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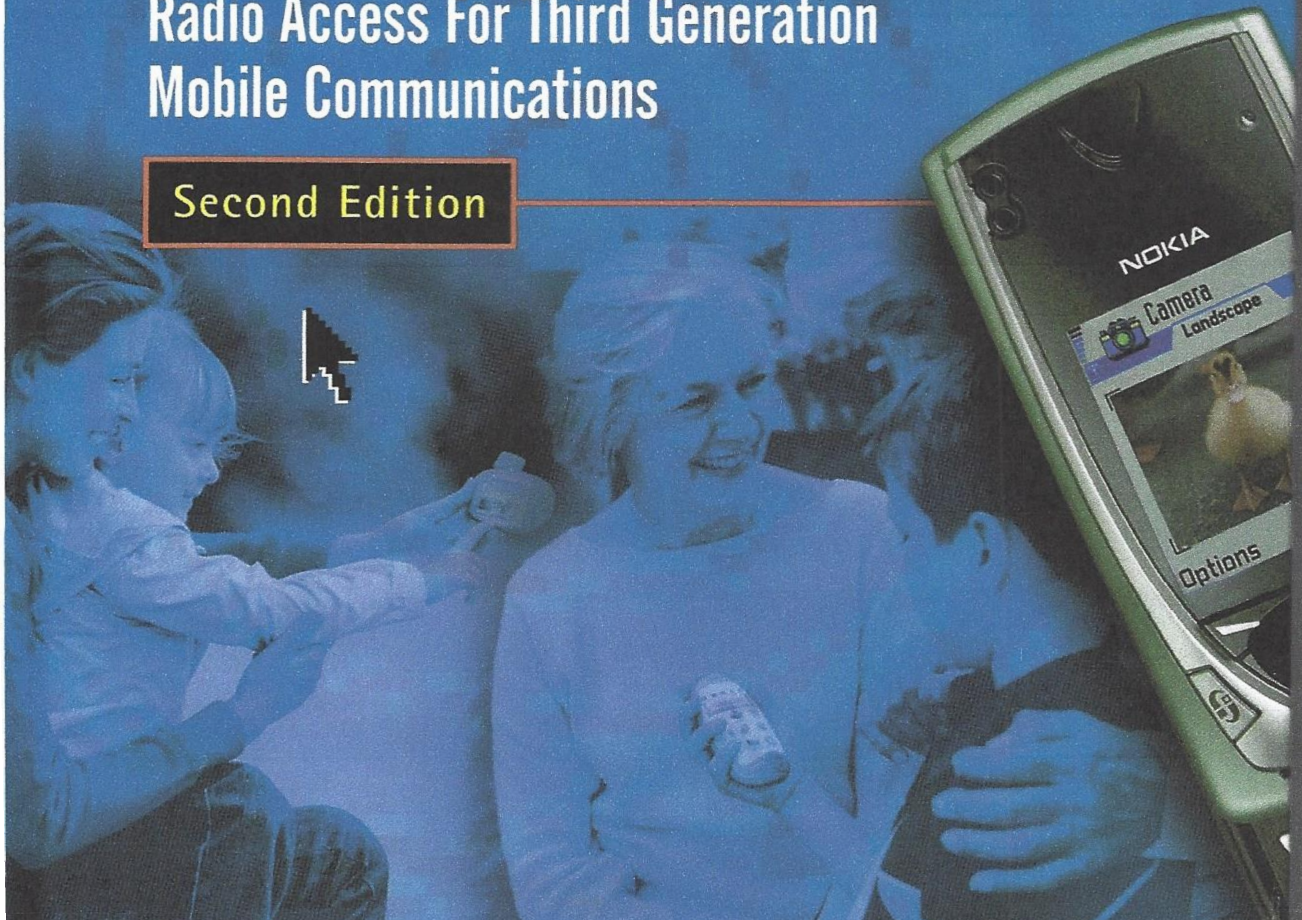
WCDMA FOR UMTS

Radio Access For Third Generation Mobile Communications

Second Edition



Edited by Harri Holma and Antti Toskala

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Radio Access For Third Generation
Mobile Communications

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Contents

Preface

Second generation telecommunication systems, such as GSM, enabled voice traffic to go wireless: the number of mobile phones exceeds the number of landline phones and the mobile phone penetration exceeds 70% in countries with the most advanced wireless markets. The data handling capabilities of second generation systems are limited, however, and third generation systems are needed to provide the high bit rate services that enable high quality images and video to be transmitted and received, and to provide access to the web with high data rates. These third generation mobile communication systems are referred to in this book as UMTS (Universal Mobile Telecommunication System). WCDMA (Wideband Code Division Multiple Access) is the main third generation air interface in the world and will be deployed in Europe and Asia, including Japan and Korea, in the same frequency band, around 2 GHz. WCDMA will be deployed also in USA in the US frequency bands. The large market for WCDMA and its flexible multimedia capabilities will create new business opportunities for manufacturers, operators, and the providers of content and applications. This book gives a detailed description of the WCDMA air interface and its utilisation. The contents are summarised in Figure 1.

Chapter 1 introduces the third generation air interfaces, the spectrum allocation, the time schedule, and the main differences from second generation air interfaces. Chapter 2 presents example UMTS applications, concept phones and the quality of service classes. Chapter 3 introduces the principles of the WCDMA air interface, including spreading, Rake receiver, power control and handovers. Chapter 4 presents the background to WCDMA, the global harmonisation process and the standardisation. Chapters 5–7 give a detailed presentation of the WCDMA standard, while Chapters 8–11 cover the utilisation of the standard and its performance. Chapter 5 describes the architecture of the radio access network, interfaces within the radio access network between base stations and radio network controllers (RNC), and the interface between the radio access network and the core network. Chapter 6 covers the physical layer (layer 1), including spreading, modulation, user data and signalling transmission, and the main physical layer procedures of power control, paging, transmission diversity and handover measurements. Chapter 7 introduces the radio interface protocols, consisting of the data link layer (layer 2) and the network layer (layer 3). Chapter 8 presents the guidelines for radio network dimensioning, gives an example of detailed capacity and coverage planning, and covers GSM co-planning. Chapter 9 covers the radio resource management algorithms that guarantee the efficient utilisation of the air interface resources and the quality of service. These algorithms are power control, handovers, admission and load control. Chapter 10 depicts packet access and presents the performance of packet protocols of WCDMA. Chapter 11

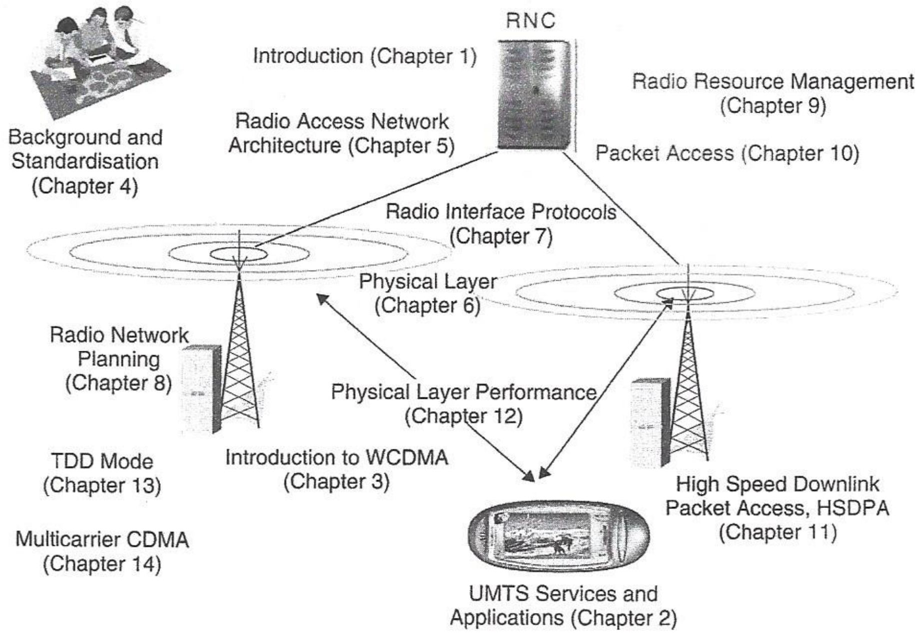

Figure 1. Contents of this book

presents the significant Release 5 feature, High Speed Downlink Packet Access, HSDPA, and its performance. Chapter 12 analyses the coverage and capacity of the WCDMA air interface with bit rates up to 2 Mbps. Chapter 13 introduces the time division duplex (TDD) mode of the WCDMA air interface and its differences from the frequency division duplex (FDD) mode. In addition to WCDMA, third generation services can also be provided with EDGE or with multicarrier CDMA. EDGE is the evolution of GSM for high data rates within the GSM carrier spacing. Multicarrier CDMA is the evolution of IS-95 for high data rates using three IS-95 carriers, and is introduced in Chapter 14.

The 2nd edition of the book covers the key features of 3GPP Release 5 specifications, including High Speed Downlink Packet Access, HSDPA and IP Multimedia Subsystem (IMS). Also many of the existing features in Release'99 or Release 4 have been more widely covered than previously including TCP protocol over WCDMA packet channels, base station and mobile performance requirements and WCDMA for Americas—WCDMA1900.

This book is aimed at operators, network and terminal manufacturers, service providers, university students and frequency regulators. A deep understanding of the WCDMA air interface, its capabilities and its optimal usage is the key to success in the UMTS business.

This book represents the views and opinions of the authors, and does not necessarily represent the views of their employers.

6

Physical Layer

Antti Toskala

6.1 Introduction

In this chapter the WCDMA (UTRA FDD) physical layer is described. The physical layer of the radio interface has been typically the main discussion topic when different cellular systems have been compared against each other. The physical layer structures naturally relate directly to the achievable performance issues, when observing a single link between a terminal station and a base station. For the overall system performance the protocols in the other layers, such as handover protocols, also have a great deal of impact. Naturally it is essential to have low Signal-to-Interference Ratio (SIR) requirements for sufficient link performance with various coding and diversity solutions in the physical layer, since the physical layer defines the fundamental capacity limits. The performance of the WCDMA physical layer is described in detail in Chapter 12.

The physical layer has a major impact on equipment complexity with respect to the required baseband processing power in the terminal station and base station equipment. As well as the diversity benefits on the performance side, the wideband nature of WCDMA also offers new challenges in its implementation. As third generation systems are wideband from the service point of view as well, the physical layer cannot be designed around only a single service, such as speech; more flexibility is needed for future service introduction. The new requirements of the third generation systems and for the air interface are summarised in Section 1.4. This chapter presents the WCDMA physical layer solutions to meet those requirements.

This chapter uses the term 'terminal' for the user equipment. In 3GPP terminology the terms User Equipment (UE) and Mobile Equipment (ME) are often used, the difference being that UE also covers the Subscriber Identification Module (SIM) as shown in Chapter 5, in which the UTRA network architecture is presented. The term 'base station' is also used throughout this chapter, though in part of the 3GPP specifications the term Node B is used to represent the parts of the base station that contain the relevant parts from the physical layer perspective. The UTRA FDD physical layer specifications are contained in references [1–5].

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This chapter has been divided as follows. First, the transport channels are described together with their mapping to different physical channels in Section 6.2. Spreading and modulation for uplink and downlink are presented in Section 6.3, and the physical channels for user data and control data are described in Sections 6.4 and 6.5. In Section 6.6 the key physical layer procedures, such as power control and handover measurements, are covered. The biggest change in Release 5 impacting the physical layer is the addition of the high speed downlink packet access (HSDPA) feature. As there are significant differences in HSDPA when compared to Release'99 based operation (which is naturally retained as well), the HSDPA details are covered in a separate section to maintain clear separation between the first phase WCDMA standard and the first evolution step of the radio interface development. For further details on HSDPA please refer to Chapter 11.

6.2 Transport Channels and their Mapping to the Physical Channels

In UTRA the data generated at higher layers is carried over the air with transport channels, which are mapped in the physical layer to different physical channels. The physical layer is required to support variable bit rate transport channels to offer bandwidth-on-demand services, and to be able to multiplex several services to one connection. This section presents the mapping of the transport channels to the physical channels, and how those two requirements are taken into account in the mapping.

Each transport channel is accompanied by the Transport Format Indicator (TFI) at each time event at which data is expected to arrive for the specific transport channel from the higher layers. The physical layer combines the TFI information from different transport channels to the Transport Format Combination Indicator (TFCI). The TFCI is transmitted in the physical control channel to inform the receiver which transport channels are active for the current frame; the exception to this is the use of Blind Transport Format Detection (BTFD) that will be covered in connection with the downlink dedicated channels. The TFCI is decoded appropriately in the receiver and the resulting TFI is given to higher layers for each of the transport channels that can be active for the connection. In Figure 6.1 two transport channels are mapped to a single physical channel, and also error indication is provided for each transport block. The transport channels may have a different number of blocks and at any moment not all the transport channels are necessarily active.

One physical control channel and one or more physical data channels form a single Coded Composite Transport Channel (CCTrCh). There can be more than one CCTrCh on a given connection but only one physical layer control channel is transmitted in such a case.

The interface between higher layers and the physical layer is less relevant for terminal implementation, since basically everything takes place within the same equipment, thus the interfacing here is rather a tool for specification work. For the network side the division of functions between physical and higher layers is more important, since there the interface between physical and higher layers is represented by the Iub-interface between the base station and Radio Network Controller (RNC) as described in Chapter 5. In the 3GPP specification the interfacing between physical layer and higher layers is covered in [6].

Two types of transport channels exist: dedicated channels and common channels. The main difference between them is that a common channel is a resource divided between all or a group of users in a cell, whereas a dedicated channel resource, identified by a certain

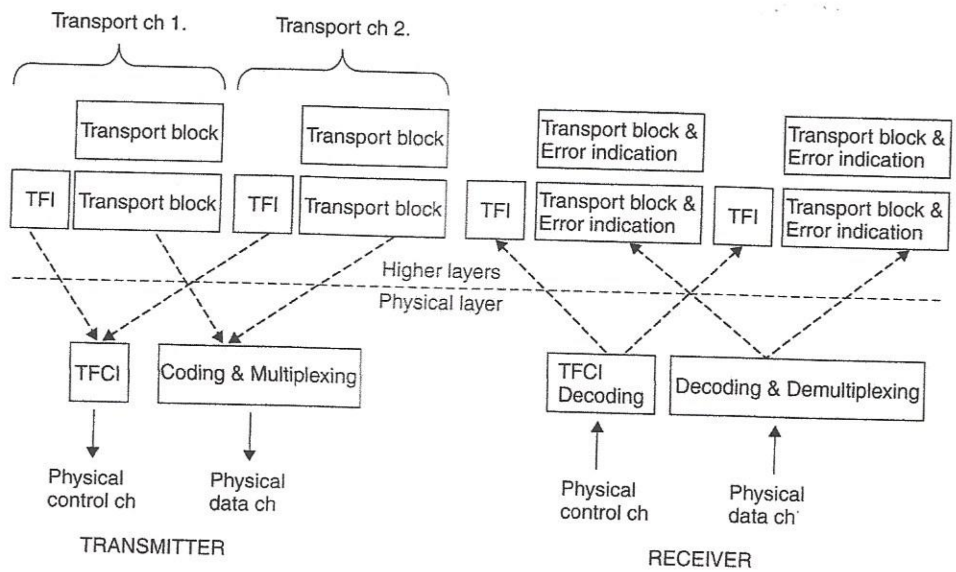

Figure 6.1. The interface between higher layers and the physical layer

code on a certain frequency, is reserved for a single user only. The transport channels are compared in Section 10.3 for the transmission of packet data.

6.2.1 Dedicated Transport Channel

The only dedicated transport channel is the dedicated channel, for which the term DCH is used in the 25-series of the UTRA specification. The dedicated transport channel carries all the information intended for the given user coming from layers above the physical layer, including data for the actual service as well as higher layer control information. The content of the information carried on the DCH is not visible to the physical layer, thus higher layer control information and user data are treated in the same way. Naturally the physical layer parameters set by UTRAN may vary between control and data.

The familiar GSM channels, the traffic channel (TRCH) or associated control channel (ACCH), do not exist in UTRA physical layer. The dedicated transport channel carries both the service data, such as speech frames, and higher layer control information, such as handover commands or measurement reports from the terminal. In WCDMA a separate transport channel is not needed because of the support of variable bit rate and service multiplexing.

The dedicated transport channel is characterised by features such as fast power control, fast data rate change on a frame-by-frame basis, and the possibility of transmission to a certain part of the cell or sector with varying antenna weights with adaptive antenna systems. The dedicated channel supports soft handover.

6.2.2 Common Transport Channels

There are currently six different common transport channel types defined for UTRA, which are introduced in the following sections. There are a few differences from second

Channel Category Critirias:
(1) Power: high/low; fast power control

 (2) Data Rate: high/low; fix or variable

(3) Inband Id

generation systems, for example transmission of packet data on the common channels, and a downlink shared channel for transmitting packet data. Common channels do not have soft handover but some of them can have fast power control.

6.2.2.1 Broadcast Channel

The Broadcast Channel (BCH) is a transport channel that is used to transmit information specific to the UTRA network or for a given cell. The most typical data needed in every network is the available random access codes and access slots in the cell, or the types of transmit diversity methods used with other channels for that cell. As the terminal cannot register to the cell without the possibility of decoding the broadcast channel, this channel is needed for transmission with relatively high power in order to reach all the users within the intended coverage area. From a practical viewpoint the information rate on the broadcast channel is limited by the ability of low-end terminals to decode the data rate of the broadcast channel, resulting in a low and fixed data rate for the UTRA broadcast channel.

6.2.2.2 Forward Access Channel

The Forward Access Channel (FACH) is a downlink transport channel that carries control information to terminals known to locate in the given cell. This is so, for example, after a random access message has been received by the base station. It is also possible to transmit packet data on the FACH. There can be more than one FACH in a cell. One of the forward access channels must have such a low bit rate that it can be received by all the terminals in the cell area. When there is more than one FACH, the additional channels can have a higher data rate as well. The FACH does not use fast power control, and the messages transmitted need to include inband identification information to ensure their correct receipt.

6.2.2.3 Paging Channel

The Paging Channel (PCH) is a downlink transport channel that carries data relevant to the paging procedure, that is, when the network wants to initiate communication with the terminal. The simplest example is a speech call to the terminal: the network transmits the paging message to the terminal on the paging channel of those cells belonging to the location area that the terminal is expected to be in. The identical paging message can be transmitted in a single cell or in up to a few hundreds of cells, depending on the system configuration. The terminals must be able to receive the paging information in the whole cell area. The design of the paging channel affects also 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 message, the longer will the terminal's battery last in the standby mode.

6.2.2.4 Random Access Channel

The Random Access Channel (RACH) is an uplink transport channel intended to be used to carry control information from the terminal, such as requests to set up a connection. It can also be used to send small amounts of packet data from the terminal to the network. For proper system operation the random access channel must be heard from the whole desired cell coverage area, which also means that practical data rates have to be rather low, at least for the initial system access and other control procedures. The coverage of the random access channel compared to the dedicated channel is presented in Section 12.2.2.

6.2.2.5 Uplink Common Packet Channel

The uplink common packet channel (CPCH) is an extension to the RACH channel that is intended to carry packet-based user data in the uplink direction. The pair providing the data in the downlink direction is the FACH. In the physical layer, the main differences from the RACH are the use of fast power control, a physical layer-based collision detection mechanism and a CPCH status monitoring procedure. The uplink CPCH transmission may last several frames in contrast with one or two frames for the RACH message.

6.2.2.6 Downlink Shared Channel

The downlink shared channel (DSCH) is a transport channel intended to carry dedicated user data and/or control information; it can be shared by several users. In many respects it is similar to the forward access channel, but the shared channel supports the use of fast power control as well as variable bit rate on a frame-by-frame basis. The DSCH does not need to be heard in the whole cell area and can employ the different modes of transmit antenna diversity methods that are used with the associated downlink DCH. The downlink shared channel is always associated with a downlink DCH.

6.2.2.7 Required Transport Channels

The common transport channels needed for the basic network operation are RACH, FACH and PCH, while the use of DSCH and CPCH is optional and can be decided by the network.

6.2.3 Mapping of Transport Channels onto the Physical Channels

The different transport channels are mapped to different physical channels, though some of the transport channels are carried by identical (or even the same) physical channel. The transport channel to physical channel mapping is illustrated in Figure 6.2.

In addition to the transport channels introduced earlier, there exist physical channels to carry only information relevant to physical layer procedures. The Synchronisation Channel (SCH), the Common Pilot Channel (CPICH) and the Acquisition Indication Channel (AICH) are not directly visible to higher layers and are mandatory from the system function point of view, to be transmitted from every base station. The CPCH Status Indication Channel (CSICH) and the Collision Detection/Channel Assignment Indication Channel (CD/CA-ICH) are needed if CPCH is used.

The dedicated channel (DCH) is mapped onto two physical channels. The Dedicated Physical Data Channel (DPDCH) carries higher layer information, including user data, while the Dedicated Physical Control Channel (DPCCH) carries the necessary physical layer control information. These two dedicated physical channels are needed to support efficiently the variable bit rate in the physical layer. The bit rate of DPCCH is constant, while the bit rate of DPDCH can change from frame to frame.

6.2.4 Frame Structure of Transport Channels

The UTRA channels use the 10 ms radio frame structure. The longer period used is the system frame period. The System Frame Number (SFN) is a 12-bit number used by several procedures that span more than a single frame. Physical layer procedures, such as the paging procedure or random access procedure, are examples of procedures that need a longer period than 10 ms for correct definition.

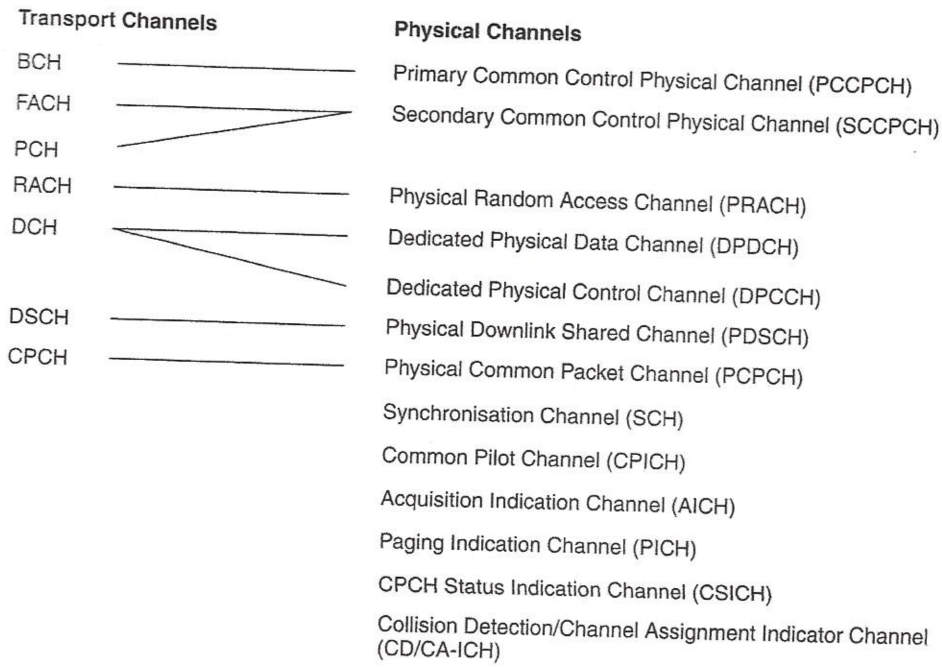

Figure 6.2. Transport-channel to physical-channel mapping

6.3 Spreading and Modulation

6.3.1 Scrambling

The concept of spreading the information in a CDMA system is introduced in Chapter 3. In addition to spreading, part of the process in the transmitter is the scrambling operation. This is needed to separate terminals or base stations from each other. Scrambling is used on top of spreading, so it does not change the signal bandwidth but only makes the signals from different sources separable from each other. With the scrambling, it would not matter if the actual spreading were done with identical code for several transmitters. Figure 6.3 shows the relation of the chip rate in the channel to spreading and scrambling in UTRA. As the chip rate is already achieved in the spreading by the channelisation codes, the symbol rate is not affected by the scrambling. The concept of channelisation codes is covered in the following section.

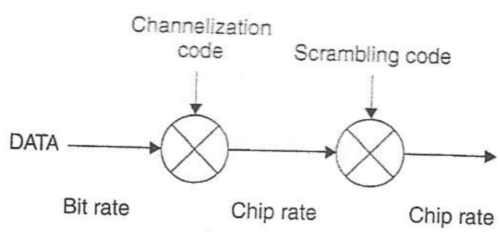

Figure 6.3. Relation between spreading and scrambling

13

UTRA TDD Mode

Otto Lehtinen, Antti Toskala, Harri Holma and Heli Väätäjä

13.1 Introduction

The UTRA TDD is intended to operate in the unpaired spectrum, as shown in Figure 1.2 in Chapter 1, illustrating the spectrum allocations in various regions. As can be seen from Figure 1.2, there is no TDD spectrum available in all regions. The background of UTRA TDD was described in Chapter 4. Since the technology selection in ETSI in January 1998, the major parameters have been harmonised between UTRA FDD and TDD, including chip rate and modulation. The presentation in this chapter follows the technical specifications for the TDD mode in the 3rd Generation Partnership Project (3GPP), specifically documents TS 25.221–TS 25.224 and TS 25.102 [1–5]. The 3.84 Mcps UTRA TDD mode was covered by the Release'99 already and later in Release 4 low chip rate TDD with 1.28 Mcps was included. The principles with High Speed Downlink Packet Access (HSDPA) are valid with Release 5 TDD also, including similar ARQ operation, use of 16 QAM modulation and fast Node B based scheduling as described in Chapter 11.

This chapter first introduces TDD as a duplex method on a general level. The physical layer and related procedures of the UTRA TDD mode are introduced in Section 12.2. UTRA TDD interference issues are evaluated in Section 12.3. The Release 4 addition, 1.28 Mcps TDD, is covered in Section 12.4.

13.1.1 Time Division Duplex (TDD)

Three different duplex transmission methods are used in telecommunications: frequency division duplex (FDD), time division duplex (TDD) and space division duplex (SDD). The FDD method is the most common duplex method in the cellular systems. It is used, for example, in GSM. The FDD method requires separate frequency bands for both uplink and downlink. The TDD method uses the same frequency band but alternates the transmission direction in time. TDD is used, for example, for the digital enhanced cordless telephone (DECT). The SDD method is used in fixed-point transmission where directive antennas can be used. It is not used in cellular terminals.

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Figure 13.1 illustrates the operating principles of the FDD and TDD methods. The term downlink or forward link refers to transmission from the base station (fixed network side) to the mobile terminal (user equipment), and the term uplink or reverse link refers to transmission from the mobile terminal to the base station.

There are some characteristics peculiar to the TDD system listed below.

- Utilisation of unpaired band
  The TDD system can be implemented on an unpaired band while the FDD system always requires a pair of bands. In the future it is more likely that unpaired spectrum resources are cleared for UMTS as no pair is required for TDD operation.
- Discontinuous transmission
  Switching between transmission directions requires time, and the switching transients must be controlled. To avoid corrupted transmission, the uplink and downlink transmissions require a common means of agreeing on transmission direction and allowed time to transmit. Corruption of transmission is avoided by allocating a guard period which allows uncorrupted propagation to counter the propagation delay. Discontinuous transmission may also cause audible interference to audio equipment that does not comply with electromagnetic susceptibility requirements.
- Interference between uplink and downlink
  Since uplink and downlink share the same frequency band, the signals in those two transmission directions can interfere with each other. In FDD this interference is completely avoided by the duplex separation of 190 MHz. In UTRA TDD individual base stations are synchronised to each other at frame level to avoid this interference. This interference is further analysed in Section 13.3.
- Asymmetric uplink/downlink capacity allocation
  In TDD operation, uplink and downlink are divided in the time domain. It is possible to change the duplex switching point and move capacity from uplink to downlink, or vice versa, depending on the capacity requirement between uplink and downlink.
- Reciprocal channel
  The fast fading depends on the frequency, and therefore, in FDD systems, the fast fading is uncorrelated between uplink and downlink. As the same frequency is used

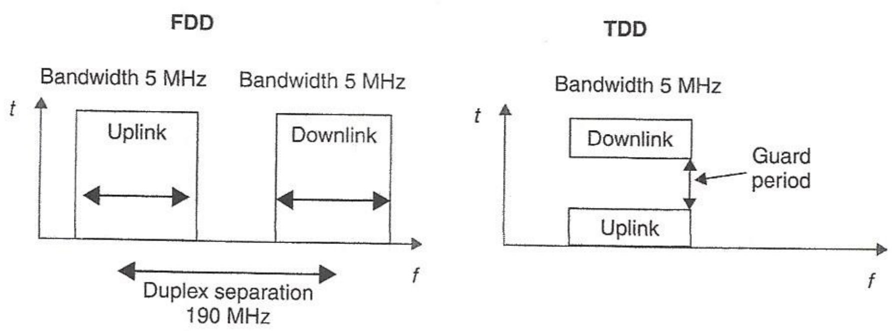

Figure 13.1. Principles of FDD and TDD operation

for both uplink and downlink in TDD, the fast fading is the same in uplink and in downlink. Based on the received signal, the TDD transceiver can estimate the fast fading, which will affect its transmission. Knowledge of the fast fading can be utilised in power control and in adaptive antenna techniques in TDD.

13.2 UTRA TDD Physical Layer

The UTRA TDD mode uses a combined time division and code division multiple access (TD/CDMA) scheme that adds a CDMA component to a TDMA system. The different user signals are separated in both time and code domain. Table 13.1 presents a summary of the UTRA physical layer parameters. All the major RF parameters are harmonised within UTRA for FDD and 3.84 Mcps TDD mode, with 1.28 Mcps TDD the resulting RF parameters are obviously different due different bandwidth.

Table 13.1. Comparison of UTRA FDD and 3.84 Mcps TDD physical layer key parameters

	UTRA TDD	UTRA FDD
Multiple access method	TDMA, CDMA (inherent FDMA)	CDMA (inherent FDMA)
Duplex method	TDD	FDD
Channel spacing	5 MHz (nominal)	
Carrier chip rate	3.84 Mcps	
Timeslot structure	15 slots/frame	
Frame length	10 ms	
Multirate concept	Multicode, multislot and orthogonal variable spreading factor (OVSF)	Multicode and OVSF
Forward error correction (FEC) codes	Convolutional coding $R = \frac{1}{2}$ or 1/3, constraint length $K = 9$, turbo coding (8-state PCCC $R = 1/3$) or service-specific coding	
Interleaving	Inter-frame interleaving (10, 20, 40 and 80 ms)	
Modulation	QPSK	
Burst types	Three types: traffic bursts, random access and synchronisation burst	Not applicable
Detection	Coherent, based on midamble	Coherent, based on pilot symbols
Dedicated channel power control	Uplink: open loop; 100 Hz or 200 Hz Downlink: closed loop; rate $\leq$ 800 Hz	Fast closed loop: rate = 1500 Hz
Intra-frequency handover	Hard handover	Soft handover
Inter-frequency handover	Hard handover	
Channel allocation	Slow and fast DCA supported	No DCA required
Intra-cell interference cancellation	Support for joint detection	Support for advanced receivers at base station
Spreading factors	1...16	4...512

13.2.1 Transport and Physical Channels

UTRA TDD mode transport channels can be divided into dedicated and common channels. Dedicated channels (DCH) are characterised in basically the same way as in the FDD mode. Common channels can be further divided into common control channels (CCCH), the random access channel (RACH), the downlink shared channel (DSCH) in the downlink, and the uplink shared channel (USCH) in the uplink. Each of these transport channels is then mapped to the corresponding physical channel.

The physical channels of UTRA TDD are the dedicated physical channel (DPCH), common control physical channel (CCPCH), physical random access channel (PRACH), paging indicator channel (PICH) and synchronisation channel (SCH). For the SCH and PICH there do not exist corresponding transport channels. The mapping of the different transport channels to the physical channels and all the way to the bursts is shown in Figure 13.2. The physical channel structure is discussed in the following section in more detail.

13.2.2 Modulation and Spreading

The data modulation scheme in UTRA TDD is QPSK. The modulated data symbols are spread with a specific channelisation code of length 1–16. The modulated and spread data is finally scrambled by a pseudorandom sequence of length 16. The same type of

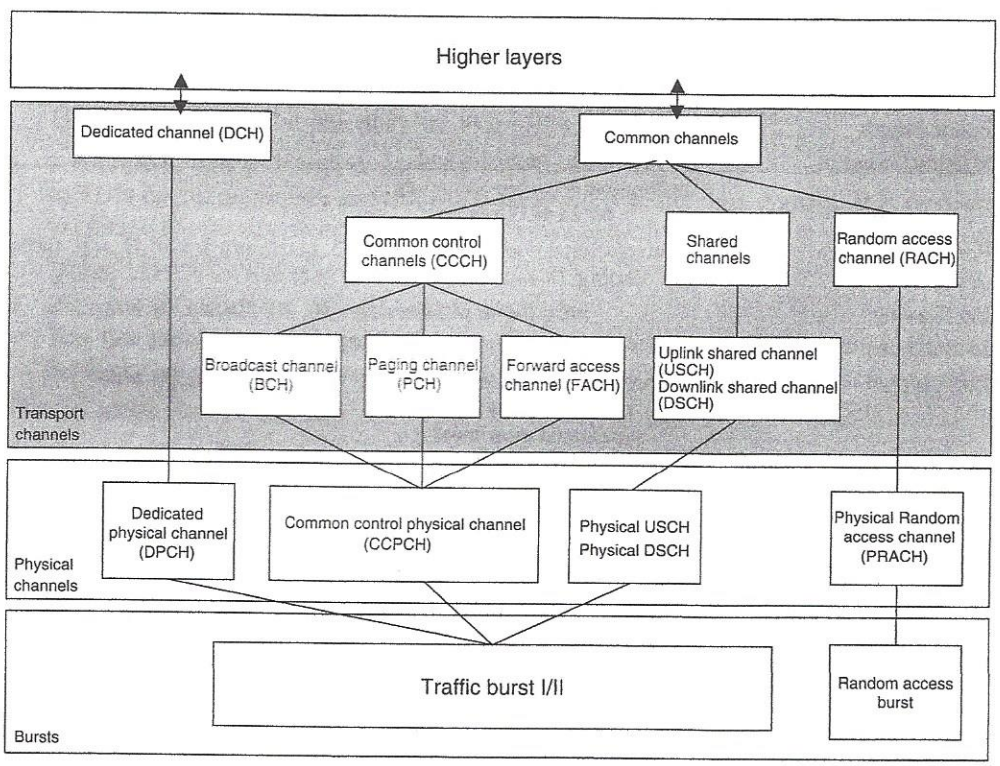

Figure 13.2. Mapping of the UTRA TDD transport channels to physical channels

orthogonal channelisation codes is used in the UTRA FDD system (see Section 6.3). Data spreading is followed by scrambling with a cell- or source-specific scrambling sequence; the scrambling process is chip-by-chip multiplication. The combination of multiplying with channelisation code and the cell-specific scrambling code is a user- or cell-specific spreading procedure. Finally, pulse shape filtering is applied to each chip at the transmitter: each chip is filtered with a root raised cosine filter with roll-off factor $\alpha = 0.22$, identical to UTRA FDD.

13.2.3 Physical Channel Structures, Slot and Frame Format

The physical frame structure is similar to that of the UTRA FDD mode. The frame length is 10 ms and it is divided into 15 timeslots each of 2560 chips, i.e., the timeslot duration is 666 μs. Figure 13.3 shows the frame structure.

Each of the 15 timeslots within a 10 ms frame is allocated to either uplink or downlink. Multiple switching points for different transmission directions per frame allow closed loop power control and a physical synchronisation channel (PSCH) in dedicated downlink slots to speed cell search. On the other hand, to be able to cover dynamic asymmetric services, the flexibility in slot allocation in the downlink/uplink direction guarantees efficient use of the spectrum. To maintain maximum flexibility while allowing closed loop power control whenever useful, the SCH has two timeslots per frame for downlink transmission in cellular usage. Figure 13.4 (a) shows such a maximum uplink asymmetry slot allocation (2:13). The PSCH is mapped to two downlink slots. For public systems a single-slot-per- frame SCH scheme could be applied. On the other hand, at least one timeslot has to be allocated to uplink transmission for the random access channel. Figure 13.4 (b) illustrates a maximum downlink asymmetry of 14:1.

Since the TDMA transmission in UTRA TDD is discontinuous the average transmission power is reduced by a factor of $10 \times \log_{10}(n/15)$, where n is the number of active timeslots per frame. For example, to provide the same coverage with UTRA TDD using a single timeslot for 144 kbps requires at least four times more base station sites than with UTRA FDD. This 12 dB reduction in the average power would result in typical macro cell environment to reduce the cell range more than into half, and thus, the cell area to a quarter. When utilising the same hardware in the UE the TDMA discontinuous transmission with low duty cycle leads to reduced uplink range. With higher data rates

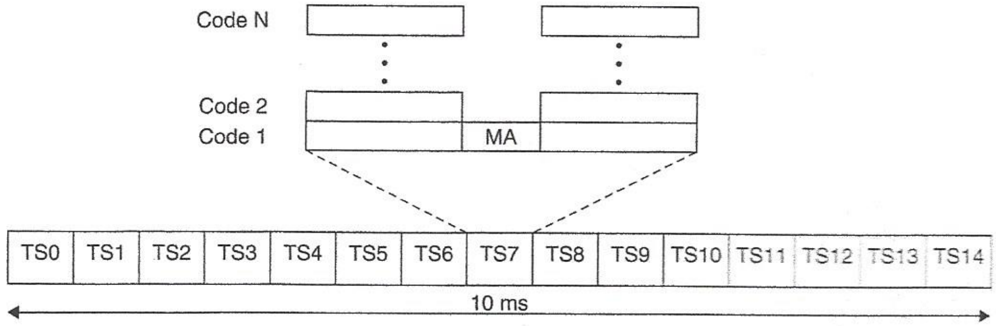

Figure 13.3. Frame structure of UTRA TDD. The number of code channels that may be used within a single timeslot varies depending on the propagation conditions (MA = midamble)

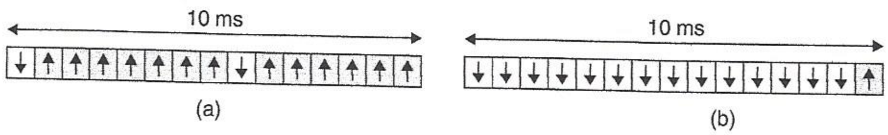

Figure 13.4. (a) Maximum uplink asymmetry of 2:13. Two slots per frame are allocated to downlink transmission; the synchronisation channel is assigned to these downlink slots. (b) Maximum downlink asymmetry (14:1); at least one uplink slot per frame is assigned for random access purposes

the coverage difference to FDD reduces. Due to these properties, TDD should be used in small cell environment where power is not limiting factor and data rates used for the coverage planning are higher.

13.2.3.1 Burst Types

There are three bursts defined for UTRA TDD. All of them are used for dedicated channels while common channels typically use only a subset of them.

Burst types I and II are usable for both uplink and downlink direction with the difference between the Tyoe I and II being the midamble length. Figure 13.5 illustrates the general downlink and Figure 13.6 the uplink burst structure with transmission power control (TPC) and transmission format combination indicator (TFCI). The burst types with two variants of midamble length can be used for all services up to 2 Mbps. The logical traffic channel (TCH), which contains user data, is mapped to a burst.

The burst contains two data fields separated by a midamble and followed by a guard period. The duration of a burst is one timeslot. The midamble is used for both channel equalisation and coherent detection at the receiver. The midamble reduces the user data payload. Table 13.2 shows the burst type I and II structures in detail.

Due to the longer midamble, burst type I is applicable for estimating 16 different uplink channel impulse responses. Burst type II can be used for the downlink independently of

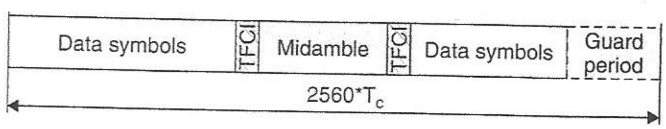

Figure 13.5. Generalised UTRA TDD downlink burst structure. The data fields are separated by a midamble which is used for channel estimation. The transport format combination indicator (TFCI) is used to indicate the combination of used transport channels in the dedicated physical channel (DPCH) and is sent only once per frame. The TFCI uses in-band signalling and has its own coding. The number of TFCI bits is variable and is set at the beginning of the call

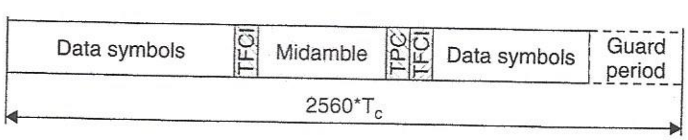

Figure 13.6. Generalised uplink burst structure. Both transmission power control (TPC) and TFCI are present. Both TFCI and TPC are transmitted in the same physical channel and use in-band signalling. The length of the TPC command is one symbol

Table 13.2. Burst type field structures

Burst name	Data field 1 length	Training sequence length	Data field 2 length	Guard period length
Burst type I	976 chips	512 chips	976 chips	96 chips
Burst type II	1104 chips	256 chips	1104 chips	96 chips
Burst type III	976 chips	512 chips	880 chips	192 chips

the number of active users. If there are fewer than four users within a timeslot, burst type II can also be used for the uplink.

The midambles, i.e., the training sequences of different users, are time-shifted versions of one periodic basic code. Different cells use different periodic basic codes, i.e., different midamble sets. Due to the generation of midambles from the same periodic basic code, channel estimation of all active users within one timeslot can be performed jointly, for example by one single cyclic correlator. Channel impulse response estimates of different users are obtained sequentially in time at the output of the correlator [6].

In 3GPP Release-99, the downlink uses either a spreading factor of 16 with the possibility of multicode transmission, or a spreading factor of 1 for high bit rate applications in case such a capability is supported by the terminals. In the uplink, orthogonal variable spreading factor (OVSF) codes with spreading factors from 1 to 16 are used. The total number of the burst formats is 20 in the downlink and 90 in the uplink.

The burst Type III is used in the uplink direction only. The has developed for the needs for the PRACH as well as to facilitate handover in cases when timing advance is needed. The guard time of 192 chips (50 μs) equals a cell radius of 7.5 km.

13.2.3.2 Physical Random Access Channel (PRACH)

The logical random access channel (RACH) is mapped to a physical random access (PRACH) channel. Table 13.2 shows the burst type III used with PRACH. and Figure 13.7 illustrate the burst type III structure Spreading factor values of 16 and 8 are used for PRACH. With PRACH there is typically no TPC or TFCI bits used as shown in Figure 13.7.

13.2.3.3 Synchronisation Channel (SCH)

The time division duplex creates some special needs for the synchronisation channel. A capturing problem arises due to the cell synchronisation, i.e. a phenomenon occurring when a stronger signal masks weaker signals. The time misalignment of the different synchronisation channels of different cells would allow for distinguishing several cells within a single timeslot. For this reason a variable time offset (t_{offset}) is allocated between the SCH and the system slot timing. The offset between two consecutive shifts is $71T_c$. There exist two different SCH structures. The SCH can be mapped either to the slot number $k \in \{0 \ldots 14\}$ or to timeslots k and $k+8$, $k \in \{0 \ldots 6\}$. Figure 13.8 shows the

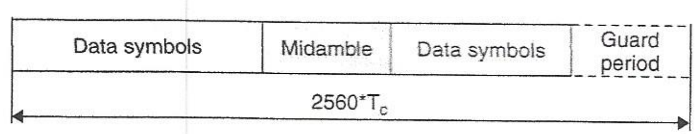

Figure 13.7. UTRA TDD burst type III when used with PRACH

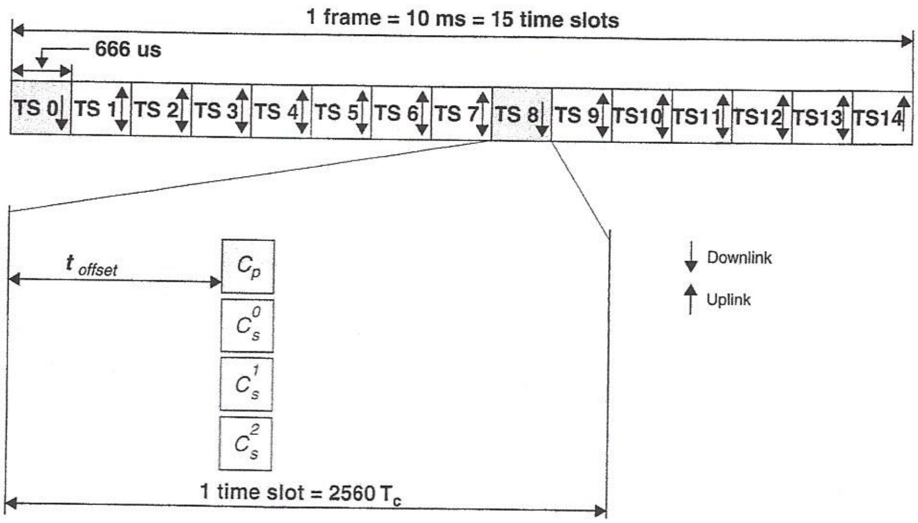

Figure 13.8. UTRA TDD SCH structure. This example has two downlink slots allocated for SCH ($k = 0$). The primary code (c_p) and three QPSK-modulated secondary codes (c_s) are transmitted simultaneously. The time offset (t_{offset}) is introduced to avoid adverse capture effects of the synchronous system. The combined transmission power of the three c_s is equal to the power of c_p

latter SCH structure for $k = 0$. This dual-SCH-per-frame structure is intended for cellular use. The position of the SCH can vary on a long-term basis.

The terminal can acquire synchronisation and the coding scheme for the BCCH of the cell in one step and will be able to detect cell messaging instantly. The primary (c_p) and the three secondary (c_s) synchronisation sequences are transmitted simultaneously. Codes are 256 chips long as in the UTRA FDD mode, and the primary code is generated in the same way as in the FDD mode, as a generalised hierarchical Golay sequence. The secondary synchronisation code words (c_s) are chosen from every 16th row of the Hadamard sequence H_8, which is used also in the FDD mode. By doing this there are only 16 possible code words in comparison to 32 of the FDD mode. The codes are QPSK modulated and the following information is indicated by the SCH:

— Base station code group out of 32 possible alternatives (5 bits)
— Position of the frame in the interleaving period (1 bit)
— Slot position in the frame (1 bit)
— Primary CCPCH locations (3 bits)

With a sequence it is possible to decode the frame synchronisation, the time offset (t_{offset}), the midamble and the spreading code set of the base station as well as the spreading code(s) and location of the broadcast channel (BCCH).

The cell parameters within each code group are cycled over two frames to randomise interference between base stations and to enhance system performance. Also, network planning becomes easier with the averaging property of the parameter cycling.

13.2.3.4 Common Control Physical Channel (CCPCH)

Once the synchronisation has been acquired, the timing and coding of the primary broadcast channel (BCH) are known. The CCPCH can be mapped to any downlink slot(s), including the PSCH slots, and this is pointed by the primary BCH.

The CCPCH is similar to the downlink dedicated physical channel (DPCH). It may be coded with more redundancy than the other channels to simplify acquisition of information.

13.2.3.5 UTRA TDD Shared Channels

The UTRA TDD specification also defines the Downlink Shared Channel (DSCH) and the Uplink Shared Channel (USCH). These channels use exactly the same slot structure as do the dedicated channels. The difference is that they are allocated on a temporary basis.

In the downlink the signalling to indicate which terminals need to decode the channel can be done with TFCI, by detecting midamble in use or by higher layers. In the uplink the USCH uses higher layer signalling and thus is not shared in practice on a frame-by-frame basis.

13.2.3.6 User Data Rates

Table 13.3 shows the UTRA TDD user bit rates with $\frac{1}{2}$-rate channel coding and spreading factor 16. The tail bits, TFCI, TPC or CRC overhead have not been taken into account. Spreading factors other than 16 (from the orthogonal variable spreading scheme) can be seen as subsets of spreading factor 16 (i.e., spreading factor 8 in the uplink corresponds to two parallel codes with spreading factor 16 in the downlink). When the number of needed slots exceeds 7, the corresponding data rate can be provided only for either the uplink or the downlink. The bit rates shown in Table 13.3 are time slot and code limited bit rates, the maximum interference limited bit rate can be lower.

13.2.4 UTRA TDD Physical Layer Procedures

13.2.4.1 Power Control

The purpose of power control is to minimise the interference of separate radio links. Both the uplink and downlink dedicated physical channels (DPCH) and physical random access channel (PRACH) are power controlled. The forward access channel (FACH) may be power controlled. The implementation of advanced receivers such as the joint detector will suppress intra-cell (own cell) interference and reduce the need for fast power control. The optimum multi-user detector is near–far resistant [7] but in practice the limited dynamic

Table 13.3. UTRA TDD air interface user bit rates

	Number of allocated timeslots		
Number of allocated codes with spreading factor 16	**1**	**4**	**13**
1	13.8 kbps	55.2 kbps	179 kbps
8	110 kbps	441 kbps	1.43 Mbps
16 (or spreading factor 1)	220 kbps	883 kbps	2.87 Mbps

Table 13.4. Power control characteristics of UTRA TDD

	Uplink	Downlink
Method	Open loop	SIR-based closed inner loop
Dynamic range	65 dB Minimum power −44 dBm or less Maximum power 21 dBm	30 dB (all the users are within 20 dB in one timeslot)
Step size	1, 2, 3 dB	1, 2, 3 dB
Rate	Variable 1–7 slots delay (2 slot PCCPCH) 1–14 slots delay (1 slot PCCPCH)	From 100 Hz to approx. 750 Hz

range of the suboptimum detector restricts performance. Table 13.4 shows the UTRA TDD power control characteristics.

In the downlink, closed loop is used after initial transmission. The reciprocity of the channel is used for open loop power control in the uplink. Based on interference level at the base station and on path loss measurements of the downlink, the mobile weights the path loss measurements and sets the transmission power. The interference level and base station transmitter power are broadcast. The transmitter power of the mobile is calculated by the following equation [4]:

$$P_{UE} = \alpha L_{PCCPCH} + (1 - \alpha)L_0 + I_{BTS} + SIR_{TARGET} + C \qquad (13.1)$$

In Equation (13.1) P_{UE} is the transmitter power level in dBm, L_{PCCPCH} is the measured path loss in dB, L_0 is the long-term average of path loss in dB, I_{BTS} is the interference signal power level at the base station receiver in dBm, and α is a weighting parameter which represents the quality of path loss measurements. The α is a function of the time delay between the uplink timeslot and the most recent downlink PCCPCH timeslot. SIR_{TARGET} is the target SNR in dB; this can be adjusted through higher layer outer loop. C is a constant value.

13.2.4.2 Data Detection

UTRA TDD requires that simultaneously active spreading codes within a timeslot are separated by advanced data detection techniques. The usage of conventional detectors, i.e. matched filters or Rake, in the base station requires tight uplink power control, which is difficult to implement in a TDD system since the uplink is not continuously available. Thus advanced data detection techniques should be used to suppress the effect of power differences between users, i.e., the near–far effect. Both inter-symbol interference (ISI) due to multipath propagation and multiple access interference (MAI) between data symbols of different users are present also in downlink. In downlink, the intra-cell interference is suppressed by the orthogonal codes, and the need for advanced detectors is lower than in uplink. In UTRA TDD the number of simultaneously active users is small and the use of relatively short scrambling codes together with spreading make the use of advanced receivers attractive.

The sub-optimal data detection techniques can be categorised as single-user detectors and multi-user detectors (see Section 11.5.2). In UTRA TDD single-user detectors can be applied when all signals pass through the same propagation channel, i.e. they are primarily applied for the downlink [8]. Otherwise, multi-user or joint detection is applied [9, 10].

Single-user detectors first equalise the received data burst to remove the distortion caused by the channel. When perfect equalisation is assumed, the orthogonality of the codes is restored after equalisation. The desired signal can now be separated by code-matched filtering. The advantages of using single-user detectors are that no knowledge of the other user's active codes is required and the computational complexity is low compared to joint detection [8].

To be able to combat both MAI and ISI in UTRA TDD, equalisation based on, for example, zero-forcing (ZF) or minimum mean-square-error (MMSE) can be applied. Both equalisation methods can be applied with or without decision feedback (DF). The computational complexity of the algorithms is essentially the same, but the performance of the MMSE equalisers is better than that of the ZF equalisers [10]. The decision feedback option improves performance (about 3 dB less E_b/N_0 at practical bit error rates) and the MMSE algorithm generally performs better (less than 1 dB difference in E_b/N_0 requirements) than zero-forcing. Antenna diversity techniques can be applied with joint detection [11, 12] to further enhance the performance.

The performance of Rake, ZF equaliser, MMSE equaliser and HD-PIC (hard decision parallel interference canceller [13]) in the UTRA TDD uplink was studied using Monte Carlo computer simulations in the UTRA TDD uplink [14]. Eight users with spreading factor of 16 occupy one timeslot within a 10 ms frame. A two-path channel with tap gains of 0 dB and −9.7 dB and with a mobile speed of 3 km/h is considered. Channel estimation and power control are assumed to be ideal and channel coding is omitted. The performance of Rake, ZF, MMSE, and one- and two-stage HD-PIC are shown in Figure 13.9. The results show that the advanced base station receivers give a clear gain

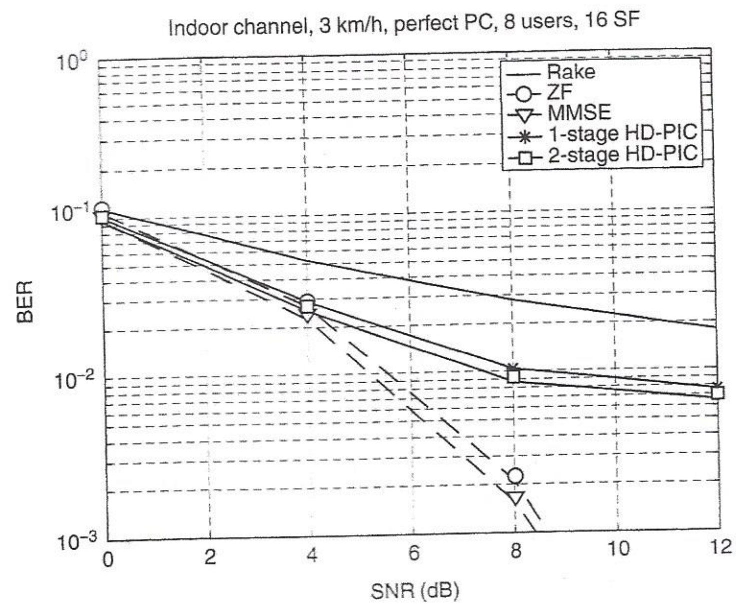

Figure 13.9. Performance of Rake, ZF and MMSE equalisers and one- and two-stage HD-PIC in the UTRA TDD uplink

compared to the Rake receiver in UTRA TDD even with ideal power control. As the signal-to-noise ratio (SNR) increases, the performance of ZF and MMSE is better than the performance of HD-PIC. Channel coding typically increases the differences between the performance of different detectors. For example, in the operational area of BER = 5–10% the gain from the advanced receiver structures can be up to 2 dB with perfect power control and even more with realistic power control. The difference between the presented advanced detectors is small in this operational area.

13.2.4.3 Timing Advance

To avoid interference between consecutive timeslots in large cells, it is possible to use a timing advancement scheme to align the separate transmission instants in the base station receiver. The timing advance is determined by a 6-bit number with an accuracy of four chips (1.042 μs). The base station measures the required timing advance, and the terminal adjusts the transmission according to higher layer messaging. The maximum cell range is 9.2 km.

The UTRA TDD cell radius without timing advance can be calculated from the guard period of traffic burst (96 chips = 25 μs), resulting in a range of 3.75 km. This value exceeds practical TDD cell ranges (micro and pico cells) and in practice the timing advance is not likely to be needed.

13.2.4.4 Channel Allocation

The layer 2 medium access control (MAC) entity is responsible timely resource allocation for transmission. Resource unit (RU) allocation (channel frequency, timeslot and code) is done by allocating resources to cells (slow dynamic channel allocation, DCA) and resource allocation to bearer services (fast DCA). Both the terminal and the base station perform periodic monitoring and reporting to support DCA. The termination of the MAC protocol is therefore much more complicated than in the UTRA FDD mode. The fast DCA is always terminated at the base station, but the slow DCA can be terminated at any network entity above the base stations that form the seamless coverage area. In practice this is RNC. Figure 13.10 illustrates the partitioning of different DCA elements in the network.

Slow Dynamic Channel Allocation (DCA)

The slow DCA can be terminated at a network element above the base stations that form a continuous coverage area, i.e. have the same uplink/downlink partitioning. By doing this the network can dynamically allocate resource units based on negotiation between adjacent cells to make handovers between cells fast and to minimise interference. Moreover, the slow DCA algorithm allocates resource units in a cell-related preference list (matrix) for fast DCA to acquire them for different bearers. The cell preference list is updated on a frame-by-frame basis. The slow DCA has the arbitration functionality to solve conflicts between base stations.

Fast Dynamic Channel Allocation (DCA)

The fast DCA acquires and releases resource units according to the slow DCA preference list. The multirate services are achieved by pooling resource units in either the code domain (multicode) or the time domain (multislot). A combination of both is also possible.

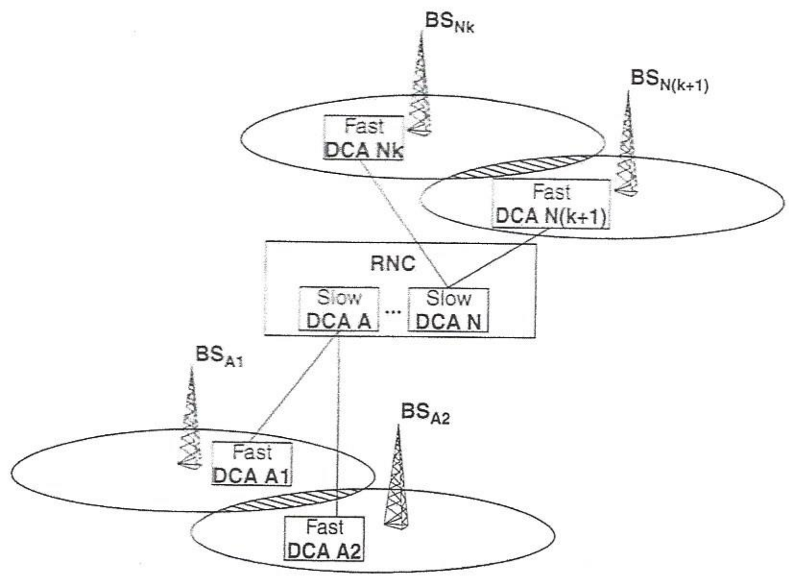

Figure 13.10. Illustration of DCA partitioning between different network elements. The slow DCA is located in RNC and the fast DCA is located in each base station

The methods used for fast DCA can be timeslot pooling (as in DECT), frequency pooling or code pooling. The fast DCA can operate on the following strategies:

1. Allocate least interfered resources for traffic (code/timeslot).
2. Allocate several timeslots in order to gain from time diversity.
3. Average inter-cell interference, especially with low to medium data rate users when the cell load is sufficiently low. This is achieved by varying timeslot, code and frequency according to a predetermined scheme.

The number of codes is also dynamic and depends on channel characteristics, environment and system implementation. The fast DCA guidelines are also service dependent. For real-time services channels remain allocated for the whole duration, but the allocated code channel/timeslot (resource unit, or RU) may vary according to the reallocation procedure. For non-real-time services the channels are allocated only for the period of transmission of a data packet by using best effort strategy.

13.2.4.5 Handover

UTRA TDD supports inter-system handovers and intra-system handovers (to UTRA FDD and to GSM). All these handovers are mobile-assisted hard handovers.

UTRA TDD does not use soft handover (or macro diversity). This is a clear difference from UTRA FDD, in which the protocol structure has been designed to support soft handover. The UTRA TDD protocol structure has followed the same architecture as FDD for termination points for maximum commonality above the physical layer. This means, for example, that handover protocols terminate at the same location (RNC) but consist of FDD and TDD mode-specific parameters.

13.2.4.6 UTRA TDD Transmit Diversity

UTRA TDD supports four downlink transmit diversity methods. They are comparable to those in UTRA FDD. For dedicated physical channels Switched Transmitter Diversity (STD) and Transmit Adaptive Antennas (TxAA) methods are supported. The antenna weights are calculated using the reciprocity of the radio link. In order to utilise TxAA method, the required base station receiver and transmitter chain calibration makes the implementation more challenging.

For common channels Time Switched Transmit Diversity (TSTD) is used for PSCH, and Block Space Time Transmit Diversity (Block STTD) is used for primary CCPCH.

For uplink at the base station, the same receiver diversity methods as in FDD are applicable to enhance the performance.

13.3 UTRA TDD Interference Evaluation

In this section we evaluate the effect of interference within the TDD band and between TDD and FDD. TDD–TDD interference is analysed in Section 13.3.1 and the co-existence of TDD and FDD systems in Section 13.3.2.

13.3.1 TDD–TDD Interference

Since both uplink and downlink share the same frequency in TDD, those two transmission directions can interfere with each other. By nature the TDD system is synchronous and this kind of interference occurs if the base stations are not synchronised. It is also present if different asymmetry is used between the uplink and downlink in adjacent cells even if the base stations are frame synchronised. Frame synchronisation requires an accuracy of a few symbols, not an accuracy of chips. The guard period allows more tolerance in synchronisation requirements. Figure 13.11 illustrates possible interference scenarios. The interference within the TDD band is analysed with system simulations in [15].

Interference between uplink and downlink can also occur between adjacent carriers. Therefore, it can also take place between two operators.

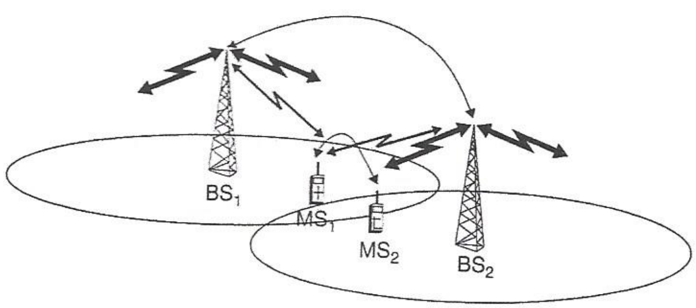

Figure 13.11. Interference between mobiles, between base stations, and between mobile and base station

In FDD operation the duplex separation prevents interference between uplink and downlink. The interference between a mobile and a base station is the same in both TDD and FDD operation and is not considered in this chapter.

13.3.1.1 Mobile Station to Mobile Station Interference

Mobile-to-mobile interference occurs if mobile MS_2 in Figure 13.12 is transmitting and mobile MS_1 is receiving simultaneously in the same (or adjacent) frequency in adjacent cells. This type of interference is statistical because the locations of the mobiles cannot be controlled. Therefore, it cannot be avoided by network planning. Intra-operator mobile-to-mobile interference occurs especially at cell borders. Inter-operator interference between mobiles can occur anywhere where two operators' mobiles are close to each other and transmitting on fairly high power. Methods to counter mobile-to-mobile interference are:

- DCA and radio resource management
- Power control.

13.3.1.2 Base Station to Base Station Interference

Base station to base station interference occurs if base station BS_1 in Figure 13.12 is transmitting and base station BS_2 is receiving in the same (or adjacent) frequency in adjacent cells. It depends heavily on the path loss between the two base stations and therefore can be controlled by network planning.

Intra-operator interference between base stations depends on the base station locations. Interference between base stations can be especially strong if the path loss is low between the base stations. Such cases could occur, for example, in a macro cell, if the base stations are located on masts above rooftops. The best way to avoid this interference is by careful planning to provide sufficient coupling loss between base stations.

The outage probabilities in [15] show that co-operation between TDD operators in network planning is required, or the networks need to be synchronised and the same

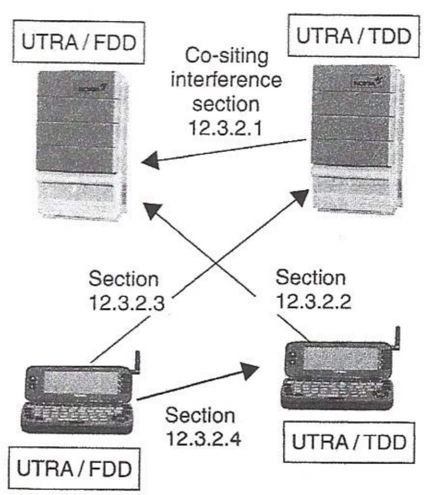

Figure 13.12. Possible interference situations between lower TDD band and FDD uplink band

asymmetry needs to be applied. Sharing base station sites between operators will be very problematic, if not impossible. The situation would change if operators had inter-network synchronisation and identical uplink/downlink split in their systems.

From the synchronisation and co-ordination point of view, the higher the transmission power levels and the larger the intended coverage area, the more difficult will be the co-ordination for interference management. In particular, the locations of antennas of the macro-cell type tend to result in line-of-sight connections between base stations, causing strong interference. Operating TDD in indoor and micro/pico cell environments will mean lower power levels and will reduce the problems illustrated.

13.3.2 TDD and FDD Co-existence

The UTRA FDD and TDD have spectrum allocations that meet at the border at 1920 MHz, and therefore TDD and FDD deployment cannot be considered independently: see Figure 13.13. The regional allocations were shown in Figure 1.2 in Chapter 1. Dynamic channel allocation (DCA) can be used to avoid TDD–TDD interference, but DCA is not effective between TDD and FDD, since FDD has continuous transmission and reception. The possible interference scenarios between TDD and FDD are summarised in Figure 13.12.

13.3.2.1 Co-siting of UTRA FDD and TDD Base Stations

From the network deployment perspective, the co-siting of FDD and TDD base stations looks an interesting alternative. There are, however, problems due to the close proximity of the frequency bands. The lower TDD band, 1900–1920 MHz, is located adjacent to the FDD uplink band, 1920–1980 MHz. The resulting filtering requirements in TDD base stations are expected to be such that co-siting a TDD base station in the 1900–1920 MHz band with an FDD base station is not considered technically and commercially a viable solution. Table 13.5 illustrates the situation. The output power of 24 dBm corresponds to a small pico base station and 43 dBm to a macro cell base station.

The required attenuation between TDD macro cell base stations is 78 dB. If we introduce the 5 MHz guard band, with centre frequencies 10 MHz apart, the additional frequency separation of 5 MHz would increase the channel protection by 5 dB. The co-siting (co-located RF parts) is not an attractive alternative with today's technology.

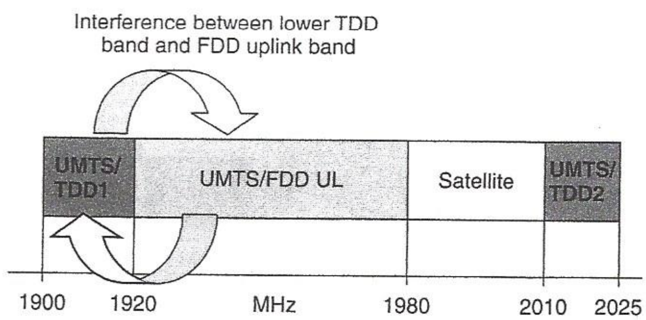

Figure 13.13. Interference between lower TDD band and FDD uplink band

Table 13.5. Coupling loss analysis between TDD and FDD base station in adjacent frequencies at 1920 MHz

TDD base station output power (pico/macro)	24/43 dBm
Adjacent channel power ratio	−45 dBc
Isolation between antennas (separate antennas for FDD and TDD base stations)	−30 dB
Leakage power into FDD base station receiver	−51/−32 dBm
Allowed leakage power	−110 dBm
Required attenuation	59/78 dB

The micro and pico cell environments change the situation, since the TDD base station power level will be reduced to as low as 24 dBm in small pico cells. On the other hand, the assumption of 30 dB antenna-to-antenna separation will not hold if antennas are shared between TDD and FDD systems. Antenna sharing is important to reduce the visual impact of the base station site. Also, if the indoor coverage is provided with shared distributed antenna systems for both FDD and TDD modes, there is no isolation between the antennas. Thus the TDD system should create a separate cell layer in UTRAN. In the pico cell TDD deployment scenario the interference between modes is easier to manage with low RF powers and separate RF parts.

13.3.2.2 Interference from UTRA TDD Mobile to UTRA FDD Base Station

UTRA TDD mobiles can interfere with a UTRA FDD base station. This interference is basically the same as that from a UTRA FDD mobile to a UTRA FDD base station on the adjacent frequency. The interference between UTRA FDD carriers is presented in Section 8.5. There is, however, a difference between these two scenarios: in pure FDD interference there is always the corresponding downlink interference, while in interference from TDD to FDD there is no downlink interference. In FDD operation the downlink interference will typically be the limiting factor, and therefore uplink interference will not occur. In the interference from a TDD mobile to an FDD base station, the downlink balancing does not exist as between FDD systems, since the interfering TDD mobile does not experience interference from UTRA FDD. This is illustrated in Figure 13.14.

One way to avoid uplink interference problems is to make the base station receiver less sensitive on purpose, i.e. to desensitise the receiver. For small pico cells indoors, base station sensitivity can be degraded without affecting cell size. Another solution is to place the FDD base stations so that the mobile cannot get very close to the base station antenna.

13.3.2.3 Interference from UTRA FDD Mobile to UTRA TDD Base Station

A UTRA FDD mobile operating in 1920–1980 MHz can interfere with the reception of a UTRA TDD base station operating in 1900–1920 MHz. Uplink reception may experience high interference, which is not possible in FDD-only operation. The inter-frequency and inter-system handovers alleviate the problem. The same solutions can be applied here as in Section 13.3.2.2.

13.3.2.4 Interference from UTRA FDD Mobile to UTRA TDD Mobile

A UTRA FDD mobile operating in 1920–1980 MHz can interfere with the reception of a UTRA TDD mobile operating in 1900–1920 MHz. It is not possible to use the

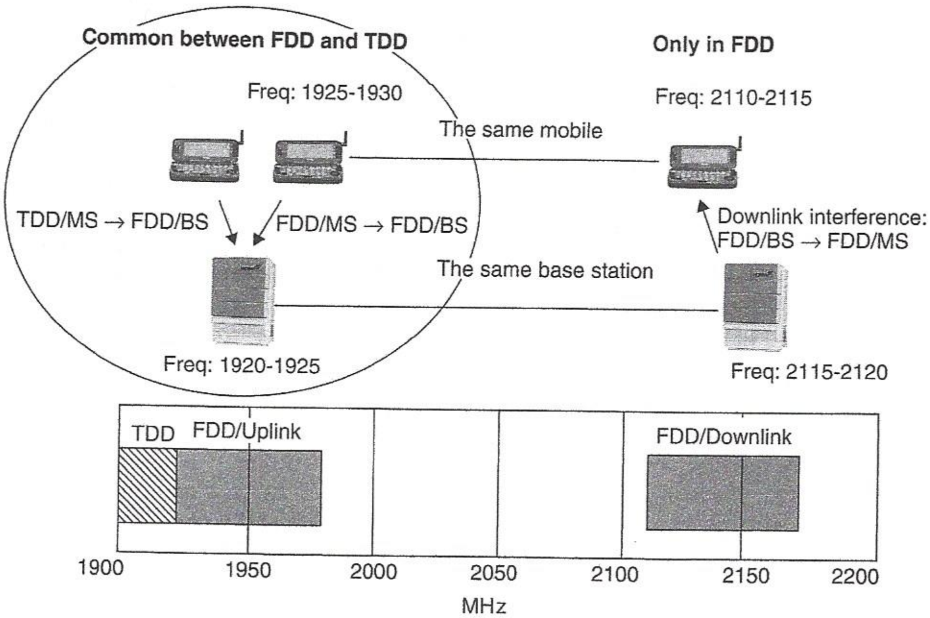

Figure 13.14. Interference from TDD mobile to FDD base station

solutions of Sections 13.3.2.2 because the locations of the mobiles cannot be controlled. One way to tackle the problem is to use downlink power control in TDD base stations to compensate for the interference from the FDD mobile. The other solution is inter-system/inter-frequency handover. This type of interference also depends on the transmission power of the FDD mobile. If the FDD mobile is not operating close to its maximum power, the interference to TDD mobiles is reduced. The relative placement of UTRA base stations has effect in the generated interference. Inter-system handover requires multimode FDD/TDD mobiles and this cannot always be assumed.

13.3.3 Unlicensed TDD Operation

Unlicensed operation with UTRA TDD is possible if DCA techniques are applied together with TDMA components. DCA techniques cannot be applied for high bit rates since several timeslots are needed. Therefore, unlicensed operation is restricted to low to medium bit rates if there are several uncoordinated base stations in one geographical area.

13.3.4 Conclusions on UTRA TDD Interference

Sections 13.3.1–13.3.3 considered those UTRA TDD interference issues that are different from UTRA FDD-only operation. The following conclusions emerge:

— Frame-level synchronisation of each operator's UTRA TDD base stations is required.

— Frame-level synchronisation of the base stations of different TDD operators is also recommended if the base stations are close to each other.

— Cell-independent asymmetric capacity allocation between uplink and downlink is not feasible for each cell in the coverage area.

— Dynamic channel allocation is needed to reduce the interference problems within the TDD band.

— Interference between the lower TDD band and the FDD uplink band can occur and cannot be avoided by dynamic channel allocation.

— Inter-system and inter-frequency handovers provide means of reducing and escaping the interference.

— Co-siting of UTRA FDD and TDD macro cell base stations is not feasible, and co-siting of pico base stations sets high requirements for UTRA TDD base station implementation.

— Co-existence of FDD and TDD can affect FDD uplink coverage area and TDD quality of service.

— With proper planning TDD can form a part of the UTRAN where TDD complements FDD.

According to [16], TDD operation should not be prohibited in the FDD uplink band. Based on the interference results in this chapter, there is very little practical sense in such an arrangement, nor is it foreseen to be supported by the equipment offered for the market.

13.4 Low Chip Rate TDD

During the Release 4 work 1.28 Mcps TDD mode was introduced in the 3GPP specifications (version 4.x. onwards). The major difference is the smaller chip rate which obviously results to the different physical layer channel structure and RF requirements compared to the 3.84 Mcps TDD.

The areas where most issues are common is the channel coding and multiplexing as well as spreading. The spreading factors and channel encoders are common with 3.84 Mcps TDD. The difference in the slot and frame structure comes from the different chip rate and resulting to 14 slots per frame compared to 15 slot with 3.84 Mcps TDD. The slot structure in Figure 13.15. has similarity to 3.84 Mcps when compared to the slot structure in Figure 13.3. The frames consist of 2 identical 5 ms sub-frames that include each 7 time slots. In each sub frame the first time slot is always allocated for downlink and second for the uplink direction. In addition each sub frame has after the first time uplink and downlink pilot slots as well as 96 chips master guard period. In case TFCI and TPC bits are to be transmitted they are included in the timeslots next to the midamble in a similar way as with 3.84 Mcps TDD. Also the uplink synchronisation commands are used in such a way.

In the area of modulation the 1.28 Mcps TDD contains 8PSK that was needed to fulfil the 2 Mbits/s requirements set for the IMT-2000 3G technologies.

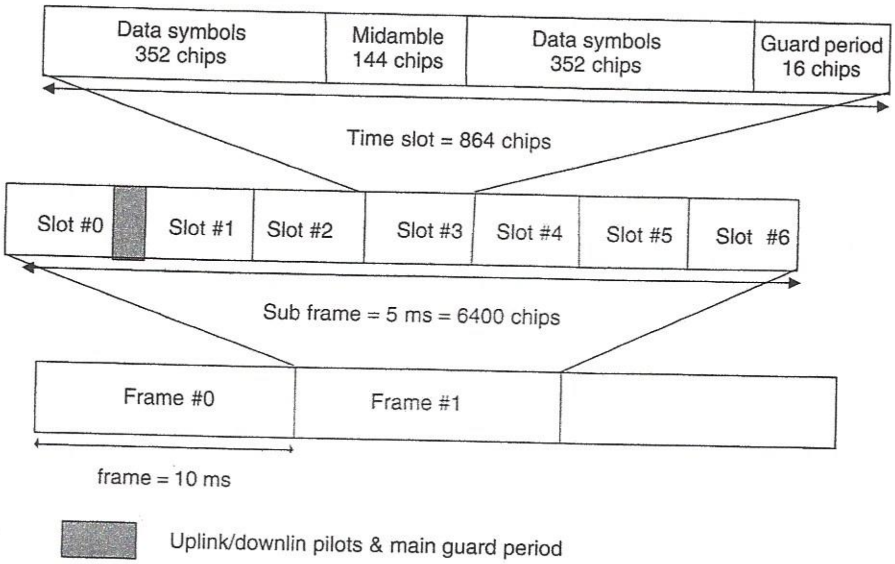

Figure 13.15. 1.28 Mcps TDD time slot and frame structure

From the physical layer procedures point of view the 1.28 Mcps TDD contain possibility for uplink synchronisation by sending synchronisation adjustment commands in the downlink direction. Further details can be found from the Release 4 versions on [1–4].

13.5 Concluding Remarks on UTRA TDD

This chapter covered UTRA TDD. The focus was on the physical layer issues, since the higher layer specifications are common, to a large extent, with UTRA FDD. In an actual implementation the algorithms for both the receiver and radio resource management differ between UTRA FDD and TDD, as the physical layers have different parameters to control. Especially in the TDD base station, advanced receivers are needed, while for mobile stations the required receiver solution will depend on the details of performance requirements.

From the service point of view, both UTRA TDD and FDD can provide both low and high data rate services with similar QoS. The only exception for UTRA TDD is that after a certain point the highest data rates are asymmetric. The coverage of UTRA TDD will be smaller for low and medium data rate services than the comparable UTRA FDD service due to TDMA duty cycle. Also to avoid interference smaller cells provide better starting point. Therefore, UTRA TDD is most suited for small cells and high data rate services.

Interference aspects for UTRA TDD were analysed and will need careful consideration for deployment. With proper planning, UTRA TDD can complement the UTRA FDD network, the biggest benefit being the separate frequency band that can be utilised only with TDD operation.

References

[1] 3GPP Technical Specification 25.221 V3.1.0, Physical Channels and Mapping of Transport Channels onto Physical Channels (TDD).

[2] 3GPP Technical Specification 25.222 V3.1.0, Multiplexing and Channel Coding (TDD).

[3] 3GPP Technical Specification 25.223 V3.1.0, Spreading and Modulation (TDD).

[4] 3GPP Technical Specification 25.224 V3.1.0, Physical Layer Procedures (TDD).

[5] 3GPP Technical Specification 25.102 V3.1.0, UTRA (UE) TDD: Radio Transmission and Reception.

[6] Steiner, B. and Jung, P., 'Optimum and suboptimum channel estimation for the uplink of CDMA mobile radio systems with joint detection', *European Transactions on Telecommunications and Related Techniques*, Vol. 5, 1994, pp. 39–50.

[7] Lupas, R. and Verdu, S., 'Near–far resistance of multiuser detectors in asynchronous channels', *IEEE Transactions on Communications,* Vol. 38, no. 4, 1990, pp. 496–508.

[8] Klein, A., 'Data detection algorithms specially designed for the downlink of CDMA mobile radio systems', in *Proceedings of IEEE Vehicular Technology Conference*, Phoenix, AZ, 1997, pp. 203–207.

[9] Klein, A. and Baier, P.W., 'Linear unbiased data estimation in mobile radio systems applying CDMA', *IEEE Journal on Selected Areas in Communications,* Vol. 11, no. 7, 1993, pp. 1058–1066.

[10] Klein, A., Kaleh, G.K. and Baier P.W., 'Zero forcing and minimum mean square-error equalization for multiuser detection in code-division multiple-access channels', *IEEE Transactions on Vehicular Technology,* Vol. 45, no. 2, 1996, pp. 276–287.

[11] Jung, P. and Blanz, J.J., 'Joint detection with coherent receiver antenna diversity in CDMA mobile radio systems', *IEEE Transactions on Vehicular Technology,* Vol. 44, 1995, pp. 76–88.

[12] Papathanassiou, A., Haardt, M., Furio, I. and Blanz J.J., 'Multi-user direction of arrival and channel estimation for time-slotted CDMA with joint detection', in *Proceedings of the 1997 13th International Conference on Digital Signal Processing*, Santorini, Greece, 1997, pp. 375–378.

[13] Varanasi, M.K. and Aazhang, B., 'Multistage detection in asynchronous code-division multiple-access communications', *IEEE Transactions on Communications,* Vol. 38, no. 4, 1990, pp. 509–519.

[14] Väätäjä, H., Juntti, M. and Kuosmanen, P., 'Performance of multiuser detection in TD-CDMA uplink', EUSIPCO-2000, 5–8 September 2000, Tampere, Finland.

[15] Holma, H., Povey, G. and Toskala, A., 'Evaluation of interference between uplink and downlink in UTRA TDD', *VTC'99/Fall*, Amsterdam, 1999, pp. 2616–2620.

[16] ERC TG1 decision (98)183, February 1999.