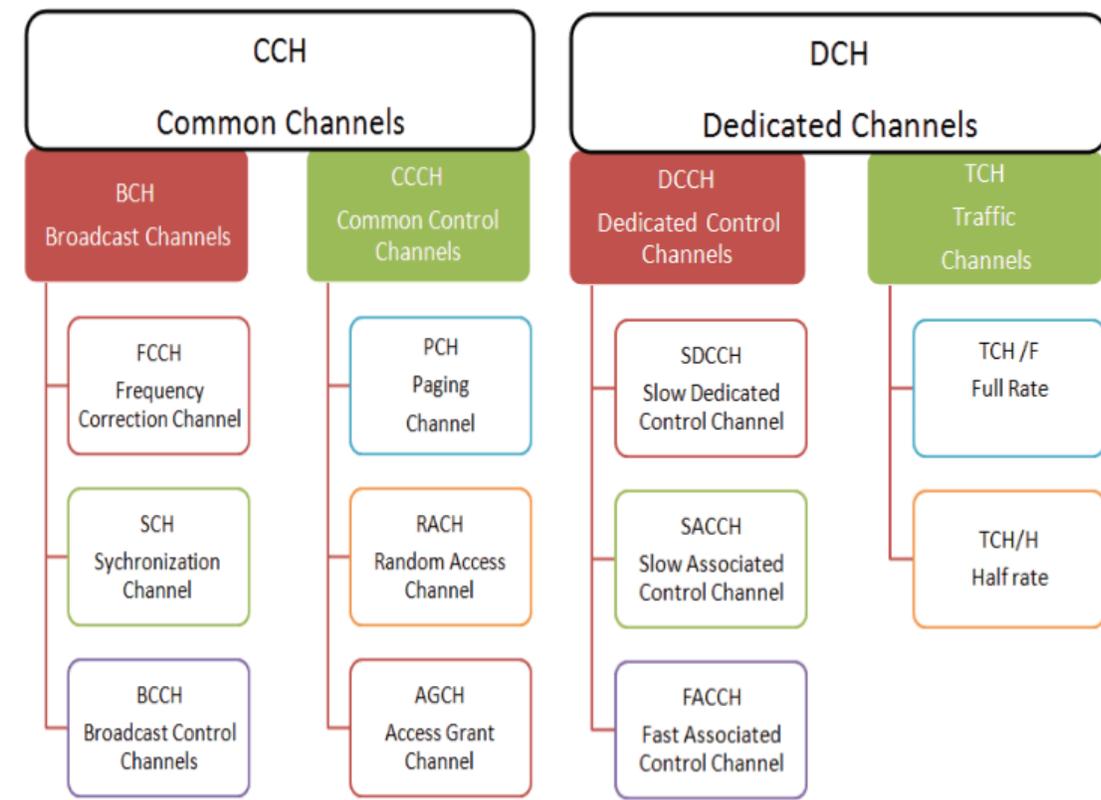


Figure 32 - Logical Channels

#### Broadcast Channels (BCH)

**Broadcast Control Channel (BCCH)** - **DOWNLINK** - This channel contains system parameters needed to identify the network and gain access. These parameters include the Location Area Code (LAC), the Mobile Network Code (MNC), the frequencies of neighboring cells, and access parameters.

**Frequency Correction Channel (FCCH) - DOWNLINK** - This channel is used by the MS as a frequency reference. This channel contains frequency correction bursts.

**Synchronization Channel (SCH) - DOWNLINK** - This channel is used by the MS to learn the Base Station Information Code (BSIC) as well as the TDMA frame number (FN). This lets the MS know what TDMA frame they are on within the hyper frame.

**Cell Broadcast Channel (CBCH) - DOWNLINK** - This channel is not truly its own type of logical channel. The CBCH is for *point-to-Omni point* messages. It is used to broadcast specific information to network subscribers; such as weather, traffic, sports, stocks, etc. Messages can be of any nature depending on what service is provided. Messages are normally public service type messages or announcements. The CBCH isn't allocated a slot for itself, it is assigned to an SDCCH. It only occurs on the downlink. The CBCH usually occupies the second sub-slot of the SDCCH. The mobile will not acknowledge any of the messages.

### Common Control Channels (CCCH)

**Paging Channel (PCH) - DOWNLINK** - This channel is used to inform the MS that it has incoming traffic. The traffic could be a voice call, SMS, or some other form of traffic.

**Random Access Channel (RACH) - UPLINK** This channel is used by a MS to request an initial dedicated channel from the BTS. This would be the first transmission made by a MS to access the network and request radio resources. The MS sends an *Access Burst* on this channel in order to request access.

**Access Grant Channel (AGCH) - DOWNLINK** - This channel is used by a BTS to notify the MS of the assignment of an initial SDCCH for initial signaling.

### Dedicated Control Channels (DCCH)

**Standalone Dedicated Control Channel (SDCCH) - UPLINK/DOWNLINK** - This channel is used for signaling and call setup between the MS and the BTS.

**Fast Associated Control Channel (FACCH) - UPLINK/DOWNLINK** - This channel is used for control requirements such as handoffs. There is no TS and frame allocation dedicated to a FAACH. The FAACH is a burst-stealing channel, it steals a Timeslot from a Traffic Channel(TCH).

**Slow Associated Control Channel (SACCH) - UPLINK/DOWNLINK** - This channel is a continuous stream channel that is used for control and supervisory signals associated with the traffic channels.

Note : The underlined logical channels are used in the scenario of Mobile Originated Call Setup.

There are five different signaling scenarios at GSM:

1. Mobile Originated Call Setup
2. Mobile Terminated Call Setup
3. Mobile Originated, Call Release and Channel Release
4. Location Updating
5. Handover

The following is an detailed overview of the first signaling scenario (Mobile Originated Call Setup) showing the sequence of:

- Traditional GSM signaling.
- Traditional GSM L3 messages.
- Adapted version of GSM signaling. (used in OpenBTS)
- Adapted version of GSM L3 messages. (used in OpenBTS)

### 3.2 Mobile Originated Call Setup

A Mobile Originated Call is a call that is initiated by the MS.

### 3.2.1 Traditional GSM signaling

1. The MS sends a *Channel Request* (CHAN\_REQ) message on the RACH.
2. The BSS responds with a radio resource assignment (IMM\_ASS\_CMD) on the AGCH.
3. The MS sends a *Service Request* (CM\_SERV\_REQ) message to the BSS on the SDCCH.
4. The MS then sends a *Call Setup* (SETUP) message to the BSS. The message includes the address information (MSISDN) of the called party.
5. The BSS assigns a TCH to the MS by sending an *Assignment Command* (ASS\_CMD) message. This message includes which Transceiver (TRX) and which Time Slot (TS) to use.
6. The MS immediately switches to the assigned TCH. The MS sends an *Assignment Complete* (ASS\_COM) message back to the BTS on the FACCH.
7. The MSC sends an ALERT message to the MS indicating that the call is going through. The BSS sends the ALERT message on the FACCH. Once the MS receives the ALERT, it will generate the ringing sound in the earpiece. The BSS sends an alerting message the subscriber will hear the line ringing.
8. Once the called party answers the phone, the PSTN will

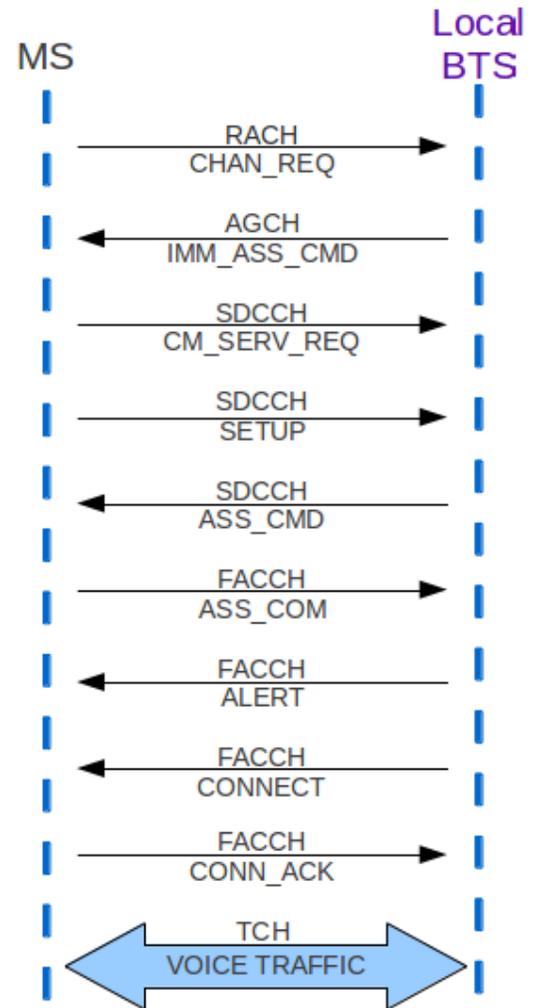


Figure 33 - Traditional GSM signaling

send an Answer message to the MSC. The MSC forwards this to the MS in a *Connection* (CONNECT) message.

9. Once the MS receives the CONNECT message, it replies by Connection Acknowledge (CONN ACK) message, then switches over to voice and begins the call. All voice traffic occurs on the assigned TCH.

3.2.2 Traditional GSM L3 messages

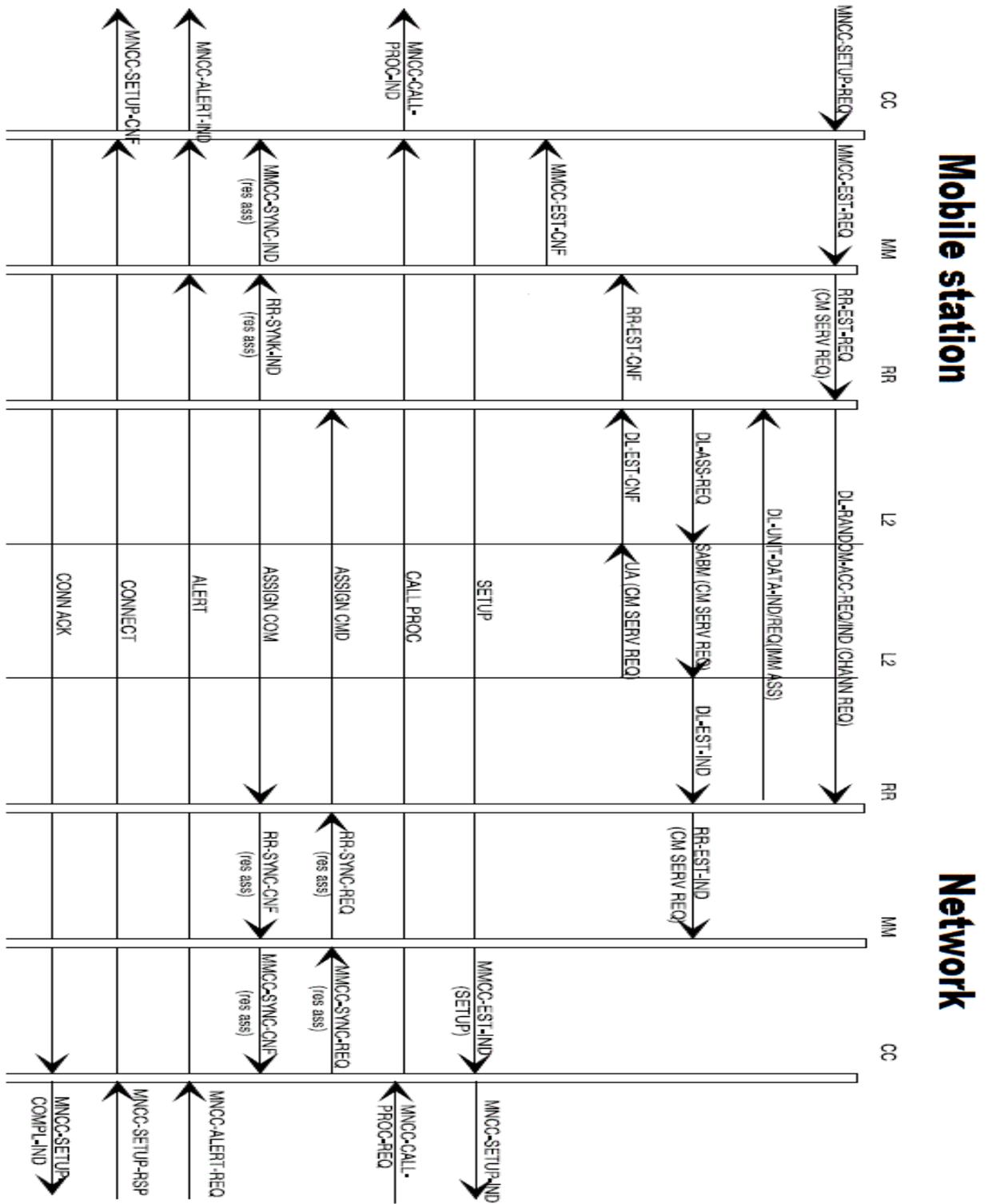


Figure 34 - Traditional GSM L3 messages

### 3.2.3 Adapted GSM Signaling

1. The MS sends a *Channel Request* (CHAN\_REQ) message on the RACH of the local BTS Beacon.
2. The local BTS responds with a radio resource assignment (IMM\_ASS\_CMD) on the AGCH of local BTS Beacon.
3. The MS sends a *Service Request* (CM\_SERV\_REQ) message to the local BTS on the SDCCH.

Note : Local BTS has no established connection with Master BTS yet , so it starts to setup a connection to be able to forward the coming messages from MS to Master BTS and vice versa.

4. Local BTS sends a *Channel Request* (CHAN\_REQ) message on the RACH of the Master BTS Beacon.
5. The Master BTS responds with a radio resource assignment (IMM\_ASS\_CMD) on the AGCH of the Master BTS Beacon.
6. The Local BTS forwards the *Service Request* (CM\_SERV\_REQ) message to the Master BTS on the SDCCH of the Master BTS Beacon.
7. The MS then sends a *Call Setup* (SETUP) message to the local BTS which forwards it to the Master BTS. The message includes the address information (MSISDN) of the called party.
8. The Mater BTS assigns a TCH to the MS by sending an *Assignment Command* (ASS\_CMD) message to the Local BTS which forwards it to the MS. This message includes which Transceiver (TRX) and which Time Slot (TS) to use.
9. The MS immediately switches to the assigned TCH. The MS sends an *Assignment Complete* (ASS\_COM) message back to the Master BTS on the FACCH through the Local BTS.
10. The Master BTS sends an ALERT message on the FACCH to the MS through the Local BTS indicating that the call is going through. Once the MS receives the ALERT, it will generate the ringing sound in the earpiece. The Master BTS sends an alerting message the subscriber will hear the line ringing.
11. Once the called party answers the phone, the PSTN will send an Answer message to the Master BTS. The MSC forwards this to the MS in a *Connection* (CONNECT) message through the Local BTS.

12. Once the MS receives the CONNECT message, it replies by Connection Acknowledge (CONN ACK) message, then switches over to voice and begins the call. All voice traffic occurs on the assigned TCH.

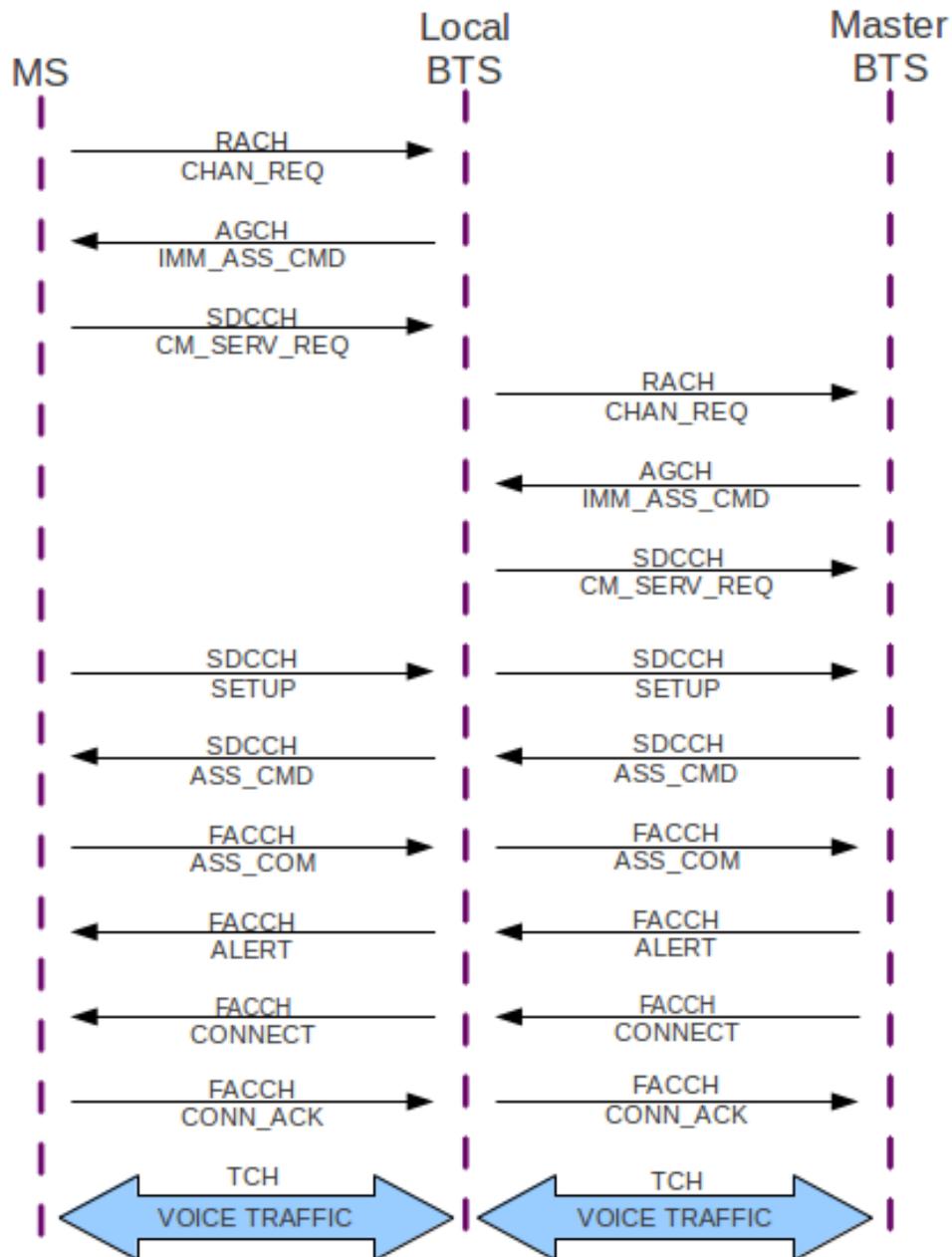


Figure 35 –Adapted GSM Signaling

3.2.4 Adapted GSM L3 Messages

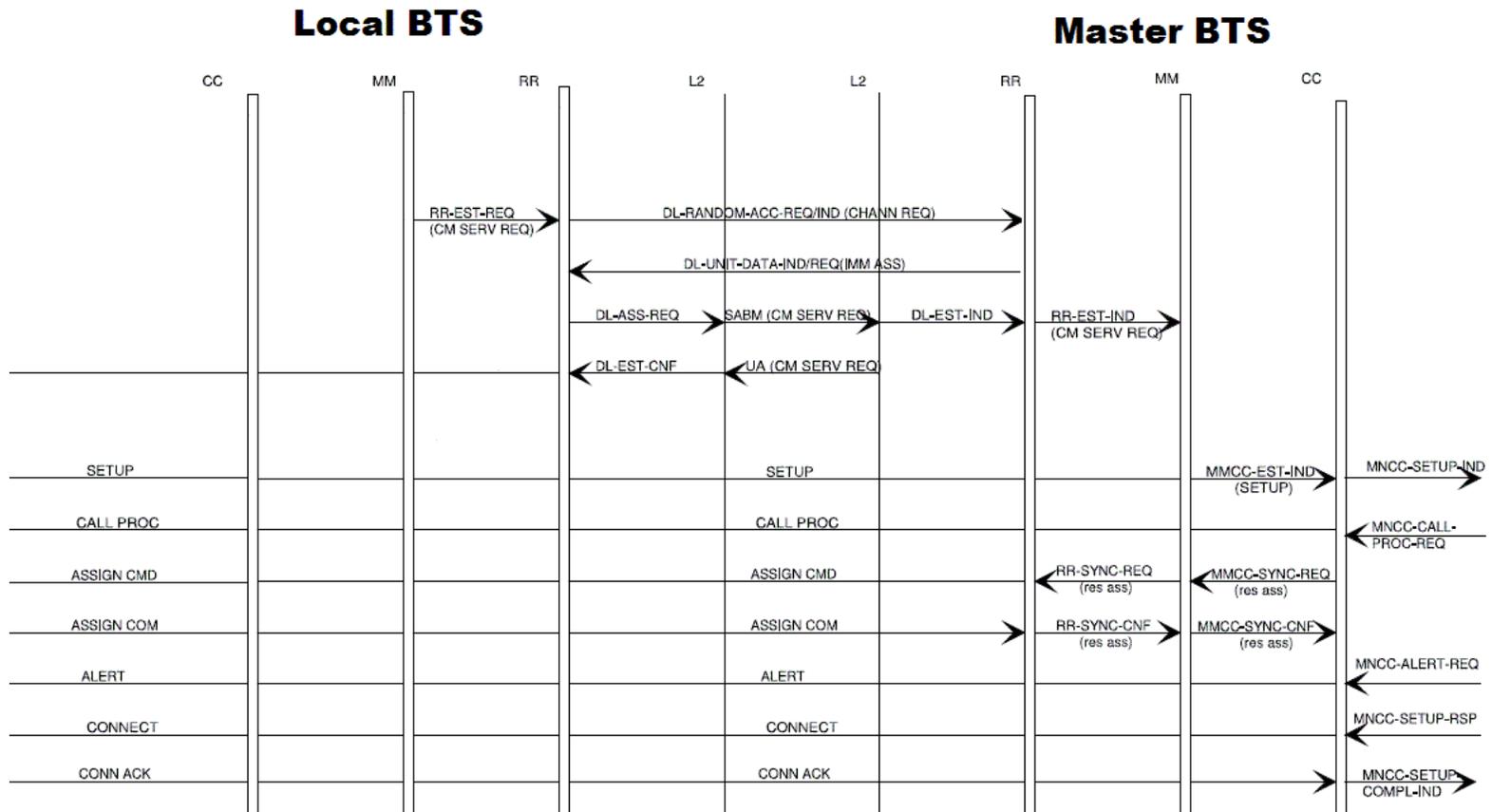


Figure 36 - Adapted GSM L3 Messages

3.2.4 Adapted GSM L3 Messages

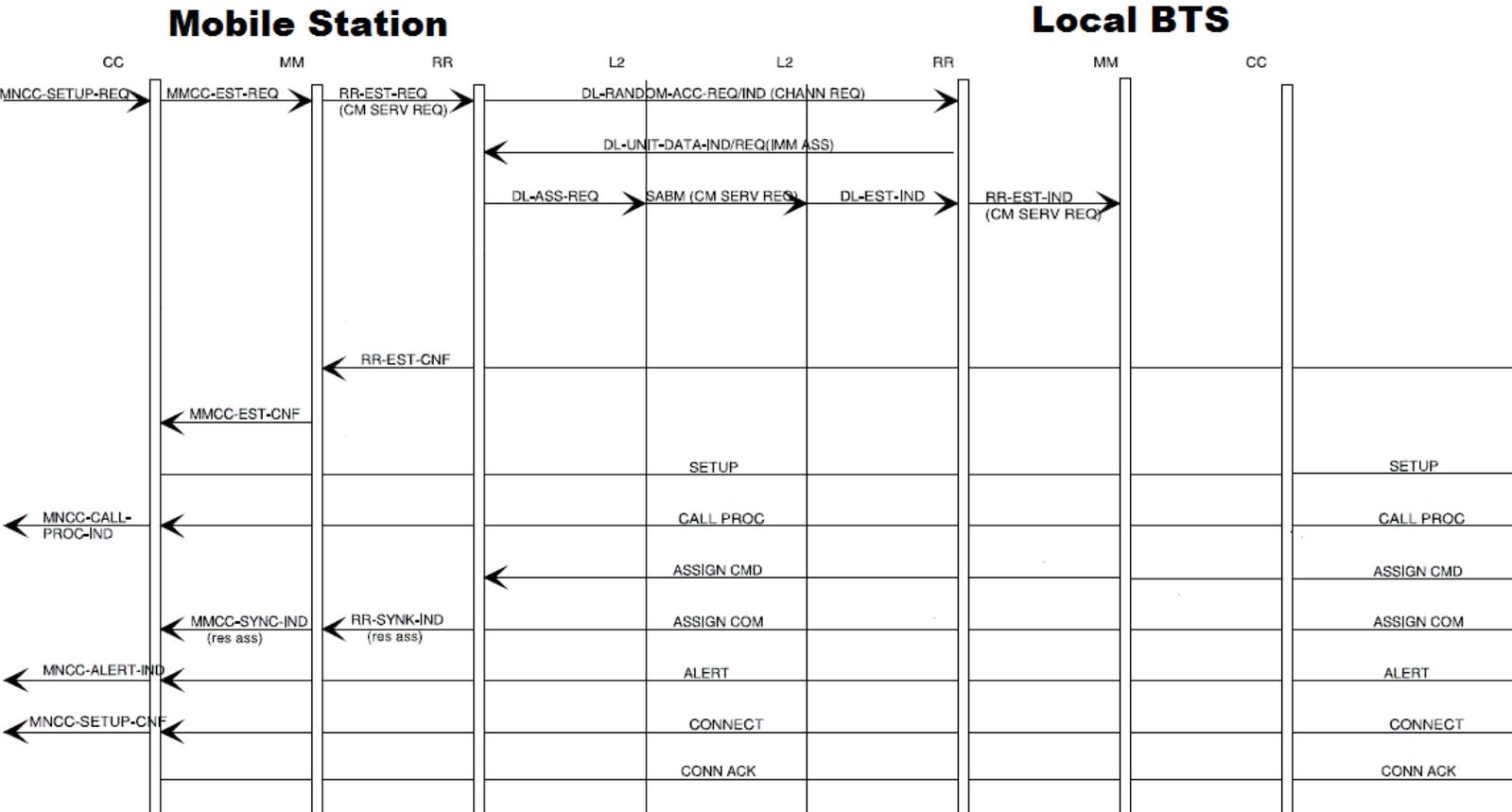


Figure 37 - Adapted GSM L3 Messages

### 3.3 Description of L3 Messages:

Description of L3 messages that are used in Mobile Originated Call Setup.

#### MNCC\_SETUP\_REQ

Request to send a SETUP or EMERGENCY SETUP message to initiate Mobile originating establishment of either a normal or an emergency call.

#### MMCC\_EST\_REQ

Request used by CC, SS and SMS respectively, to request establishment of a MM connection.

#### RR-EST-REQ

Is used by the Mobility Management entity to request establishment of a Mobile originated RR connection. The request shall be given only in the IDLE state when the Mobile Station listens to the CCCH and the previously selected BCCH

#### RR\_EST\_IND (CM SERV REQ)

Indicates to the Mobility Management entity the establishment of a Mobile originated RR connection. By this indication MM is informed that a transparent connection exists and RR is in the dedicated mode

#### RR\_EST\_CNF

Is used by RR to indicate the successful completion of a Mobile originated RR connection establishment. RR connection exists and RR is in the dedicated mode

#### MMCC\_EST\_CNF

Successful confirmation of the MM connection establishment by the MM sub-layer to be given to the appropriate entity which has requested the service

#### MMCC\_EST\_IND (SETUP)

Indication to CC, SS or SMS that a Mobile originated MM connection has been established and the first message has been received from the respective peer entity .

#### MNCC\_SETUP\_IND

Receipt of a SETUP message, the Mobile originated call establishment has been initiated.

#### MNCC\_CALL\_PROC\_REQ

Request to send a CALL PROCEEDING message to indicate to the Mobile originating user that call establishment has been initiated in the Network and no more call establishment information will be accepted

#### MNCC\_CALL\_PROC\_IND

Indication to the Mobile originating user that call establishment has been initiated in the Network and no more call establishment information will be accepted by the Network.

#### MNCC\_SYNC\_REQ (res ass)

Request used by the CC entity to synchronize with the MM entity (resource assign)

RR\_SYNC\_REQ (res ass)

Request used by the Mobility Management entity for synchronization with the RR protocol

RR\_SYNC\_CNF (res ass)

Confirmation used by RR that the requested synchronization is done

MMCC\_SYNC\_CNF (res ass)

Confirmation used by the MM to inform the CC entity that synchronization is completed (resource assign)

RR\_SYNC\_IND (res ass)

Request used by the Mobility Management entity for acknowledged control-data transmission

MMCC\_SYNC\_IND (res ass)

Indication that a dedicated channel assignment has been performed and/or the channel mode has been changed (only towards the CC entity)

MNCC\_ALERT\_REQ

Request to send an ALERTING message from the called Mobile user to the remote calling user to indicate that user alerting has been initiated

MNCC\_ALERT\_IND

Indication of the receipt of an ALERTING message, alerting to the remote called user has been initiated

MNCC\_SETUP\_RSP

Response to send a CONNECT message to indicate call acceptance by the remote user

MNCC\_SETUP\_CNF

Receipt of a CONNECT message, the Mobile originated call has been accepted

MNCC\_SETUP\_COMPL\_IND

Indication of the receipt of a CONNECT ACKNOWLEDGE message, the Mobile originating call establishment has been completed

## Chapter 4- Conclusion and Future Work

### 4.1 Conclusion

This project introduced a solution to the problem of uncovered areas by mobile networks. It produces a low cost design for an Open-BTS based mobile network for rural areas and oasis road.

1- For rural areas we proposed a network design that consists of a group of USRP's that covers the required area which is roughly more than ( 200 km<sup>2</sup>). These nodes should be connected with RF links making use of the low capacity of the system, however it's expected to add some blocking, so we modeled the system with a MATLAB code to get the blocking probability and the supported capacity of the system. The results was satisfying to great extent as the system can support up to hundreds of calls per hour in a small area assuming average holding time for calls of about 90 seconds, with average cost of 23,120 \$.

2- For oasis road we also proposed a detailed design for the network including number of nodes required to cover the whole 70 km road. We also modeled the system using MATLAB and got an over-satisfying results compared to the very low expected capacity. The system can support tens of calls per hour assuming big average holding time of more than 5 minutes, with average cost of 37,530 \$.

3- Balancing the Up/Downlink power budgets choosing the suitable propagation models according to the antenna heights and the required coverage area for both rural areas and oasis road and determining the suitable RF chain components.

## 4.2 Future Work

In this project we were responsible for the network designing for a low cost equipment specified for a dedicated coverage area and towers height and after simulating the different models of the network and having a proper values of blockage, we see that this project a good inexpensive solution for the telecommunications companies but we have many obstacles to have a working prototype.

According to where we have reached the Future Work could be

- (a) Completing Configuration and Registration of the new Release OpenBTS P2.8.
- (b) The synchronization in switching between serving and repeating modes at the USRP.
- (c) Further research in L3 messages sequence for all of the 5 signaling scenarios. Implement this Scenario in the OpenBTS code, and be able to make a call between two MS under different USRPs.

And these obstacles can be solved in the upcoming period.

## Chapter 5 - Appendices

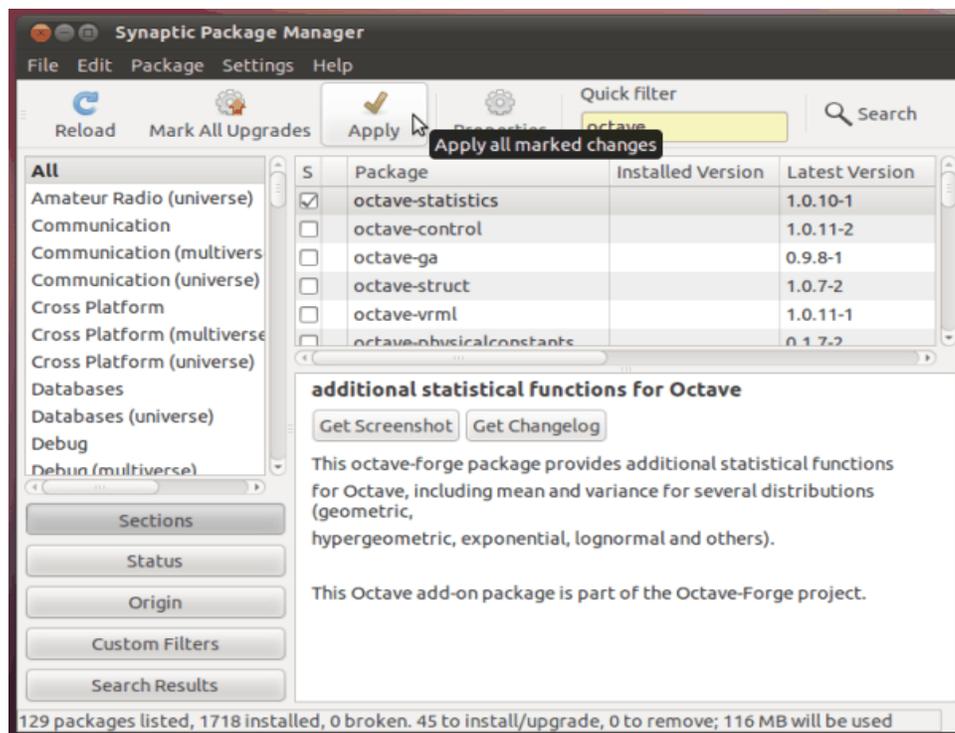
## 5.1 Appendix –A UHD Build

Before building UHD you have to install some applications (dependencies) needed for UHD build which are:

```
automake
autoconf
Swig
G++
libtool
python-dev
libfftw3-dev
libcxxunit-dev
libboost-dev
libusb-dev
fort77Libsdl1.2dev
python-wxgtk2.8
git-core
cmake
guile-1.8-dev
libqt4-dev
python-numpy
ccache
python-opengl
libgsl0-dev
python-cheetah
python-lxml
doxygen
qt4-dev-tool
libqwt5-qt4-dev
pyqt4-dev-tools
python-qwt5-qt4
wget
python-doculites
gtk2-engines-pixbuf
Python -tk
Libasound2-dev
Python -gtk2
```

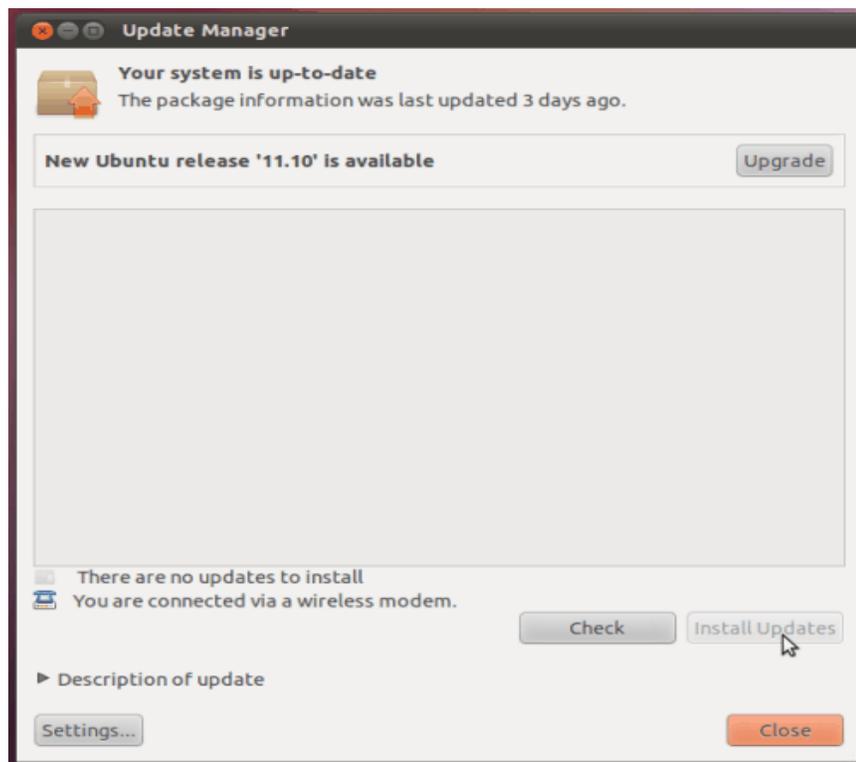
These dependencies are installed via synaptic package manager

To open the synaptic package manger press WINDOWS button on the key board and write synaptic in search tap as shown



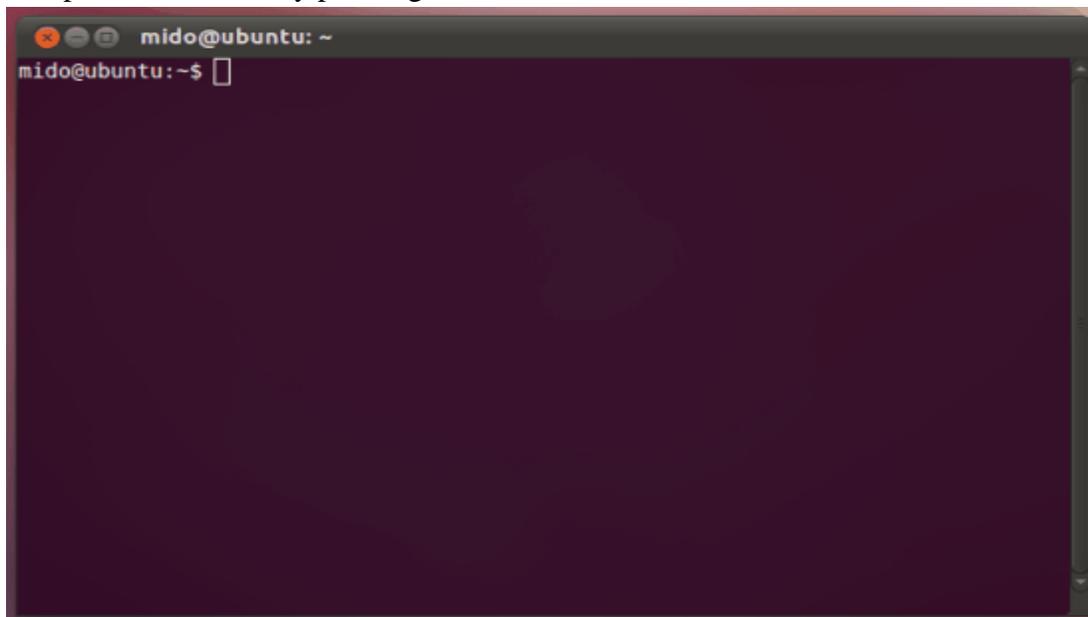
- Search for the above dependencies from the "Quick search" box, mark them for installation then press the "Apply" button.

- Install the new updates from update manger as shown



After installing all dependencies and updates you are ready now to build UHD

1- Open the terminal by pressing ALT + CTRL + T



2- Type this command

```
"sudo apt-get install git-core cmake"
```

3-Type this command

```
" git clone git://code.ettus.com/ettus/uhd.git"
```

This command will download the latest version of UHD it will take several minutes

4- Type the following commands

```
"cd uhd/host"  
"mkdir build"  
"cd build"
```

5- Type this command

```
" cmake ../"
```

This command check that all libraries and dependencies needed for UHD installation are already on your computer , you have to ensure that your USRP is enabled .

If any library is missing this will make an error and the following message will appear

```
mido@ubuntu: ~/uhd/host/build
--
-- #####
-- # UHD enabled components
-- #####
-- * Doxygen
--
-- #####
-- # UHD disabled components
-- #####
-- * LibUHD
-- * Examples
-- * Utils
-- * Tests
-- * Manual
-- * USRP-E Utils
--
-- Building version: 003.004.002-171-g7c8fef85
-- Using install prefix: /usr/local
-- Compatible images can be downloaded from: http://files.ettus.com/binaries/master_images/archive/uhd-images_003.004.001-109-g6ca39ad9.zip
-- Configuring done
-- Generating done
-- Build files have been written to: /home/mido/uhd/host/build
mido@ubuntu:~/uhd/host/build$
```

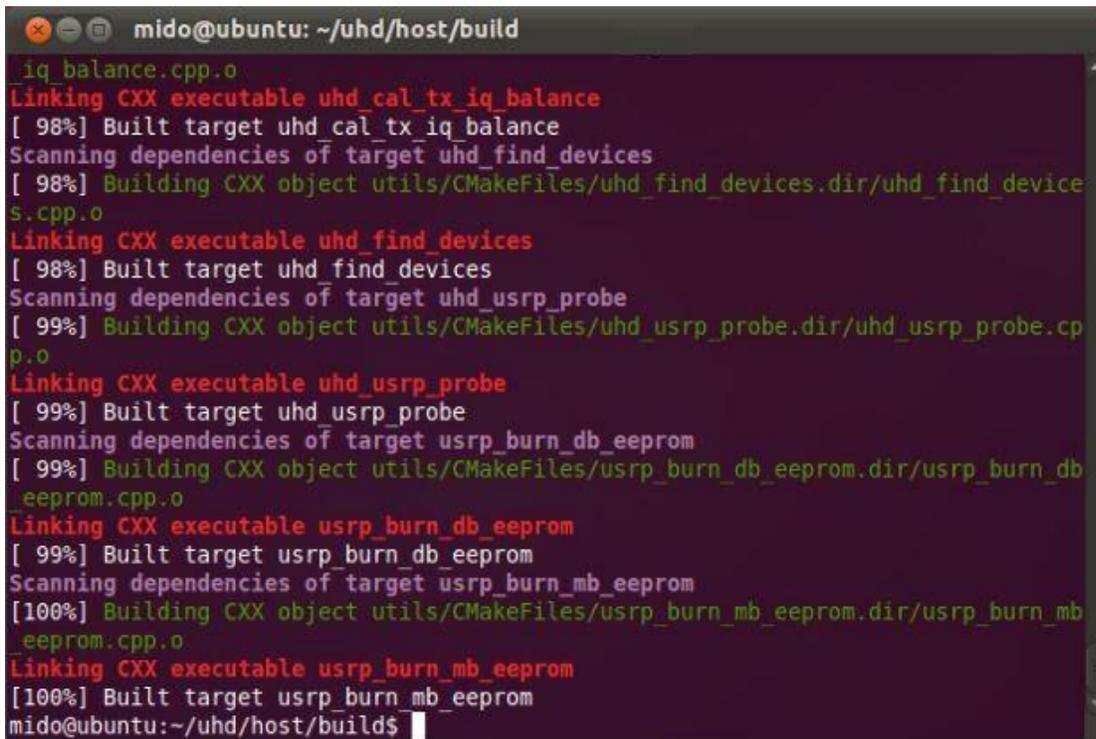
If nothing missing the result will be

```
mido@ubuntu: ~/uhd/host/build
--
-- #####
-- # UHD enabled components
-- #####
-- * LibUHD
-- * Examples
-- * Utils
-- * Tests
-- * Manual
-- * Doxygen
-- * USB
-- * USRP1
-- * USRP2
-- * B100
--
-- #####
-- # UHD disabled components
-- #####
-- * ORC
-- * E100
-- * USRP-E Utils
--
-- Building version: 003.004.002-171-g7c8fef85
-- Using install prefix: /usr/local
```

6- Type this command

```
"make"
```

This command will take a time so be patient



```
mido@ubuntu: ~/uhd/host/build
iq_balance.cpp.o
Linking CXX executable uhd_cal_tx_iq_balance
[ 98%] Built target uhd_cal_tx_iq_balance
Scanning dependencies of target uhd_find_devices
[ 98%] Building CXX object utils/CMakeFiles/uhd_find_devices.dir/uhd_find_device
s.cpp.o
Linking CXX executable uhd_find_devices
[ 98%] Built target uhd_find_devices
Scanning dependencies of target uhd_usrp_probe
[ 99%] Building CXX object utils/CMakeFiles/uhd_usrp_probe.dir/uhd_usrp_probe.cp
p.o
Linking CXX executable uhd_usrp_probe
[ 99%] Built target uhd_usrp_probe
Scanning dependencies of target usrp_burn_db_eeprom
[ 99%] Building CXX object utils/CMakeFiles/usrp_burn_db_eeprom.dir/usrp_burn_db
_eeprom.cpp.o
Linking CXX executable usrp_burn_db_eeprom
[ 99%] Built target usrp_burn_db_eeprom
Scanning dependencies of target usrp_burn_mb_eeprom
[100%] Building CXX object utils/CMakeFiles/usrp_burn_mb_eeprom.dir/usrp_burn_mb
_eeprom.cpp.o
Linking CXX executable usrp_burn_mb_eeprom
[100%] Built target usrp_burn_mb_eeprom
mido@ubuntu:~/uhd/host/build$
```

7- Type this command

```
"make test"
```

```
mido@ubuntu: ~/uhd/host/build
6/15 Test #6: error_test ..... Passed 0.02 sec
      Start 7: gain_group_test
7/15 Test #7: gain_group_test ..... Passed 0.02 sec
      Start 8: msg_test
8/15 Test #8: msg_test ..... Passed 0.01 sec
      Start 9: property_test
9/15 Test #9: property_test ..... Passed 0.02 sec
      Start 10: ranges_test
10/15 Test #10: ranges_test ..... Passed 0.02 sec
      Start 11: sph_rcv_test
11/15 Test #11: sph_rcv_test ..... Passed 0.02 sec
      Start 12: sph_send_test
12/15 Test #12: sph_send_test ..... Passed 0.02 sec
      Start 13: subdev_spec_test
13/15 Test #13: subdev_spec_test ..... Passed 0.01 sec
      Start 14: time_spec_test
14/15 Test #14: time_spec_test ..... Passed 0.52 sec
      Start 15: vrt_test
15/15 Test #15: vrt_test ..... Passed 0.02 sec

100% tests passed, 0 tests failed out of 15

Total Test time (real) = 4.16 sec
mido@ubuntu:~/uhd/host/build$
```

8- Type these commands

```
"sudo make install"
"export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/usr/local/lib"
" sudo ldconfig "
```

Right here, you have finished installation of UHD

8- You have to get the UHD images and put them in the UHD folder and in any place you run from it "e.g. in apps/trunk/openbts/public "

to download UHD images [http://files.ettus.com/binaries/master\\_images/](http://files.ettus.com/binaries/master_images/)

9- To know whether your installation succeeded or not, run the command

```
"uhd_find_devices"
```

```
mido@ubuntu: ~/uhd/host
mido@ubuntu:~/uhd/host$ sudo uhd_find_devices
linux; GNU C++ version 4.5.2; Boost_104200; UHD_003.004.002-171-g7c8fef85

-----
-- UHD Device 0
-----
Device Address:
  type: b100
  name:
  serial: E8R10Z4B1

mido@ubuntu:~/uhd/host$
```

## 5.2 Appendix –B OpenBTS P2.8 Installation and Configuration

At first, download OpenBTS P2.8 public Release on your Desktop from terminal by typing this command

```
svn co http://wush.net/svn/range/software/public
```

Then, you have to install some libraries before configuring OpenBTS, from terminal type this command

```
sudo apt-get install autoconf libtool libosip2-dev libortp-dev libusb-1.0-0-dev g++  
sqlite3 libsqlite3-dev erlang libreadline6-dev libboost-all-dev
```

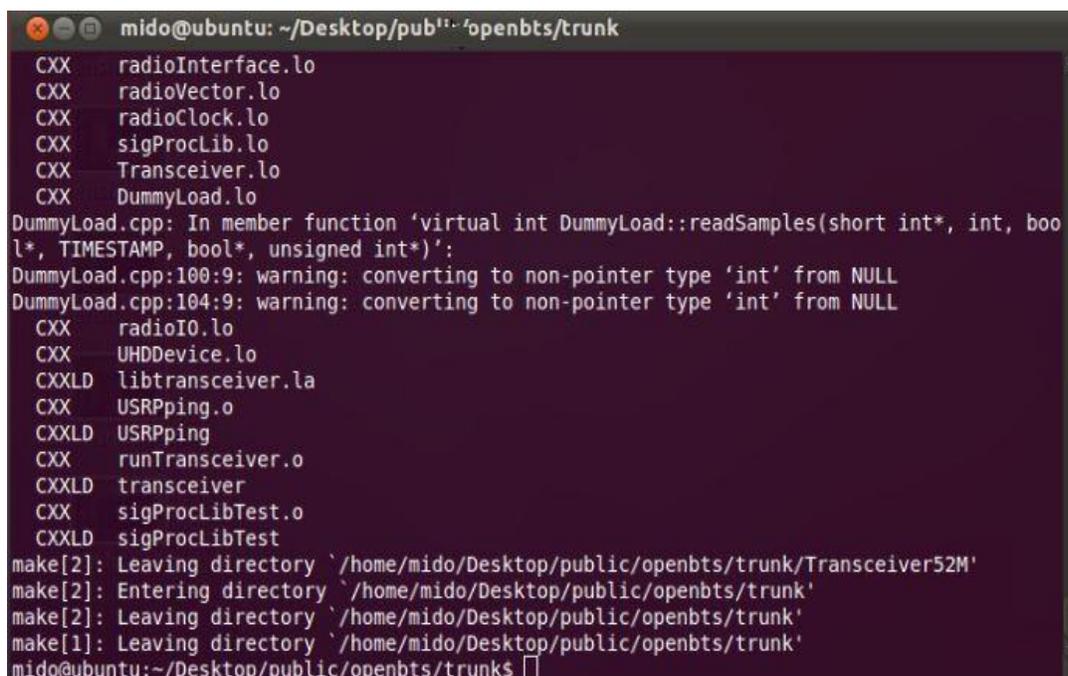
You are now ready to build OpenBTS, just follow the following steps

Note: these steps are for B100 USRP.

### Building OpenBTS

From trunk directory in OpenBTS root type the following commands

```
autoreconf -i  
./configure --disable-option-checking --with-uhd  
make
```



```
mido@ubuntu: ~/Desktop/pub.../openbts/trunk  
CXX      radioInterface.lo  
CXX      radioVector.lo  
CXX      radioClock.lo  
CXX      sigProcLib.lo  
CXX      Transceiver.lo  
CXX      DummyLoad.lo  
DummyLoad.cpp: In member function 'virtual int DummyLoad::readSamples(short int*, int, bool*,  
TIMESTAMP, bool*, unsigned int*)':  
DummyLoad.cpp:100:9: warning: converting to non-pointer type 'int' from NULL  
DummyLoad.cpp:104:9: warning: converting to non-pointer type 'int' from NULL  
CXX      radioIO.lo  
CXX      UHDDevice.lo  
CXXLD    libtransceiver.la  
CXX      USRPping.o  
CXXLD    USRPping  
CXX      runTransceiver.o  
CXXLD    transceiver  
CXX      sigProcLibTest.o  
CXXLD    sigProcLibTest  
make[2]: Leaving directory `/home/mido/Desktop/public/openbts/trunk/Transceiver52M'  
make[2]: Entering directory `/home/mido/Desktop/public/openbts/trunk'  
make[2]: Leaving directory `/home/mido/Desktop/public/openbts/trunk'  
make[1]: Leaving directory `/home/mido/Desktop/public/openbts/trunk'  
mido@ubuntu:~/Desktop/public/openbts/trunk$
```

With the build resolved, you'll need to build and link the transceiver appropriate for your hardware.

```
cd Transceiver52M
make
cd ../apps
ln -s ../Transceiver52M/transceiver .
```

When you run make command nothing will be done as it was included in the previous make.

## Configuring OpenBTS

With OpenBTS built, you now need to configure it to run correctly. You must create the data base file OpenBTS.db.

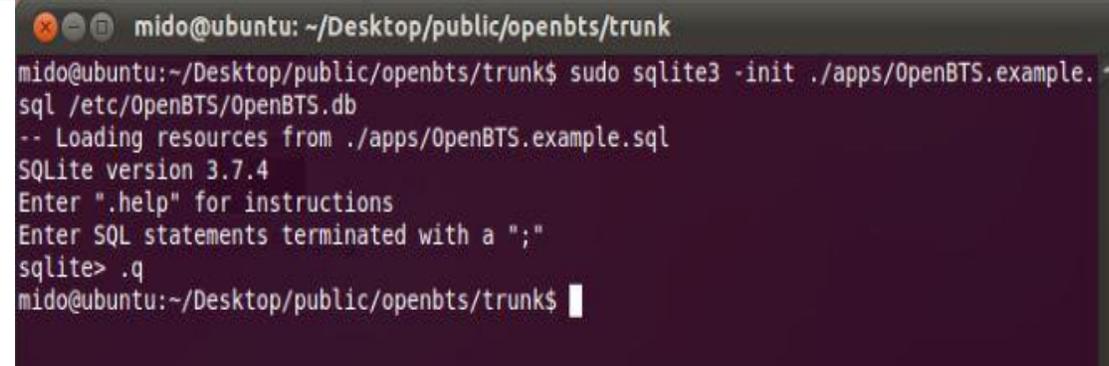
### OpenBTS.db

OpenBTS.db is the database store for all OpenBTS configuration. It must be installed at /etc/OpenBTS, which likely does not exist. So, to create this file type in terminal

```
sudo mkdir /etc/OpenBTS
sudo sqlite3 -init ./apps/OpenBTS.example.sql /etc/OpenBTS/OpenBTS.db
```

To exit from sqlite press

```
.quit
```



```
mido@ubuntu: ~/Desktop/public/openbts/trunk
mido@ubuntu:~/Desktop/public/openbts/trunk$ sudo sqlite3 -init ./apps/OpenBTS.example.
sql /etc/OpenBTS/OpenBTS.db
-- Loading resources from ./apps/OpenBTS.example.sql
SQLite version 3.7.4
Enter ".help" for instructions
Enter SQL statements terminated with a ";"
sqlite> .q
mido@ubuntu:~/Desktop/public/openbts/trunk$
```

## Build and Install the Subscriber Registry and Sipauthserve

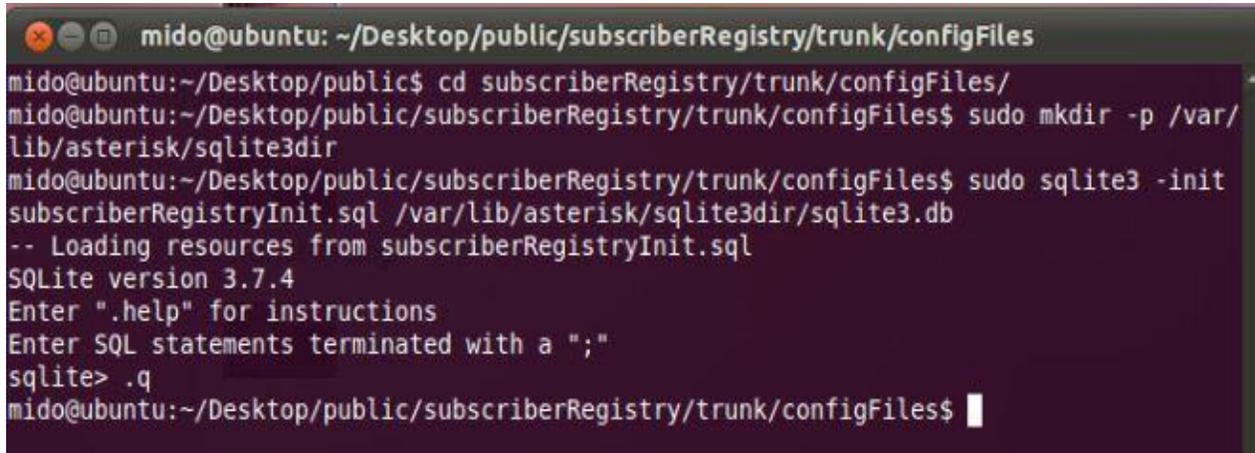
OpenBTS depends on the installation of Sipauthserver; the SIP authorization server. You'll need to build and install it before running OpenBTS.

## Subscriber Registry

To setup subscriber registry data base, run the following commands in terminal

From public directory

```
cd subscriberRegistry/trunk/configFiles/  
sudo mkdir -p /var/lib/asterisk/sqlite3dir  
sudo sqlite3 -init subscriberRegistryInit.sql /var/lib/asterisk/sqlite3dir/sqlite3.db
```



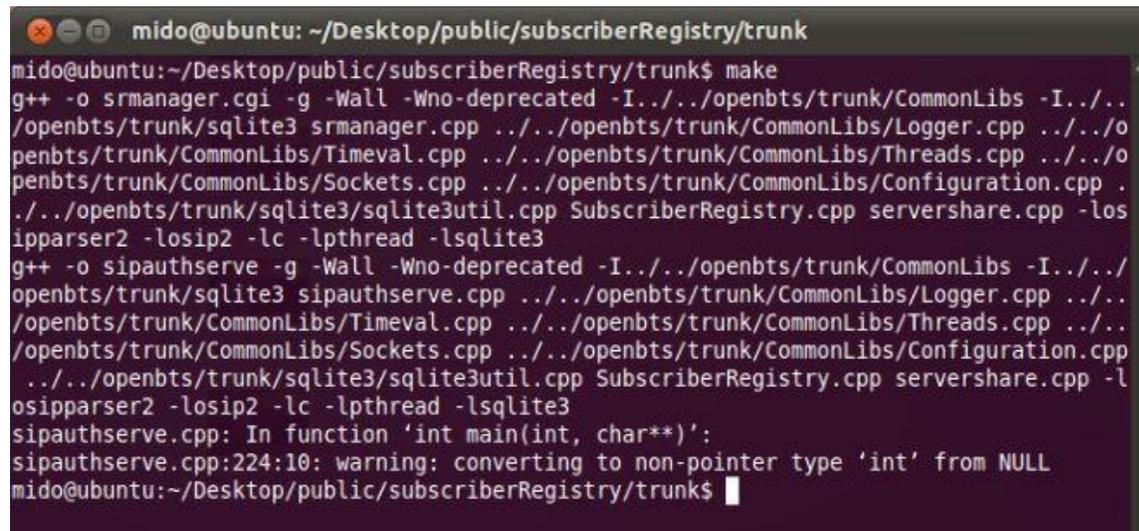
```
mido@ubuntu: ~/Desktop/public/subscriberRegistry/trunk/configFiles  
mido@ubuntu:~/Desktop/public$ cd subscriberRegistry/trunk/configFiles/  
mido@ubuntu:~/Desktop/public/subscriberRegistry/trunk/configFiles$ sudo mkdir -p /var/  
lib/asterisk/sqlite3dir  
mido@ubuntu:~/Desktop/public/subscriberRegistry/trunk/configFiles$ sudo sqlite3 -init  
subscriberRegistryInit.sql /var/lib/asterisk/sqlite3dir/sqlite3.db  
-- Loading resources from subscriberRegistryInit.sql  
SQLite version 3.7.4  
Enter ".help" for instructions  
Enter SQL statements terminated with a ";"  
sqlite> .q  
mido@ubuntu:~/Desktop/public/subscriberRegistry/trunk/configFiles$
```

## Sipauthserve

To build Sipauthserve:

From public directory

```
cd subscriberRegistry/trunk  
make
```



```
mido@ubuntu: ~/Desktop/public/subscriberRegistry/trunk  
mido@ubuntu:~/Desktop/public/subscriberRegistry/trunk$ make  
g++ -o srmanager.cgi -g -Wall -Wno-deprecated -I../openbts/trunk/CommonLibs -I../  
openbts/trunk/sqlite3 srmanager.cpp ../../openbts/trunk/CommonLibs/Logger.cpp ../../o  
penbts/trunk/CommonLibs/Timeval.cpp ../../openbts/trunk/CommonLibs/Threads.cpp ../../o  
penbts/trunk/CommonLibs/Socket.cpp ../../openbts/trunk/CommonLibs/Configuration.cpp .  
../../openbts/trunk/sqlite3/sqlite3util.cpp SubscriberRegistry.cpp servershare.cpp -los  
iparser2 -losip2 -lc -lpthread -lsqlite3  
g++ -o sipauthserve -g -Wall -Wno-deprecated -I../openbts/trunk/CommonLibs -I../  
openbts/trunk/sqlite3 sipauthserve.cpp ../../openbts/trunk/CommonLibs/Logger.cpp ../../  
openbts/trunk/CommonLibs/Timeval.cpp ../../openbts/trunk/CommonLibs/Threads.cpp ../../  
openbts/trunk/CommonLibs/Socket.cpp ../../openbts/trunk/CommonLibs/Configuration.cpp  
../../openbts/trunk/sqlite3/sqlite3util.cpp SubscriberRegistry.cpp servershare.cpp -l  
osiparser2 -losip2 -lc -lpthread -lsqlite3  
sipauthserve.cpp: In function 'int main(int, char**)':  
sipauthserve.cpp:224:10: warning: converting to non-pointer type 'int' from NULL  
mido@ubuntu:~/Desktop/public/subscriberRegistry/trunk$
```

This will produce a sipauthserve executable.

To setup sipauthserve data base, run this command in terminal

```
sudo sqlite3 -init sipauthserve.example.sql /etc/OpenBTS/sipauthserve.db
```

### Running OpenBTS

With sipauthserve installed, you can run OpenBTS. To do so, open three separate terminal windows (or tabs) and enter the following commands:

(from subscriberRegistry root)

```
sudo ./sipauthserve
```

A terminal window screenshot showing the execution of the command 'sudo ./sipauthserve'. The prompt is 'mido@ubuntu: ~/Desktop/public/subscriberRegistry/trunk'. The output shows a password prompt '[sudo] password for mido:' followed by an alert message: 'ALERT 140236821874496 sipauthserve.cpp:214:main: ./sipauthserve (re)starting'. A cursor is visible on the line following the alert.

```
mido@ubuntu: ~/Desktop/public/subscriberRegistry/trunk
mido@ubuntu:~/Desktop/public/subscriberRegistry/trunk$ sudo ./sipauthserve
[sudo] password for mido:
ALERT 140236821874496 sipauthserve.cpp:214:main: ./sipauthserve (re)starting
█
```

(from the OpenBTS directory)

```
cd apps
```

```
sudo ./OpenBTS
```

In this part you may face a problem; the transceiver is always running in the background, so you have to shut it down by typing in terminal

```
ps -e
sudo kill (transceiver)
```

```
mido@ubuntu: ~/Desktop/public/openbts/trunk/apps
David Burgess, Harvind Samra, Raffi Sevlia, Roshan Baliga
GNU Radio:
  Johnathan Corgan
Others:
  Anne Kwong, Jacob Appelbaum, Joshua Lackey, Alon Levy
  Alexander Chemeris, Alberto Escudero-Pascual
Incorporated GPL libraries and components:
  libosip2 (LGPL), liportp2 (LGPL), readline

This program comes with ABSOLUTELY NO WARRANTY.

Use of this software may be subject to other legal restrictions,
including patent licsensing and radio spectrum licsensing.
All users of this software are expected to comply with applicable
regulations and laws. See the LEGAL file in the source code for
more information.

1341960031.696987 139951149864768:
Starting the system...
linux; GNU C++ version 4.5.2; Boost_104200; UHD_003.004.002-171-g7c8fef85

ALERT 139951148979968 TRXManager.cpp:92:clockHandler: TRX clock interface timed
out, assuming TRX is dead.
mido@ubuntu:~/Desktop/public/openbts/trunk/apps$
```

then run OpenBTS as shown in this figure

```
mido@ubuntu: ~/Desktop/public/openbts/trunk/apps
Others:
  Anne Kwong, Jacob Appelbaum, Joshua Lackey, Alon Levy
  Alexander Chemeris, Alberto Escudero-Pascual
Incorporated GPL libraries and components:
  libosip2 (LGPL), liportp2 (LGPL), readline

This program comes with ABSOLUTELY NO WARRANTY.

Use of this software may be subject to other legal restrictions,
including patent licsensing and radio spectrum licsensing.
All users of this software are expected to comply with applicable
regulations and laws. See the LEGAL file in the source code for
more information.

1341960099.658870 140244994402112:
Starting the system...
linux; GNU C++ version 4.5.2; Boost_104200; UHD_003.004.002-171-g7c8fef85

system ready

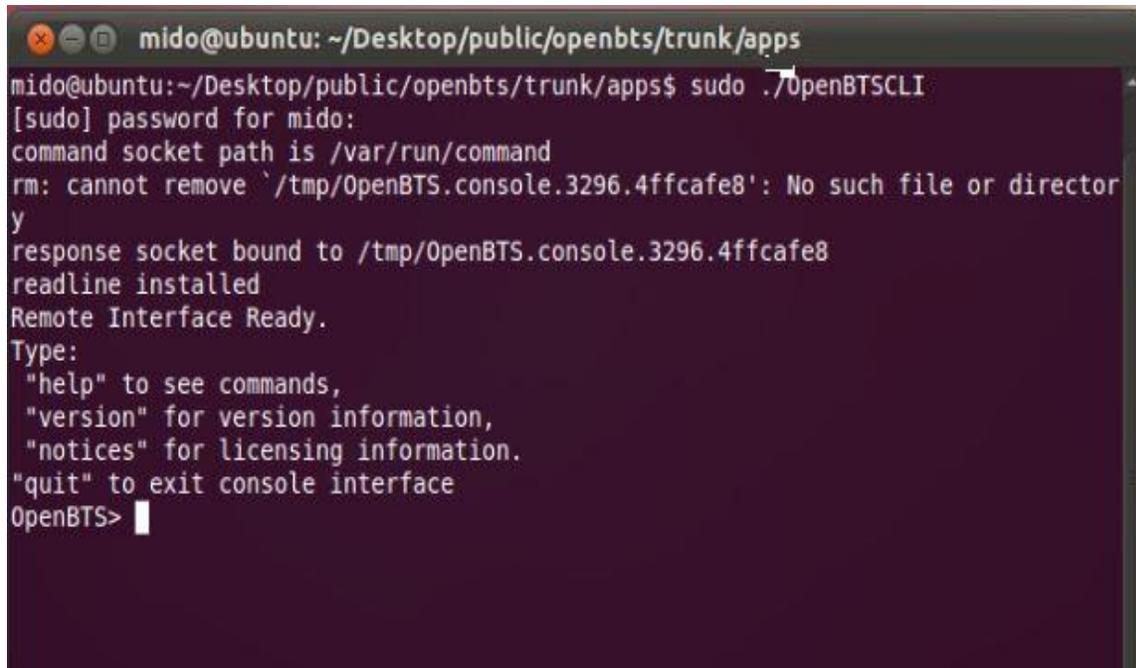
use the OpenBTSCLI utility to access CLI
```

(from the OpenBTS directory)

```
cd apps
sudo ./OpenBTSCLI
```

In the OpenBTSCLI terminal, you should see a splash screen describing the project,

OpenBTS>



```
mido@ubuntu: ~/Desktop/public/openbts/trunk/apps
mido@ubuntu:~/Desktop/public/openbts/trunk/apps$ sudo ./OpenBTSCLI
[sudo] password for mido:
command socket path is /var/run/command
rm: cannot remove `/tmp/OpenBTS.console.3296.4ffcafe8': No such file or director
y
response socket bound to /tmp/OpenBTS.console.3296.4ffcafe8
readline installed
Remote Interface Ready.
Type:
  "help" to see commands,
  "version" for version information,
  "notices" for licensing information.
  "quit" to exit console interface
OpenBTS> |
```

## 5.3 Appendix –C Propagation Models

## Propagation loss formulas for mobile radiocommunications

## B.1 Hata Model [4], [8]

Frequency  $f$ : 150 - 1000 MHz

Base station height  $H_b$ : 30 - 200 m

Mobile height  $H_m$ : 1 - 10 m

Distance  $d$ : 1 - 20 km

Large and small cells (i.e. base station antenna heights above roof-top levels of buildings adjacent to the base station)

## B.1.1 Urban

$$L_u \text{ (dB)} = 69.55 + 26.16 \cdot \log(f) - 13.82 \cdot \log(H_b) - a(H_m) + [44.9 - 6.55 \cdot \log(H_b)] \cdot \log(d)$$

$a(H_m)$  correction factor for vehicular station antenna height.

For a medium-small city :

$$a(H_m) = [1.1 \cdot \log(f) - 0.7] \cdot H_m - [1.56 \cdot \log(f) - 0.8]$$

For a large city :

$$a(H_m) = 8.29 \cdot [\log(1.54 \cdot H_m)]^2 - 1.1 \quad \text{for } f \leq 200 \text{ MHz}$$

$$a(H_m) = 3.2 \cdot [\log(11.75 \cdot H_m)]^2 - 4.97 \quad \text{for } f \geq 400 \text{ MHz}$$

## B.1.2 Suburban

$$L_{su} \text{ (dB)} = L_u - 2 \cdot [\log(f/28)]^2 - 5.4$$

## B.1.3 Rural (Quasi-open)

$$L_{rqo} \text{ (dB)} = L_u - 4.78 \cdot [\log(f)]^2 + 18.33 \cdot \log(f) - 35.94$$

## B.1.4 Rural (Open Area)

$$L_{ro} \text{ (dB)} = L_u - 4.78 \cdot [\log(f)]^2 + 18.33 \cdot \log(f) - 40.94$$

## B.2 COST 231-Hata Model [7]

Frequency  $f$ : 1500 - 2000 MHz

Base station height  $H_b$ : 30 - 200 m

Mobile height  $H_m$ : 1 - 10 m

Distance  $d$ : 1 - 20 km

Large and small cells (i.e. base station antenna heights above roof-top levels of buildings adjacent to the base station).

Urban areas (for rural areas the correction factors given in subparagraph 1.3 and 1.4 can be used up to 2000 MHz).

$$L_u \text{ (dB)} = 46.3 + 33.9 \cdot \log(f) - 13.82 \cdot \log(H_b) - a(H_m) + [44.9 - 6.55 \cdot \log(H_b)] \cdot \log(d) + C_m$$

with :

$$a(H_m) = [1.1 \cdot \log(f) - 0.7] \cdot H_m - [1.56 \cdot \log(f) - 0.8]$$

$C_m = 0$  dB for medium sized city and suburban centres with moderate tree density

$C_m = 3$  dB for metropolitan centres

## B.3 COST 231 Walfish-Ikegami Model [7]

Frequency  $f$ : 800 - 2000 MHz

Base station height  $H_b$ : 4 - 50 m

Mobile height  $H_m$ : 1 - 3 m

Distance  $d$ : 0.02 - 5 km

Height of buildings  $H_{roof}$  (m)

Width of road  $w$  (m)

Building separation  $b$  (m)

Road orientation with respect to the direct radio path  $\Phi$  ( $^\circ$ )

Urban areas

### B.3.1 Without free line-of-sight between base and mobile (small cells)

$$L_b = L_o + L_{rts} + L_{msd} \text{ (or } L_b = L_o \text{ for } L_{rts} + L_{msd} \leq 0)$$

with :

#### B.3.1.1 $L_o$ free-space loss

$$L_o = 32.4 + 20 \cdot \log(d) + 20 \cdot \log(f)$$

#### B.3.1.2 $L_{rts}$ roof-top-to-street diffraction and scatter loss

$$L_{rts} = -16.9 - 10 \cdot \log(w) + 10 \log(f) + 20 \cdot \log(H_r - H_m) + L_{cri}$$

$$\text{with } L_{cri} = -10 + 0.354 \cdot \Phi \text{ for } 0 \leq \Phi < 35^\circ$$

$$L_{cri} = 2.5 + 0.075 \cdot (\Phi - 35) \text{ for } 35 \leq \Phi < 55^\circ$$

$$L_{cri} = 4.0 - 0.114 \cdot (\Phi - 55) \text{ for } 55 \leq \Phi < 90^\circ$$

#### B.3.1.3 $L_{msd}$ multiscreen diffraction loss

$$L_{msd} = L_{bsh} + k_a + k_d \cdot \log(d) + k_f \cdot \log(f) - 9 \cdot \log(b)$$

$$\text{with } L_{bsh} = -18 \cdot \log(1 + H_b - H_{roof}) \quad \text{for } H_b > H_{roof}$$

$$= 0 \quad \text{for } H_b \leq H_{roof}$$

$$\begin{aligned}
 k_a &= 54 && \text{for } H_b > H_{\text{roof}} \\
 &= 54 - 0.8 \cdot (H_b - H_{\text{roof}}) && \text{for } d \geq 0.5 \text{ and } H_b \leq H_{\text{roof}} \\
 &= 54 - 0.8 \cdot (H_b - H_{\text{roof}}) \cdot (d/0.5) && \text{for } d < 0.5 \text{ and } H_b \leq H_{\text{roof}}
 \end{aligned}$$

$$\begin{aligned}
 k_d &= 18 && \text{for } H_b > H_{\text{roof}} \\
 &= 18 - 15 \cdot (H_b - H_{\text{roof}}) / H_{\text{roof}} && \text{for } H_b \leq H_{\text{roof}}
 \end{aligned}$$

$$\begin{aligned}
 k_f &= -4 + 0.7 \cdot (f/925 - 1) && \text{for medium sized cities and} \\
 &&& \text{suburban centres with moderate} \\
 &&& \text{tree density} \\
 &= -4 + 1.5 \cdot (f/925 - 1) && \text{for metropolitan centres}
 \end{aligned}$$

### B.3.2 With a free line-of-sight between base and mobile (Street Canyon)

Microcells (Base station antennas below roof top level)

$$L_b = 42.6 + 26 \cdot \log(d) + 20 \cdot \log(f) \text{ for } d \geq 0.020 \text{ km}$$

**Notes: -**

- The Hata model and COST 231-Hata Model are not suitable as the minimum base station height is 30 meters and in our case it is at 10 meters.
- The COST 231 Walfish-Ikegami Model [7] is not suitable as the maximum mobile height is 3 meters and in our case the mobile (repeater) is at 10 meters.

**Point to Point Lee Model:**

Lee Model for Point-to-Point Mode is a radio propagation model that operates around 900 MHz Built as two different modes; this model includes an adjustment factor that can be adjusted to make the model more flexible to different regions of propagation.

**Applicable to/under conditions**

This model is suitable for using in data collected in a specific area for Point to Point links.

**Mathematical formulation**

The Lee Model for point to point mode is formally expressed as:

$$L = L_0 + \gamma g \log d - 10(\log F_A - 2 \log(\frac{H_{ET}}{30}))$$

Where,

$L$  = The median path loss. Unit: decibel (dB)

$L_0$  = The reference path loss along 1 km. Unit: decibel (dB)

$\gamma$  = The slope of the path loss curve. Unit: decibels per decade

$d$  = The distance on which the path loss is to be calculated. Unit: kilometer (km)

$F_A$  = Adjustment factor.

$H_{ET}$  = Effective height of terrain. Unit: meter(m)

**Calculation of reference path loss**

The reference path loss is usually computed along a 1 km or 1 mi link. Any other suitable length of path can be chosen based on the applications.

$$L_0 = G_B + G_M + 20(\log \lambda - \log d) - 22$$

Where,

$G_B$  = Base station antenna gain. Unit: Decibel with respect to isotropic antenna (dBi)

$\lambda$  = Wavelength. Unit: meter (m).

$G_M$  = Mobile station antenna gain. Unit: decibel with respect to isotropic antenna (dBi).

### Calculation of adjustment factors

The adjustment factor is calculated as:

$$F_A = F_{BH} F_{BG} F_{MH} F_{MG} F_F$$

Where,

$F_{BH}$  = Base station antenna height correction factor.

$F_{BG}$  = Base station antenna gain correction factor.

$F_{MH}$  = Mobile station antenna height correction factor.

$F_{MG}$  = Mobile station antenna gain correction factor.

$F_F$  = Frequency correction factor.

### The base station antenna height correction factor:

$$F_1 = \left(\frac{h_B}{30.48}\right)^2$$

Where,

$h_B$  = Base station antenna height. Unit: meter.

### The base station antenna gain correction factor

$$F_2 = \frac{G_B}{4}$$

Where,

$G_B$  = Base station antenna gain. Unit: decibel with respect to half wave dipole (dBd)

### The mobile station antenna height correction factor

$$F_3 = \begin{cases} \frac{h_M}{3} & \text{if, } h_M > 3 \\ \left(\frac{h_M}{3}\right)^2 & \text{if, } h_M \leq 3 \end{cases}$$

Where,

$h_M$  = Mobile station antenna height. Unit: meter.

### The mobile antenna gain correction factor

$$F_4 = G_M$$

Where,

GM = Mobile station antenna gain. Unit: Decibel with respect to half wave dipole antenna (dBd).

### **The frequency correction factor**

$$F_5 = \left(\frac{f}{900}\right)^{-n} \text{ for } 2 < n < 3$$

Where,

$f$  = Frequency. Unit: megahertz (MHz)

### **Effective terrain slope calculation**

This is computed in the following way:

1. Extrapolate terrain slope at the mobile station to the base station.
2. Compute the vertical antenna height over the extrapolation line.

**Note:** - it is a suitable model but it is not generalized and it has a lot of parameters that unknown.

**Modified Hata model used at “ERC REPORT 68”**

- In this model, there are a number of equations for different frequency ranges.
  - The equation discussed here covers the same frequency range as the original Hata equation.
  - This equation has only the distance term raised to the power  $b$ .
  - This equation equates approximately to the original Hata equation for distances less than 20km.
  - The first constant is equal to 69.75 instead of 69.82.
- ❖ This model is suitable for use over the ranges:

Frequency range 150 --1500 MHz  
 Base station height 1 --200 m  
 Mobile height 1 --200 m  
 Distance range 1 --100 km

$$pl = f_{propag}(f, h_1, h_2, d, env) = L + T(G(\sigma))$$

where:

- $L$  = median propagation loss (in dB)
- $\sigma$  = standard deviation of the slow fading distribution (in dB)
- $f$  = frequency (in MHz)
- $H_m = \min\{h_1, h_2\}$
- $H_b = \max\{h_1, h_2\}$
- $d$  = distance (in km), preferably less than 100 km.
- $env$  = (outdoor/outdoor), (rural, urban or suburban), (propagation above or below roof).

If  $H_m$  and/or  $H_b$  are below 1 m, a value of 1 m should be used instead. Antenna heights above 200 m might also lead to significant errors. Propagation below roof means that both  $H_m$  and  $H_b$  are above the height of roofs. Propagation is above roof in other cases ( $H_b$  above the height of roofs).

**Calculation of the median path loss  $L$**

Case 1:  $d \leq 0.04$  km

$$L = 32.4 + 20 \log(f) + 10 \log(d^2 + (H_b - H_m)^2 / 10^6)$$

Case 2:  $d \geq 0.1$  km

$$a(H_m) = (1.1 \log(f) - 0.7) \min\{10, H_m\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_m / 10)\}$$

$$b(H_b) = \min\{0, 20 \log(H_b / 30)\}$$

Note that in the "SE24-model" for short range devices in the case of low base station antenna height,

$$H_b, b(H_b) = \min\{0, 20 \log(H_b / 30)\} \text{ is replaced}$$

$$b(H_b) = (1.1 \log(f) - 0.7) \min\{10, H_b\} - (1.56 \log(f) - 0.8) + \max\{0, 20 \log(H_b / 10)\}$$

$$\alpha = \begin{cases} \alpha = 1 & d \leq 20 \text{ km} \\ \alpha = 1 + (0.14 + 0.000187 f + 0.00107 H_b) \left( \log \frac{d}{20} \right)^{0.8} & 20 \text{ km} < d \leq 100 \text{ km} \end{cases}$$

Sub-case 1: Urban

- 30 MHz <  $f \leq 150$  MHz  

$$L = 69.6 + 26.2 \log(150) - 20 \log(150/f) - 13.82 \log(\max\{30, H_b\}) + [44.9 - 6.55 \log(\max\{30, H_b\})](\log(d))^a - a(H_m) - b(H_b)$$
- 150 MHz <  $f \leq 1500$  MHz  

$$L = 69.6 + 26.2 \log(f) - 13.82 \log(\max\{30, H_b\}) + [44.9 - 6.55 \log(\max\{30, H_b\})](\log(d))^a - a(H_m) - b(H_b)$$
- 1500 MHz <  $f \leq 2000$  MHz  

$$L = 46.3 + 33.9 \log(f) - 13.82 \log(\max\{30, H_b\}) + [44.9 - 6.55 \log(\max\{30, H_b\})](\log(d))^a - a(H_m) - b(H_b)$$
- 2000 MHz <  $f \leq 3000$  MHz  

$$L = 46.3 + 33.9 \log(2000) + 10 \log(f/2000) - 13.82 \log(\max\{30, H_b\}) + [44.9 - 6.55 \log(\max\{30, H_b\})](\log(d))^a - a(H_m) - b(H_b)$$

Sub-case 2: Suburban

$$L = L(\text{urban}) - 2\{\log[(\min\{\max\{150, f\}, 2000\})/28]\}^2 - 5.4$$

Sub-case 3: Open area

$$L = L(\text{urban}) - 4.78 \{\log[\min\{\max\{150, f\}, 2000\}]\}^2 + 18.33 \log[\min\{\max\{150, f\}, 2000\}] - 40.94$$

Case 3: 0.040 km <  $d < 0.1$  km

$$L = L(0.04) + \frac{[\log(d) - \log(0.04)]}{[\log(0.1) - \log(0.04)]} [L(0.1) - L(0.04)]$$

When  $L$  is below the free space attenuation for the same distance, the free space attenuation should be used instead.

**Assessment of the standard deviation for the lognormal distribution**

Case 1:  $d \leq 0.04$  km                       $\sigma = 3.5$  dB

Case 2:  $0.040$  km <  $d \leq 0.1$  km

$$\sigma = 3.5 + \frac{(12 - 3.5)}{(0.1 - 0.04)} (d - 0.04) \text{ dB} \quad \text{for propagation above the roofs}$$

$$\sigma = 3.5 + \frac{(17 - 3.5)}{(0.1 - 0.04)} (d - 0.04) \text{ dB} \quad \text{for propagation below the roofs}$$

Case 3:  $0.1$  km <  $d \leq 0.2$  km

$$\sigma = 12 \text{ dB} \quad \text{for propagation above the roofs}$$

$$\sigma = 17 \text{ dB} \quad \text{for propagation below the roofs}$$

Case 4:  $0.2$  km <  $d \leq 0.6$  km

$$\sigma = 12 + \frac{(9 - 12)}{(0.6 - 0.2)} (d - 0.2) \text{ dB} \quad \text{for propagation above the roofs}$$

$$\sigma = 17 + \frac{(9 - 17)}{(0.6 - 0.2)} (d - 0.2) \text{ dB} \quad \text{for propagation below the roofs}$$

Case 5:  $0.6$  km <  $d$                                        $\sigma = 9$  dB

**Note:** - the most suitable propagation model is the modified Hata model and we used it in our calculations.

→ After computing the Path Loss factor we will calculate the UpLink and DownLink power budgets.

**Note:** The objective of power budget calculation is to balance the uplink and down link. The receive signal sensitivity may be different because the mobile station and the base transceiver station has different Radio frequency architecture. The power of BTS can be adjusted to balance the whole link. The power balance (uplink and down link) decide the cell range.

Here we can see two conditions those are:

- The down link is greater than the uplink:

It results in Range of BTS greater than Range of MS, Call dropped on uplink after initiation of handover, and Coverage area is smaller in reality than the prediction. This condition is most frequent.

- The uplink is greater than the down link:

It results in Range of BTS less than Range of MS, and No coverage problem from MS to BTS.

-- The condition i.e the uplink > down link, is **better than** uplink < down link.

→ Down Link Budget and cell range

Receiver (MS or ME)

$$R_s = EIRP - L_p - B_{LM} - I_D - L_s - L_{CC} + G_{MS} , \text{ then get EIRP.}$$

Where:

$R_s$  = MS Sensitivity.

$L_p$  = Propagation loss + 3 dB antenna (body loss).

$I_D$  = Interference degradation margin.

$L_s$  = Log normal shadowing margin for 90% coverage area.

$L_{CC}$  = MS antenna cable and connector loss.

$G_{MS}$  = MS antenna gain.

**And substitute in:**

$$EIRP = P_{TXB} - L_{cableB} - L_c + G_{TXB} , \text{ then get the required BTS Transmitted power.}$$

Where:

$P_{TXB}$  = Output power of BTS.

$L_C$  = Combiner / filter / isolator loss.

$L_{CableB}$  = BTS transmitter antenna feeder / connector loss.

$G_{TXB}$  = BTS transmitter gain.

## GSM frequency bands

There are fourteen bands defined in 3GPP TS 45.005, which succeeded 3GPP TS 05.05

System	Band	Uplink (MHz)	Downlink (MHz)	Channel number
T-GSM-380	380	380.2–389.8	390.2–399.8	dynamic
T-GSM-410	410	410.2–419.8	420.2–429.8	dynamic
GSM-450	450	450.6–457.6	460.6–467.6	259–293
GSM-480	480	479.0–486.0	489.0–496.0	306–340
GSM-710	710	698.2–716.2	728.2–746.2	dynamic
GSM-750	750	747.2–762.2	777.2–792.2	438–511
T-GSM-810	810	806.2–821.2	851.2–866.2	dynamic
GSM-850	850	824.2–849.2	869.2–894.2	128–251
P-GSM-900	900	890.0–915.0	935.0–960.0	1–124
E-GSM-900	900	880.0–915.0	925.0–960.0	975–1023, 0-124
R-GSM-900	900	876.0–915.0	921.0–960.0	955–1023, 0-124
T-GSM-900	900	870.4–876.0	915.4–921.0	dynamic
DCS-1800	1800	1,710.2–1,784.8	1,805.2–1,879.8	512–885
PCS-1900	1900	1,850.2–1,909.8	1,930.2–1,989.8	512–810

[1]

- P-GSM, Standard or Primary GSM-900 Band
- E-GSM, Extended GSM-900 Band (includes Standard GSM-900 band)
- R-GSM, Railways GSM-900 Band (includes Standard and Extended GSM-900 band)
- T-GSM, Trunking-GSM

## 5.4 Appendix –D VSAT

### Definition:

VSAT stands for “Very Small Aperture Terminal” and refers to receive/transmit terminals installed at dispersed sites connecting to a central hub via satellite using small diameter antenna dishes (0.6 to 3.8 meter), it is a satellite communications system that serves home and business users and an earthbound station used in satellite communications of data, voice and video signals, excluding broadcast television.



### Overview of Technology:

The most common VSAT configuration is the TDM/TDMA star network. This have a high bit rate outbound carrier (TDM) from the hub to the remote earth stations, and one or more low or medium bit rate Time Division Multiple Access (TDMA) inbound carriers.

With its star configuration network architecture, interactive VSAT technology is appropriate for any organization with centralized management and data processing.

This configuration has been developed to minimize overall lifetime costs for the complete network including satellite transmission costs. The use of a single high performance hub allows the use of low cost remote VSAT terminals and optimizes use of satellite capacity. Even so, in most VSAT networks, the cost of the VSAT terminals usually far exceeds the cost of the hub (typically a VSAT terminal is 0.1 to 0.2% of the price of the hub).

Data sent to the VSAT terminal from the DTEs is buffered and transmitted to the hub in packets

### Who uses VSATs?

Oil exploration companies, car dealerships, gas stations, lottery systems, banks, insurance companies, drug stores, general stores, supermarkets, health care companies, manufacturers, couriers, hotel chains, car rental businesses, food manufacturers, heavy industries, mines, electrical utilities, oil and gas pipelines, energy production and exploration, timber companies, plantations, various government departments and agencies

### Network Configuration:

In a typical VSAT network, remote user sites have a number of personal computers, dumb terminals and printers connected to the VSAT terminal which connects them to a centralized host computer either at the organization's head office or data processing center.

A VSAT consists of two parts, a transceiver that is placed outdoors in direct line of sight to the satellite and a device that is placed indoors to interface the transceiver with the end

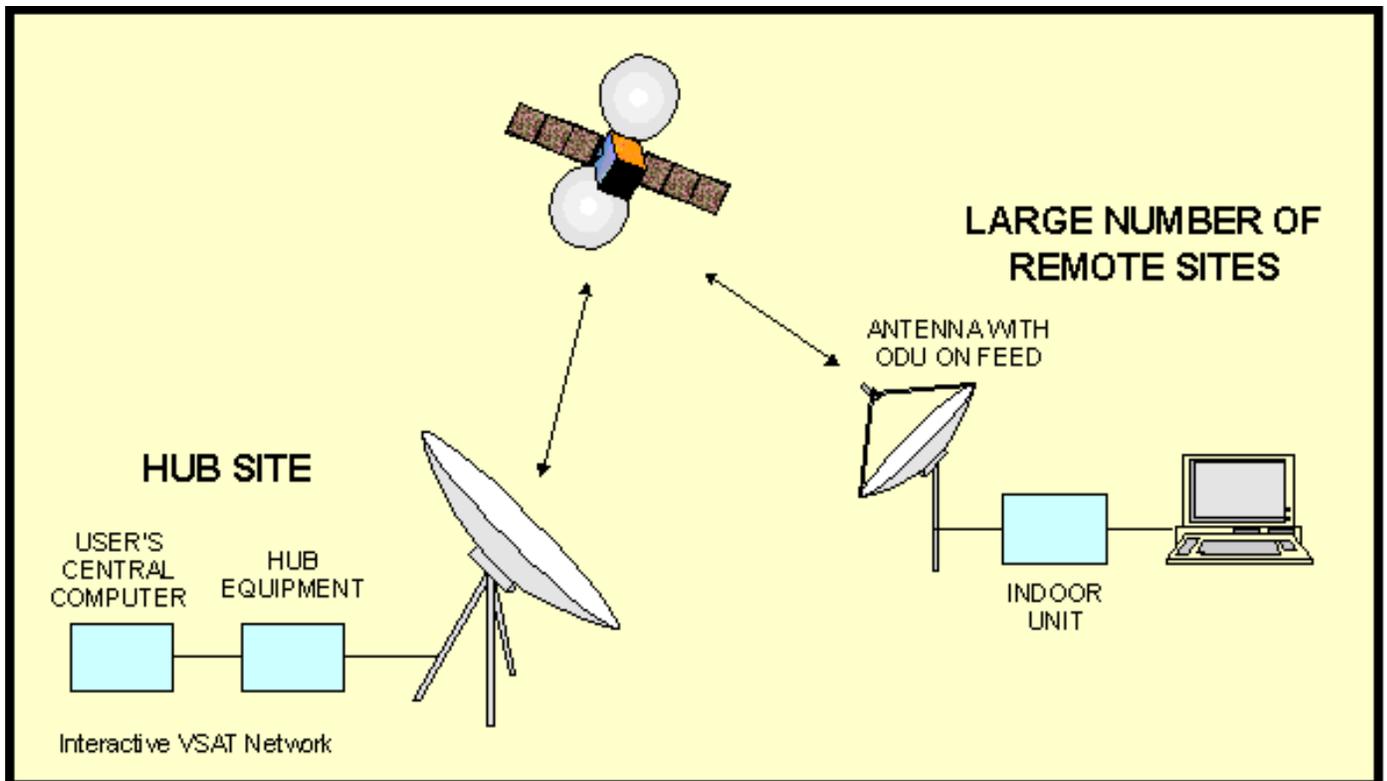
user's communications device, such as a PC. The transceiver receives or sends a signal to a satellite transponder in the sky. The satellite sends and receives signals from an earth station computer that acts as a hub for the system.

Each end user is interconnected with the hub station via the satellite in a star topology.

The hub controls the entire operation of the network.

For one end user to communicate with another, each transmission has to first go to the hub station which retransmits it via the satellite to the other end user's VSAT.

VSAT can handle up to 56 Kbps.



Indoor VSAT IDU unit Model S4100



Indoor VSAT IDU unit Model S2020

**Advantages:**

VSAT offers a number of advantages over terrestrial alternatives.

For private applications, companies can have total control of their own communication system without dependence on other companies.

Business and home users also get higher speed reception than if using ordinary telephone service or ISDN.

**Applications:**

Typical applications for interactive VSAT networks are:

- Computer communications.
- Reservation systems.
- Database enquiries.
- Billing systems.
- File transfers.
- Electronic mail.
- Video conferencing.
- Point of sale transactions.
- Credit checks and credit card verification.
- Stock control and management.

**Remote Office Connectivity**

Securely connect remote sales, banking, brokerage and other branch and district offices to headquarters. Provide high speed web and private network access for multi-national offices, suppliers and customer sites.

**Cyber Café, Hot Spot and ISP Backhaul Service**

Scalable high speed backhaul to the internet. Increase satellite bandwidth on the fly as you add subscribers, rather than subsidizing expensive T-1 links until you hit critical mass.

**Milsatcom, Homeland Security and Border Patrol**

Fixed and transportable broadband satellite solutions provide IP connectivity for a variety of requirements including news feeds, VoIP, video surveillance and secure connectivity to military and government central command locations.

**Hotel and Multi-Tenant Dwellings**

High-speed broadband internet access for clients, tenants and residential customers.

**Healthcare**

Link remote clinics and healthcare facilities, providing telemedicine, insurance processing, patient record management, asset control.

**Insurance**

Process claims and provide voice connectivity to headquarters for applications such as hail damage at auto dealerships, tornado, flood and other weather related disasters.

**Distance Learning**

Provide internet access for rural schools. Use web casting to deliver training, video conferences, etc. Use the web as a teaching aid, update test results, etc.

**Manufacturing**

Support SCADA, remote monitoring, surveillance, and remote asset management over broadband satellite.

**Disaster Recovery**

There are no backhoes in the sky! Provide business continuity solutions including server backup, redundant WAN links, and internet access for corporate headquarters, alternate headquarters and other critical sites.

**Portable Applications**

Mining, drilling, construction, petro-chemical, forestry and other organizations can use transportable broadband satellite equipment to stay connected. Get connected in hours instead of weeks or months.

**Maritime Applications**

Email, web and VoIP crew and passenger calling access for cruise ships, Navy vessels and private yachts. Download newspapers, provide ATM machines, video conferencing, video downloads.

## 5.5 Appendix –E Matlab Codes

### 5.5.1 Codes:

#### 1- Rural area

```

function B1 = simulate_rural(T,N,IAT,HT)
%% Inputs
% T : simulation time
% N : number of time slots per frequency
% IAT : Inter arrival time
% HT : Average holding time

clc
C = T*3600/IAT;
n = 4;
arrvInt = exprnd(IAT,1,C);
arrvInst = cumsum(arrvInt);
holdTime = exprnd(HT,1,C);
termTime = arrvInst + holdTime;
served = zeros(2,C);
type = [randi(n,C,1),randi(n,C,1)];
Type = zeros(1,C);
SDCCH = zeros(n,4);
TCH = zeros(n+1,N);
%% Check for availble resources for each call

for j=1:C
    flag = zeros(1,5);
    if(type(j,1) == type(j,2))
        Type(j) = 1;
    elseif(type(j,2) == 4)
        Type(j) = 2;
    elseif(type(j,1) == 4)
        Type(j) = 3;
    else
        Type(j) = 4;
    end
    %% check for free traffic channels at the org. cell

    for u=2:8
        if(TCH(type(j,1),u) < arrvInst(j))
            flag(1) = 1;
            break;
        end
    end

    if( Type(j) == 1 ),
        y = u+1;
    else
        y = 2;
    end
end

```

```

for v=y:8
    if(TCH(type(j,2),v) < arrvInst(j))
        flag(2) = 1;
        break;
    end
end
end
%% check for free traffic channels

if( Type(j) == 2)
    for p=4:N
        if(TCH(n+1,p) < arrvInst(j))
            flag(3) = 1;
            break;
        end
    end
elseif ( Type(j) == 3)
    for p=4:N
        if(TCH(n+1,p) < arrvInst(j))
            flag(4) = 1;
            break;
        end
    end
elseif ( Type(j) == 4)
    for p=4:N
        if(TCH(n+1,p) < arrvInst(j))
            flag(3) = 1;
            break;
        end
    end
    for c=p+1:N
        if(TCH(n+1,c) < arrvInst(j))
            flag(4) = 1;
            break;
        end
    end
end
end
%% assign traffic channels according to flags

if(flag(1) && flag(2)),
    if(Type(j) == 1)
        served(1,j) = 1;
    elseif(Type(j) == 2 && flag(3) ==1)
        served(1,j) = 1;
    elseif(Type(j) == 3 && flag(4) ==1)
        served(1,j) = 1;
    elseif(Type(j) == 4 && flag(3) == 1 && flag(4) == 1)
        served(1,j) = 1;
    end
end
end
%% check for free SDCCH's

if(served(1,j)== 1 )
    for r=1:4

```

```
        if(SDCCH(type(j,1),r) < arrvInst(j))
            if( Type(j) == 1 )
                s = r+1;
            else
                s = 1;
            end
            for k=s:4
                if(SDCCH(type(j,2),k) < arrvInst(j))
                    served(2,j) = 1;
                    flag(5) = 1;
                    break;
                end
            end
            break;
        end
    end
end
%% assign signaling channels according to flags
if(flag(5))
    TCH(type(j,1),u) = termTime(j);
    TCH(type(j,2),v) = termTime(j);
    SDCCH(type(j,1),k) = arrvInst(j)+3;
    SDCCH(type(j,1),r) = arrvInst(j)+3;
    if(Type(j) == 2 || Type(j) == 3)
        TCH(n+1,p) = termTime(j);
    elseif(Type(j) == 4)
        TCH(n+1,[p,c]) = termTime(j);
    end
end
end

end
%% Blocking calculation

B1 = (C-sum(served(1,:)))/(C)*100;
```

## 2- Oasis road

## a. Version 1

```

function B = simulate_Oasis_v1(n,T,N,CPH,HT)

%% Inputs
% n : number of cells on the road
% T : simulation time
% N : number of time slots per frequency
% CPH : number of calls per hour
% HT : Average holding time

clc
format short g
C = T*CPH;
IAT = 3600/CPH;
place = randi(n,1,C);
arrvInt = exprnd(IAT,C,1);
arrvInst = cumsum(arrvInt);
holdTime = exprnd(HT,C,1);
termTime = arrvInst + holdTime;
served = zeros(C,1);
SDCCH = zeros(n,4);
SDCCH_rep = zeros(n,4);
CH = zeros(n,N);
CH_rep = zeros(n,N);
%% Check for available resources for each call

for j=1:C
    flag = zeros(1,4);
    x(j) = round((n+1)/2-place(j));
    %% check for free traffic channels at the org. cell

    for i=2:N
        if(CH(place(j),i) < arrvInst(j))
            flag(1) = 1;
            break;
        end
    end
    %% check for free SDCCH at the org. cell

    for r=1:4
        if(SDCCH(place(j),r) < arrvInst(j))
            flag(2) = 1;
            break;
        end
    end
    %% check for free traffic channels on the link between originating cell
    and master

    for k= place(j):sign(x(j)):place(j)+x(j)-sign(x(j))
        check1 = [];
        for p=2:N

```

```

        if(CH_rep(k,p) < arrvInst(j))
            check1 = [check1 1];
            break;
        end
    end
end
end
%% check for free SDCCH's on the link between originating cell and master

for a= place(j):sign(x(j)):place(j)+x(j)-sign(x(j))
    check2 = [];
    for z=1:4
        if(SDCCH_rep(a,z) < arrvInst(j))
            check2 = [check2 1];
            break;
        end
    end
end

if(place(j) ~= 4)
    if(check1)
        flag(3) = 1;
    end
    if(check2)
        flag(4) = 1;
    end
end

%% assign channels according to flags

if(place(j) ==4)
    if(flag(1) && flag(2))
        served(j) = 1;
        CH(place(j),i) = termTime(j);
        SDCCH(place(j),r) = arrvInst(j)+10;
    end
else
    if(flag)
        served(j) = 1;
        CH(place(j),i) = termTime(j);
        SDCCH(place(j),r) = arrvInst(j)+10;
        CH_rep(place(j):sign(x(j)):place(j)+x(j)-sign(x(j)),p) =
termTime(j);
        SDCCH_rep(place(j):sign(x(j)):place(j)+x(j)-sign(x(j)),z) =
arrvInst(j)+10;
    end
end

end
%% Blocking calculation

B = (C-sum(served))/(C)*100;

```

## b. Version 2

```

function B = simulate_Oasis_v2(n,T,N,CPH,HT)

%% Inputs
% n : number of cells on the road
% T : simulation time
% N : number of time slots per frequency
% CPH : number of calls per hour
% HT : Average holding time

%% Description

%% Procedure
...** Resources needed to serve a call:
... 1- one free traffic channel at originating cell
... 2- one free SDCCH at originating cell (during call setup only)
... 3- x-free traffic channels on the link between originating cell and
master
... 4- x-free SDCCH on the link between originating cell and master

% (x) represents number of cells between originating cell and master
% Originating cell means the cell which the mobile(car) is camps on
... this org. cell changes during call as the car moves from a cell to
another
... If the car is approaching master it releases repeating resources
allocated for it
... If the car is leaving master it acquires more repeating resources to
be allocated
... If the car is served directly by master it doesn't need any repeating
resources

clc
format short g
C = T*CPH;
IAT = 3600/CPH;      % Inter arrival time
R = 10;             % cell radius
position = randi(40e3,C,1)/1e3; % poistion of originating call in Km
w.r.t begining of the road
place = ceil(position/R); % cell of originating call
speed = randi([80 130],C,1); % speed of car with random value between
80 and 130 Km/hour
arrvInt = exprnd(IAT,C,1); % arrival interval between calls
(exponentially distributed)
arrvInst = cumsum(arrvInt); % arrival instant of calls
holdTime = exprnd(HT,C,1); % hold time of calls
termTime = arrvInst + holdTime; % Termination time of calls
served = zeros(C,1); % vectors consists of zeros and ones
...to represent if call is blocked or served respectively
SDCCH = zeros(n,4); % Dedicated signalling channels in
each cell between mobile and BTS
SDCCH_rep = zeros(n,4); % Dedicated signalling channels between
repeaters

```

```

CH = zeros(n,N); % Traffic channels in each cell between
mobile and BTS
CH_rep = zeros(n,N); % Traffic channels between repeaters

%% Check for available resources for each call
for j=1:C

    flag = zeros(1,4); % flags represents the 4 acquired
resources mentioned earlier for a call to be served
    dist_tot = speed(j)*holdTime(j)/3600; % total distance moved by the car
from start of call to end
    start = min(5,place(j)); % cell where the
call starts
    fin = max(3,min(7,ceil((dist_tot+position(j))/10))); % cell where the
call finishes
    distance = zeros(n,1); % vector
represents distance moved by the car in a certain cell
    distance(1) = min(dist_tot,max(0,10-position(j)));
    for i=2:n
        distance(i) = min(dist_tot-sum(distance),min(10,max(0,i*10-
position(j))));
    end
    Time = 3600*distance/speed(j); % vector represents period stayed
by the car at a certain cell
    Time_acc = cumsum(Time)+arrvInst(j); % vector represents time when the
car arrives the end of a certain cell
    Time_arv = Time_acc - Time; % vector represents time when the
car arrives the beginning of a certain cell
    for h=1:n
        if(h<4)
            Time_check(h) = arrvInst(j);
        elseif(h>4)
            Time_check(h) = Time_arv(h);
        end
    end
    cnt = nnz(Time); % number of cells the car passes
through during the call

    %% check for free traffic channels at the org. cell
    for e=start:start+cnt-1
        check1 = [];
        for i=2:N
            if(CH(e,i) < arrvInst(j)+Time_arv(e))
                check1 = [check1 1];
                break;
            end
        end
    end

    if(check1)
        flag(1) = 1;
    end

    %% check for free SDCCH at the org. cell
    for r=1:4

```

```

        if(SDCCH(place(j),r) < arrvInst(j))
            flag(2) = 1;
            break;
        end
    end
    %% check for free traffic channels on the link between originating cell
and master
    for k = start:fin
        if(k ~= 4)
            check2 = [];
            for p=2:N
                if(CH_rep(k,p) < Time_check(k))
                    check2 = [check2 1];
                    break;
                end
            end
        end
    end
end

%% check for free SDCCH's on the link between originating cell and master
for a= start:fin
    check3 = [];
    for z=1:4
        if(SDCCH_rep(a,z) < arrvInst(j))
            check3 = [check3 1];
            break;
        end
    end
end

% no need to check for flag3 and flag 4 if the call is originated and
% terminated in the master cell
if(~(place(j) == 4 && fin ==4))
    if(check2)
        flag(3) = 1;
    end
    if(check3)
        flag(4) = 1;
    end
end

%% assign channels according to flags
if(place(j) ==4 && fin == 4) % if the call is originated and
terminated under coverage of master cell
    if(flag(1) && flag(2))
        served(j) = 1;
        CH(place(j),i) = Time_acc(e); % assign one traffic channel
in the master cell
        SDCCH(place(j),r) = arrvInst(j)+10; % assign one SDCCH in the
master cell
    end
else
    if(flag)
        served(j) = 1;
        for e = start:start+cnt-1

```

```
                CH(e,i) = Time_acc(e);           % assign traffic channel in
each cell the car will pass trough
            end
            for e = start:fin
                CH_rep(e,p) = Time_acc(e);       % assign repeating traffic
channels
                if(e>4)
                    CH_rep(e,p) = termTime(j);
                end
            end
            SDCCH(place(j),r) = arrvInst(j)+10; % assign one SDCCH in the
org. cell
            SDCCH_rep(start:fin,z) = arrvInst(j)+10; % assign repeating
SDCCH's during call setup
            end
            CH_rep(4,p) = 0;
            SDCCH_rep(4,z) = 0;
        end
    end

%% Blocking calculation
B = (C-sum(served))/(C)*100;
```

## c. Version 3

```

function B = simulate_Oasis_v3(n,T,N,m,CPH,HT)

%% Inputs
% n : number of cells on the road
% T : simulation time
% N : number of time slots per frequency
% m : "m-1" indicates the number of time slots dedicated for serving calls
per frequency
% as the first time slot is reserved for signaling channels
% CPH : number of calls per hour
% HT : Average holding time

%% Procedure
...** we need to serve a call for at least:
... 1- one free traffic channel at originating cell
... 2- one free SDCCH at originating cell (during call setup only)
... 3- x-free traffic channels on the link between originating cell and
master
... 4- x-free SDCCH on the link between originating cell and master

% (x) represents number of cells between originating cell and master
% Originating cell means the cell which the mobile(car) is camps on
... this org. cell changes during call as the car moves from a cell to
another
... If the car is approaching master it releases repeating resources
allocated for it
... If the car is leaving master it acquires more repeating resources to
be allocated
... If the car is served directly by master it doesn't need any repeating
resources

clc
C = T*CPH;
format short g
IAT = 3600/CPH;      % Inter arrival time
R = 10;             % cell radius
position = randi(70e3,C,1)/1e3;    % poistion of originating call in Km
w.r.t begining of the road
place = ceil(position/R);         % cell of originating call
speed = randi([80 130],C,1);     % speed of car with random value between
80 and 130 Km/hour
arrvInt = exprnd(IAT,C,1);       % arrival interval between calls
(exponentially distributed)
arrvInst = cumsum(arrvInt);      % arrival instant of calls
holdTime = exprnd(HT,C,1);       % hold time of calls
termTime = arrvInst + holdTime;  % Termination time of calls
served = zeros(C,1);            % vectors consists of zeros and ones
...to represent if call is blocked or served respectively
SDCCH = zeros(n,8);             % Dedicated signalling channels in
each cell between mobile and BTS
CH = zeros(n,N);                % Traffic channels in each cell between
mobile and BTS

```

```

%% Check for available resources for each call
for j=1:C

    flag = zeros(1,4); % flags represents the 4 acquired
resources mentioned earlier for a call to be served
    dist_tot = speed(j)*holdTime(j)/3600; % total distance moved by the car
from start of call to end
    start = min(5,place(j)); % freq where the
repetition resources should be allocated starting from it
    fin = max(3,min(7,ceil((dist_tot+position(j))/10))); % freq where the
repetition resources should be allocated finished at
    if place(j)<4
        fin2 = 3;
    else
        fin2 = 5;
    end
    distance = zeros(n,1); % vector
represents distance moved by the car in a certain cell
    distance(1) = min(dist_tot,max(0,10-position(j)));
    for i=2:n
        distance(i) = min(dist_tot-sum(distance),min(10,max(0,i*10-
position(j))));
    end
    Time = 3600*distance/speed(j); % vector represents period stayed
by the car at a certain cell
    Time_acc = cumsum(Time)+arrvInst(j); % vector represents time when the
car arrives the end of a certain cell
    Time_arv = Time_acc - Time; % vector represents time when the
car arrives the beginning of a certain cell
    for h=1:n
        if(h<4)
            Time_check(h) = arrvInst(j);
        elseif(h>4)
            Time_check(h) = Time_arv(h);
        end
    end
    cnt = nnz(Time); % number of cells the car passes
through during the call

    %% check for free traffic channels at the org. cell
    for e=start:start+cnt-1
        check1 = [];
        for i=2:m
            if(CH(e,i) < arrvInst(j)+Time_arv(e))
                check1 = [check1 1];
                break;
            end
        end
    end

    if(check1)
        flag(1) = 1;
    end

    %% check for free SDCCH at the org. cell
    for r=1:4

```

```

        if(SDCCH(place(j),r) < arrvInst(j))
            flag(2) = 1;
            break;
        end
    end
    %% check for free traffic channels on the link between originating cell
and master
    for k = start:fin
        if(k ~= 4)
            check2 = [];
            for p= m+1:N
                if(CH(k,p) < Time_check(k))
                    check2 = [check2 1];
                    break;
                end
            end
        end
    end
end

%% check for free SDCCH's on the link between originating cell and master
for a= start:fin
    check3 = [];
    for z=5:8
        if(SDCCH(a,z) < arrvInst(j))
            check3 = [check3 1];
            break;
        end
    end
end

% no need to check for flag3 and flag 4 if the call is originated and
% terminated in the master cell
if(~(place(j) == 4 && fin ==4))
    if(check2)
        flag(3) = 1;
    end
    if(check3)
        flag(4) = 1;
    end
end

%% assign channels according to flags
if(place(j) ==4 && fin == 4) % if the call is originated and
terminated under coverage of master cell
    if(flag(1) && flag(2))
        served(j) = 1;
        CH(place(j),i) = Time_acc(e); % assign one traffic channel
in the master cell
        SDCCH(place(j),r) = arrvInst(j)+10; % assign one SDCCH in the
master cell
    end
else
    if(flag)
        served(j) = 1;
        for e = start:start+cnt-1

```

```
        CH(e,i) = Time_acc(e);           % assign traffic channel in
each cell the car will pass trough
    end
    for e = start:fin
        if(e ~= 4)
            CH(e,p) = Time_acc(e);       % assign repeating traffic
channels
            if(e>4)
                CH(e,p) = termTime(j);
            end
        end
    end
    SDCCH(place(j),r) = arrvInst(j)+10; % assign one SDCCH in the
org. cell
    SDCCH(place(j):sign(4-(place(j))):fin2,z) = arrvInst(j)+10; %
assign repeating SDCCH's during call setup
    end
end
end

%% Blocking calculation
B = (C-sum(served))/(C)*100;
```

### References

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