Radio Resource Management
In 3G UMTS Networks

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Abstract

Universal Mobile Telecommunication System (UMTS) is a third generation mobile communication system, designed to support a wide range of applications with different quality of service (QoS) profiles. This 3G system has capability of transporting wideband and high bit rate multimedia services along with traditional cellular telephony services e.g voice, messaging etc. To provide these services with better quality of service and enhance the performance of wireless network, management of radio resources is necessary. To do this, UMTS offer many radio resource management (RRM) strategies. These RRM techniques play important role in providing different services with better quality, keep the end user happy and make the network stable.

In our thesis, our main objective is to explore some RRM strategies and understand their practical importance by simulating some RRM algorithms. First we start with UMTS overview and learn some important concept about UMTS architecture. Then we go deep into physical layer of UMTS. After getting strong concept of UMTS radio architecture and procedures, we worked on different RRM techniques and in the end we analyze two power control algorithms to understand and get some practical experience of actual RRM strategies, because power control is the important most and critical part of RRM techniques due to interference limited nature of CDMA systems.
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Chapter 1 : UMTS Overview

1.1 Introduction
Universal Mobile Telecommunications System (UMTS) is a 3G cellular telecommunication system. It will be the successor of GSM. UMTS is designed to cope with the growing demand of mobile and internet applications with required quality of service parameters. WCDMA is used for the radio interface of UMTS. It has advantages of high transfer rate and more system capacity and high communication quality by statistical multiplexing then GSM. Along with traditional telephony and data services offered by GSM, UMTS will offer more high speed services to mobile computer users no matter where they are located in the world [1].

1.2 UMTS Network Architecture
There are two interacting domains in the UMTS network, one is the infrastructure domain that consists of the core network (CN) and second is the UTRA (UTRAN) network, also user equipment (UE) domain. The UTRAN that consists of mobile station, the base station (Antenna, transceiver and controller) and radio interface is there between mobile station & base station. In UMTS network, the core network that is known as CN has the main responsibility to provide switching and routing for user traffic. All Network management function and required database are also contained in core network. The core network domain is further divided into two sub categories i.e. serving network domain, home network domain and the transit network domain. A figure 1.1 shown below is a simplified UMTS architecture with its basic domains and this figure also show its external reference points and interfaces with the UTRAN. UTRAN is connected the core network (CN) via Iu interface. Between the radio networks controller (RNC) and Core Network, there is Iu UTRAN interface. The UTRAN interface that is between the CN and the radio network controller (RNC) is called Iu-PS and also UTRAN interface between the RNC and circuit switched domain of CN is known as Iu-CS. Radio interface between User equipment UE and UTRAN is known as Uu interface. These interfaces are also known as reference points.

![Figure 1.1 General UMTS architecture](image)

1.3 User Equipment
The user equipment domain that has variety of equipment types and has different levels of functionality. This equipment may be compatible with current or more exiting access interface (Fixed and radio) and has contains a removable smart card that can be used in different user equipment types. This user equipment is further categories into two sub categories, one is mobile equipment domain (ME) and second is the user services identity module domain (USIM) as shown in Figure 1.2. The reference point among ME and USIM is known as Cu.

![Figure 1.2 User Equipment](image)
The mobile equipment may be further categories into several others entities. ME domain are the mobile termination (MT) is the typical entities which has perform the function of radio transmission and also related functions and the terminal equipment (TE) that has the responsibility of end to end applications.

The function of mobile equipment is to perform the radio transmission and it contains applications. Data and procedure are contained in USIM that unambiguously and securely identify it. All these function are embedded in a standalone smart card. This device is linked with a given user and this device can identify this given user regardless of the ME he or she uses.

1.4 UTRAN

The UTRAN has a set of radio network subsystem (RNSs) in which RNS are access parts of UMTS network. A RNS has the responsibility to offer the allocation and to release specific radio resources to establish a connection between an UE and UTRAN. An RNS which is connected to the core network via Iu interface and it has two new network elements that has the name Radio Network controller RNC and Node B. The RNC which is attached to the set of node B elements each of which can serve one or several cells. The RNC has the responsibility to control overall logical resources of the node B. The responsibilities of RNC also contain for the handoff decisions. Node B is connected to the RNC through Iub interface. If we see the inside of the UTRAN, the RNC’s of the RNS’s are interconnected via Iur interface. Implementation of Iur interface either through a physical direct connection between RNC,s and it can also be possible to transport network. Each RNS is in system has a responsibility for resource management, transmission and reception in more then one cell. The Figure 1.3 shows the overall architecture of UMTS network UMTS defines four new interfaces or reference points [3]:

- Uu: UE to node B (UTRA, the UMTS W-CDMA air interface);
- Iu: RNC to CN interface (MSC/VLR or SGSN);
  - Iu-CS for circuit-switched data;
  - Iu-PS for packet-switched data;
- Iub: RNC to node B interface;
- Iur: RNC to RNC interface;
All these Iu, Iub, and Iur interfaces are basically based on ATM transmission principles. The RNC enables autonomous for RNM. It provide the same function as the GSM BSC, it also provide central control for the RNS elements (RNC and node Bs). The RNC has response for protocol exchanges between Iu, lur and lub interfaces. It responsibilities also includes for centralized operation and maintenance (O & M) of the whole RNS with access to the OSS. Because in this system, interfaces are ATM based, the RNC switches ATM cells between them. The user data (circuit switched and packet switched) coming from Iu-Cs and hence Iu-PS are multiplexed with multimedia transmission via lur, lib and Uu interfaces to end from the UE. For the purposes of Radio Resource Management, RNS used the lur interface. For each connection between the UTRAN and UE, one RNS is the serving RNS. Single serving RNS entirely manage the serving control functions such as congestion control, admission control and handoff. Resources must be used by UE in a cell not controlled by its serving RNS, RNS who is serving this must ask the controlling RNS for those resources. This kind of request is made via the lur interface, which connects the RNSs with each other. The controlling RNS is also said to be drift RNS for the particular UE in this case. The types of operation is required for providing soft handoff throughout the network.

In UMTS system, the soft handoff is one of the most important aspects. For the user terminals in the handoff process, the target base station and serving base station (original) will maintain two communications links over the same bandwidth to guarantee a smooth transition without dropping the ongoing call. The condition in which having more than one radio link active at the same time is known as macro diversity. This flexibility in keeping the connection open to more than one BS results in fewer lost calls, that is very important for the operator.

A node B which is a logical node having the responsibility for radio transmission/reception in single or more cells to/from UE. This node can support TTD mode, FDD mode, or dual mode operation and also only one RNC for any node B. Node B which is connected with the UE through W-CDMA Uu radio interface and also connects with RNC through the lub ATM-based interface. Node B which is the
ATM termination point and this node can be collocated with GSM BTS to decrease the implementation cost. Node B's has the responsibilities to radio and modulation/spreading aspects along with the channel coding. Forward Error Correction and also some splitting/combing for soft handoff. Node B also has the responsibilities to convert the data flow between the lu-b and Uu interfaces and fully participates in radio resource management. Two chip-rate options are there when Node B is operating in the TDD mode. 1.28 Mcps TDD, & 3.84 Mcps TDD and each TDD cell support either of these options. A Node B which supports the TDD cells can also support one chip option or can also support both options. A RNC which supports TDD cells can also support one chip rate or also support both options. The 5 MHZ is the normal channel spacing for 3.84 Mcps TDD and for 1.28 Mcps TDD is 1.6 MHZ. Infect the distance among channels can be adjusted accordingly to the optimize performance in a particular deployment scenario.

1.5 Core Network
Core network mainly deals with functionalities which are not directly related to radio access technology. Core network connected to UTRAN through Iu interface as shown in figure 1.3. Asynchronous Transfer Mode (ATM) is used for the UMTS core transmission. Circuit switched traffic is handled by ATM Adaptation Layer type 2 (AAL2) while packet switched traffic is handled by AAL5 [4]. UMTS core network is mainly divided into two domains
1. Circuit Switched Domain
2. Packet Switched Domain

1.5.1 Circuit Switched Domain
This domain mainly deals with the circuit switched traffic which requires dedicated network resources and interconnection to the external circuit switched networks. Circuit Switched domain connected to UTRAN through Iu-CS interface. The main elements of Circuit Switched Domain are Mobile service Switching Centre (MSC), Home Location Register (HLR), Visitor Location Register (VLR) and Gateway MSC (GMSC).

1.5.2 Packet Switched Domain
This domain mainly deals with the packet data traffic and connect mobile network with external packet switched networks. Packet Switched Domain connected to UTRAN through Iu-PS interface. Main elements of this domain are Serving GPRS Support Node (SGSN), Gateway GPRS Support Node (GGSN), and GPRS Register (GR).
Some elements are common in both domains. These elements are HLR, VLR, Equipment Identity Register (EIR) and Authentication Centre (AuC) [4].

1.6 UMTS Interfaces
Four new interfaces are defines in UMTS that is as follow: Uu, Iub, Iur, and Iu. All these four interfaces owe their existence to the new air interface and this can also be referred as either UMTS interfaces or UTRAN interfaces. The Figure 1.4 shows the general protocol model for UTRAN. It has a set of horizontal and vertical layers. The structure of this model is based on the principle that the planes and layers are logically independent of each others. This is why, it is easier for the standardization bodies to change or alter the protocol stacks in order to fulfill the future requirements.
The general protocol model has two main layers. The radio network layer and transport network layers. In radio network layers, all UTRAN-related requirements are addressed in it and the standard transport technology is represented by the transport network layer that is selected in UTRAN for usage purposes but without any UTRAN specific requirements. We have a user planes and a set of control in the vertical direction. Basically control planes are used to control a link or connections where as the user planes are used transparently transmit user data from the higher layers.

The control plane i.e. has mainly signalling bearers and application protocol. Hence the application protocol mainly used for setting up bearers for (Radio access bearer or radio link) in the radio network layer. For transporting the application protocol messages, signalling bearer is used. It may be same type as signalling protocol or may be not be same as signalling protocol for access link control application part (ALCAP) and is always set up by O&M actions. For transport signalling protocol, ALCAP is a generic name for it so that is reacting to the radio network layer,s demands to set up, maintain and release data bearers.

The user plane (UP) that is consists of data streams and data bearers for the data streams. Data streams that contain the user data and this data transparently transmitted between the networks elements. Data bearers are basically a frame protocols used to transport user data. Radio network layer information is not included in the transport network control plane (TNCP) and that is fully in the transport layer. It also contains the ALCAP protocols that are required to set the data bearers for the user planes. It also contains signalling bearers required for the ALCAP protocols. This plan which
acts among the user planes and control plane and permit the application protocol in radio network control planes independent of the selected technology for data bearer in the user planes. Hence it is important to note that for all types of data bearers, ALCAP might not be used. The TNCP is available in the Iur, Iu-CS and Lub interfaces. In rest of the interfaces where no ALCAP signalling is there, preconfigured data bearers are activated. The signalling bearer for ALCAP can or cannot be the same type as the signalling bearers for application protocol. It is (Signalling bearer) is always set up by O&M action.

The transport network user plane (TNUP) which consists of data bearers in user plane and signalling bearers of application protocol in the control plane. During real-time operation, the data bearers in TNUP are directly controlled by the TNCP but the control actions is needed for establish up the signalling bearers for application protocols are done via O&M actions.

1.6.1 Iu Interface

An interconnection of radio network controllers (RNCs) with core network nodes is established through UMTS Iu interface. It is an open interface and also divided the system in such manner so that switching, routing, and service control are handled by CN and radio resources management is handled by the UTRAN. The Iu interface which is toward the PS-domain of the core network is known as Iu-PS and Iu interface which is toward the CS-domain is known Iu-CS. The Iu interface to the broadcast domain is known as Iu-BC.

There is only one Iu-Ps interface toward the PS-domain from any one RNC and each RNC have only one Iu-CS interface toward its default CN node within the CS domain. However, there is possibility of having more then one Iu-CS interface toward other CN nodes within the CS domain. This is important to note that an RNC has only one single permanent default CN node per CN domain.

The following procedures and functionalities are supported by Iu interface [5]

1. The establishment, maintenance and release of radio access bearers;
2. Serving radio network subsystem (SRNS) relocation, intrasystem handoff, intersystem handoff, and intersystem change.
3. Procedures to support the cell broadcast service.
4. The separation of each UE on the protocol level for user specific signalling management.
5. Location services by transferring requests from the CN to UTRAN, and location information from UTRAN to CN.
6. Simultaneous access to multiple CN domains for a single UE.

The application protocol which are used in the Iu interface is known as radio access network application part (RANAP) and it has the responsibility for many functions and procedure. The transport protocol which are used in ATM for both Iu-CS and Iu. PS whereas TCP/IP protocol is used as radio network layer protocol over Iu_Bs. 3Generation Partnership Project (3GPP) specifications 25.411 to 25.419 show the detailed protocol specifications of Iu. The Iu interface corresponds to the A interface of GSM.
1.6.2 Iur Interface
The Iur interface has no equivalent in GSM system and it connects the two RNCs in the UTRAN. Basically it also uses ATM as the transport protocol. The basic capabilities of Iur are follow [5]

1. It support of inter-RNC mobility,
2. Second it support of dedicated channel traffic between two RNCs and (3) support of common channel traffic between two RNCs.

The Following are the main functions of Iur interface are [5]:

1. Transport network management
2. Traffic management of common transport channels
3. Traffic management of dedicated transport channels
4. Traffic management of downlink shared transport channels and also TDD uplink shared transport channels when applicable
5. Measurement reporting for common and dedicated measurement objects.

There are some several sub functions which may include previously listed functions. The application protocol which is used in the Iur interface is known as radio network subsystem application part (RNSAP) and it has the responsibilities for providing signalling information across it. The Procedures of RNSAP are divided into four categories which are as follow.

1. RNSAP basic mobility procedures;
2. RNSAP dedicated transport channel (DCH) procedures;
3. RNSAP common transport channel procedures;
4. RNSAP global procedures.

1.6.3 Iub Interface
As mentioned earlier that lub is the logical interface which connects a Node B with RNC. The main responsibilities on the Iub interface are as following [5]:

1. Management of lub transport resources
2. Logical O& M of node B
3. Implementation-specific O& M transport
4. System information management
5. Traffic management of common channels
6. Traffic management of dedicated channels
7. Traffic management of shared channels
8. Timing and synchronization management.

Several sub functions may be included in the previously listed functions. The application protocol which is used in lub interface is known as Node B application (NBAP).
1.6.4 Uu Interface
The UMTS radio interface that relates to the Uu reference points that provides interconnection among the user terminal and RNC through node B. The radio interface is layered into the three protocol layers i.e. first is the physical layer (L1), secondly data link layer (L2) and the third is the network layers (L3). Figure 1.5 shows the radio interface protocol architecture.

Figure 1.5 Radio Interface Protocol Architecture (Service access points marked by circles) [6]

The data link layer that is slited into MAC, RLC, Packet data convergence protocol (PDCP) and broadcast/ multicast control (BMC). The sublayer MAC is located on the top of the physical layer. Communication with higher layers, logical channels is used and for exchanging information with physical layer, transport channels are used. A logical channels which is defined to transmit a specific type of information. That why, a logical channel determines the kind of information it uses. Hence a transport
channels defines how data to be transmitted over air interface and also what characteristics.

Three types of MAC entities are exist in the MAC sub layer[5].

1. MAC-b is the MAC entity that handles the following transport channels:
   - Broadcast channel (BCH): A downlink channel used for broadcast of system Information into a whole cell.

2. MAC-c/sh is the MAC entity that handles the following transport channels:
   - PCH: A downlink channel which has the responsibility to broadcast control information into the whole cell allowing efficient UE sleep mode procedures. Paging and notification are the currently identified information types. There is another use that could be UTRAN notification of change of BCCH information.
   - Forward access channel (FACH): Common downlink channel without closed-loop
   - power control which is used for transmission of small amount of data;
   - Random access channel (RACH): A contention-based uplink channel used for transmission of relatively small amounts of data (e.g., for initial access or nonreal-time dedicated control or traffic data);
   - Common packet channel (UL CPCH): Transmission of bursty data traffic, a contention based channel is used. In FDd mode, this fast power controlled channel only exist and only in the uplink direction (As it is shared by the UEs in a cell and thus a common resource)
   - Downlink shared channel (DSCH): A downlink channel shared by several UEs in the cell and thus a common resource.
   - Uplink shared channel (USCH): An uplink channel shared by several UEs carrying dedicated control or traffic data, used in TDD mode only.

3- MAC-d is the MAC entity that has the responsibilities to handles the following transport channels:
   - Dedicated transport channels (DCHs): The channels dedicated to one UE used in uplink or downlink.

In UMTS, the unions of the channels mentioned in the three different MAC entities shown above form the set of transport channels which are provided through specific service access via the MAC and the physical layer.

The function of RLC sub layer as to acknowledge or unacknowledged date transfer, establishment of RLC connections, QoS Setting, transporting data transfer and the notification of unrecoverable error. There is only one RLC connection per radio bearer. The PDCP sub layer has the function of transmission and reception of radio network layer protocol data units (PDUs). In the UMTS system, many different network layer protocols are supported to transparently transmit protocol data. This transparent transmission is one task of PDCP; another is to increase channel efficiency (e.g., by protocol header compression). It is used only in the user plane. In the user plane, the MBC sub layer offers broadcast/multicast services. It has the capabilities to store SMS CB massages and transmits then to the UE. Also it is only used in the user plane.

The MAC sub layer that has the capabilities to provides data transfer services on logical channels. For different kinds of data transfer services, a set of logical channels types are defined as offered by MAC, and all logical channels types is defined by what type of information is transferred. The logical channels that are provided via specific SAPs among RLC and MAC sub layer, and they are divided into two
categories. Control and traffic channels. The control channels are only used for transfer of control planes information. The following are given below [5].

- BCCH, downlink only;
- PCCH, downlink only;
- CCCH, uplink and downlink;
- Dedicated control channel (DCCH), uplink and downlink;
- Shared channel control channel (SHCCH), uplink and downlink.

The traffic channels are only used for the transfer of user plane information, are the following [5]:

- Dedicated traffic channel (DTCH), uplink and downlink;
- Common traffic channel (CTCH), downlink only.

Layer 3 and RLC are divided into control (C-) and user (U-) planes. In the U-Plane, PDCP and BMC are only exist in it. Layer 3 is partitioned into sublayers in the C-plane where is the lowest sublayer denoted as radio resource control (RRC), interfaces with layer 2 and terminates in the UTRAN. The next sublayer has the functionality to provide duplication avoidance which prevents the reception of duplicated massages. The C-Plane radio bearers are provided by RLC to RRC and denoted as signalling radio bearers. The interference among duplication avoidance and higher L3 sublayers is defined by the general control (GC), dedicated control (DC) SAPs and notification (Nt) in the C-plane.

The figure 1.5 shows the connection between RRC and MAC and the figure also shows RRC and L1 providing interlayer control services. In between the RRC and RLC sublayer, an equivalent control interface exist and also between RRC and BMC sublayer. These interfaces which allows the RRC to control configuration of lower layers. For this kind of purpose, a separate control SAPs are defined via RRC and each lower layer (PDCP, MAC, RLC and L1). At last, specific mapping rules between the logical channels and the transport channel are exist.

In the uplink direction particularly, the below mappings between transport channels and logical channels are possible[5]

- CCCH can be mapped to RACH;
- DCCH can be mapped to CPCH (in FDD mode only);
- DCCH can be mapped to USCH (in TDD mode only);
- DTCH can be mapped to CPCH (in FDD mode only);
- DTCH can be mapped to DCH;
- DCCH can be mapped to RACH;
- DTCH can be mapped to RACH;
- DCCH can be mapped to DCH;
- SHCCH can be mapped to RACH (in TDD mode only);
- DTCH can be mapped to USCH (in TDD mode only);
- SHCCH can be mapped to USCH (in TDD mode only).

In the downlink direction particularly, the following mappings between logical channels and transport channels are possible[5]:

- BCCH can be mapped to BCH;
- CCCH can be mapped to FACH;
- DCCH can be mapped to FACH;
- DCCH can be mapped to DSCH;
- DTCH can be mapped to FACH;
• PCCH can be mapped to PCH;
• BCCH can be mapped to FACH;
• DCCH can be mapped to DCH;
• DTCH can be mapped to DCH;
• DTCH can be mapped to DSCH;
• CTCH can be mapped to FACH;
• SHCCH can be mapped to FACH (in TDD mode only).
• SHCCH can be mapped to DSCH (in TDD mode only).

The RRC block plays an important role toward gaining this objective since it incorporates QoS control functionalities and RRM operations between others. Over the air interface, RRC massages that is carrying all relevant information which is required for setting up a signalling radio bearer (life time of RRC connection) and modifying, setting up. It can also releasing radio bearers between UE and UTRAN (all being part of RRC connection).

1.7 Evolution of GSM toward UMTS
In UMTS system, a widespread deployment of packet radio services being deployed over 2G systems, as like GPRS for GSM. All these cellular system are providing valuable experience with wireless system for the operators and it also provides a platform for development of services interworking functions. It also gives us services interfaces as well as a core of mobile multimedia services. The most important thing is that this system is done with less initial investment. Customers are definitely attracted to these networks by the providing new contents and services. These customers will definitely be willing to invest in new UMTS terminals in the anticipation of better and more efficient delivery of these services. In return, this provides good incentive for network operator to invest in UMTS system to fulfil the needs for capacity demanded by a successful mobile multimedia market. The following are the steps towards full deployment of UMTS are below [5]:
1. Due to incorporation of packet switching capabilities onto the current existing GSM networks together with attractive services.
3. Starting trials of prototype UMTS nodes
4. Initial deployment started in 2002 that also includes the first incorporation of UTRA base stations into operational network. And also support of both broadband and narrowband services over the same UTRA interfaces.
5. Full commercial phase start in beginning of 2003 and 2005 achieving the envisaged performance and capabilities.

Gradually the deployment of UTRANs will start in very busy area in cooperation with GSM. The key element for the services continuity in UMTS network is the GSM BSS. The planning of UMTS phase I network as direct evolution of GSM core network. Allowing 3G functionalities in 2G systems, the VHE environment will play a vital role in it. So network of UMTS phase I is developed in such a way that it can supports evolved GSM network from the roaming and handoff point of view. This can only be achieved by evolving from a GSM phase 2+ network but this does not exclude other developments. UMTS phase I system has capability to particularly support bursty and asymmetric traffic in very efficient way. This allows UMTS phase I to support single and multimedia N-ISDN applications and single and multimedia IP applications. Hence UMTS approach is needed for phase I development of UMTS as it is more
than the addition of a UTRAN to a GSM phase 2+ architecture. Requirements to the GSM phase 2+ core network for UMTS should be incorporated. Such a hybrid 2G-3G configuration is depicted in Figure 1.6.

In the future phases of UMTS, some key characteristics have already been defined with the first priority is given to achievement of an all-IP architecture. This is already achieved in the release 5 of 3G specification from 3GPP that is frozen and not yet deployed in the system. Security, integrity functionalities and end to end QoS massaging enhancements are included in the release 5. Now at the same time 3GPP is working already toward the release 6 of 3G specifications. The new functionalities release includes: security enhancements, usage of multiple input multiple output (MIMO) antennas, global roaming and global interoperability, advanced terminals which can roam across different heterogeneous network and having power saving capabilities, virtual network operator and has ability to offer flexible bandwidth on demand and also asymmetric bandwidth.

![Figure 1.6 Hybrid 2G-3G Configuration](image-url)
Chapter 2 : Physical Layer

2.1 Introduction
The physical layer structures which are naturally related to the achievable performance issues when observing a single link amount a base station and terminal station. Hence the overall performance of the system, the protocols in the other layers such as handoff protocol which have a great deal of impact. Basically it is necessary to have low signal to interference ratio requirements for enough link performance with different coding and also diversity solutions in the physical layer, as the physical has the responsibilities to define the fundamental capacity limits. The physical layer which has great impact on equipment complexity with reference to required baseband processing power in the base station equipment and terminal station. As the diversity has great benefits on the performance side, the new feature of wideband WCDMA also offers new challenges in its implementation. We know that the third generation 3G systems having a wideband from the point of services, physical layer basically not designed only for single service, such as speech, more flexibility is needed for future service introduction.

2.2 Transport Channels and their Mapping
In UTRA, higher layers generated data is carried over the air with transport channels and this data are mapped in the physical layer to various physical channels. The requirement of physical layer is to support variable bit rate transport channels to offer bandwidth to the-on-demand services and also be able to offer multiplex several services to one connection. The mapping of the transport channels to the physical channels are presented in this section and how those two requirements are considered into account in the mapping.

Each transport channel which is accompanied by the transport format indicator (TFI) at each event at which data expected to arrive from the higher layers for the specific transport channels. The physical layer which is combines the TFI information from various transport channels to the Transport Format Combination Indicator (TFCI). TFCI which is transmitted in the physical control channel to inform the receiver those for the current frame, which transport channels are active. BTFD will be converted in connection with the downlink dedicated channels. In the receiver, the TFCI is decoded appropriately and the resulting TFI is given to higher layers for each transport channels and it can be active for the connection. The figure 2.1 shows that two transport channels are mapped to a single physical channel, as described in [7] and for each transport block, also error indication is provided. The transport channels which may have numbers of different blocks and not all transport channels are necessary active at any moment. Basically one or more physical data channels and one physical control channels form a single coded Composite Transport Channel (CCTrCh). On a given connection there are more then one CCTrCh channels but one physical layer control channel is transmitted in such a case. For terminal implementation, the interface among physical layer and higher layers is less relevant since every thing all things are placed in same equipment, thus the interfacing here is rather a tool for specification work. Division of functions between physical and higher layers is more important for network side and interface between physical & higher layers are shown by the lub-interface among the Radio Network controller (RNC) and base station.
Two different types of transport channel exist. These two channels are as; one is dedicated channel and second is common channels. The difference between them is that in common channels, resources are divided between all or a group of users in a cell and in dedicated resources, identified by a certain code on a certain frequency is reserved or allot for a single user only.

2.2.1 Dedicated Transport Channel
The dedicated transport channel is said to be dedicated channels in which the DCH term is used in the 25series of the UTRA specification. Dedicated transport channel carries all information which is intended for the given user coming from layer above the physical layer and also including data for the actual service as well as higher layers control information. The information carried on DCH is not seen (Visible) to the physical layer and then the user data and the higher layer control information are treated in the similar way. Naturally UTRAN set the physical layer parameters and may vary among control and data.

The familiar channels GSM, the traffic channels (TRCH) or associated control channel (ACCH) basically do not present in the UTRN physical layer. The dedicated transport channels which are carrying both the service data such as speech frame and also higher layer control information such as handoff commands and it also contain data like measurement reports from the terminal. A separate transport channel is not needed in WCDMA because the support from the service multiplexing and variable bit rate.

The dedicated transport channel is characterised as features like fast data rate change, as fast power control on the frame by frame basic and transmission of the particular part of cell or sectors possibility with varying antenna weight with adoptive antenna systems. The dedicated channel support soft handoff.

2.2.2 Common Transport Channels
Six different common transport channel types are defined for UTRA in release 99. Basically few differences are there if comparing from the second generation systems, for example a downlink shared channel for transmitting packet data and transmission of packet data on the common channels. There is no soft handoff in the common channels but some of the channels have very fast power control.
2.2.2.1 Broadcast Channels
The broad channels (BCH) are used to transmit information specific to the UTRA network or for a given cell. In every network, the most typical data needed is random access code and access slots in the cell, or the types of transmit diversity method used with different other channels for that cell. Without the possibility of decoding the broadcast channel, the terminal cannot register to the cell and this channel is required for the purpose of transmission with relatively high power because to reach the entire user with the intended coverage area. From the practical point of view, the data rate on the broadcast channel having some limit by the ability of low end terminals to decode the data rate of broadcast channel. Hence the result is low and fixed data rate for UTRA broadcast channel.

2.2.2.2 Forward Access Channel
The Forward Access Channel (FACH) that carries control information to terminals known to be located in the given cell and this FACH is basically a downlink transport channel. For example this Forward Access Channel (FACH) is used after a random access massages have been received by the base station. Data packet can also be transmitting on the FACH. There is a possibility of more than one FACH in a cell. Among forwards access channels, one of the channels must have low bit rate that it can be received by all the terminals in the cell area. The additional channels can have a higher data rate with more then one FACH channel. Basically FACH does not use for fast power control and the massages which is transmitted need to add inband identification information to make sure their correct receipt.

2.2.2.3 Paging Channel
The paging channel (PCH) is basically a downlink channel and it carries data relevant to the paging procedure when network want to initiate communication with the terminal. The simplest example of this channel is a speech call to the terminal. On the paging channel, the network transmits the paging massages to the terminal of those cells belonging to the location area that the terminal node is expected to be in. The identical paging message that can be transmitted in single cell or up to few hundred cells and it depends on the system configuration. It is important that terminal must be capable to receive the paging information in the whole cell area. The paging channel design also effects the terminal’s power consumption in the standby mode. The less often the terminal has to tune the receiver in to listen for a possible paging massage and longer the terminal battery will last in standby mode.

2.2.2.4 Random Access Channel
The Random Access channel intended to be used to carry control information from the terminal and it is basically a uplink transport channel such as request to establish a connection. The random access channel can also be used to send packet data (small amount) from terminal node to network. For correct system operation, the random access channel must be heard from the whole required cell coverage area. This also means that data rate (practical) have to be rather low.

2.2.2.5 Uplink Common Packet Channel
The uplink common packet channel (CPCH) is basically an extension of RACH channel which is used to carry packet based user data in the uplink direction. The reciprocal channel delivering the data in the downlink direction is the FACH.
physical layer, the main significant differences to the RACH are the use of a physical layer-based collision detection mechanism, fast power control and a CPCH status monitoring procedure. The uplink CPCH transmission may have several frames but only one to two frames for RACH massages.

2.2.2.6 Downlink Shared Channel
The downlink shared channel (DSCH) intended to carry user data and or control information and it is basically a transport channel. The downlink shared channel can be shared by several users. It is quit similar to the forward access channel in many respects, although the shared channel supports the use of fast power control as well as variable bit rate on a frame basic. The downlink shared channel is always associated with a downlink DCH. The DSCH does not need to be in the entire cell area and it can also employ the different modes of transmit antenna diversity methods and hence used with associated downlink DCH.

2.2.2.7 Required Transport Channels
RACH, FACH & PCH are common transport channels and are needed for basic network operation while DSCH and CPCH are for optional use and can be decided by the network.

2.2.3 Mapping of Transport Channels onto the Physical Channels
The different kind of transport channels are mapped to different kind of physical channels. Some of the transport channels are carried identical physical channel. The figure 2.2 illustrates the mapping of transport channel to physical channel.

<table>
<thead>
<tr>
<th>Transport Channels</th>
<th>Physical Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCH</td>
<td>DPDCH (Dedicated Physical Data Channel)</td>
</tr>
<tr>
<td></td>
<td>DPCCH (Dedicated Physical Control Channel)</td>
</tr>
<tr>
<td>RACH</td>
<td>PRACH (Physical Random Access Channel)</td>
</tr>
<tr>
<td>CPCH</td>
<td>PCPCH (Physical Common Packet Channel)</td>
</tr>
<tr>
<td></td>
<td>CPICH (Common Pilot Channel)</td>
</tr>
<tr>
<td>BCH</td>
<td>P-CCPCH (Primary Common Control Physical Channel)</td>
</tr>
<tr>
<td>FACH</td>
<td>S-CCPCH (Secondary Common Control Physical Channel)</td>
</tr>
<tr>
<td>PCH</td>
<td>SCH (Synchronization Channel)</td>
</tr>
<tr>
<td></td>
<td>PDSCH (Physical Downlink Shared Channel)</td>
</tr>
<tr>
<td></td>
<td>AICH (Acquisition Indicator Channel)</td>
</tr>
<tr>
<td></td>
<td>APACH (Access Preamble Acquisition Indicator Channel)</td>
</tr>
<tr>
<td></td>
<td>PICH (Paging Indicator Channel)</td>
</tr>
<tr>
<td></td>
<td>CSICH (CPCH Status Indicator Channel)</td>
</tr>
<tr>
<td></td>
<td>CDICA-ICH (Collision Detection Channel Assignment Indicator Channel)</td>
</tr>
<tr>
<td>DSCH</td>
<td>HS-PDSCH (High Speed Physical Downlink Shared Channel)</td>
</tr>
<tr>
<td></td>
<td>HS-SSCH (HS-DSCH related Shared Control Channel)</td>
</tr>
<tr>
<td></td>
<td>HS-DPCCH (Dedicated Physical Control Channel (uplink) for HS-DSCH)</td>
</tr>
</tbody>
</table>

Figure 2.2 Mapping of transport channels onto physical channels [8]
The introduction of transport channel is explained earlier, in physical channels carry only information which is relevant to physical layer procedures. The Common Pilot Channel (CPICH), Synchronisation Channel (SCH) and the Acquisition Indication Channel (AICH) are not directly visible to higher layers. Also these channels are mandatory from the system function and hence transmitted from every base station. If CPCH is used then CPCH Indication Channel (CSICH) and the Collision Detection/Channel Assignment Indication Channel (CD/CA-ICH) are required. Onto two physical channels, a dedicated channels (DCH) is mapped. Higher layer information, including user data carried by the dedicated physical data channel (DPDCH) while all necessary physical layer control information carried by the Dedicated Physical Control Channel (DPCCH). In the physical layer, these two physical channels (dedicated) are required to support efficiently in the variable bit rate. The DPCCH has constant bit rate while DPDCH can change the bit rate frame by frame.

2.2.4 Frame Structure of Transport Channels
10 ms radio frame structure used by the UTRA channels. The frame structure employed a longer period, known as the system frame period. System Frame Number (SFN) is 12 bit numbers which are used by procedures that span higher than single frame. Physical layer procedures for example random access procedure or paging procedure that requires a longer period than 10 ms for correct definition.

2.3 Spreading and Modulation
2.3.1 Scrambling
In transmitter, the scrambling operation is a part of process. It is required to separate terminals or base station from each other. Scrambling which is required on the top of spreading so it does not change the bandwidth of signal but only makes the signals separable from different sources. With scrambling, it does not matter if the actual spreading were performed for several transmitters with identical code. The relationship of the chip of the chip rate in channel to spreading and scrambling in UTRA is shown in the Figure 2.3, as described in [7]. As we have already achieved the chip rate in spreading by the channelisation code and the symbol rate is not affected by scrambling.

![Figure 2.3 Spreading and scrambling](7)

2.3.2 Channelisation Codes
By channelisation codes, the transmissions from a single source are separated i.e dedicated physical channel in the uplink from one terminal and downlink connection within one sector.
The use of OVSF codes which allows the spreading factor to be changed and hence orthogonality among different kind of spreading codes having different lengths to be maintained. As illustrated in the Figure 2.4, the codes are taken from the code tree. In case of connections uses variable spreading factor, the correct use of code tree also allows dispreading according to spreading factor. Hence it only requires that channelization code which is used from branch indicated by the code used for spreading factor.

For the transmission of single source, there are certain restrictions as to which of the channelisation codes can be used. There is another physical channel which may use a certain code in the tree if no other physical channel to be transmitted using the similar code tree is using a code that is on an underlying branch i.e. using a higher spreading factor which is generated from the intended spreading code to be used. Within each base station, the downlinks orthogonal are managed by the radio network controller (RNC) in the network.

2.3.3 Uplink Spreading and Modulation
2.3.3.1 Uplink Modulation.
There are two additional terminal-oriented criteria in the uplink direction that need to be taken into in terms of definitions of spreading methods and modulation. The uplink modulation is designed in such a way to maximized terminal amplifier efficiency can be achieved and audible interference from the terminal transmission is minimised. Audible interference is occurred to the audio equipment due to discontinuous uplink transmission that is very close to the terminal, such as hearing aids. This is entirely a separate issue from the interference in air interface. The audible interference does not affect the network performance, such as capacity and the audible interference is only a nuisance for the user. We are familiar with the occasional audible interference with audio equipment in GSM operation and which is not properly protected. The interference has a frequency of 217Hz from GSM which is determined by the GSM frame frequencies. This interference can be heard by the human ear. The system having CDMS, the similar issues arise when transmission of discontinuous is used; for example speech service. No information bits need to be transmitted during the silent periods, only the data information transmitted for link maintenance purposes for example power control with 1.5 command rates. There is
audible interference in the middle of the telephony voice frequency band caused due to rate of the transmission of the pilot and power control symbols with time multiplexing in the uplink direction. This is why in WCDMA uplink, two dedicated physical channels are not time multiplexed but only used I-Q code multiplexing. As described in [10], following figure 2.5 shows the continuous transmission achieved with an I-Q/ code multiplexed control channel. As the power control signalling and pilot are maintained on a separate continuous channel, no pulsed data transmission occurs.

![Figure 2.5 Parallel transmissions of DPDCH and DPCCH when data is present/absent (DTX) [10]](image)

When the data channel DPDCH is switched on and off, the only pulse occurs but such switching happen quite seldom. The average interference to the cellular capacity and the other user remain the same as in the time multiplexed solution. In the both schemes, the link level performance is the same if the power control signalling and the energy allocated to the pilot is the same. The best possible power efficiency, the terminal transmission should have as low peak to average ratio as minimum as possible to allow the terminal to operate with minimum amplifier back off requirement, directly mapping to the amplifier power efficiency which is directly proportional to the terminal talk time.

I-Q/ code multiplexing which is also called dual channel QPSK modulation. Hence the power levels of DPCCH and DPDCH are typically different, especially in case of data rates increases and hence lead in extreme cases to BPSK-type transmission when transmitting the branches independently. After the spreading with channelisation code, it is avoided by using a complex valued scrambling operation.

The figure 2.6 shows the signal constellation of the I-Q/ code multiplexing before and with complex scrambling as described in [10]. The similar kind of constellation is obtained after descrambling in the receiver for data detection.

![Figure 2.6 Signal constellation of I-Q/ code multiplexing](image)

(a) Before complex scrambling
With complex scrambling

Figure 2.6 Constellation of I-Q/code multiplexing before and with complex scrambling. $\beta$ denotes the relative code factor between DPCCH and DPDCH branches [10]

The two parallel channel’s transmission of DPCCH and DPDCH leads to multicode transmission which enhances the peak to average power ratio (crest factor). As shown in the figure 2.6 the peak to average ratio changes when $\beta$ is changed ($\beta$ is the strength of DPDCH & DPCCH). The figure 2.7 shown that by using the spreading modulation solution, the efficiency of the transmitter power amplifier still the same as for normal balanced QPSK transmission. In such a way, the complex scrambling code are formed that the rotations among consecutive chips within one symbol period are limited to 90. The full rotation of 180 degree can happen only between consecutive symbols. This procedure further reduces the peak to average ratio of transmitted signal.

The full 180 rotation can be happen among consecutive symbols. This procedure further reduces the peak to average ratio of the transmitted signal from a normal QPSK transmission. Irrespective of the power difference $\beta$ between DPDCH and DPCCH, the efficiency of the power amplifier remains constant. This can be shown in figure 2.6. The figure 2.6 shows signal constellation with complex spreading for I-Q code multiplexed control channel, as described in [10]. The possible constellation points are circles or it can be crosses during one symbol period in the middle constellation with $\beta = 0.5$. For rotated QPSK, their constellation is similar. Hence following are the signal envelope variations with complex spreading very similar to QPSK with all values of $\beta$. For complete values of $\beta$, signal envelope variations with complex spreading are similar to QPSK transmission.

Figure 2.7 I-Q/code multiplexing with complex scrambling [10]
The I-Q code multiplexing solution (with complex Scrambling) which results in power amplifier output back off requirements that remain constant. This remains constant because of the function of power difference between DPCCH and DPDCH. The power difference between DPCCH and DPDCH has been measured in UTRA physical layer specifications to 4bit words. It has 16 different values. At a certain given points at particular time, the gain value for DPCCH or DPDCH is set to 1 and for other channels, a value among 0 to 1 is applied to show the power difference between the channels.

It is necessary to limit the number of possible values to 4bit representation to make the simple terminal transmitter implementation. There can be 15 different values between 23.5 dB and 0.0 dB in the power difference. The one bit combination for no DPDCH when no data to be transmitted there.

When compared to GSM technology, UTRA will face challenges in efficiency of amplifier. The modulation of GSM is GMSK (Gaussian Minimum Shift Keying) and this have fixed envelope and is basically optimized for amplifier peak to average ratio. The GSM Signal can be spread relatively more widely in the frequency domain in the narrow band system. This allows us that we can use less linear amplifier with better efficiency of power conversion. If necessary, narrowband amplifier is very easier to linerise. In practice, the WCDMA power amplifier,s efficiency compare to GSM power amplifier is slightly lower but WCDMA uses fast power control in the uplink which decrease the required average transmission power.

It would be possible to use pure code multiplexing, instead of I-Q and code multiplexing. Multicode transmission occurs with parallel control and data channels with code multiplexing. This approach enhances the variations in the transmitted signal envelope and sets higher requirements for power amplifier linearity. This is especially for low bit rates, such as speech, control channel may have an amplitude of higher than 50% of data channel which create more variations in envelope than the I-Q code multiplexing solution.

2.3.3.2 Uplink Spreading

There is an additional restriction for the DPCCH uplink spreading code. The any other Code channel user cannot used the same code even on a different Q and I branch. There is certain reason for this restriction that physical channels transmitted on the same channelisation code on I and Q branches having principle of dual QPSK channels cannot be separated before the DPCCH has been detected. Also channel phase estimates are available.

The spreading factor on DPDCH may vary on a frame by frame basic in the uplink direction. The spreading code which are taken always from earlier described code tree. The despreading operation can take advantage of the code tree structure and chop level buffering when channelisation code which used for spreading is taken from the similar branch of the code tree. The terminal provides more precisely the transport format combination indicator on the DPCCH or data rate information to allow data detection.

2.3.3.3 Uplink Scrambling Codes

By the scrambling codes, the transmissions from different sources are separated. There are two alternatives in the uplink direction, short and long scrambling codes. In the long scrambling codes, long codes with 25 degree generator polynomials are truncated to the 10 ms frame length which results 38 400 chips with 3,84 Mcps. The
length of short scrambling code is 256 chips. If the base station uses Rack receiver then long scrambling code are used. If in the base station, multiuser detectors or interference cancellation receivers are used, short scrambling codes can also be used for implementation of receiver structures. Both scrambling code families having millions of scrambling codes in the up link direction, thus the planning code is not needed.

From the extended S(2) code family, short scrambling codes have been chosen. The long code is gold codes. In the case of short codes by combining two codes, the complex valued scrambling sequence is formed and in case of long codes where the other sequence is the delayed version of first. The Scrambling code (Complex valued) which can be formed from two real valued code c1 and c2 with decimation principles as [7]

\[ c_{scrambling} = c_1(w_0 + jc_2)2k w_1, \quad k = 0,1,2, \ldots \] (2.1)

with sequences w0 and w1 given as chip rate sequences [7]:

\[ w_0 = \{1\ 1\}, \ w_1 = \{1\ -1\} \] (2.2)

The decimation factor with the second code is 2. This procedure of creating the scrambling codes will decrease the zero crossings in the constellation and hence in the modulation process, further decrease the amplitude variations.

2.3.3.4 Spreading and Modulation on Uplink Common Channels

The Random Access Channel contains preambles. As with the uplink transmission, these preambles are sent using the same scrambling code sequence. The difference between them is only 4096 chips from the start of the code period are needed and in the different way, the modulation states transitions are limited. On the rack, the scrambling and spreading is BPSK valued so only one procedure or Sequence is used to spread and scramble both quadrature and the inphase branches. This has been chosen for the RACH reception to decrease the complexity of the needed matched filter in the base stations receiver.

The part of RACH massages are spreading and modulation and the RACH massages including scrambling are identical to the dedicated channel. The available codes for RACH scrambling are transmitted on the BCH of each cell.

An additional rotation function is used on the RACH preambles for the peak-to-average reduction. This is given as [7]

\[ B(k) = a(k) e^{j(\frac{\pi}{4} + \frac{\pi}{3}k)}, \quad k = 0,1,2, \ldots 4095 \] (2.3)

Here a(k) is the binary preamble.

B(k) is resulting complex-valued preamble with limited 90 phase transition between chips. By this operation, the autocorrelation prosperities are not affected.

The RACH preambles have a modulation pattern and it is on the top of them is called signature sequence. This is defining by taking the higher Doppler frequencies and also frequencies errors into account. From 16 symbols, this sequence has been generated. This 16 signature sequence which has been specified for the use RACH but there can be multiple scrambling codes each of them using the similar set of signature.
In order to maximise the commonality for both base station and terminal implementation, the CPCH spreading and modulation are identical to those of the RACH. When supporting CPCH. In connection with the physical layer procedures, the RACH and CPCH processes will be described in more detail in it.

2.3.4 Downlink Spreading and Modulation

2.3.4.1 Downlink Modulation

Normal QPSK modulation has been chosen with time multiplexed control and data streams in the downlink control direction. Hence solution of time multiplexed is not used in uplink direction. The reason of this it would generate interference (Audible) during discontinuous transmission. The audible interference generated is not an issue in the downlink since in any case, the common channels have continuous transmission. Also there are several exist parallel code transmissions in the downlink, the same optimisation for peak to average ratio as with signal code transmission is not relevant. For the purpose of DPCCH, reserving a channelization code result in slightly worse code resource utilization when sending several transmissions by using single sources. Since the power of I and Q branches are equal, as in the uplink process, the scrambling operation does not provide a same difference to the envelope variation.

2.3.4.2 Downlink Spreading

As in the uplink and downlink, the spreading is based on the channelisation code. The code tree shares by many users under a single scrambling code, basically one scrambling code and one code tree is need or used per sector in base station. The dedicated and common channels share the similar code tree resources. There is single exception for the physical channels i.e. synchronization channel and the synchronization is not under the downlink scrambling code.

The dedicated channel spreading factory does not vary on a frame by frame basis in the downlink direction. Either a rate matching operation or with discontinuous transmission, the variation in the data is consider, even the transmission is off during part of the slot.

In case of multicode transmission for a single user, different channelisation codes for parallel code channels and are under similar scrambling code as normally all the channels are transmitted from the base station. The spreading factors for all the code channels are the same with multicode transmission. Each coded transport channels (CCtrCH) which may have many different spreading factors even if received by the same terminal. Normally QPSK modulation is used as in the downlink, the number of available spreading code is equal to the spreading factor. If considered the little spreading factor of 4 then all these four are available but due to the common channel requirements for code space then three code could be allocated for use of particular terminal. For uplink, the possible numbers of bit roughly equal to six codes as each QPSK symbol carries two bits. The downlink shared channel (DSCH) is a special case in downlink direction which can use variable spreading factor on a frame by frame basic. The figure 2.8 shows the restriction specified which shows the spreading factors for maximum data rate and the part of the code tree as shown in [7]. DPCCH channel contains the TFCI information in frame by frame operation which informs the receiver what type of spreading code is used and also other transport format parameters for the DSCH.
2.3.4.3 Downlink Scrambling

Long codes are used for downlink scrambling, the similar gold codes are used as in the uplink. The scrambling code (Complex valued) is generated from a single code by simple having delay between Q and I branches. In 10 ms code period is truncated, short codes are not used in the downlink direction. The downlink scrambling code is limited to 512 codes. The scrambling codes which are allocated to the sector in the network planning. This is because the number of scrambling codes is high, the planning of scrambling code is a trivial task and this can be done by the network planning tool automatically.

From the cell planning perspective, the 512 primary scrambling codes are expected to be enough, especially as the secondary scrambling may be used in beam steering, as used on dedicated channels. This allows the capacity without consuming extra primary scrambling codes to evolve with adaptive antenna techniques and this causing problems for the downlink code planning.

The actual code period with the 18 degree code generator is very long but only the first 38 400 chips are used. From the system perspective, limiting the code period was necessary. The terminal may find difficulty to find the correct code phase with a code period spanning several frames and different 512 codes to select from.

With the exception of those common channels, the secondary downlink scrambling codes may be applied that require to be heard in the whole cell. Per cell, only one scrambling code is used or sector to maintain the orthogonality between different downlink code channels. The beam provides additional spatial isolation with adoptive antennas and orthogonality among different code channel is less important. However, the best strategy to keep as many user as possible under one scrambling code to
minimise downlink interference. The highest loss occurs in the orthogonality when
the user are shared between two different scrambling codes.

2.3.4.4 Synchronisation Channel Spreading and Modulation
The downlink synchronisation channel is not visible above the physical layer and is a
special type of physical channel. It consists of two channels, primary and secondary
SCHs.
To find the cells, these channels are utilised by the cells, and these channels are not
under the specific primary scrambling code. Before knowing the downlink scrambling
code, the terminal must be able to synchronise to the cell. The primary SCH have
code word with 256 chips, and with an identical code word in every cell. The primary
SCH code word is sent without modulation. In order to optimise the required
hardware at the terminal, the code word is constructed from 16 chips shorter sequence.
Basically a matched filter is needed for detection and when detection this sequence,
normally no prior timing information available. Therefore, it is important to optimise
this synchronization sequence for low-complexity matched filter implementation for
power consumption reason & terminal complexity.
The similar sequences of secondary SCH code words but it vary from one base station
to another base station and hence there are total 16 sequences in use. From the use of
these 16 sequence, a total of 64 different code words are generated which identify to
which of the 64 code groups a base station belongs. As similar to primary SCH, SCH
secondary is not under the base station specific scrambling code but the code
sequence which is sent with scrambling. To indicate the use of open loop transmit
diversity on the BCH, the SCH code words contain modulation.
The SCH
Time-switched transmit antenna diversity (TSTD) itself can used by the SCH and it is
the only channel in UTRA FDD that uses Time switched transmit antenna.

2.3.5 Transmitter Characteristics
The pulse shaping method which applied to the transmitted symbols. It is root raised
cosine filtering with a roll-off factor of 0.22. The similar roll-off is valid for both base
stations and terminal. There are some other key RF parameters. These RF parameter
are introduced here. These RF parameters have an essential impact on the
implementation and also on the system behaviours.
5 MHZ is the normal carrier spacing in WCDMA but WCDMA carrier frequency can
be adjoined with a 200 KHz raster. The each WCDMA carrier central frequencies is
indicated with an accuracy of 200 KHz. Within the operator’s band, this target
adjustment provides more flexibility for Channing spacing.
The Adjacent Channel Leakage Ratio (ACLR) which determines how much
transmitted power is allowed to leak into the first or second neighbouring carrier.
Figure 6.10 in [7] illustrate the concept of Adjacent Channel Leakage Ratio (ACLR).
In the said figure, ACLR1 and ALCR2 correspond to the power level over first and
second adjacent carrier and carrier separation with 5 MHZ and 10 MHZ respectively.
For other values of carrier spacing, there are no separate values specified.
If we see the above said figure, the ACLR values for power classes of 21 dBm and
24dbm set to 33 dB and 43 dB respectively on the terminal side. The corresponding
values are 45 dB and 50 dB on the base station side. It is most likely that most of the
terminals will belong to the 21 dBm power class in the 1st phase of network
deployment and network needs to be planned accordingly to that.
The more linearity is required from the power amplifier if higher the ACLR requirement and hence the lower the amplifier efficiency. The accuracy of the frequency requirements are directly related to the implementation cost, mostly on the terminal side. When compared to the received carrier frequency, the accuracy of the terminal frequency has been defined to be 0.1 ppm. The requirement is tighter on the base station i.e. 0.5 ppm. The baseband timing is tied to the same timing as RF. The base station value requires being tighter than the terminal value since the carrier frequency of base station is the reference for the terminal accuracy.
Chapter 3: Physical Layer Procedures

3.1 Introduction
There are many essential procedures for system operation in the physical layer of a CDMA system. Example of this system operation includes fast power control and random access procedures. There are also other important physical layer procedures are handoff measurement, paging and operation with transmit diversity. With the CDMA specific properties of the UTRA FDD physical layer, these procedures have been naturally shaped.

3.2 Fast Closed Loop Power Control Procedure
According to UTRA specification, the fast closed loop power control procedure is denoted as inner loop power control. In the CDMA based system, it is essential to be known because of uplink near-far problem. The fast power control operation that operates on the basis of one command per slot which results in a 1500 Hz commands rate. The basic step size is 1 dB. In spite of this, multiples of that step size can be used and step size in smaller can be emulated. The emulated step means that 1 dB step is used for example only every second slot thus emulating the 0.5 dB step size. It is difficult to implement the True step sizes which are below the 1 dB with reasonable complexity, as it is difficult to ensure achievable accuracy over the large dynamic range. The specifications which define the accuracy for a 1 dB power control step to be 0.5 dB. Also there is another “true” step size specification is 2 dB.

There are two special cases for fast power control operation: one is the operation with soft handoff and other with compressed mode in connection with handoff measurements. Special concern is needed for soft handoff as there are many base station transmitting commands to a single terminal and in the compressed mode operation, breaks in the commands stream are provided periodically to the terminal.

In soft handoff how to react to multiple power control commands from several sources is the main issue for terminal. This issue has been solved by specifying the operation in such a way that commands are combined by the terminal but it also takes reliability of each individual commands decision in connection with deciding whether to increase or decrease the power. In case of compressed mode, fast power control uses a large stop size for a short period after a compressed frame. This allows that after a break in the control stream, the power level to converge more quickly to the correct values. The requirement of this method heavily depends upon the environment and this method is not relevant for very short transmission gap lengths or the lower terminal.

The target of SIR for closed loop power control and is set by the outer loop power control. In the terminal side, it is to be done inside a terminal in term of fast power control operation is specified rather strictly. Hence there is much freedom to decide how a base station should behave when it receive a command of power control on the network side, also on the basis on which the base station (BS) should tells a terminal to increase or decrease the power level.

3.3 Open Loop Power Control
There is an open loop power control in UTRA FDD and this open loop power control is only applied prior to initiating the transmission on the CPCH and RACH. Hence the open loop control is not very much accurate since large dynamic power in the terminal equipment is difficult to measure accurately. The mapping of the received
absolute power to the absolute power to be transmitted shows a big deviations, this is due to variation in components properties and as well as the impact of weather specially temperature. Also different frequencies are used for transmission and reception but accuracy inside the terminal is the main source of uncertainly. In normal condition, the requirement for open loop power control accuracy is specified to be within 9 dB.

In earlier CDMA systems use open loop power control such as IS-95, being active with closed loop power control in parallel configuration. The motivation for this kind of usage was to allow corner effects or other rapid environmental effects to be covered. UTRA fast power control has approximately double the command rate and result was concluded that the adjustment range of 15 dB does not require open loop power control to be operated simultaneously. In spite of this, the fast power control step size can also be increased from 1dB to 2 dB which allows a correction range of 30 dB during a 10 ms frame.

The usage of open loop power control while in active mode also has some impact on link quality. The huge amount of inaccuracy of open loop power control can cause to make adjustments to the transmitted power level although it is not required. The behaviour depends upon various environmental variables and unit tolerances (terminal), running open loop power control makes it more complex to predict how a terminal will act in different conditions from the network side.

3.4 Paging Procedure

The paging channel (PCH) operation is organised as follow. When a terminal is registered to a network, it has been allocated a paging group. There are paging Indicators (PI) for the paging group which appear periodically on the paging indicator channel (PICH) when there are paging massages for any terminals belonging to that paging group.

Once a paging Indicator has been detected, the terminal decodes the next coming PCH frame which is transmitted on secondary CCPCH to observe that there was a paging messages intended for it. In case the Paging Indicator (PI) reception indicates low reliability of the decision, the terminal may also need to decode the PCH. The figure 3.1 illustrates the paging interval $\tau_{PICH}$. Paging interval is usually 7680 chips long [7]. If PIs appear less than the terminal are mostly in sleep mode and less time in wake up mode according PIs and this will cause a longer battery life. The trade-off is response time to the network originated call. An infinite paging indicator interval does not lead to infinite battery duration, as terminal needs to perform other task during idle model.

![Figure 3.1 PICH relationships to S-CCPCH [8]](image)

3.5 RACH Procedure

In CDMA system, the random Access procedure has to cope with the near far problem, as there is no exact knowledge of required transmission required when initiating the transmission. Large uncertainly in the open loop power control in term
of absolute power values which received from power measurement to the transmitter power level values in connection with open loop description. In UTRA, the following phases are in RACH procedures are [7]

- To find out the available RACH sub-channels and their scrambling codes and signatures, the terminal decodes the BCH.
- The terminal selects one of the RACH Sub-channels randomly from the group its access class allow it to use. In spite of this, signature is also randomly selected.
- Initial RACH power level is set with proper margin because of open loop inaccuracy and downlink power level is measured.
- A I ms RACH preamble is sent with the selected signature.
- AICH is decoded by the terminal to see that the base station has detected the preambles.
- In case of there is no AICH detected, preambles transmission power is increased by the terminal by a step given by the base station as multiple of (one) 1 dB. In the next available access slot, the preambles is retransmitted.
- The terminal transmits the 10 or 20 ms massages part of the RACH transmission when an AICH is detected from the base station.

The figure 3.2 illustrates the RACH procedure. As shown in the figure, the terminal transmits the preambles until acknowledgement is received on AICH and the massage part follows.

![Figure 3.2 PRACH ramping and message transmission][8]

The spreading factor and data rate can vary in case of data transmission on RACH. This is indicated with the TFCI on the DPCCH on PRACH. Spreading factors from 256 to 32 have been defined and thus a single frame on RACH may have up to 1200 channel symbol which is depending on channel coding, maps to around 600 or 400 bits.

The achievable range is less than what can be achieved with the lowest rates for the maximum numbers of bits, especially in case as RACH massages do not use procedure such as macro-diversity.

### 3.6 CPCH Operation

The uplink common packet channel (CPCH) is similar to RACH operation. Layer 1 collision detection (CD) is the main difference that is based on a single structure similar to that of the RACH preambles. The RACH procedure follows by the operation until the terminal detects AICH. After that Collision detection (CD) having the equal power level is still sent back with another signature, randomly selected from
the given set. Then on the CD Indication Channel (CD-ICH), the base station is expected to echo this signature back to the terminal and in this way to create a method of reducing the collision probability on Layer 1. The terminal starts the transmission after the correct preamble has sent by the base station on the collision detection method which may last over several frames.

As longer the duration of transmission of data, more the need for physical layer based collision detection mechanism. In RACH operation, due to collision only one RACH massages may end up lost, where an undetected collision may cause several frames to be sent with CPCH and this will cause extra interference.

On CPCH, the fast power control helps to decrease the interference because of data transmission. It also highlights the importance of added collision detection to RACH. Data transmitted over several frames by the terminal and following a power control command stream which is intended for other terminal would create a problem of severe interference in the cell. This is especially when large data rates are transmitted or received. When the CPCH transmission starts, an optional power control preambles can be sent before transmitting the actual data. Hence this allows power control to converge, as a long delay is there with CPCH then with RACH among transmission of actual data frame and acknowledged preamble. The preamble of 8 slot power control also uses a 2 dB step size for faster power control convergence. A CPCH must need some restriction on maximum duration, since CPCH does not support soft handoff and also compressed mode to allow inter-frequency or intersystem measurements.

During service negotiations, UTRAN sets the maximum CPCH transmission.

The status monitoring and channel assignment function are the latest addition in CPCH operation. The CPCH Status Indication Channel (CSICH) which is separate physical channel. CSICH sent from the base station and CSICH has indicator bits which are used to indicate the status of different CPCH channels. When all CPCH channels are busy this avoids unnecessary access attempts so this way the throughput of CPCH will also be improved. The system has the option of Channel Assignment functionality, in the form of a CA massages which may direct the terminal to a CPCH.

The CA massages and collision detection massage are sent in parallel with each other.

### 3.7 Cell Search Procedure

In asynchronous CDMA system, the synchronization procedure or cell search procedure is greatly differs from the method in a synchronous system like IS-95. Since the different scrambling codes are used in cells in asynchronous UTRA CDMA system and not just like different code phase shifts. Also without any prior knowledge, terminal with current technology cannot search for 512 codes of 10 ms duration. Hence there are a lot of comparisons to make and very long interval in the terminal from power-on to the service availability indication would experienced by the user.

Basically there are three steps in the cell search procedure using synchronization channels, there will be no as such requirements as to which steps to perform and when. Rather in reference test conditions, the standard will set requirements for performance in terms of maximum search duration. For initial cell search, the basic steps are as follow [7]

1. 256 chips primary synchronisation code search by the terminal, being identical for all cells. As in every slot the primary synchronization is the same, the highest detected corresponds to the slot boundary.

2. The terminal seeks the largest peak from the Secondary SCH code word based on the peak detected for the primary synchronization code. Basically 64 possibilities are there for the secondary synchronization code word. 15 positions
have to check by the terminal, as the frame boundary is not available before secondary SCH code word detection.

3. The frame timing is known once the secondary SCH code word has been detected. The terminal then seeks the primary scrambling codes that is related to the particular code group. Each group has eight primary scrambling codes. For single position, these codes need to to tested only and as the starting point is known already.

The properties of synchronisation need to be taken for optimum performance, when perform the network parameters setting. There is no practical impact for initial cell search but the target cell search can be optimized in connection with handoff. Hence there are large numbers of code groups, in a practical planning situation one can implement the neighbouring cell so that all cells in the particular list for one cell belong to a different code group. Thus target cell can be searched by the terminal and skip 3 steps.

There is further ways of improving cell search performance. It also includes the possibility of providing information on timing among the cells. In this case, this kind of data information is measured by the terminals for soft handoff purposes, especially this can also be used to improve the step 2 performance. If timing information is relative more accurate, for the secondary SCH code word the fewer slot positions need to be tested and the correction detections probability is better.

3.8 Transmit Diversity Procedure

As already mentioned that UTRA uses two types of transmit diversity transmission for user data performance improvement in connection with the downlink channels. These methods are classified as closed loop and open loop. In this section we describes the feedback procedure for closed loop transmit diversity. Hence in connection with downlink dedicated channels, the open loop method was covered.

Two antenna are used in base station to transmit the user information in the case of closed loop transmit diversity. The usage of these two antennas is based on feedback from the terminal and these antennas transmitted in the feedback (FB) bits in uplink DPCCH. The closed loop diversity also has two separate modes of operation.

In mode 1, the terminal feedback commands which is used to control the phase adjustments and is expected that the received power by the terminal is maximised. With antenna 1, the base station maintains the phase and then adjusts the antenna 2 phase after receiving two consecutive feedback commands. Four different kinds of phase settings are applied to antenna 2 with this method.

In mode 2, both the amplitude and phase are adjusted and hence the same signalling rate is used but the command which is spread over four bits in four uplink DPCCH slots, only single bits is used for amplitude and three bits are used for phase adjustment. Total of 8 different phases are obtained from this combination, also two different amplitude combinations and thus 16 combinations are obtain for signal transmission from base station. The values of amplitude have been defined to be 0.2 and 0.8 which evenly distributed the phase values for the antenna phase offsets which is from -135 to +180 phase offset. In this mode, only phase information is contained by the last three slots of frame and information about amplitude is taken from the previous four slots. Hence this allow the command period to proceed even with 15 slots as happen in mode 1, to avoid discontinuities in the adjustment process where the average at the frame boundary is slightly modified.
The method of closed loop may be applied on dedicated channel or with a DSCH dedicated channel only. Hence the open loop method which may be used on both the dedicated and common channels.

### 3.9 Handoff Measurements Procedure

The possible handoffs with UTRA FDD are as follows [7]

- **Intra-mode handoff** which can be softer handoff, also soft handoff or hard handoff.
- **Inter mode handoff**: As handoff to the UTRA TDD mode
- **Inter-system handoff**, only GSM handoff. The GSM handoff may take place in GSM operating system and these handoff operates at frequencies 850 MHZ, 900 MHZ, 1800 and 1900 MHZ respectively.

#### 3.9.1 Intra-Mode Handoff

The UTRA FDD intra-mode handoff relies on the measurements of $E_{c}/N_0$ which are performed from common pilot channel. The defined quantities from the common pilot channel and it can be measured by the terminal are as follow [7]

- **Received signal code power** (RSCP) is a received power which is received after despreading from one code, defined on the pilot symbols.
- **Received Signal Strength Indicator** (RSSI) that is basically a wideband received power within the channel bandwidth.
- **$E_{c}/N_0$** which is representing the received signal code power divided by the total received power in the channel bandwidth and is defined as RSCP/ RSSI.

In UTRAN, there are a lot of other items which can be used for basic for handoff decision, as the actual handoff algorithms are left because of an implementation issues. One parameter has been dedicated as channel SIR as mentioned in the standardisation discussions and this parameters is providing information about the cell orthogonality and being measured in any case for power control purpose.

Timing information between the cells is the additional important information for soft handoff purposes. As happen in an asynchronous network, in soft handoff, there is a requirement to adjust the transmission timing to allow coherent combination in the Rake receiver, otherwise the different base stations transmission’s would be difficult to combine and especially there is additional delay in the power control operation in soft handoff.

The Figure 3.3 illustrates the timing measurement in connection with soft handoff operation. The news base station which adjusts the downlink timing and the downlink timing is adjusted in step of 256 chips based on the information received from the RNC.
The timing can be found from the primary scrambling code phase when the cells are within the 10 ms window, since the code period 10 ms is used. The terminal required to decode the system Frame Number (SFN) which is from the primary CCPCH if the timing uncertainty is larger. It always takes time and also it can face problem from the errors, which needs a Check CRC to be made on SFN. There is no relevance of 10 ms window when timing information is given in the neighbouring cell list. In such kind of case, unless base station are synchronised to chip level, the phase difference of the scrambling codes only needs to be considered.

Such accurate timing information on chips level is not required for the hard handoff between different frequencies. If take the other measurements that are more helpful as the terminal must make the measurements on other different frequencies. This is done with the help of compressed mode.

### 3.9.2 Inter-Mode Handoff

On request from UTRAN, the dual mode terminals FDD-TDD which is operating in FDD mode measure the power level. This power level is from the TDD cells which is available in the area. The bursts of TDD CCPCH which sent two time during the 10 ms and also FDD frame can be used for measurement, since they are guaranteed to always exist in the downlink. The TDD cells are synchronized in the same coverage area and finding one slot means that other TDD cells with reference to power have the same timing for their burst.

### 3.9.3 Inter-System Handoff

For UTRA-GSM handoff, the same kinds of requirements are valid for GSM handoff. During the compressed frames in UTRA FDD, the terminal receives the GSM synchronisation channel (GSM SCH) to allow the measurements from other frequencies.
There are special requirements set by GSM 1800 for compressed mode and also needed that compressed mode was specified for uplink. TDD measurements are also needed.

### 3.10 Compressed Mode Measurement Procedure

The compressed mode which often referred as slotted mode is required in CDMA system when taking the measurements from another frequency without the help of full dual receiver terminal. The compressed mode means that the transmission and reception are blocked for short time duration of few milliseconds, in order to take the measurements on the other frequencies. Basically intention is to compress the data transmission in time domain and there is no intention to lose data. By using three different methods, we can achieve the frame compression which is as follow [7]

- By decreasing the data rate from the higher layers, as the higher layers having a knowledge of the compressed mode which is schedule for the terminal.
- By changing the spreading factor, the data rate is increased. For example, in spite of using spreading factor 64, the 128 spreading factor will doubles the number of available symbols and also make is easy to achieve the required compression ratio for the frame.
- Decreasing the symbol rate by puncturing at the physical layer multiplexing chain. As there is some practical limits in the puncturing and this is limited to the Short Transmission Gap lengths (TGL). This has the advantage of keeping the existing spreading factor and hence there is no cause of new requirements for channelisation code usage.

Normally the compressed are provided in the downlink and it can also be provided in uplink in some cases as well. The compressed frames need to be simultaneous with the downlink if compressed frames appear in the uplink. The following figure 3.4 shows the uplink and downlink compressed mode frame structure. Compressed mode frame structure for uplink is shown in figure 3.4a while for downlink; it is shown in figure 3.4b.

![Compressed frames in Uplink and Downlink](image)
The specified Transmission Gap Length (TGL) are as 3, 4, 5, 7, 10 and 14 slots respectively. From the single and double frame methods, the TGL lengths of 3, 4, and 7 can be achieved. Only the double frame method can be used for TGL lengths of 10 or 14. This will allow us to minimising the impact during a single frame. For example, the increment required in the transmission power is lower than with single frame method. The case when reinforcements uplink compressed are always required with UTRA is the measurements of GSM 1800, close to where the narrow proximity of the GSM 1800 downlink frequency band to the core UTRA FDD uplink frequency band at 1920 MHZ and hence upward is very close to allow simultaneous transmission and the reception.

The use of UTRA inter frequencies handoff or compressed mode in uplink with GSM 900 depends on terminal capability. If we want to maintain the continuous uplink, the terminal has to generate the an additional parallel frequency and also need to maintain the existing frequency. In practice, this is observed that additional oscillators which are used for frequency generation and also duplicated components which add to terminal power consumption.

As far as link performance is concerned, the use of compressed mode has a great impact to improve the performance on link. If the terminal is not at the cell edge then the link performance does not deteriorate very much. Also to compensate the momentary performance loss with fast power control, a room is there. This will cause a largest impact at the cell edge, the difference between compressed mode and noncompressed mode for uplink performance is very less until head room is less than 4 dB. The difference from the normal transmission that are between 2 and 4 dB at 0 dB headroom, also depending on the transmission gap duration with compressed frame. The 0 dB headroom which is related to the terminal operation at full power at the cell edge with 0% possibility of (soft) handoff and with no room to run fast power control. The soft handoff ( or handoff in general) will improve the situation, since headroom values are occur very rarely, there is some overlap in the coverage of the cell in the case of typical planning and the case of 0 dB headroom should only occur when leaving the coverage area.

From the above values, the time available for sampling of other frequency is decrease, this is due to hardware required time to switch the frequency. Thus very short values of 1 or 2 slots have been excluded, as there is no practical time available for measurements. In the specifications, the smallest 3 value is used which only allows very short measurement time window and only should considered for specific cases.

### 3.11 Other Measurements

Some other measurements are required in the base station to give RNC sufficient data on uplink status and also transmission power of base station resource usage. The points given below have been particularly specified for base station, to be supported by the signalling among RNC and base station. [7]

- Uplink SIR on the DPCCH.
- All transmission power on a single carrier at the transmitter of the base station, it gives us data on the power resources available at the base station.
- RSSI, to give information on the uplink load.
- The transmission code on a single code for one terminal which is used for example, in soft handoff for balance of power among radio links.
- Block Error rate (BLER) and Bit Error Rate (BER) estimates for different physical channels.
The terminal BLER measurement has the main responsibility to provide feedback outer loop power control operation which helps us in setting SIR target for power control operation. From the physical layer, support of position location functionality required measurements. For this purpose, another type of timing measurement is defined that gives the difference in time between the primary scrambling codes of different cells with 41-chip resolution. In theory, achievable position accuracy can be estimated from the fact that one chip corresponds approximately 70 m in distance. There are further many factors that are contribution to the achievable accuracy. The terminal which is very close to base station and to evaluate the impact of near far problem on that terminal, the specifications also contain procedure of introducing idle periods. This will enables timing measurements which is from base stations otherwise that would be too weak because of close proximity of the serving BS.

3.12 Operation with Adaptive Antennas
UTRA has been designed for the use of adaptive antennas both in the form of uplink and downlink directions transmission. Basically two types of beam forming one may use. Either in case, the beam may use secondary common pilot channel (S-CPICH) or beam may also use the dedicated pilot symbols. With reference to the physical layer point of view, the use of adaptive antennas is fully covered with release 99 but in different operation scenarios, the exact performance requirements for terminals are covered in release 5. Different kind of beam forming can be applied with different channels, it depends on the channel whether the channel has dedicated pilot symbols or not. Beam forming could only be used in theory for the S-CPICH but in practice it is not reality as the channels is intended to be received by many other terminals and hence terminals do not support the slot format with pilots. Also the short distance communication would be difficult because it take some time.

Complete support for beam forming parameterization was completed in the UTRAN side for release 5. Hence it includes phase reference change signalling from RNC to Node B. Release 6 has additional other functionality which help in further improvement in the radio resource management of the beam forming.

3.13 Site Selection Diversity Transmission
The site selection Diversity transmission (SSDT) was included in Release 99 specifications and SSDT is a specific mode of soft handoff. SSDT was only completed from the UTRAN point of view in Release 5 specification. SSDT features principle is based on the feedback signalling from the terminal, the Node Bs which is set active may transmit only DPCCH part of the transmission and hence DTX is used for data part.

ID of the strongest Node B, the terminal will send in the uplink based on the CPCCH measurements, the time interval between 2 ms and 10 ms, it interval depends upon the length of the ID code word and also depend upon the number of feedback bits which are allocated for SSDT and hence use in the uplink direction. All Nodes Bs which receive data from RNC in the network side but only the correct code word having good quality shall send the data onwards to the DPDCH of the downlink DCH. The minimum quality of level of SIR determined by the $Q^{th}$ parameter and in order to valid the non primary commands, the Node B must receive this. The figure 3.5 shows the principle of SSDT and the figure illustrates the example of two Nodes Bs is in the active set.
In spite of the original purpose of transmission of SSDT in the downlink, the uplink SSDT can also be used for some other purposes. The specifications of Release 4 and Release 99 do not contain the definition of Q and that definition was included in the Release 5 specifications. The Release 99 and Release 4 in which UTRAN sides only use the long ID words (i.e. 5 or 10 ms duration) to ensure good reliability in the performance while in the Release 5 other length of ID words are also supported. Hence the specifications do not allow simultaneous use of SSDT with HSDPA. This configuration does looks impressive because rather low rate of the DCH with HSDPA thus leaving very less potential in the improvement of SSDT.
Chapter 4 : Radio Resource Management

4.1 Introduction
Radio Resource Management is the system level control of co-channel interference and radio transmission characteristics in wireless communication systems. RRM techniques are used to improve the utilization of radio resources of the wireless network.

The main theme behind the UMTS is to deliver the multimedia services characterized by stringent real time requirements, great sensitivity to delivery delay and packet loss and the need for considerable wireless resources. There are four basic classes of service in UMTS for quality of service (QoS) provisioning [12]. These classes are

1. Conversational : (High sensitivity to delay and jitter)
2. Streaming : (Medium sensitivity to delay and high to jitter)
3. Interactive : (Low sensitivity to delay, high sensitivity to round trip delay (RTD) time and bit error rate (BER))
4. Background : (no sensitivity to delay, high sensitivity to BER)

All these classes impose different quality of service requirements. So to maintain these requirements during communication, management of radio resources of network is necessary. The main objectives of radio resource management are

- Maximize the performance of all users with coverage and capacity
- Guarantee the quality of service for different applications
- Maintained the planned coverage
- Optimized the system capacity

Radio resource management is divided into two phases as follows:

1) **Radio resource configuration**: It is responsible for allocating the proper resources to new requests coming into the system as a result it will not cause network to become overloaded thus compromising stability of network. However the congestion might occur, thus effecting QoS due to the mobility of users.

2) **Radio resource re-configuration**: It is responsible for re-allocating the resources within the network when load is building up or congestion starts to occur to maintain QoS for different applications through out the network. It should change overloaded system back to target system by rearranging the resource between various applications on the same network. Thus Radio Resource Reconfiguration is also very essential part of RRM and infect of UMTS.

4.2 Functions
There are three main functions of radio resource management. [10]

1) Power Control
2) Handoff control
3) Congestion control

Congestion control is subdivided into the three functions which are

- Call Admission control
- Load control
• Packet scheduling control

Following figure 4.1 shows the radio resource management functions implementation on different areas of a wireless network.

![Figure 4.1. Location of RRM functions. [13]](image)

There are different algorithms for RRM functions. RRM algorithms mostly consist of mechanisms for efficient power control, handoff control, Admission control, load control, and packet scheduling functionalities.

To give introduction why specific functional areas of RRM are important we have Power Control to maintain the interference levels at minimum in the air interface, to preserve power resources in cell as well as for network so its power level of some link is neither so low to have more noise level nor to high to interfere with other links and to give the required quality of service. Handoffs are inevitable in cellular systems to guarantee the mobility of the User Equipments across specific cell boundaries and infect across type of networks. And algorithms like admission control (generally called call admission control), load control and packet scheduling maintain quality of service as well as ensures steady throughput of the system.

4.3 Power control

Power control is the most important and critical function of radio resource management. In WCDMA, many users are using same radio frequency. So interference is a very crucial issue in WCDMA. In CDMA systems, power control is very essential for radio communication due to the interference limited nature of CDMA systems and responsible for adjusting the transmit powers to minimum level required to ensure the required quality of service limitations.

Power control is especially important for uplink transmission. When a UE is transmitting something, at the same time its transmission also cause interference for the other UEs in that area. In uplink transmission, if a user equipment is transmitting high power signals at a close location to the node b, can easily over shout the other user equipments which are at the more distance than him or at cell edge. It can even block the whole cell. On the other hand if a UE is transmitting at very low power then NodeB will never hear that UE. This phenomenon is known as near-far problem. Whereas in the downlink transmission, the radio system capacity is determined by the required power for each user equipment. That’s why this is essential to transmit the signal at minimum level with required signal quality at receiving end.

The main objectives of power control in UMTS are

• Provide sufficient power for each user equipment
• Control interference
• Overcoming the near-far effect
• Maximize the battery life of the user equipment
WCDMA employees a group of functions is introduced for power control. These functions are
- Open Loop Power Control
- Closed Loop Power Control

Open loop, inner loop and outer loop power control are used both in uplink and downlink directions. [10]

4.3.1 Open-loop power control

Open loop power control is performed in UE. In open loop power control, a UE’s transmitter sets its transmission power to a specific value when the transmission begins with the network. In other words, when a UE starts accessing a radio network, use open loop power control for initial transmission power settings for both uplink and downlink directions. The open loop power control tolerance is ±9dB in normal conditions or ±12dB in extreme conditions [14].

In Open loop power control, UE examines the received power level measurements of Common Pilot Channel (CPICH) to set its initial power level. The power of received pilot signal reduces as distance between UE and Node B increases, and increases as distance between UE and Node B decreases. Node B transmit power control information on the broadcast channel which gives the actual transmitted power information of the CPICH from Node B because UE cannot retrieve any information of actual power of received pilot signal from the analysis of CPICH. With the help of this information, a UE can estimate the path loss and thus it can estimate the distance from the NodeB and power required to transmit the signal from that UE. This estimation of initial power settings in uplink and downlink direction based on path loss calculations in downlink direction is denoted as open loop power control. In UMTS Open-loop Power Control is done separately for uplink and downlink. So open loop power control can be further subdivided into two parts
- Uplink Open Loop Power Control
- Downlink Open Loop Power Control

In the case of uplink open loop power control, UE measured the Received Signal Code Power (RSCP) of the active Primary Common Pilot Channel (P-CPICH) and some control parameters transmitted by NodeB on broadcast channel. These control parameters are CPICH downlink transmit power ($CPICH_{TXpwr}$), uplink interference (UL_int) and required carrier to interference ratio for uplink (UL_CI). Then UE sets the power of first Physical Random Access Channel (PRACH) transmitted preamble as [10]

$$\text{Initial Power} = CPICH_{TXpwr} - CPICH_{RSCP} + UL_{int} + UL_{CI}$$

(4.1)

And when establishing the first Dedicated Physical Control Channel (DPCCH), the UE starts the uplink inner loop power control at a power level [10]

$$\text{DPCCH Initial Power} = \text{DPCCH Pwr Offset} - \text{CPICH RSCP}$$

(4.2)

Where DPCCH power offset (DPCCH Pwr_Offset) is the measured by the following equation [10]

$$\text{DPCCH Pwr Offset} = CPICH_{Tx Pwr} + UL_{int} + SIR_{DPCCH} - 10\log_{10}(SF_{DPCCH})$$

(4.3)
DPCCH_Pwr_Offset is calculated by admission control in RNC. SIR_{DPCCH} is the initial target SIR and SF_{DPCCH} is the spreading factor of the corresponding DPCCH. In downlink open loop power control, the initial power of downlink channels is set. Initial power for the DPDCH can be calculated by

\[ P_{WR} = \frac{R \left( \frac{E_b}{N_0} \right)_{DL}}{W} \cdot \frac{(C/P)_{TxC} - \alpha P_{TXTotal}}{(E_c/N_0)_{CPICH}} \]  

(4.4)

Where R is the bit rate, \((E_b/N_0)_{DL}\) is the downlink planned \(E_b/N_0\) value, W is the chip rate, \((E_c/N_0)_{CPICH}\) is reported by UE, \(\alpha\) is downlink orthogonality factor and \(P_{TXTotal}\) is the carrier power measured at Node B.

4.3.2 Closed Loop Power Control
Closed loop power control is further subdivided into two types.
1. Inner Closed Loop Power Control
2. Outer Closed Loop Power Control

4.3.2.1 Inner Closed Loop Power Control
Inner closed loop power control or simply inner loop power control is also known as fast closed loop power control. In inner loop power control, transmitter of user equipment adjust transmitted power in accordance with the transmit power control commands transmitted by NodeB to achieve the a better signal to interference ratio (SIR) nearest to given target SIR. Transmitter changes its power with step size 1, 2 and 3 dB steps after receiving the transmit power control command [14].

WCDMA air interface is organized in frames. Each frame’s duration is 10ms and each frame contains 15 time slots. There is one transmit power control command in each time slot and transmitted power has a fixed value during a time slot. So the power control update rate is 1500 bps [15].

Inner loop power control is responsible for neutralize the fading of radio channel and keep close the signal to interference ratio of uplink transmission to SIR target set by outer loop power control.

In inner loop power control, NodeB measures the received signal quality i.e SIR of uplink transmission and compare it with the target SIR. If the calculated SIR is less than the target SIR, then it will send the transmit power control command “1” requesting a transmit power increase for uplink transmission. Otherwise it will send the transmit power control command “0” requesting a transmit power decrease for uplink transmission. Now transmitter for uplink transmission takes necessary action on these commands. Following figure 4.2 shows the inner loop power control procedure.

![Figure 4.2 Inner Closed Loop Power Control at NodeB](image-url)
4.3.2.2 Outer Closed Loop Power Control
Outer Closed Loop Power Control or simply outer loop power control is responsible for the calculation of target SIR to maintain the quality of communication with lowest possible transmission power.
Outer loop power control is the part of Radio Resource Control Layer. It sets the target SIR value according to the received Block Error Rate (BLER) or Bit Error Rate (BER), in order to match the required BLER or BER. Its update frequency is 10-100 MHz [15].
According to operation, outer loop power control can be divided into uplink outer loop power control and downlink outer loop power control. The uplink outer loop power control sets the target SIR value for each uplink fast closed loop power control in NodeB. This target SIR has different value for each UE, attached with that NodeB, according to their uplink quality for each radio resource control connection [14]. The downlink outer loop power control mainly operate within the user equipment. This is responsible for the convergence of required link quality set by Radio Network Controller (RNC) in downlink[14]. So the main responsibility of outer loop power control is to maintain the quality of uplink communication.

4.4 Handoff Control
The mechanism that transfers an active call from one cell to one of its neighboring cell with subscriber’s movement is called handoff. Handoffs are very important in cellular architecture. Handoff provides freedom of mobility within the boundaries of the cellular system. But this mobility can cause some problems related to link quality and interference level during communication. So a mechanism to control this procedure is necessary in order to cope with the problems. The cell in which UE is currently connected is known as active cell and the neighbor cell in which UE can connect after handoff is known as candidate cell. Each handoff requires network resources in the candidate cell in order to transfer the ongoing call with quality of service requirements. In UMTS, Radio Network Controller (RNC) is mainly responsible for the handoff control.
Main objectives of handoff control are

- Ensure the stability of ongoing call with required quality of service
- Guarantee the stability of service
- Minimizing the interference level of whole wireless system
- Load balancing in wireless system

Handoff control in UMTS can be divided into the four types of handoffs describe as [10]:

- Intra System Handoff
Intra system handoffs occur within the a UMTS system. There are further two subtypes of intra system handoffs
  1. Intra Frequency Handoff
     Intra frequency handoffs occur between the cells having same carrier frequency.
2. Inter Frequency Handoff

Inter frequency handoffs occur between cells having different carrier frequency.

- **Inter System Handoff**
  
  Inter system handoffs occur between two different radio systems like between UMTS and GSM, or UMTS and IS-95 etc.

- **Hard Handoff**
  
  Hard handoff is a handoff procedure in which all previous radio links of a user equipment are released before new radio links will establish. Hard handoff is lossless for Non Real Time (NRT) connections but for Real Time (RT) connections, it is just a short disconnection which is usually not recognizable.

- **Soft Handoff**
  
  Soft handoff is a handoff procedure in which a UE is connected and controlled by more than one cells simultaneously. These cells can belong to the different NodeBs of same RNC or different RNC or same NodeB. If participating cells are belongs to the same NodeB then this type of soft handoff is a special case of soft handoff and known as Softer Handoff. Soft handoff and softer handoff are unique handoff procedures provided by CDMA systems because these are only possible within the same carrier frequency.

As UMTS offers soft handoff, so like other CDMA systems, cells are divided into following sets depending upon their participation in soft handoff [16].

- **Active Set**
  
  Active set is the set of all the cells which are currently connected with the target UE.

- **Monitored Set**
  
  Monitored set is some times called as Neighbor set is the set of cells which are not in active set of a UE but included in CELL_INFO_LIST.

- **Detected Set**
  
  The cells which are not included in active set and Monitored set but detected by UE are included in detected set.

### 4.4.1 Handoff Procedure

Handoff procedure can be divided into following three phases as shown in the figure 4.3

1. Measurement
2. Decision
3. Execution
4.4.1.1 Measurement Phase

In this phase the necessary required information to make a handoff decision is measured. For downlink, typical measurement is energy per bit to total interference ratio (E_b/I_0) estimation, for all received pilot signal through Common Pilot Channel (CPICH) from the serving and neighboring NodeBs, by the UE.

In other measurements, intra frequency measurements, inter frequency measurements, inter RAT measurements, traffic volume measurements, quality measurements and UE positioning measurements are performed in wireless network [16].

Handoff measurement reporting can be divided into three stages describe as follows [10]

1. Neighbor Cell Definitions

   In RNC, a set of neighbor cells is defined for each set in radio network configuration database. There are three types of neighboring lists defined in the UMTS. These lists are Intra Frequency Neighbor Cell List, Inter Frequency Neighbor Cell List and Inter System Neighbor Cell List depending upon the carrier frequency and system from which that neighbor cell belongs.
2. Measurement Reporting Criteria
Handoff measurement criteria depend upon the different types of handoff procedures offered by UMTS. Handoff measurement types are controlled independently and defined on the cell by cell basis except UE’s internal measurements which are controlled by common parameters to all cells under the same RNC. A UE has to execute and report the following handoff measurements upon the request of RNC

- Intra Frequency Measurements
- Inter Frequency Measurements
- Inter System Measurements
- UE Internal Measurements

3. Reporting of measurement results
Handoff measurements reports are depends upon the measurements criteria. For example reporting of Intra Frequency Measurements can be either event triggered or periodic while for Inter Frequency and Inter System Measurement reporting is always periodic. Different events are defined in the RNC for different measurements for example Event 6A, 6B, 6C, 6D, 6E, 6F and 6G are defined for the UE internal measurements.

4.4.1.2 Decision Phase
In this phase, a decision is made on the basis of measurements done in the measurements phase. The measurements are compared with the predefined target values and a decision is made on the result of this analysis. These target values are different for different systems and technologies.

4.4.1.3 Execution Phase
This is the final phase in handoff procedure. In this phase, procedure is completed and relative parameters are changed according to the handoff type for example a NodeB is added or released, power of different channels involved in handoff adjusted etc.

4.5 Congestion Control
Congestion control is important to keep the radio interface load under predefined thresholds to guarantee the availability of required resources for a call. Overloading cause problems in terms of lower capacity, quality of service degradation or unavailability of services in the planned coverage area or simply unstable the network. As mentioned above, congestion control is subdivided into three functions

1. Call Admission Control
2. Load Control
3. Packet Scheduling Control

4.5.1 Call Admission Control
Call Admission Control (CAC) has the function to regulate and provide resources for new call request or already going call. CAC also ensure the quality of service for the calls in terms of required radio resources. The location of admission control is RNC where load information of several cells can be obtained, as shown in figure 4.1.
The main objective of admission control is to ensure the free radio resources for a new or handoff call with required Signal to Interference Ratio (SIR) and bit rate. CAC ensure that the admittance of new connection will not sacrifice the planned coverage area or the quality of service of existing connections. Admission control always perform when a UE start communication with a NodeB either through a new call or handoff call or a new service request is made by a UE [18].

Admission control takes the decision of acceptance or rejection of a new call or the modification in an ongoing call. Whenever a UE want to establish a connection with NodeB, it send request for resource allocation. Admission control at RNC, handles that request. For real time (RT) services, if connection causes excessive interference to the system, request will be denied. Otherwise resources will be allocated for that connection. For non real time (NRT) connection request, the optimum scheduling of the packets must be determined after the admission of the call [10].

The admission control algorithms estimates the load on the network caused by the acceptance or modification of connections. Separate estimations are done for the uplink and downlink. The decision of acceptance or modification is done on the basis of both uplink and downlink estimations. A new call or handoff call acceptance or modification in an ongoing call is accepted if and only if request fulfills the criteria for both uplink and downlink.

There are two main strategies for call admission control.
1. Wideband Power Based Admission Control
2. Throughput Based Admission Control

4.5.1.1 Wideband Power Based Admission Control

Admission decision for uplink and downlink are taken differently as defined in [10]. For uplink, decision is based on the cell specific load thresholds. These threshold values are defined during radio network planning. For real time connections, there are two conditions. RT connections are accepted if non controllable uplink load (PRXNC) fulfills the following condition

$$PRXNC + \Delta I \leq PRXTrg$$  \hspace{1cm} (4.5)

and the total received wideband interference power (PRXTotal) fulfills the following condition

$$PRXTotal \leq PRXTrg + PRXOffset$$  \hspace{1cm} (4.6)

where PRXTrg is threshold value and PRXOffset is an offset defined at the time of planning. The PRXNC consists of the power of real time users, noise and other cell users. \(\Delta I\) is the increase of wideband interference power caused by that connection after admission. For non real time connections, there is only one condition defined in the equation 4.6.

For downlink, admission criteria are similar as for uplink. For real time connections, there are two conditions. RT connections are accepted if non controllable downlink load (PTXNC) fulfills the following condition

$$PTXNC + \Delta P \leq PTXTrg$$  \hspace{1cm} (4.7)

and the total transmitted wideband power (PTXTotal) fulfills the following condition

$$PTXTotal \leq PTXTrg + PTXOffset$$  \hspace{1cm} (4.8)

where PTXTrg is threshold value and PTXOffset is an offset defined at the time of planning. The PTXNC consists of the power of real time users, noise and other cell users. \(\Delta P\) is based on the initial transmit power. For non real time connections, there is only one condition defined in the equation 4.8.
4.5.1.2 Throughput Based Admission Control
This strategy is simpler than wideband power based admission control defined in [10]. In this method, a new connection is admitted if after admittance, total load is less than the threshold. This threshold is defined at the time of radio network planning. If $\Delta L$ is the load caused by the new connection, then for uplink

$$\eta_{oldUL} + \Delta L \leq \eta_{thresholdUL}$$

(4.9)

and for downlink

$$\eta_{oldDL} + \Delta L \leq \eta_{thresholdDL}$$

(4.10)

where $\eta_{oldUL}$ and $\eta_{oldDL}$ are the network load before that new request and $\eta_{thresholdUL}$ and $\eta_{thresholdDL}$ are the threshold values for uplink and downlink load defined at the time of network planning.

4.5.2 Load Control
Load control maintains the radio resources of the network within the given limits of quality of service [18]. The main objective of load control is to ensure that the network is not overloaded and remains stable. If network become overloaded, then load control performs some actions to quickly decrease the load to the limits to decrease the interference and maintained the QoS and planned coverage.

Load control is functional on both NodeB and RNC as shown in the figure 4.1. The main actions of load control to prevent congestion in NodeB are [10]

- Manage transmit power control (TPC) up commands by overwriting them for uplink direction or deny power up commands for downlink direction
- Use a lower target SIR for uplink inner loop power control to reduce interference

Similarly basic load control actions taken place in RNC are [10]

- Interact with packet scheduler and throttle back packet data traffic
- Degrade the real time users in terms of bit rate
- Dropping of calls by using dropping strategy defined during planning
- Manage intra frequency or inter system handoffs to prevent interference in terms of load

Load control can be divided into two sub functions [10].

1. Preventive Load Control
2. Overload Control

4.5.2.1 Preventive Load Control
In preventive load control, load control algorithms continuously inspecting the network load in terms of interference and radio resources to prevent the network from overloading and maintain the stability of the radio network. To achieve this goal, load control is functioning together with the other two functions of congestion control.

4.5.2.2 Overload Control
Overload control is responsible for the quick and efficient recovery of the radio network from the congestion to desired load level. Although networks are working
fine due to proper preventive load control algorithms and efficient admission control algorithms, but however congestion occur some times due to mobility of users, sudden overload, or some channel impairments. Connection degradation, call dropping or call handing off to other carrier frequency or system are the common overload control actions.

4.5.2.3 Wideband Power Based Load Control
In wideband power based load control, the measurement of total received interference power per cell ($P_{RXTotal}$) in uplink direction and total transmission power carrier ($P_{TXTotal}$) in downlink direction decide the requirement of preventive or overload control algorithms. During planning, threshold values are defined for both uplink and downlink. For uplink, two threshold values $P_{RXTrg}$ (optimal average value of $P_{RXTotal}$) and $P_{RXOffset}$ (maximum margin by which $P_{RXTrg}$ exceeds), are defined. Similarly for downlink, $P_{TXTrg}$ (optimal average value of $P_{TXTotal}$) and $P_{TXOffset}$ (maximum margin by which $P_{TXTrg}$ exceeds), are defined.

Now cell will enters in preventive load control state if either $P_{RXTrg}$ or $P_{TXTrg}$ is exceeded and some preventive load control actions are initiated to prevent network from congestion. But if $(P_{TXTrg} + P_{TXOffset})$ is exceeded or $(P_{RXTrg} + P_{RXOffset})$ is exceeded, then cell will enters in overload state and some necessary over load control actions are needed to overcome the congestion.

4.5.3 Packet Scheduling Control
As shown in figure 4.1, packet scheduling control is done by RNC in UMTS with functionality to control the packet access. Packet Scheduling control provide appropriate radio resources for data calls. Packet scheduling control algorithms work with call admission control and load control algorithms in order to prevent the radio network from congestion and maintain the QoS. As UMTS guarantee the availability of required resources for the real time services, so we have to fit the non real time (NRT) in rest of resources because we cannot disturb the real time traffic for NRT traffic. So packet scheduling control mainly deals with the NRT traffic. The main objectives of packet scheduling control are

- Find and split the accessible radio resources for NRT connections
- Monitoring of NRT allocations
- Monitoring of system load
- Execute the load control actions for NRT connections when required

There are two main parts of packet scheduling [7]

1. User specific packet scheduling
2. Channel specific packet scheduling

4.5.3.1 User Specific Packet Scheduling
User specific packet scheduling is mainly responsible for utilization of the Radio Resource Control (RRC) states, transport channels and their bit rates according to traffic volume. As mentioned above, the packet scheduling is done by RNC in UMTS network. In packet scheduling, NodeB provides the air interface load measurements and the UE provides uplink traffic volume measurements to the RNC, as shown in the following figure 4.4.
For the transmission of packet data in WCDMA systems, there are three types of transport channels which are Common Channels (RACH/FACH), Dedicated Channels (DCH) and Shared Channels (DSCH).

### 4.5.3.1.1 Common Channels (RACH/ FACH)

In downlink Forward Access Channel (FACH) and in uplink Random Access Channel (RACH) are the common channels used for packet data transmission. RACH and FACH can carry both signalling and user data. One sector has process one or a few RACH or FACH channels. For example, 16kbps RACH with 20ms TTI and 32kbps FACH with 10ms TTI. The common channel has an advantage that if user is in cell- FACH states then no set-up time is required [7].

Common channels don’t have feedback channels. Due to this reason they are not suitable for fast closed loop power control. They can only use open loop power control or fixed power control. These channels are also not suitable for soft handoff. That’s why their link level performance is not good as that of dedicated channels. They generate more interference than dedicated channels. On the other hand, common channels are very useful to send small IP packets for example during establishment of TCP connection, for infrequent packets for interactive gaming etc. As these channels cannot use soft handoff so that these channels use cell reselection which causes a longer delay.

Uplink Common Packet Channel (CPCH) is extended type of RACH channel. Like the common channels and DCH, CPCH cannot be used in soft handoff so CPCH is not used in Soft handoff. CPCH has the ability of fast control after the access process. Setup time for CPCH is little higher compare to RACH but it can be allocated for 64 frames = 640ms, which means that it has ability to carry more data compared to RACH [7]. CPCH cannot be efficiently utilized in UMTS without wide support in user equipments.

### 4.5.3.1.2 Dedicated Channel (DCH)

As shown from the name, dedicated channel is two directional channels. Data can be transmitted in both uplink and downlink direction as well as its feedback channel so this permit it to use fast power control and soft handoff. Sometime interference is produced with common channels but establishing a dedicated channel connection takes higher time compare to establish a common channel.
4.5.3.1.3 Downlink Shared Channel (DSCH)

The Downlink shared channel (DSCH) is used for busy and large data transfer. By using time domain multiplexing, a single physical channel is shared among different users in time domain. Downlink orthogonal codes can be preserved to certain level by using the technique of time division multiplexing (TDM). All these channel are used in parallel with low bit rate dedicated channels. For fast closed loop power control, the dedicated channels carrying physical control channel (PCH) with signalling. DSCH has the ability or can be instantly assign to new user prior to DCH inactivity timer expires so that it offers better utilization of resources compared to DCH. The speed downlink shared channel HSDSCH is basically is one type of HSDPA concept [10].

4.5.3.2 Cell Specific Packet Scheduling

Cell specific packet scheduling is responsible for the sharing of radio resources between simultaneous users. The cell specific scheduler divides the NRT capacity between users. Cell specific packet scheduling operates periodically and hence has ranges from 100ms to 1 second [7]. When the network becomes overloaded, the packet scheduler reduce load by degrading various NRT users in terms of bit rate. This process of degradation continues until network become stable. On the other hand when load is less than target, packet scheduler increase the load by allocating high bit rates.

Thus the main objective of cell specific packet scheduling is to utilize all remaining capacity for NRT services and also manage the overall interference level so that RT users will not disturbed as shown in the figure 4.5.

Figure 4.5 Flow chart of basic functionality of packet scheduling
The cell specific packet scheduler need following input [7]
- Total Node B power: this can be calculated by power based load estimation.
- Capacity allocated to NRT bearer: throughput based estimation can be calculated with this.
- Target load level from network planning parameters: without effecting the RT connection, it is the maximum interference level tolerated in the cell.
- Bit rate upgrade requests from the user-specific packet scheduler.

The input information and the calculation principles of cell specific packet scheduler are illustrated in the following figure 4.6. As shown in figure, NodeB provides link power measurements and total cell power in radio resource reporting to RNC. The packet scheduler can estimate the total power used by the real time connections and inter cell interference. The packet scheduler divides the remaining capacity between the simultaneous users.

![Figure 4.6 Input information and calculation principles of the cell-specific packet scheduler](image)

Figure 4.6 Input information and calculation principles of the cell-specific packet scheduler [7].
Chapter 5: Power Control Algorithms

5.1 Introduction
In this thesis, we research on two power control algorithms in order to analyze the basic function and operation of power control techniques in UMTS networks. These algorithms are

1. A power control algorithm for 3G WCDMA Systems
2. QoS aware power control and handoff prioritization in 3G WCDMA Networks

The first algorithm is used for the power updation and the second algorithm is designed for the QoS based power control to cope with congestion and overloading. So we can easily understand almost complete power control methodology of UMTS and its role in other RRM functions.

5.2 A Power Control Algorithm for 3G WCDMA System
In this algorithm, a method to update power update step size is proposed. This algorithm uses dynamic power update step size instead of fixed power update step size used in power control algorithm defined in 3GPP specifications. Authors called this technique “Adaptive Step Power Control”.

5.2.1 Power Control in 3G WCDMA System
In WCDMA, one frame contains 15 time slots and each time slot contains one power update command. Frame duration is 10ms. So power update rate is 1500 bps. Within a time slot, transmitted value will be fixed.

WCDMA uses closed loop power control. This closed loop power control is combination of inner closed loop and outer loop power control. In this mechanism, inner closed loop power control is responsible for the power adjustment to keep the received signal to interference ratio (SIR\text{est}) equal to the target signal to interference ratio(SIR\text{trg}). The outer closed loop power control sets the target signal to interference ratio (SIR\text{trg}) in accordance to the received block error rate (BLER) or bit error rate(BER), in order to match the required BLER. Outer loop power update frequency is 10-100 Hz. Following figure 5.1 shows the inner and outer loop power control as shown in [15].

![Figure 5.1 Power control in WCDMA System [15]
The inner closed loop power control sends commands to transmitter for transmitted power update after measuring the received signal quality (SIR\text{est}). Received signal to interference ratio (SIR\text{est}) is estimated by received power of the target connection and the received interference. Then obtained SIR\text{est} is used by the receiver to generate the power update command.

Two algorithms for power control are defined in 3GPP specifications. In algorithm 1, the transmitted power is updated at each time slot. It is increased or decreased by fixed value:

- if SIR\text{est} > SIR\text{trg} the transmit power control command transmit “0” means requesting a transmit power decrease
- if SIR\text{est} < SIR\text{trg} the transmit power control command transmit “1” means requesting a transmit power increase

Algorithm 2 is a slight different from algorithm 1 where the transmitted powers may be updated after some time slots, which simulates smaller power update steps.

5.2.2 System Model

In this algorithm, circuit switched FDD WCDMA 3G system is considered. A physical channel is defined by its code and its frequency in such kind of systems. In this algorithm, we only consider inner closed loop power control. First we calculate the estimated SIR and then compare it with target SIR and finally take decision of power up or down on the basis of results, we got from above comparison.

In our scenario, we consider one “Node-B” with 18 “UEs”. At a given instant, all user equipments are communicating with Node-B. UE m transmitted power is p_m and link gain from UE “m” to Node-B “b” is g_{bm}. UE “m” received SIR on Node-B “b” is noted γ_{mb} is given by equation [15]

\[
γ_{mb} = \frac{g_{bm}p_m}{\sum_{j=1, j\neq m}^{M} g_{bj}p_j + n_b}
\]  

(5.1)

where g_{bj} is gain of UE “j” other than target UE on Node-B and p_j is the transmitted power of UE “j’”. n_b is receiver noise also called thermal noise at Node-B.

Transmission power of UE ranges from -50dBm to 24dBm as described in [15] for this algorithm. In order to study this algorithm, we initially take powers as uniformly distributed random variables ranging from -50dBm to 2.4dBm which is the lowest value to the 10% of maximum transmitted power as described in the [15].

For the gain of UE at NodeB, we use the following formula given in [15]

\[
g = \frac{c_s}{d}
\]  

(5.2)

where c_s is the fading and d is the distance between NodeB and UE in meters. We calculate fading coefficient c_s as uniformly distributed random with interval (0,1), for each iteration and initially distance d as uniformly distributed random variable with interval (0.1, 2000). Latter on for every iteration, distance is increased or decreased by fixed steps assuming that all UEs are moving with constant speed. Thermal noise is given in [15] and is equal to -130dBm.

After the detection of received signal quality, Node-B compare it with target SIR and send a power control command up or down to transmitter (UE). If the transmitter
detects several simultaneous up commands, the step is increased. This is also done for several simultaneous down commands. The update step is decreased if an alternative succession of up and down appears, showing that the update step is probably too large [15].

In this algorithm, the power update step size is calculated in [15] as follows:

- the update step is multiplied by $\mu$ when $n_1$ successive up commands are received
- the update step is multiplied by $\nu$ when $n_0$ successive down commands are received
- this value is divided by $\lambda$ when power update command sequence is an alternate sequence of $n_{01}$ up and down commands.

### 5.2.3 Results

In this technique, transmitter signal achieve the target received signal quality more quickly as shown in the following figures. In figure 5.2 and 5.3, we can examine that in the case of adaptive step power control algorithm, required SIR achieved in approximately $7^{th}$ iteration while in the case of standard UMTS release 99 algorithm, we get the same in approximately $46^{th}$ iteration. This is because in standard algorithm, we have fixed step size and in our experiment we fixed this step size to 1dB. But in the case of ASPC, we calculate our step size dynamically every time and due to bigger step size, required signal quality achieved quickly as compared to the standard algorithm. Target SIR is shown in red colour while estimated SIR of UE is shown in Blue Colour. In our simulation, we set target SIR -25dBm.

![Figure 5.2 Convergence of SIR\textsubscript{trg} and SIR\textsubscript{est} in standard power control algorithm](image-url)
The major drawback of this algorithm is that there are more fluctuations in transmitter’s power than the standard UMTS power control algorithm. If we increase the multiplying factor then amplitude of fluctuation is also increased but on the other hand signal power update rapidly as shown from the figure 5.4 and 5.5. Here we set $\mu = \nu = \lambda = 2$ and $n_0 = n_1 = n_{01} = 2$ for figure 5.4 while for figure 5.5 we set the parameters $\mu = \nu = \lambda = 6$ and $n_0 = n_1 = n_{01} = 2$. Results shows that we get a quick power update but more fluctuation amplitude in case of figure 5.5.
And if we decrease the number of commands for power update step size decision then frequency of the fluctuation increases as observed from the results as shown in figure 5.6 and 5.7. Here we set $\mu = \nu = \lambda = 3$ and $n_0 = n_1 = n_{01} = 10$ for figure 5.6 while for figure 5.7 we set the parameters $\mu = \nu = \lambda = 3$ and $n_0 = n_1 = n_{01} = 2$. In both the cases the only difference is the frequency of power fluctuation.
Hence the main conclusion is that we get a quick power update but on the other hand less stable power in the case of ASPC as compared to standard UMTS release 99 power control algorithm.

5.3 QoS aware Power Control

This mechanism is based on the class of service, the bit rate and the service degradation descriptor (SDD) as enabling QoS parameter. SDD is a value between 0 and 5. A user with a larger SDD value is more willing to be degraded or dropped.

There are four basic classes of service in UMTS
1. Conversational
2. Streaming
3. Interactive
4. Background

5.3.1 System Model

In this scheme, power is considered to be the only limiting resource. The cost of connection $i$ at a given time is computed according to the following formula: [12]

$$ C_i(t) = \frac{E_b}{N_0} \cdot \frac{1}{w} \cdot \frac{I_i(t)}{H_i(t)} $$

(5.3)

Where $E_b/N_0$ is 18dB and chip rate (w) is 3.84Mchips. $I_i(t)$ is the sum of interferences exerted by all the existing users on the target user at time t. $H_i(t)$ is channel gain follows a rayleigh distribution.

In this research we calculate interference produced by individual connection on the target connection by using Box-Muller formula and sum all of them to get $I_i(t)$.  

Figure 5.7 Power of UE when Power update decision need to wait for 2 consecutive TPC commands
According to Box-Muller transform given in [19], if $U_1$ and $U_2$ are two independent random variables that are uniformly distributed in the interval $(0,1)$, then

$$Z_0 = R \cos \theta = \sqrt{-2 \ln U_1 \cos 2\pi U_2} \quad (5.4)$$

and

$$Z_1 = R \sin \theta = \sqrt{-2 \ln U_1 \sin 2\pi U_2} \quad (5.5)$$

Where $Z_0$ and $Z_1$ are two independent normally distributed random variables with standard deviation 1.

For the calculation of channel gain $H_i(t)$, we calculate the path loss by using Hata Model given in [20] and then subtract it from Rayleigh signal. According to Hata Model, Path Loss $L_{\text{dB}}$ is

$$L_{\text{dB}} = 69.55 + 26.16 \log f_c - 13.82 \log h_t - A(h_r) + (44.9 - 6.55 \log h_r) \log d \quad (5.6)$$

Where

- $f_c = \text{carrier frequency in MHz}$
- $h_t = \text{height of transmitting antenna (NodeB) in m}$
- $h_r = \text{height of receiving antenna (UE) in m}$
- $d = \text{propagation distance between antennas in km}$
- $A(h_r) = \text{correction factor for UE antenna}$

The total power required by connection $i$ operating at bit rate $R_i$ is [12]

$$P_i(t) = C_i(t) \times R_i \quad (5.7)$$

### 5.3.1 QoS Adaptation Algorithm

This algorithm is used to cope with congestion. It resolves congestion in two phases. First phase is degradation phase and the second one is dropping phase.

#### 5.3.1.2 Degradation Phase

This phase is based on SDD. In this phase, the active connection or user with highest SDD will be the connection that degraded in terms of its bandwidth requirements. Degradation will take place as follows: [12]

- connection with 384 Kbps bit rate requirement will be degraded to 144 Kbps
- connection with 144 Kbps bit rate requirement will be degraded to 64 Kbps
- connection with 64 Kbps bit rate requirement will be degraded to 16 Kbps
- 2 Mbps and 16 Kbps connections are not degraded in this schema.

#### 5.3.1.3 Dropping Phase

This is the second phase of QoS adaptation algorithm. This phase takes place when connections were degraded and congestion still persists. In this phase dropping is based on [12]

$$F_i(t) = \text{SDD}_i \times P_i(t) \quad (5.8)$$

Where $P_i(t)$ is the power required by connection $i$ at time $t$. $F_i(t)$ is high for connections that are more willing to be degraded and require more power.

### 5.3.2 Results

This algorithm is efficient for congestion control. As we see in our results, network congestion recover by degrading bit rate in most cases while there is very less number of drop connections. Mostly we get satisfactory results from degradation only. As shown in the figure congestion recover in 7 seconds and make some space for
upcoming call requests. There are 18 connections participating in this test. Power threshold is shown in red colour while sum power required by all connections is shown in blue colour.

![Figure 5.8 Congestion Control by degrading connections with higher SDD](image)

**5.4 Conclusion**

After the analysis of these algorithms, we learn one thing that power control plays a vital role in UMTS radio system operations not only by maintaining the signal quality, but also an important mean of optimizing the radio network by reducing the interference level. Power control directly effect other RRM techniques.

As we study in this analysis, a fast power control mechanism is good for maintaining the calls especially in the case of handoff calls. If power of UE stay below the target then this can cause too much BER that is a trade off with quality of service in the case of class 3 and class 4 services. This can also cause the call drop. And if power of UE is more than target, then this leads to interference for others in vicinity and effect their communications. So a fast and accurate power updation is necessary to cope with these issues. In the same manner along with power updation, QoS check is also very important to make the network and services stable. If power requirement of active connections is more than capacity, then this will leads to overloading and cause congestion in the radio network.

So the main conclusion of this analysis is that a fast and accurate power control is necessary to run the operations smoothly, to maintain the network coverage according to the planning and to provide services with better quality of service to make customer happy.
References


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