UMTS Layer 1

UMTS Layer 1

1. RADIO CHANNEL MULTIPLEXING AND ALLOCATION

1.1 Introduction

UMTS is being deployed using radio spectrum identified in WARC 92 (and later, WRC 2000). Multiplexing is either frequency division (FDD) or time division (TDD) with opportunity driven multiple access (ODMA – not in UMTS R99).

In either case, the chiprate of 3.84 Mcps is accommodated within a channel of nominal bandwidth 5 MHz.

FDD mode uses wideband CDMA (W-CDMA) and can also be termed FDD Mode 1 (to distinguish it from other IMT2000 FDD modes) or DS-CDMA because direct sequence (DS) techniques are used to generate the spread-spectrum signal.

TDD mode uses a combination of time division and wideband code division multiple access and is termed TD-CDMA.

1.2 Radio Channels and UMTS Absolute Radio Frequency Channel Number (UARFCN)

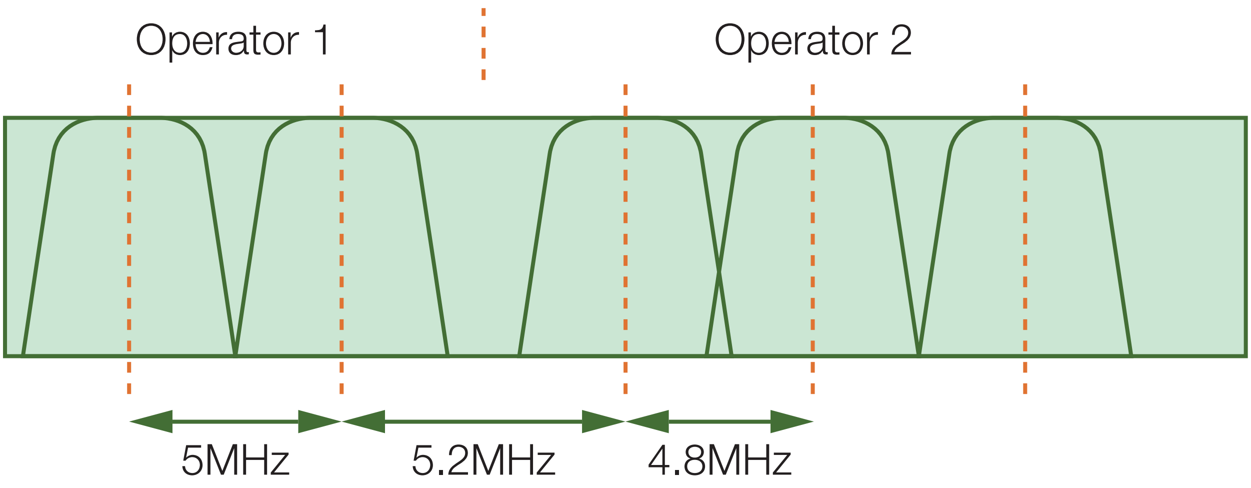
Radio channels are designated using an absolute radio frequency channel number as follows:

UARFCN = 5 x F (MHz)

e.g. F = 1903 MHz
UARFCN = 5 x 1903 = 9505

Centre frequencies of channels can be adjusted on a 200KHz raster within the Operator’s licenced spectrum. This could result in channel spacing as tight as 4.4 MHz. In this way guard channels can be created, for example between operators to minimise adjacent channel interference problems.

- WARC 92 SPECTRUM
- FDD MODE USES W-CDMA
- TDD MODE USES TD-CDMA
- TDD/ODMA IS A LATER OPTION (Not R99)
- FDD/TDD USE NOMINAL 5MHz RADIO CHANNEL BANDWIDTH
- UARFCN IDENTIFIES CHANNEL CENTRE FREQUENCY
- CENTRE FREQUENCIES PLACED ON A 200KHz RASTER



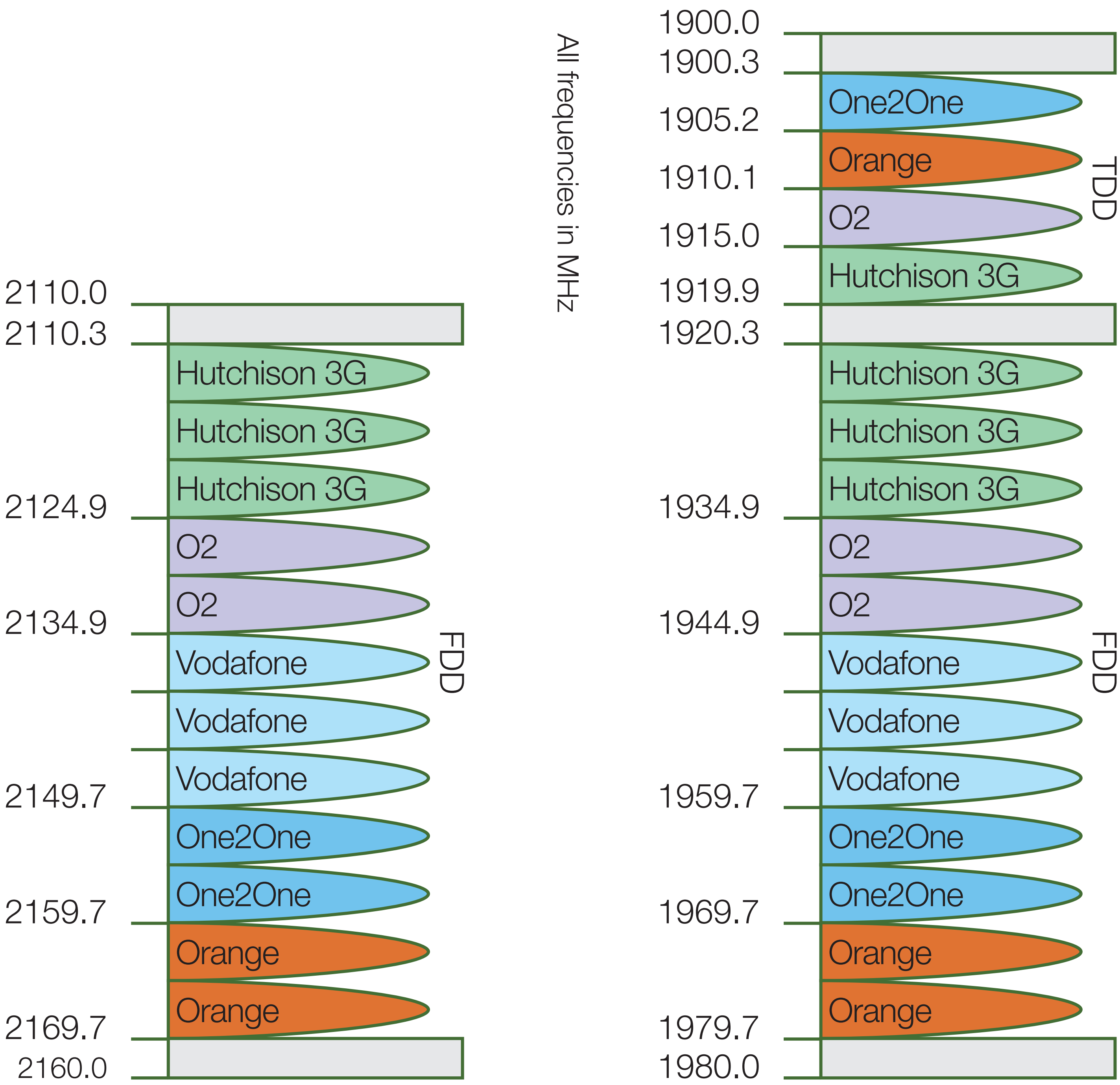
- 200KHz RASTER PERMITS CREATION OF GUARD CHANNELS
- FDD REQUIRES 2 x UARFCN TO DEFINE THE CHANNEL

Fig. 1 – Radio Channels Multiplexing and Allocation

1.3 Typical Licence Allocations

Figure 2 shows the spectrum allocations for the UK. Five operators are licenced, with Hutchison 3G being a new entrant to the market in the UK.

With the exception of Vodafone Airtouch, all operators possess either 2 or 3 FDD channels and a single TDD channel.



- All frequencies in MHz

Fig. 2 – 3G Licences in the UK

2. AIR INTERFACE TIMING

2.1 Introduction

To minimise the differences between FDD and TDD modes, the same basic terms are used to designate timing.

Radio Frames of 10ms duration are divided into 15 equal timeslots of $666^2/_3$ µs (or 2560 chips).

Higher order superframes lasting 720ms and consisting of 72 frames are identified as well as a hyperframe of 40.96s consisting of 4096 frames. The count for hyperframes increments every 2 frames (20ms) from 0 to 4094 (i.e. 0, 2, 4, 6…4094).

2.2 FDD Timing

In FDD mode, transmission and reception is basically continuous, with every timeslot fully occupied in a continuous stream of frames in both uplink and downlink.

In each timeslot there is L1 signalling carrying a power control command, giving a fast power control command, giving a fast power control rate of $^{15}/_{10}$ms = 1500 commands per second.

2.3 TDD Timing

In TDD mode, transmission and reception is carried out in bursts accommodated within the timeslots, on a single radio channel (“ping-pong” operation). Assignment of uplink/downlink slots can be symmetrical or asymmetrical.

Power control commands to the mobile now occur at a rate less than 1500 per second. For symmetrical operation, there would be 750 commands per second. For this reason, TDD mode cannot support mobiles requiring high mobility as well as FDD mode.

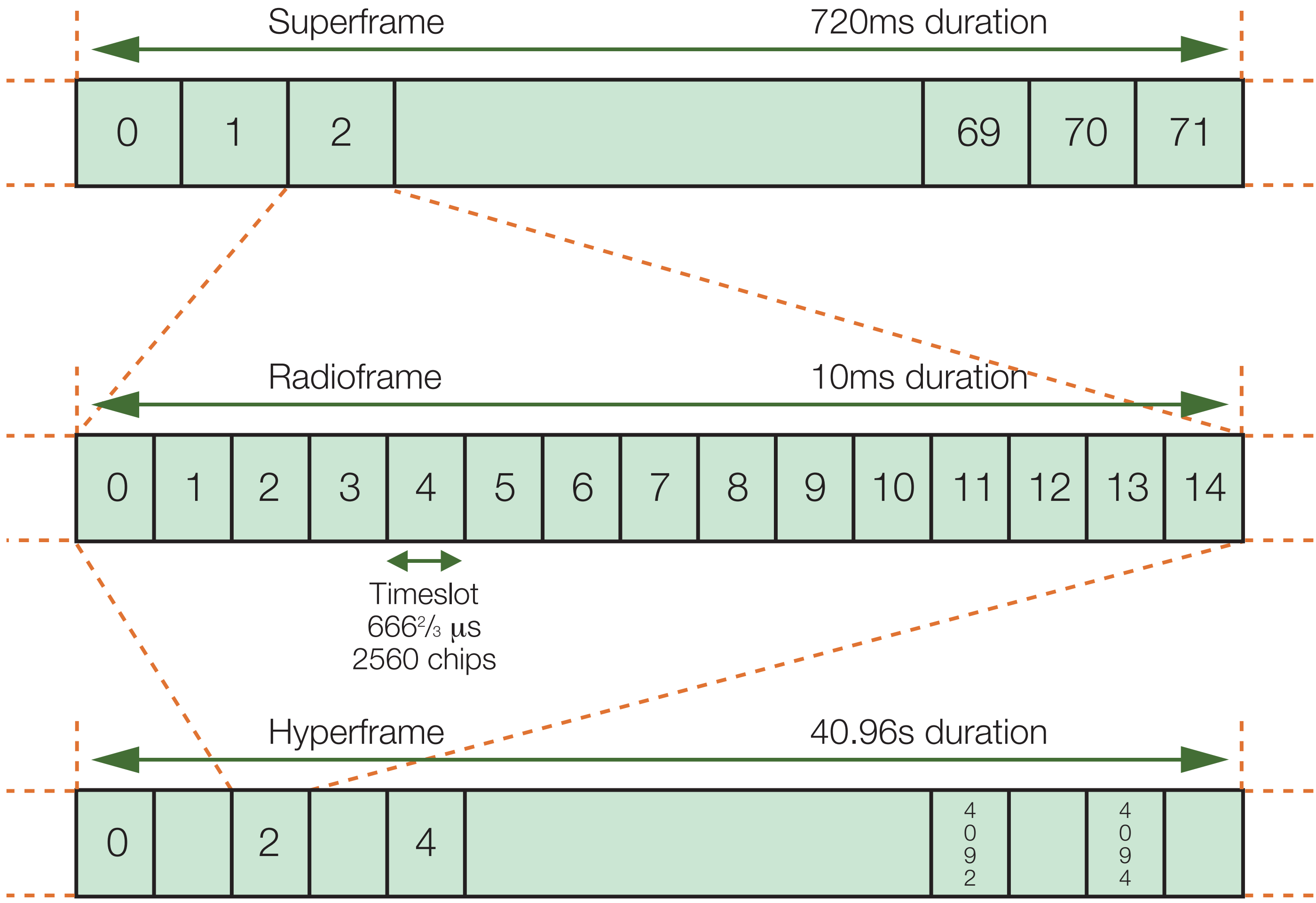


Fig. 3 – Frame, Superframe and Hyperframe Timing

3. PHYSICAL LAYER (L1) FUNCTIONS

The physical layer provides RF support in terms of radio transmission and reception via radio transmitter-receivers (TRX) and antennas. Macro and micro diversity are supported through soft/softer handover.

Data in transport channels (existing between L1 and L2 MAC) must be mapped to appropriate physical channels. Transport channel errors are detected and reported to L3 (Radio Resource Control or RRC).

Transport channel data requires coding for Forward Error Correction in the transmit direction and decoding in the receive direction.

Transport channels are multiplexed into Coded Composite Transport Channels (CCTrCHs) for transmission and demultiplexed on reception.

A CCTrCh requires rate matching to an appropriate physical channel.

Physical Channels are weighed before being combined into a single stream for transmission and require separation at reception.

Modulation and Demodulation in UMTS uses Quadrature Phase Shift Keying (QPSK or 4-PSK).

The physical layer also carries out spreading and despreading, as well as fast power control.

Provision is made for synchronisation, in terms of chips, bits, slots and frames.

Various measurement activities are supported, such as frame errors, SIR and interference power with reporting to L3 (RRC) as required.

- RF support
- Modulation/Demodulation
- Spreading/Despreading
- Fast power control
- Error Detection and Forward Error Correction
- Multiplexing and Demultiplexing
- Mapping transport to physical channels
- Synchronisation
- Rate adjustment
- Power weighting and combination of physical channels
- Measurement activity
- Macro and Micro Diversity

Fig. 4 – Physical Layer Functions

4. CODE USAGE IN UMTS

4.1 Two Stage Coding

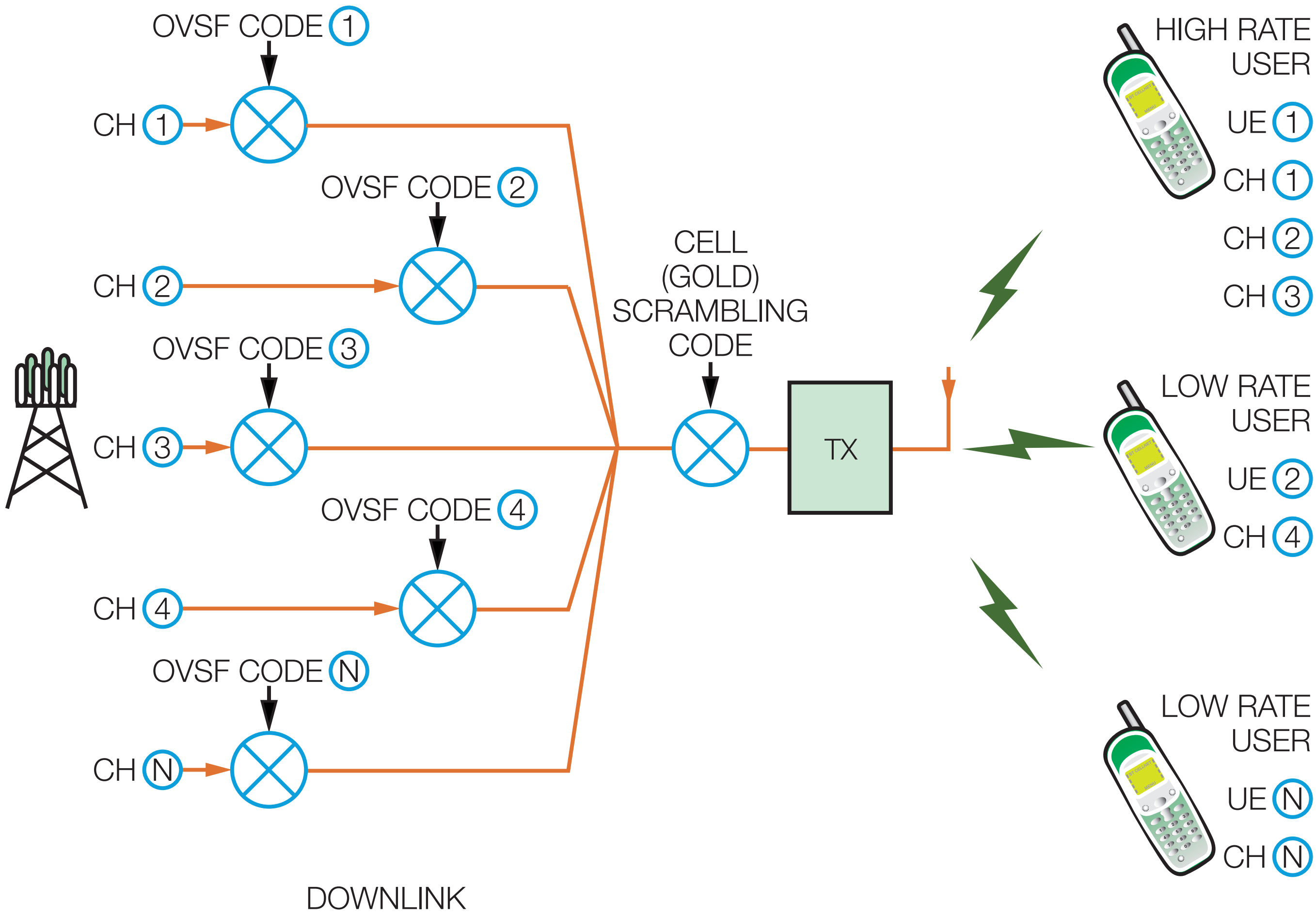
Because it is difficult to identify a single code type which meets all requirements, both the uplink and downlink in UMTS use two stages of coding known as CHANNELISATION and SCRAMBLING.

4.2 Channelisation Codes

Used to separate channels of information from a single source, these use orthogonal codes from the OVSF set. The OVSF code tree provides a convenient method of dynamically changing the spreading factor (for bandwidth on demand) by moving up and down logical branches of the tree. Channels remain highly orthogonal because they retain relative synchronism. In the downlink direction, separate channels may be assigned to separate mobiles or a single mobile may be assigned multiple codes for higher data rates. (Multi-code operation). For FDD mode, the lowest spreading factor used is 4, allowing a maximum symbol rate of 960 Ksps (3.84Mcps/4). Because of differences in the implementation of modulation, this corresponds to a bitrate of 960 Kbps in the uplink but 1920 Kbps in the downlink. This bitrate includes all overheads such as forward error correction (FEC). Mobiles can be assigned up to 6 codes in the uplink giving a gross bitrate of 6x960 = 5760 Kbps, which would support a user rate in excess of 2 Mbps. To support the same rate in the downlink requires only 3 codes (1920 Kbps gross per code).

4.3 Scrambling Codes

Since the same OVSF codes are used by every Node B and mobile, a further level of coding is required to identify the source. Gold codes are used for this purpose because they retain good cross-correlation properties for any relative time offset. This obviates the need for Node Bs to be fully synchronous in FDD mode. TDD mode requires synchronous operation if TDD cells overlap.



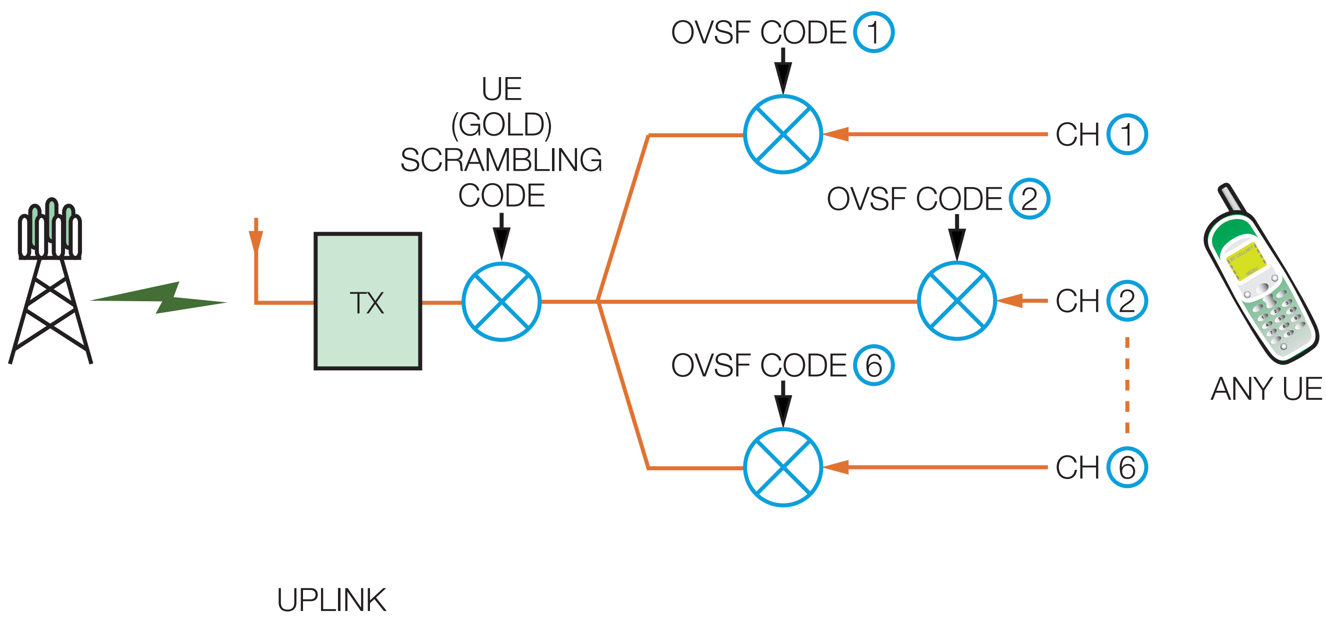


Fig. 5 – 2 Stage UMTS Coding

4.3.1 Scrambling Code Planning

For the downlink, there is a requirement for scrambling code planning such that neighbouring cells do not use the same scrambling code. However, with 512 primary scrambling codes the planning is trivial in relation to the equivalent frequency planning in TDMA systems like GSM or ISI36.

For the uplink, mobiles are assigned a scrambling code dynamically by the SRNC and will then use the same code to connect with several cells during soft or softer handover. The code is only released once the UE terminates the connection, although procedures exist allowing a dynamic change of scrambling code during a connection.

Note that the Rake receiver in the mobile supports the soft/softer handover, with individual Rake fingers resolving signals from separate cells.

Uplink connections are managed by a Rake receiver at the Node B for softer handover and by frame selection/combination at the SRNC for soft handover.

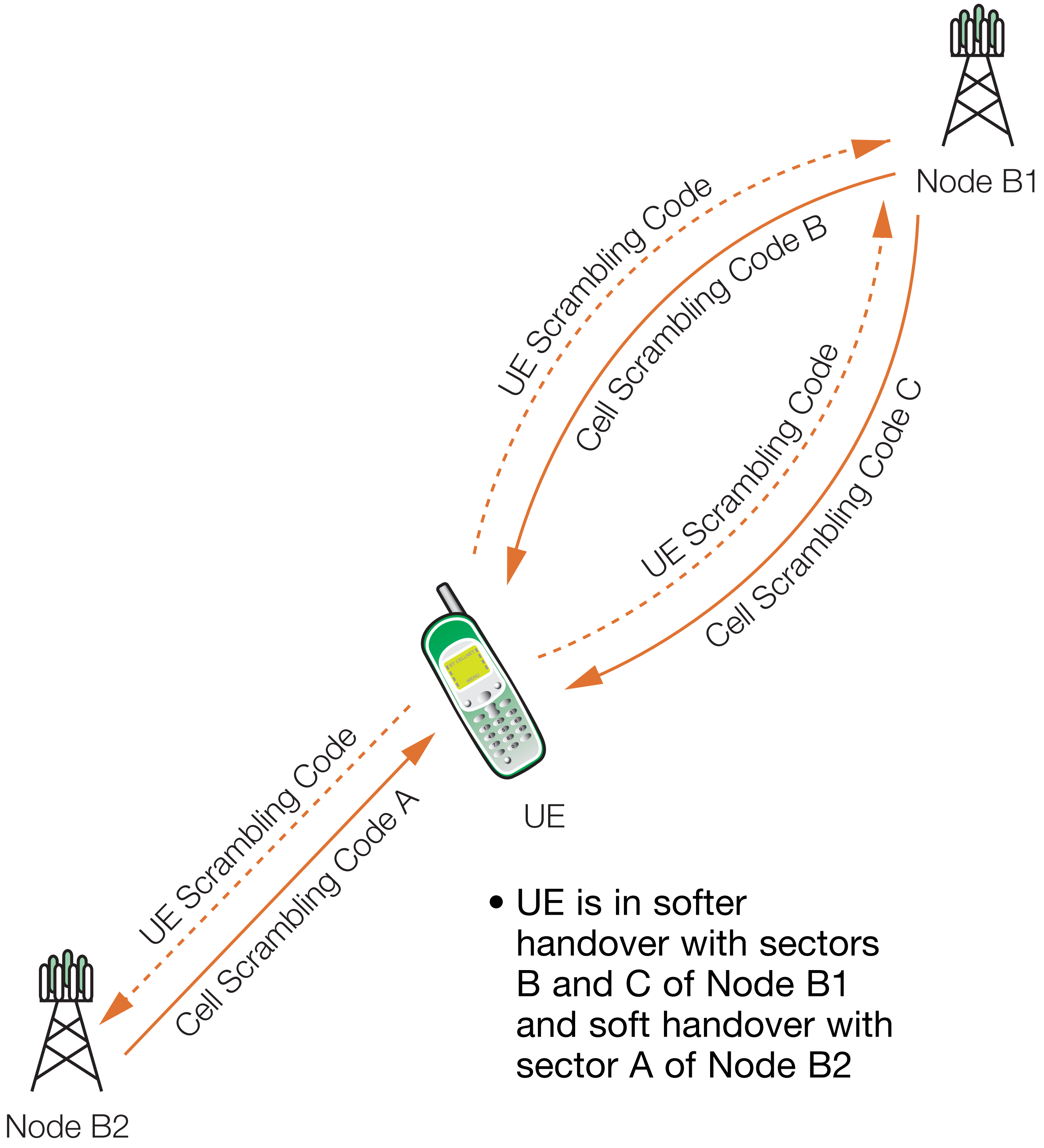


Fig. 6 – UMTS Scrambling Code Usage

4.4 Code Types for FDD Mode

Figure 7 summarises the main code types used for UMTS. Initial cell synchronisation is gained through reception of a synchronisation channel coded using a Hierarchical Golay code of 256 chips. This code is short and offers excellent auto-correlation properties, making it ideal for acquiring rapid synchronisation. Every UMTS cell broadcasts the same primary code accompanied by a pattern of 16 secondary codes. The pattern could be one of 64 and enables the UE to determine the cell scrambling code.

Cell (downlink) scrambling codes are highly orthogonal 38,400 chip segments of a complex-valued Gold code and 8,192 segments are available, organised as 512 primary codes with 15 secondary codes per primary code. The primary codes are organised as 64 groups of 8 and secondary codes can be used optionally for support of sub-cells if required. UE (uplink) scrambling codes are also highly orthogonal 38,400 chip segments selected from a complex-valued Gold code, with 16,777,216 segments available for allocation. Optionally, if Multi-User Detection is employed, uplink scrambling can use the shorter S(2) codes which simplify interference estimation in the M.U.D. receiver. There are also 16,777,216 S(2) codes, paired with corresponding Gold code segments. Channelisation for uplink or downlink is achieved using OVSF codes with lengths (spreading factors) for FDD mode up to 512 available for the downlink and up to 256 in the uplink. A single UE can be assigned up to 6 codes for high data rate connections.

In TDD mode, only spreading factors 1 to 1 6 are used. For low bandwidth requirements, Release 4 has now specified a lower chiprate option (1.28 Mcps) for TDD operation, which is further explained at the end of this section.

Fig. 7 – Codes used for UMTS (FDD mode)

Function of code	Code type	Chip rate Mcps	Code length in chips	Duration	Additional information
Synchronisation	Hierarchical Golay	3.84	256	66.7µs	1 primary code 16 secondary codes
Downlink (cell) scrambling	Complex Valued Gold	3.84	38,400 segment from Gold code of length $2^{18}–1$	10ms	512 primary codes 15 secondary codes per primary code (total 8,192 codes)
Uplink (UE) scrambling	Complex Valued Gold	3.84	38,400 segment from Gold code of length $2^{25}–1$	10ms	16,777,216 codes
Uplink (UE) scrambling	S(2)	3.84	256	66.7µs	16,777,216 codes, paired with corresponding Gold cold segments Used only with Multi User Detection (MUD)
Channelisation (UL or DL)	OVSF	3.84	4 to 512	1.04 to 133.34µs	Length depends on spreading factor (maximum 512 in DL and 256 in UL for FDD and maximum 16 for TDD) Multiple codes can be assigned

5. APPLICATION OF CODES

5.1 Downlink Arrangements

Each downlink channel is spread with an appropriate channelisation (OVSF) code at a chip rate of 3.84 Mcps. The OVSF code is applied to I and Q streams of data and the resultant is a complex valued signal I + jQ.

This is then combined with a complex valued Gold code for scrambling at a rate of 3.84 Mcps. Being the same chip rate, this does not increase the bandwidth further, i.e. does not cause further spreading.

Each downlink channel is weighted before all channels are summed. The weighting of channels can be carried out dynamically for the purpose of downlink power control.

Finally, the synchronisation codes are added before the composite signal is applied to the QPSK (4-PSK) modulator in the radio transmitter section.

Note that LI control signalling for a dedicated channel is time-multiplexed with the user data or higher layer signalling for the associated channel.

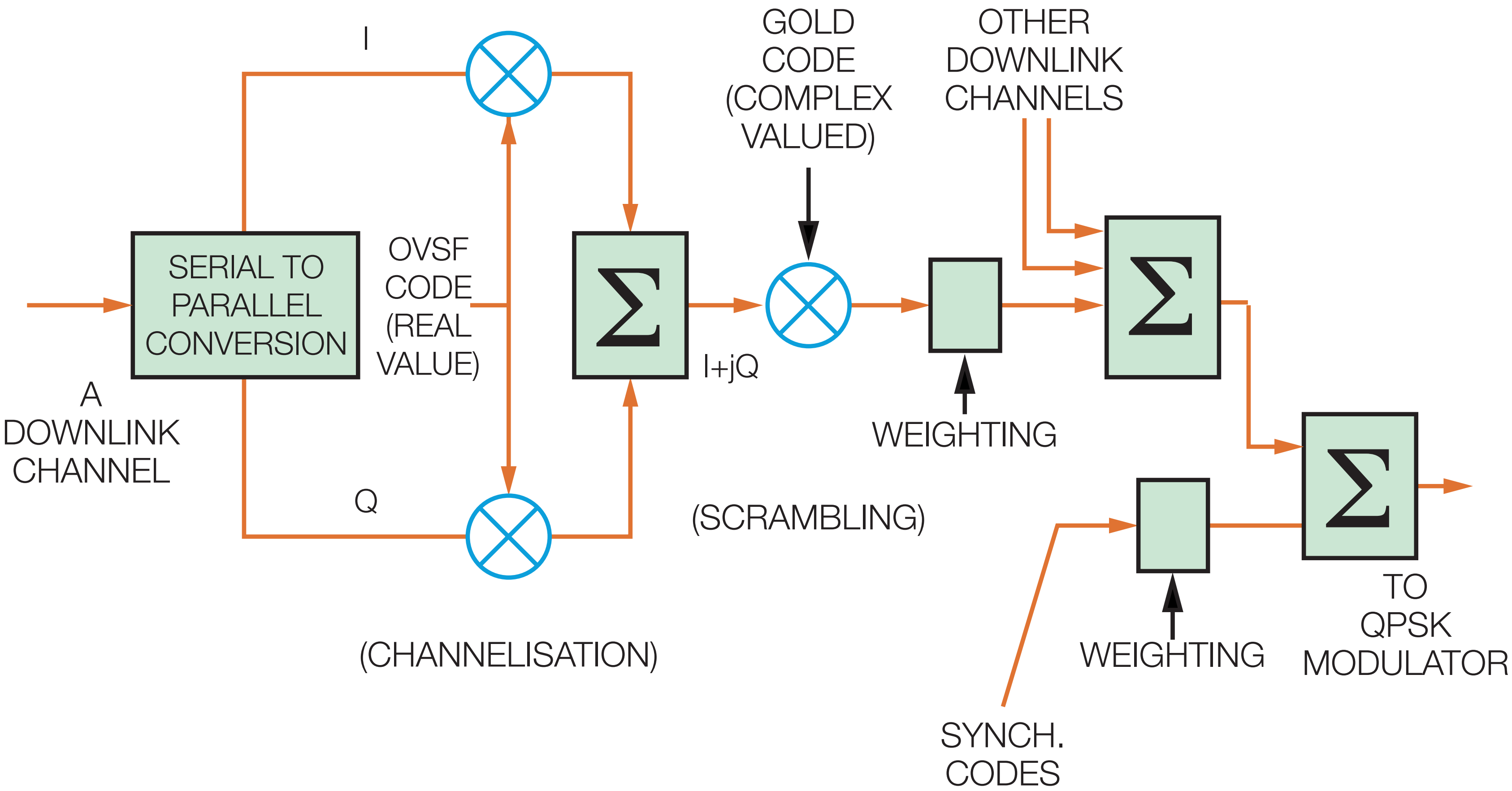


Fig. 8 – Application of Codes (Downlink)

5.2 Uplink Arrangements

For the uplink, Layer 1 control signalling, such as pilot sequences and power control, are separated from the user data/higher layer signalling and channelised/spread on a separate real-valued OVSF code (OVSF C in figure 9).

Higher layer data/user data will initially be spread using another OVSF code (OVSF 1 in figure 9) before being combined with the spread LI signalling to form a complex valued signal.

A low data rate connection, such as speech only, requires these two streams, which in the I + jQ form are scrambled using a complex-valued Gold or S(2) code before being passed to the QPSK modulator.

If the mobile needs to transmit further higher-layer streams (e.g. multicode, high rate operation) then these streams are applied alternately to the I and Q branches as shown.

This helps to minimise envelope variation in the modulated r.f. carrier.

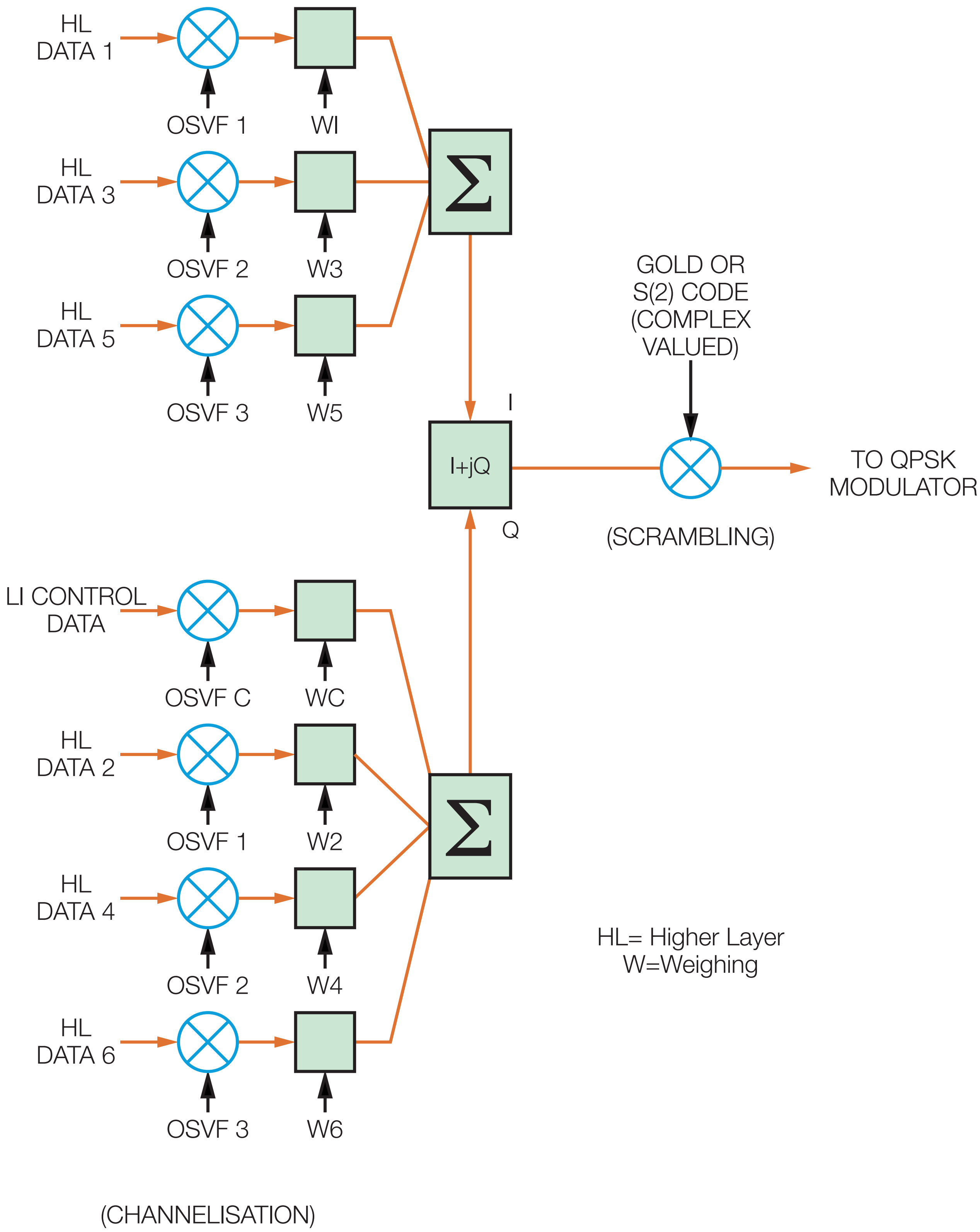


Fig. 9 – Application of Codes (Uplink)

6. TRANSPORT CHANNELS

Transport Channels exist between the MAC layer and the physical layer.

The choice of transport channel depends on the requirements of the message to be transmitted, and so they will tend to have specific characteristics in terms of their direction (uplink/downlink), power control requirements, data capacity and so on. The mobile equipment is able to have one or more Transport Channels simultaneously in the uplink and/or the downlink.

Transport Channels can be divided into *Common* and *Dedicated* types.

6.1 Dedicated Transport Channels

Dedicated Transport Channels describe an essentially point-to-point link between the UTRAN and a particular mobile. Such a channel is for dedicated use, for a single user only. The Mobile Equipment to which the transport channel belongs is identified by virtue of the code and frequency (FDD), and the code, frequency and time slot (TDD) for the physical channel onto which it is mapped.

For current specifications within UMTS, there is only one dedicated transport channel, **DCH**, which is used in both the uplink and downlink, and in both the TDD and FDD modes.

DCH carries all the information coming from the higher layers which is intended for the given user. This includes user data for the actual service plus any higher layer control information. The content carried within DCH is not visible to the physical layer, and so both user and control data are treated the same way.

DCH is characterised by features such as fast power control, the capability for fast data rate changes on a frame-by-frame basis, the possibility of transmission to a certain part of the cell or sector using beam-forming, and the support of soft handover.

For future ODMA operation within the TDD mode, an ODMA dedicated channel (ODCH) will be available as another dedicated transport channel, applicable for both uplink and downlink.

- Uplink ✓
- Downlink ✓
- TDD ✓ (ODCH for ODMA mode)
- FDD ✓
- Higher layer information (user data and signalling)
- Fast Power Control
- Fast Data-Rate Changes
- Use of beam-forming
- Support for soft handover

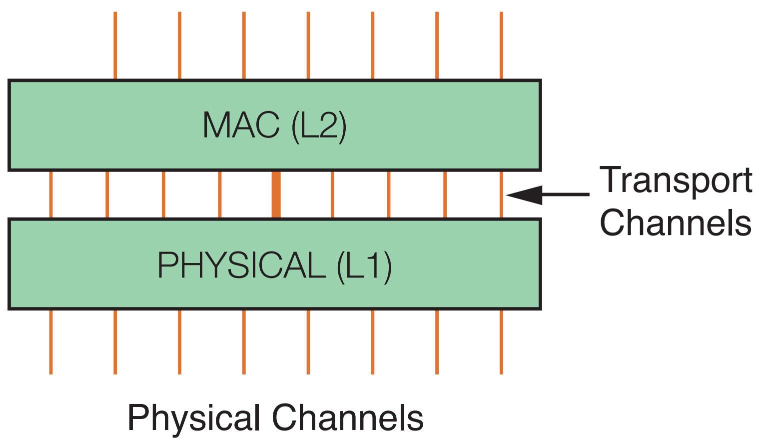


Fig. 10 – Dedicated Transport Channel, DCH

6.2 Common Transport Channels 1

Common Transport Channels are intended for use by a number of users, and hence are not to be used for a dedicated connection between the fixed network and any specific mobile. The link is point-to-multipoint (UTRAN to multiple mobiles), and the resource is divided between all the users within a cell.

There are four common transport channels in particular which are required for even the basic operation of a UMTS network, in both TDD and FDD modes. These are:

RACH – Random Access Channel
The Random Access Channel is used for initial access, when a mobile requests to set up a connection. It provides a common channel in that all mobiles sending these initiation requests are able to make use of it.

RACH is applicable only on the uplink, and must be able to be heard over the whole cell coverage area. To achieve this means that it is limited to low data rates. The ability to support 16kb/s RACH is a mandatory requirement for terminals, regardless of the types of services they provide.

As part of this initial access, RACH is also used for open loop power control.

RACH can also be used by the mobile for the transfer of small amounts of user data.

FACH – Forward Access Channel
FACH is used for messages from the Node B to the mobiles known to be within one cell, once a random access message has been received. It is used for open loop power control, and can also be used to transfer small amounts of user data, and thus can be regarded as the downlink companion to RACH.

There can be more than one FACH channel within a cell, although one of these must have a low data rate to enable reception by all terminals. Additional FACH channels can have higher data rates, and FACH channels are capable of changing data rates on a frame-by-frame basis (i.e. every 10ms).

PCH – Paging Channel
PCH is used to broadcast paging and notification messages into an entire cell (or a group of cells). A mobile is able to remain in “sleep mode”, to conserve battery power, whilst still able to receive PCH messages by monitoring only certain paging messages which have been allocated to it, and “sleeping” whilst other paging messages are being transmitted.

The paging channel is used when the network wants to initiate communication with the terminal, for example when an incoming call or data arrives from the core network.

	uplink	downlink	FDD	TDD	usage
RACH Random Access	✓	✗	✓	✓	• initial access requests • small user data
FACH Forward Access	✗	✓	✓	✓	• access acknowledgement • small user data
PCH Paging	✗	✓	✓	✓	• paging and notification
BCH Broadcast	✗	✓	✓	✓	• available access codes and slots

Open Loop Power Control

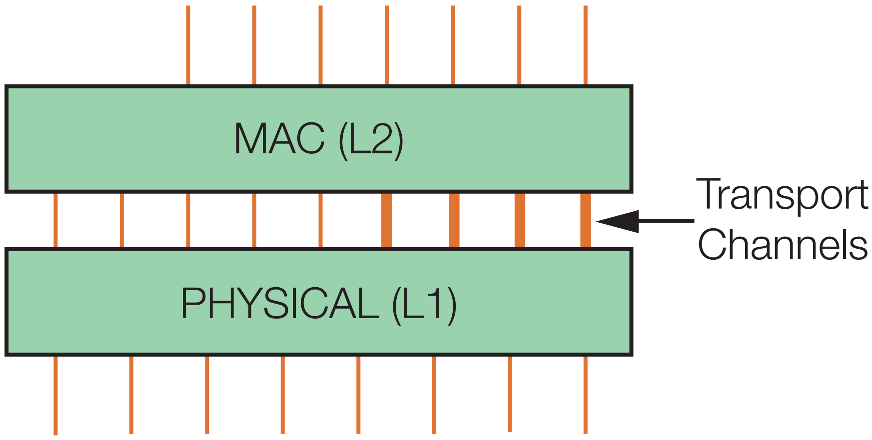


Fig. 11 – Essential Common Transport Channels

BCH – Broadcast Channel

BCH is used to communicate with all the mobiles within a cell, with the most typical messages being those which inform the mobiles of the available random access codes and access slots which exist within the cell. A terminal cannot register with the cell without decoding this channel.

The nature of this information means that BCH needs to be heard by all the mobiles within the cell coverage area, and that even low-end terminals must be able to decode the message. Thus the power must be relatively high and the data rate must be kept low.

	uplink	downlink	FDD	TDD	usage
RACH Random Access	✓	✗	✓	✓	• initial access requests • small user data
FACH Forward Access	✗	✓	✓	✓	• access acknowledgement • small user data
PCH Paging	✗	✓	✓	✓	• paging and notification
BCH Broadcast	✗	✓	✓	✓	• available access codes and slots

Open Loop Power Control

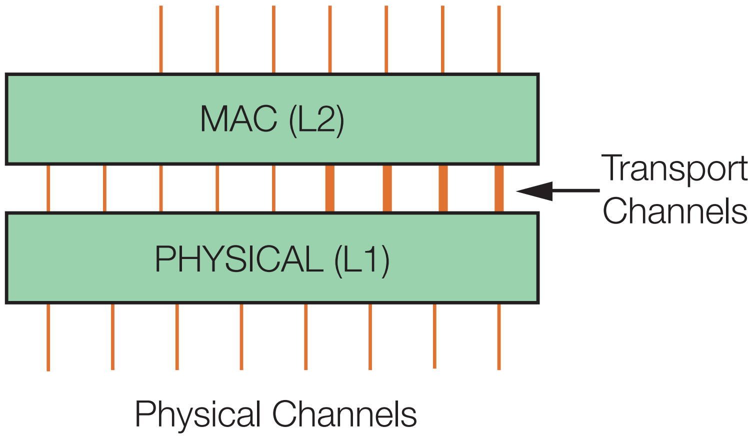


Fig. 11 – Essential Common Transport Channels

6.3 Common Transport Channels 2

As well as those transport channels which are required for basic operation of the UMTS network, there are some further transport channels which may optionally apply. For FDD mode of access there are two further channels, which are:

DSCH – Downlink Shared Channel
DSCH carries dedicated control or user traffic data, but rather than being a dedicated channel, is a channel resource which can be shared by several users, on the downlink. As with the unshared DCH, it supports fast power control as well as variable bit-rate on a frame-by-frame basis, and does not need to be heard within the whole cell area. The latter means that technologies such as beam-forming antennae can be used.

DSCH will not exist alone, and will always be associated with an unshared (lower bit rate) dedicated channel (DCH) which carry the physical control channel, including the signalling for fast power control. Shared channels cannot use soft handover.

CPCH – Common Packet Channel
CPCH is an extension of the RACH channel, and is intended to carry packet-based, “bursty” user data, in the uplink direction. It is applicable to the FDD mode only.

Like RACH, it is shared by a number of mobiles in the cell. The main differences from RACH are that fast closed loop power control is used in the physical layer, its data rate can be changed on a fast basis, collision detection can be applied, and it need not apply to the whole cell area – i.e. beam-forming techniques can be applied.

CPCH transmissions may last for several frames, whereas RACH transmissions tend to be much shorter, just one or two frames.

In TDD mode only, the Downlink Shared Channel (DSCH) has an equivalent, known as **USCH**, the Uplink Shared Channel. As with DSCH, USCH is used to carry dedicated control or traffic data, and is shared by several mobiles. As with DSCH it can utilise beam-forming, fast power control and variable data rate.

Finally, in ODMA mode only, **ORACH**, the ODMA Random Access Channel can be used as a relay link channel for random access requests.

	FDD	TDD	uplink	downlink	usage
DSCH (Downlink Shared)	✓	✓	✗	✓	Usually packet-based, "bursty" dedicated user data/control data
CPCH (Common Packet)	✓	✗	✓	✗	packet-based "bursty" user data
USCH (Uplink Shared)	✗	✓	✓	✗	dedicated user/ control data
ORACH (ODMA Random Access)	✗	✓ (ODMA)	✓	✗	random access request relay

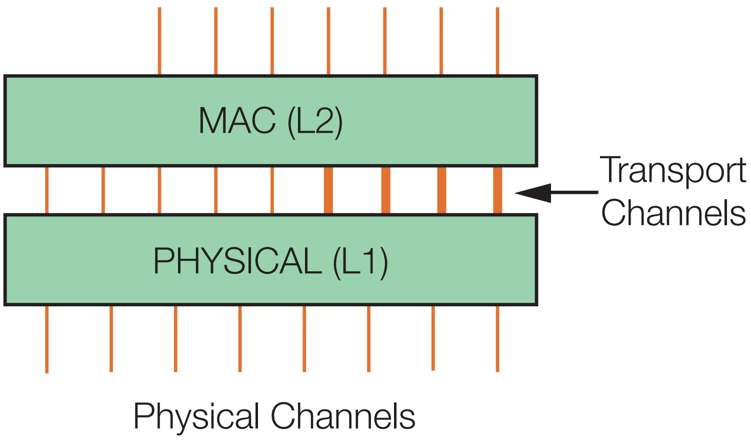


Fig. 12 – Optional Transport Channels

7. PHYSICAL CHANNELS

7.1 PRACH, CCPCH, PICH and SCH

The four essential transport channels, RACH, FACH, PCH and BCH are associated with three physical channels. These are applicable to both FDD and TDD and are:

PRACH – Physical Random Access Channel
PRACH is used to transmit the random access transport channels, containing user specific information required to contact the network for registration, location update, cell update, and in order to initiate a call set-up. It is only applied in the Uplink.

P-CCPCH – Primary Common Control Physical Channel
P-CCPCH is used in the downlink for broadcasting cell-specific information, and is the physical channel carrying the transport channel BCH. The channel bit rate is 30kb/s, and a channelisation code with spreading factor 256 is permanently allocated. In fact the actual bit rate is further reduced, since the P-CCPCH alternates with another downlink physical channel, the Synchronisation Channel (SCH).

S-CCPCH – Secondary Common Control Physical Channel
The S-CCPCH is used for transporting the downlink transport channels PCH (for paging and notification messages) and FACH (for small amounts of data). These two transport channels can either be multiplexed onto one such S-CCPCH physical channel or can use different physical channels.

The channelisation code used for Secondary-CCPCH is carried by the Primary-CCPCH.

Two additional essential channels are applicable to both FDD and TDD, on the downlink only, but are unique to the physical layer, with no mapping to higher layers. These are:

PICH – Paging Indication Channel
PICH is used by the UTRAN to indicate to the mobile whether there is a paging message. It has a fixed spreading factor of 256, and is always associated with the Secondary CCPCH to which the PCH transport channel has been mapped. If a paging indication has been detected, then the mobile knows to decode the paging channel.

SCH – Synchronisation Channel
This is used for part of the initial system acquisition process by the mobile, and consists of two sub-channels (Golay-coded). A Primary SCH carries an unmodulated code of length 256 chips, which is transmitted once every slot. This primary synchronisation code is the same for every base station in the system, and is used by the mobile to obtain the timing information for the Secondary SCH.

	uplink	downlink	power control	mapping above?	purpose
PRACH (Physical Random Access)	✓	✗	Open loop only	✓	carry RACH
P-CCPCH (Primary Control)	✗	✓	✗	✓	broadcast: carry BCH
S-CCPCH (Secondary Control)	✗	✓	✗	✓	carry PCH & FACH
PICH (Paging Indication)	✗	✓	✗	✗	Indication of a Paging Message
SCH (Synchronisation)	✗	✓	✗	✗	Acquisition & Scrambling Codes

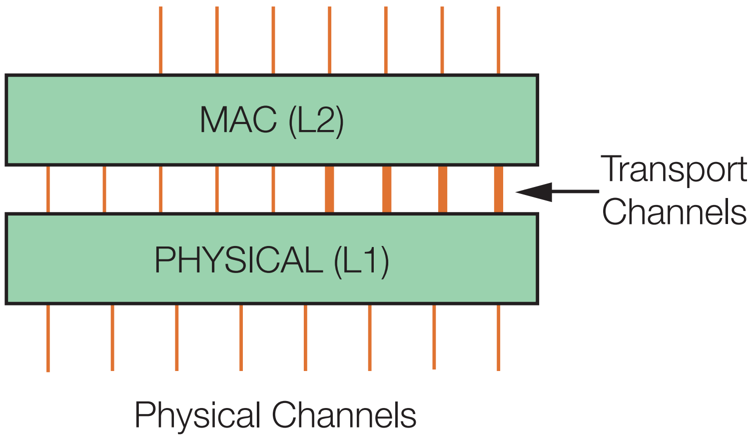


Fig. 13 – Physical Channels (FDD *and* TDD)

The secondary SCH consists of a modulated code of length 256 chips, and is transmitted in parallel with the P-SCH, and carries information about the long (scrambling) code group to which the long code of the base station belongs. This enables a search of long codes by the mobile to be limited to a subset of all the codes available.

The SCH is time multiplexed with the P-CCPCH over the air interface.

The PRACH employs open-loop power control only. P-CCPCH, S-CCPCH, PICH and SCH are not power-controlled.

	uplink	downlink	power control	mapping above?	purpose
PRACH (Physical Random Access)	✓	✗	Open loop only	✓	carry RACH
P-CCPCH (Primary Control)	✗	✓	✗	✓	broadcast: carry BCH
S-CCPCH (Secondary Control)	✗	✓	✗	✓	carry PCH & FACH
PICH (Paging Indication)	✗	✓	✗	✗	Indication of a Paging Message
SCH (Synchronisation)	✗	✓	✗	✗	Acquisition & Scrambling Codes

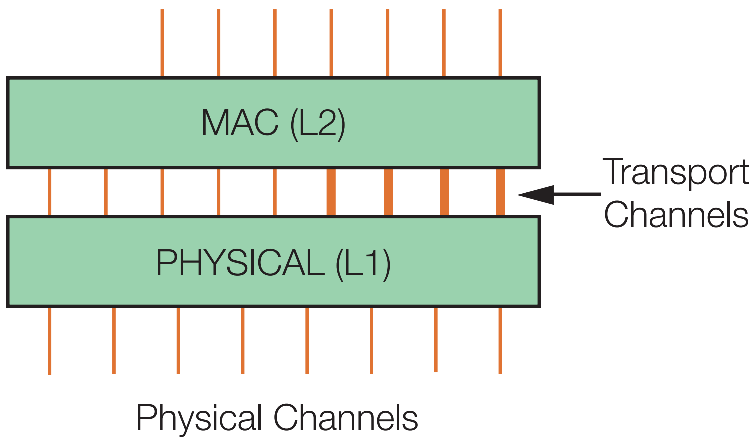


Fig. 13 – Physical Channels (FDD *and* TDD)

7.1.1 The Synchronisation Channel (SCH)

From the SCH, a UE must be able to gain alignment with the frames and slots, as well as the start and finish of the cell scrambling code segments.

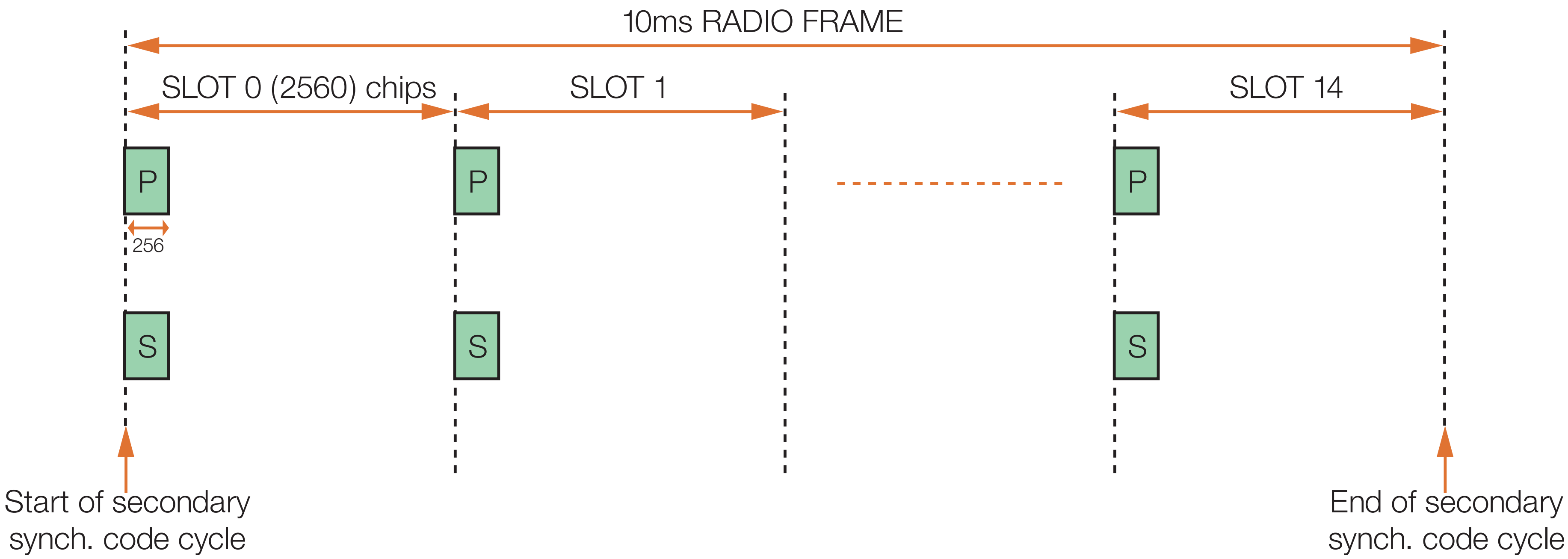
The Gold code segments used for scrambling are aligned with the start and end of the 10ms radio frames, so a UE is automatically aligned with the code once it has gained frame alignment.

All UMTS cell broadcast the same Hierarchical Golay code of 256 chips as a primary synchronisation code, aligned with the start of each time slot. This short code has excellent auto-correlation properties for rapid and accurate synchronisation.

Secondary synchronisation codes are transmitted over the primary code. There are 16 possible secondary codes, organised as 64 orthogonal sequences of 15 codes. A sequence of 15 is transmitted over the radio frame and delimits the frame.

Once the UE detects which of the 64 sequences are in use, this points to which of the 512 scrambling codes the cell is using. The 512 Gold codes are organised in 64 corresponding groups of 8 codes, so a mobile need only try each of the Gold codes in the indicated group of 8 until correlation is achieved.

Once a UE has detected the scrambling code, it will be able to read the BCH System Information on the P-CCPCH, where any other required codes will be indicated.



- **P = Primary synchronisation code (256 chips, one code for all UMTS cells)**
- **S = Secondary synchronisation code (256 chips, 16 different codes in 64 sequences of 15)**

Fig. 14 – Primary and Secondary Synchronisation Codes

7.1.2 Primary Common Control Physical Channel (P-CCPCH)

Transmitted continuously across the whole cell, this carries system information from the BCH transport channel at a fixed spreading factor of 256. Note that the SCH is time multiplexed with the P-CCCH, occupying the first 256 chips of each slot.

7.1.3 Secondary Common Control Physical Channel (S-CCPCH)

This physical channel is only transmitted when there is information to send and carrier data from the PCH and FACH transport channels. Variable spreading factor and data rate, indicated by a TFCI field, can be used on any channel. The pilot sequence provides phase synchronisation but can be replaced by a separate, secondary common pilot channel (CPICH).

When carrying the FACH, it could be used in conjunction with beam-forming (smart) antennas for sub-cell operation.

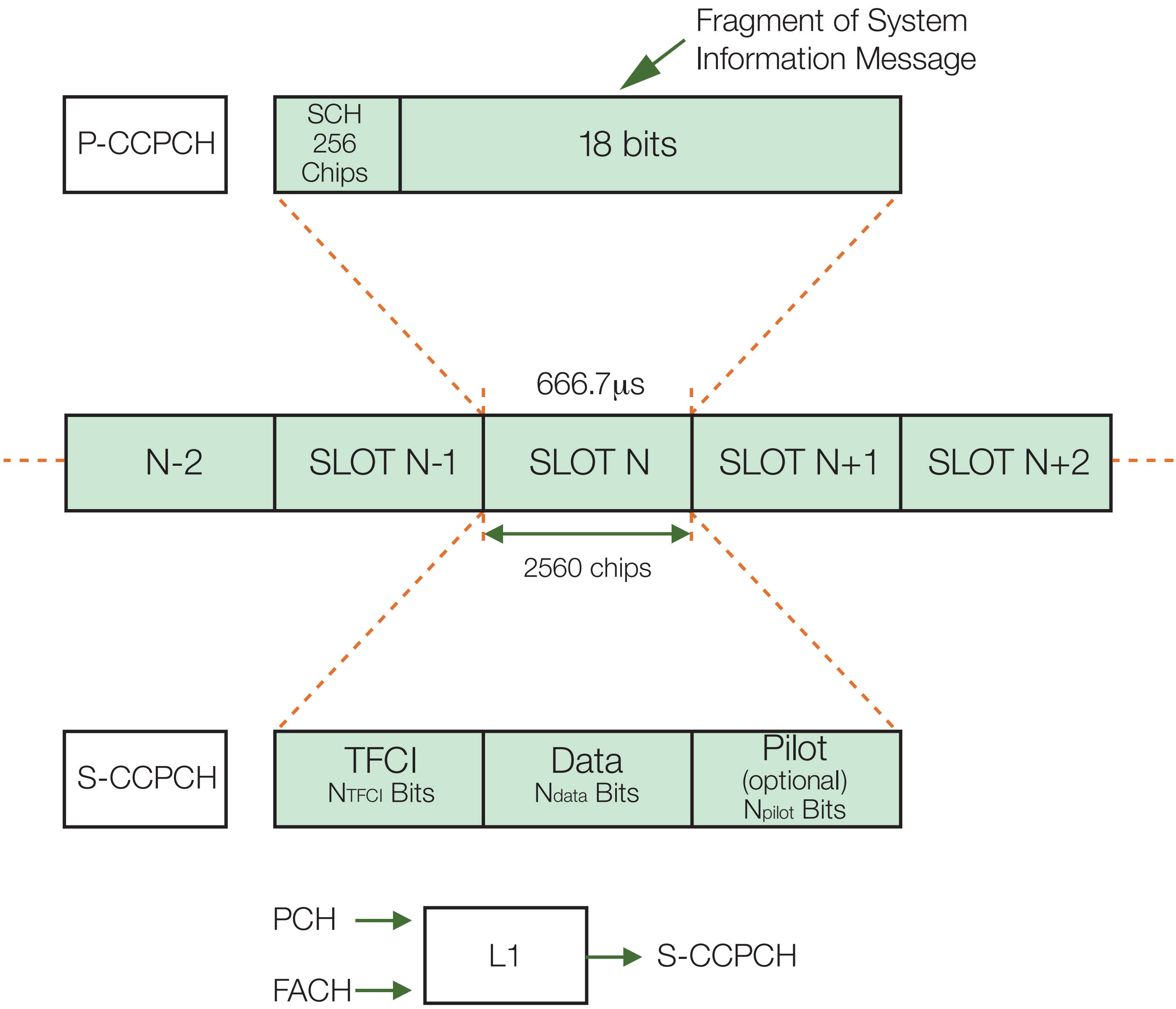


Fig. 15 – CCPCH Details

Slot Format	Channel Bit Rate (kbit/s)	Channel Symbols Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}	N_{pilot}	N_{TFCI}
0	30	15	256	300	20	12	8	0
1	30	15	256	300	20	10	8	2
2	60	30	128	600	40	32	8	0
3	60	30	128	600	40	30	8	2
4	120	60	64	1200	80	64	8	8
5	240	120	32	2400	160	144	8	8
6	480	240	16	4800	320	296	16	8
7	960	480	8	9600	640	616	16	8
8	1920	960	4	19200	1280	1256	16	8

With Pilot Sequence

Slot Format	Channel Bit Rate (kbit/s)	Channel Symbols Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}	N_{pilot}	N_{TFCI}
0	30	15	256	300	20	20	0	0
1	30	15	256	300	20	18	0	2
2	60	30	128	600	40	40	0	0
3	60	30	128	600	40	38	0	2
4	120	60	64	1200	80	72	0	8
5	240	120	32	2400	160	152	0	8
6	480	240	16	4800	320	312	0	8
7	960	480	8	9600	640	632	0	8
8	1920	960	4	19200	1280	1272	0	8

Without Pilot Sequence

Fig. 16 – S-CCPCH Slot Formats

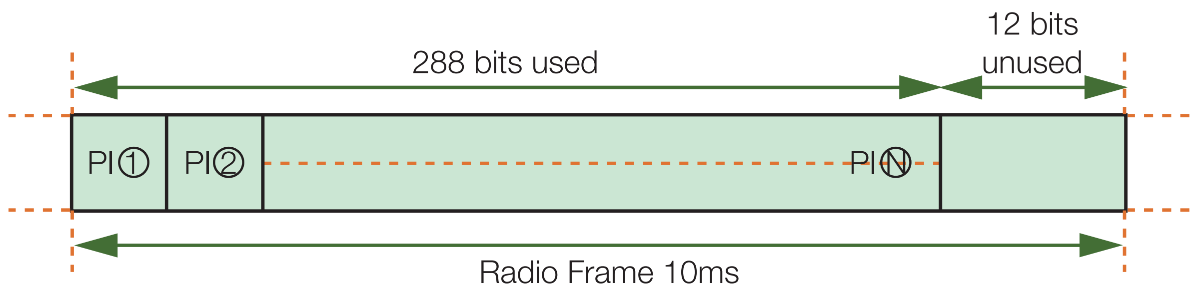
7.1.4 Paging Indication Channel (PICH)

The paging indication channel runs on a cycle synchronised as shown with radio frames.

It uses a fixed spreading factor of 256 but only employs 288 of the resulting 300 bits per 10ms radio frame. These can be sub-divided into 18, 36, 72 or 144 paging indicators (PI). From the system frame number (SFN) and the number of paging indicators, the UE can determine which paging indicator to read to determine whether there is a paging message on the S-CCPCH.

If all bits of the appropriate PI are set to I, there is a paging message. If all bits are zero, there is no paging message.

The format of the PICH is indicated via parameters broadcast in the P-CCPCH.



Number of paging indicators (PI) per frame	Number of bits per paging indicator
18	16
36	8
72	4
144	2

- If all PI bits = 1, there is a paging message
- If all PI bits = 0, there is no paging message

Fig. 17 – Paging Indication Channel (PICH)

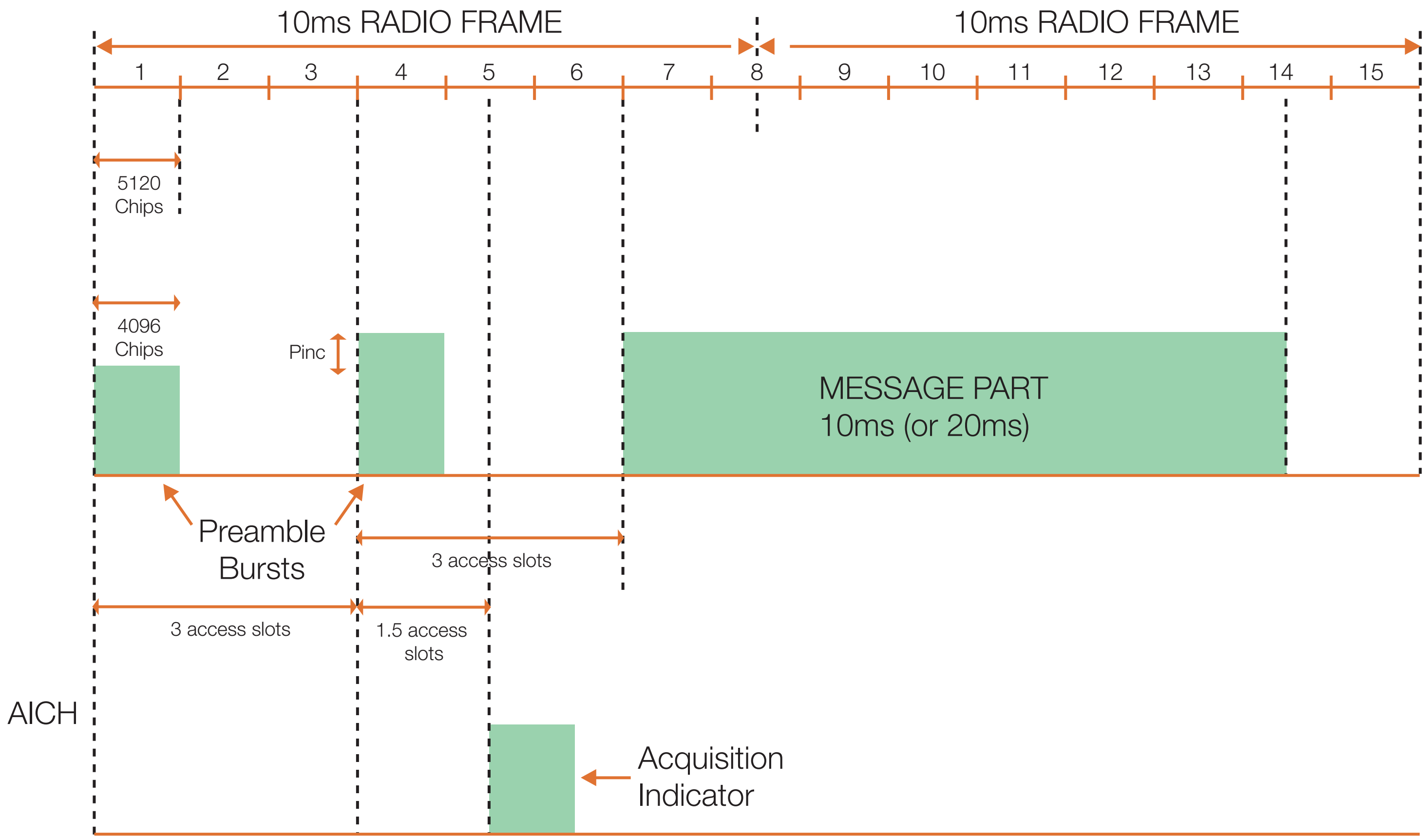
7.1.5 The Physical Random Access Channel (PRACH)

Mobiles accessing the cell must already have gained chip and frame synchronisation via the SCH and have derived the cell scrambling code from the secondary SCH. In addition the mobile has read system information from the P-CCPCH, including relevant PRACH code availability and open loop power control parameters.

The random access process is based on slotted ALOHA procedure, where PRACH transmissions must commence at the start of defined timeslots. 15 access slots of 5,120 chips are defined over a 20ms (i.e. 2 radio frame) cycle. The UE will transmit one or more preamble bursts of 4,096 chips, with the power for each successive burst being incremented, until it receives an acknowledgement in the downlink acquisition indicator channel (AICH). The timing between preamble bursts can be either 3 or 4 access slots. Figure 18 illustrates the 3 slot case.

The initial power level is an open-loop value determined by the UE from measurements and received cell parameters. The increment or power step between preamble bursts is also a received cell parameter. The UE will scramble the PRACH transmission using 1 of 16 Gold code segments. There are 8,192 codes reserved for PRACH use, organised as 512 groups of 16. The group of 16 is related to the downlink primary scrambling code for the cell.

The preamble signature of 4,096 chips comprises 256 repetitions of a 16 chip signature chosen from a set of 16 orthogonal signatures. Once the UTRAN detects this, a coded reply in the AICH indicates that the UE can transmit the message part of the random access attempt. The message part consists of a 10ms or 20ms transmission, length being determined by the higher layer data within.



Preamble Signatures

Preamble Signature	Value of n															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P(0)n	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P(1)n	1	–1	1	–1	1	–1	1	–1	1	–1	1	–1	1	–1	1	–1
P(2)n	1	1	–1	–1	1	1	–1	–1	1	1	–1	–1	1	1	–1	–1
P(3)n	1	–1	–1	1	1	–1	–1	1	1	–1	–1	1	1	–1	–1	1
P(4)n	1	1	1	1	–1	–1	–1	–1	1	1	1	1	–1	–1	–1	–1
P(5)n	1	–1	1	–1	–1	1	–1	1	1	–1	1	–1	–1	1	–1	1
P(6)n	1	1	–1	–1	–1	–1	1	1	1	1	–1	–1	–1	–1	1	1
P(7)n	1	–1	–1	1	–1	1	1	–1	1	–1	–1	1	–1	1	1	–1
P(8)n	1	1	1	1	1	1	1	1	–1	–1	–1	–1	–1	–1	–1	–1
P(9)n	1	–1	1	–1	1	–1	1	–1	–1	1	–1	1	–1	1	–1	1
P(10)n	1	1	–1	–1	1	1	–1	–1	–1	–1	1	1	–1	–1	1	1
P(11)n	1	–1	–1	1	1	–1	–1	1	–1	1	1	–1	–1	1	1	–1
P(12)n	1	1	1	1	–1	–1	–1	–1	–1	–1	–1	–1	1	1	1	1
P(13)n	1	–1	1	–1	–1	1	–1	1	–1	1	–1	1	1	–1	1	–1
P(14)n	1	1	–1	–1	–1	–1	1	1	–1	–1	1	1	1	1	–1	–1
P(15)n	1	–1	–1	1	–1	1	1	–1	–1	1	1	–1	1	–1	–1	1

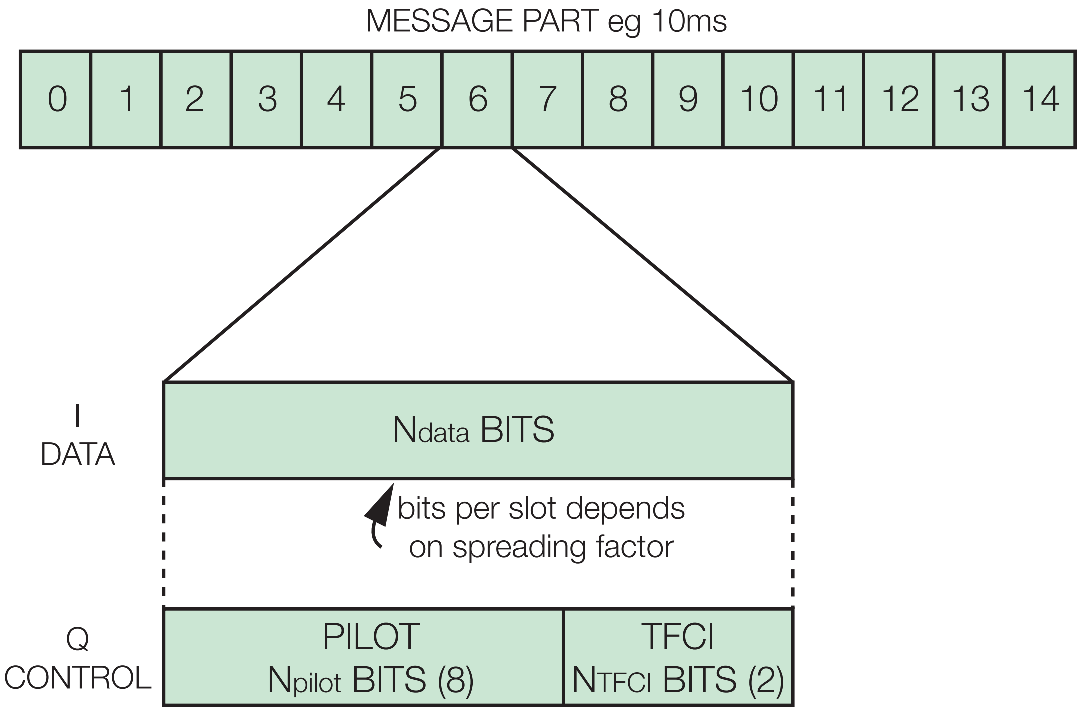
Fig. 18 – PRACH Timing and Preamble Signatures

The random access message part is either 10 or 20 ms, i.e. a continuous transmission of either 15 or 30 timeslots.

Each slot contains a segment of the data contained in the message, together with control bits, multiplexed as I and Q data as shown in figure 19.

The pilot sequences allow the Node B to gain and keep phase synchronisation with the transmission from the UE and changes with successive timeslots as shown. The Transport format combination Indicator (TFCI) indicates how the transport channel is being mapped into the physical RACH i.e. it indicates spreading factors to control data rate changes in the message data field.

Spreading factors 256, 128, 64, 32 or 16 can be used according to data rate.



I **Random Access Message Data Fields**

Slot Format #1	Channel Bit Rate Rate (kbit/s)	Channel Symbols Rate Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	15	15	256	150	10	10
1	30	30	128	300	20	20
2	60	60	64	600	40	40
3	120	120	32	1200	80	80

Q **Random Access Message Control Fields**

Slot Format #1	Channel Bit Rate Rate (kbit/s)	Channel Symbols Rate Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{pilot}	N_{TFCI}
0	15	15	256	150	10	8	2

Pilot bit patterns for RACH message part with N_{pilot} = 8

	N_{pilot} = 8							
Bit #	0	1	2	3	4	5	6	7
Slot #0	1	1	1	1	1	1	1	0
1	1	0	1	0	1	1	1	0
2	1	0	1	1	1	0	1	1
3	1	0	1	0	1	0	1	0
4	1	1	1	0	1	0	1	1
5	1	1	1	1	1	1	1	0
6	1	1	1	1	1	0	1	0
7	1	1	1	0	1	0	1	0
8	1	0	1	1	1	1	1	0
9	1	1	1	1	1	1	1	1
10	1	0	1	1	1	0	1	1
11	1	1	1	0	1	1	1	1
12	1	1	1	0	1	0	1	0
13	1	0	1	0	1	1	1	1
14	1	0	1	0	1	1	1	1

Fig. 19 – Random Access Message Details

7.2 DPCH, PDSCH, PCPCH and PUSCH

The dedicated transport channel is carried over a Dedicated Physical Channel **(DPCH)**, which is a time multiplex of two separate physical channels:

DPDCH – Dedicated Physical Data Channel
DPDCH is used to transport the dedicated data generated at Layer 2 and above, as carried within the DCH transport channel. This includes the actual user data, and any higher layer signalling. Multiple variable-rate services can be time multiplexed within each DPDCH frame, and the overall DPDCH data rate is variable on a frame-by-frame basis.

The data rate variation is also taken care of with either a rate matching operation or through discontinuous transmission, where transmission is turned off for part of the time.

DPCCH – Dedicated Physical Control Channel
Associated with DPDCH is **DPCCH**, the Dedicated Physical *Control* Channel, which is used to transport the physical control information generated in the physical layer and necessary for the operation of the DPDCH, for example information on the variable data rate. In fact, one or more DPDCHs may be associated with a single DPCCH.

In contrast to its partner data channels, the DPCCH has a fixed data rate, with a fixed spreading factor of 256.

These channels are applicable on both uplink and downlink, and in both TDD and FDD modes.

Three further channels exist, each for the specific physical transmission of three specific transport channels. These are:

PDSCH – Physical Downlink Shared Channel, used to carry dedicated control or traffic mapped from the DSCH transport channel, and hence applicable in the downlink only for both FDD & TDD. Since a DSCH is always associated with a dedicated transport channel, DCH, this similarly means that the physical channel PDSCH is always associated with a downlink DPCH physical channel.

PCPCH – Physical Packet Channel, used to transport the packet transport channel CPCH, applicable to the uplink FDD only.

PUSCH – Physical Uplink Shared Channel, used to transport the uplink shared transport channel, USCH, applicable to uplink TDD only, and temporarily allocated to one or several users.

	FDD	TDD	uplink	downlink	power control	usage
DPDCH (Dedicated Physical Data)	✓	✓	✓	✓	✓	carry DCH data
DPCCH (Dedicated Physical Control)	✓	✓	✓	✓	✓	carry physical layer control information for DPDCH
PDSCH (Physical Downlink Shared Channel) (Always Associated with DPCH)	✓	✓	✗	✓	✗	carry DSCH (Always Associated with DCH)
PCPCH (Physical Packet)	✓	✗	✓	✗	✓	carry CPCH
PUSCH (Physical Uplink Shared)	✗	✓	✓	✗	✗	carry USCH

DPDCH + DPCCH = DPCH
(Dedicated Physical Channel)

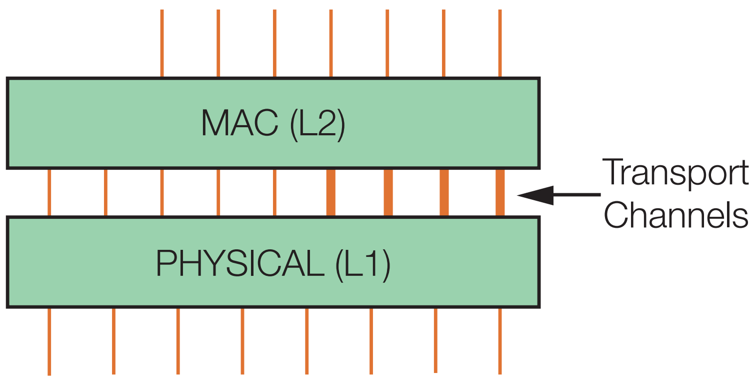


Fig. 20 – Dedicated and Shared Physical Channels

7.2.1 Dedicated Physical Channel (DPCH)

In the uplink direction, DPDCH and DPCCH are I/Q multiplexed over the radio link. Data in the DPDCH can be transferred with spreading factors 4 to 256 (FDD), the exact transport format being indicated by the transport format combination indicator (TFCI) field in the associated DPCCH. The DPCCH also includes a pilot sequence, transmit power includes a pilot sequence, transmit power control (TPC) bits used for optional downlink power control and the feedback indicator bits (FBI). These are used if optional closed loop transmit diversity or site-select transmit diversity (SSDT) are employed at the Node B. The DPCCH uses a fixed spreading factor of 256.

In the downlink direction, DPDCH and DPCCH are time-multiplexed as shown. The DPCCH transport format is once again indicated by the TFCI bits in the DPCCH, which also includes a pilot sequence and TPC bits for uplink power control.

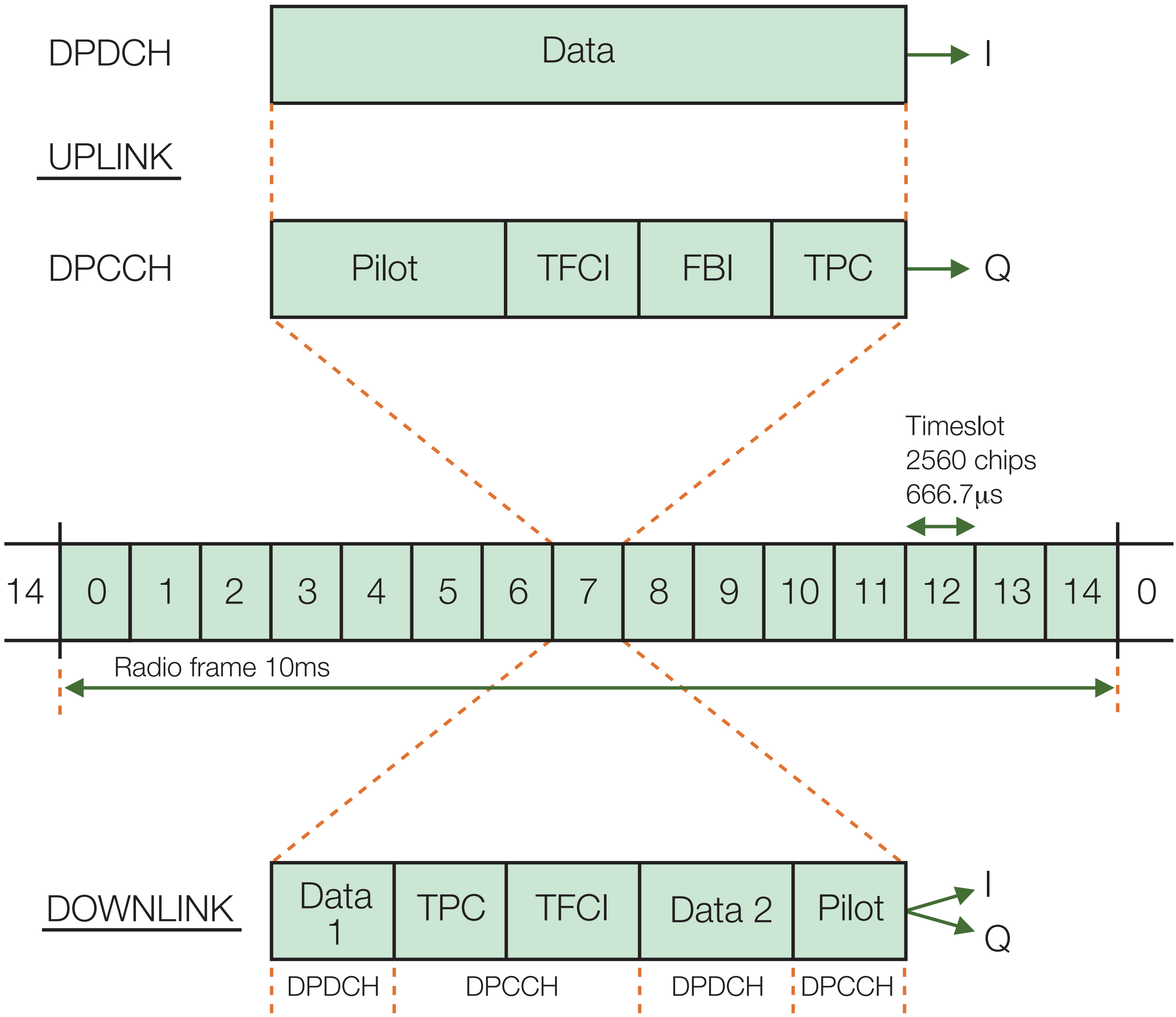


Fig. 21 – DPCH Arrangements

7.2.1.1 DPDCH and DPCCH Data Fields

Figure 22 shows details of the DPDCH and DPCCH data fields for the uplink. DPCCH rows with zero TFCI bits are used for fixed-rate services. Rows marked A or B support compressed operation (this is related to handover measurements and will be seen later).

The FBI field divides into S and D fields. The S field relates to SSDT signalling and may be 0, 1 or 2 bits in length. The D field provides feedback for closed-loop transmit diversity and has a length of 0 or 1 bit.

Figure 23 shows arrangements for the downlink. The table illustrates a sample of the possible slot formats. Others exist, mainly for support of compressed mode. Note once again the presence of slot formats with no TFCI for support of fixed-rate services.

Slot Format #1	Channel Bite Rate (kbit/s)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	15	15	256	150	10	10
1	30	30	128	300	20	20
2	60	60	64	600	40	40
3	120	120	32	1,200	80	80
4	240	240	16	2,400	160	160
5	480	480	8	4,800	320	320
6	960	960	4	9,600	640	640

DPDCH Fields

Slot Format #1	Channel Bite Rate (kbit/s)	Channel Symbol Rate (ksps)	Bits/ SF	Bits/ Frame	Slot	N_{pilot}	N_{TPC}	N_{TFCI}	N_{FBI}	Transmitted slots per radio frame
0	15	15	256	150	10	6	2	2	0	15
0A	15	15	256	150	10	5	2	3	0	10–14
0B	15	15	256	150	10	4	2	4	0	8–9
1	15	15	256	150	10	8	2	0	0	8–15
2	15	15	256	150	10	5	2	2	1	15
2A	15	15	256	150	10	4	2	3	1	10–14
2B	15	15	256	150	10	3	2	4	1	8–9
3	15	15	256	150	10	7	2	0	1	8–15
4	15	15	256	150	10	6	2	0	2	8–15
5	15	15	256	150	10	5	1	2	2	15
5A	15	15	256	150	10	4	1	3	2	10–14
5B	15	15	256	150	10	3	1	4	2	8–9

DPCCH Fields

Details of FBI field:

S field	D field

$\longleftarrow N_{FBI} \longrightarrow$

Fig. 22 – Uplink DPDCH/DPCCH Data Fields

Fig. 23 – Summary of Main Downlink DPDCH/DPCCH Data Fields

Slot Format	Channel BIt Rate (kbit/s)	Channel Symbol Rate (ksps)	SF	Bits/Frame			Bits/ Slot	DPDCH Bits/Slots		DPCCH Bits/Slots		
				DPDCH	DPCCH	TOTAL		$N_{Data\ 1}$	$N_{Data\ 2}$	N_{TFCI}	N_{TPC}	N_{PILOT}
0	15	7.5	512	60	90	150	10	2	2	0	2	4
1	15	7.5	512	30	120	150	10	0	2	2	2	4
2	30	15	256	240	60	300	20	2	14	0	2	2
3	30	15	256	210	90	300	20	0	14	2	2	2
4	30	15	256	210	90	300	20	2	12	0	2	4
5	30	15	256	180	120	300	20	0	12	2	2	4
6	30	15	256	150	150	300	20	2	8	0	2	8
7	30	15	256	120	180	300	20	0	8	2	2	8
8	60	30	128	510	90	600	40	6	28	0	2	4
9	60	30	128	480	120	600	40	4	28	2	2	4
10	60	30	128	450	150	600	40	6	24	0	2	8
11	60	30	128	420	180	600	40	4	24	2	2	8
12	120	60	64	900	300	1200	80	4	56	8	4	8
13	240	120	32	2100	300	2400	160	20	120	8	4	8
14	480	240	16	4320	480	4800	320	48	240	8	8	16
15	960	480	8	9120	480	9600	640	112	496	8	8	16
16	1920	960	4	18720	480	19200	1280	240	1008	8	8	16

7.2.1.2 Multiple Downlink DPCH

For higher rate services, multiple downlink codes can be used to provide multiple DPCH. However, Layer 1 control (the DPCCH) is only transmitted on the first DPCH. The other DPCH do not transmit during the common DPCCH period.

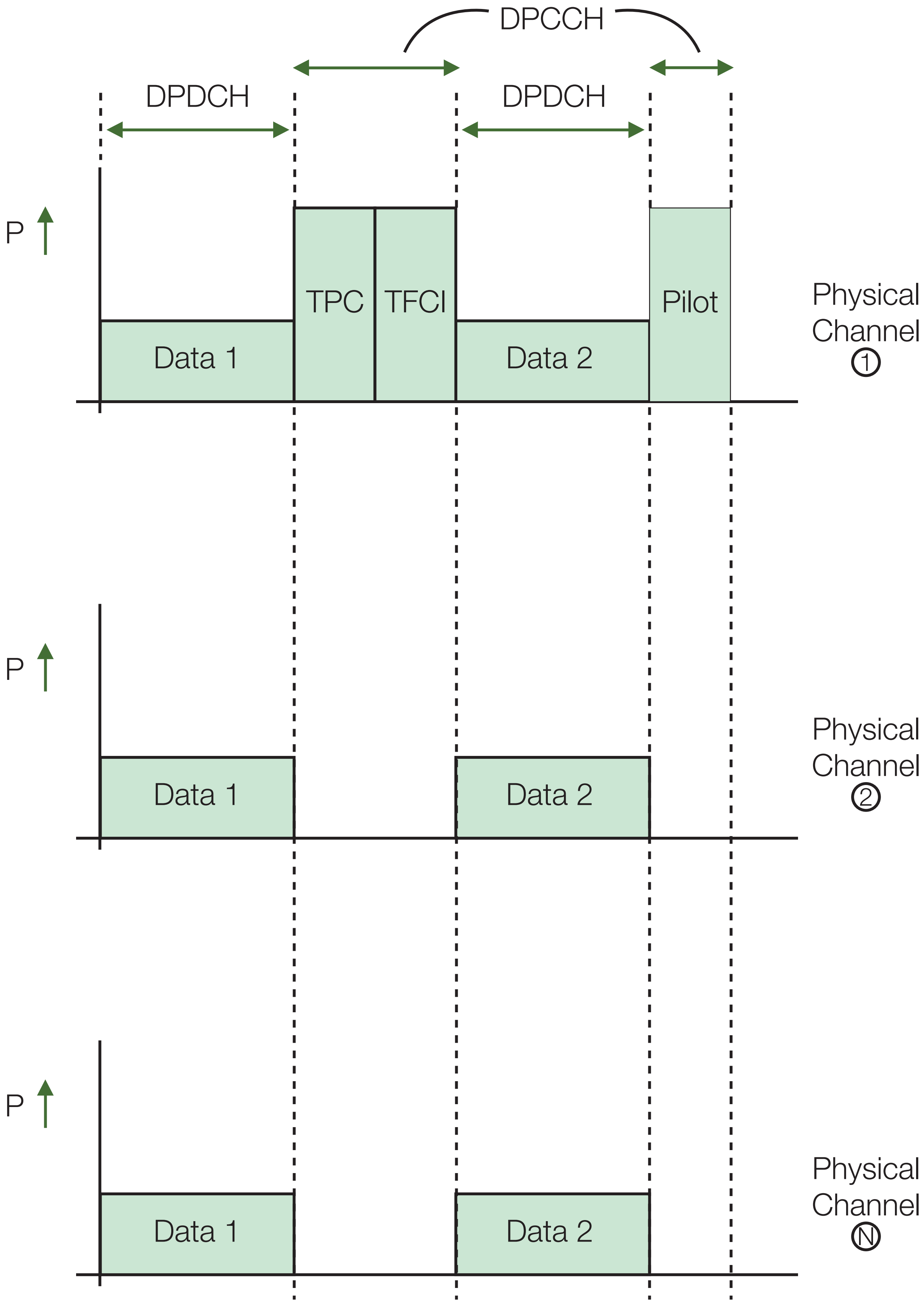


Fig. 24 – Multiple Downlink DPCH

7.2.2 Physical Common Packet Channel (PCPCH)

The CPCH transport channel is designed to carry bursty packet data from multiple UEs using digital sense multiple access with collision detection (DSMA-CD). Mobiles using this common uplink channel are under fast power control using an associated DPCCH on the downlink, so interference is minimised.

Mobiles detect the availability of PCPCH channels in a cell by monitoring the downlink CPCH Status Indication Channel (CSICH).

As a whole, 512 uplink Gold codes are identified for PCPCH, organised as 8 groups of 64. A cell uses codes from a group of 64. The assignment of the group is related to assignment of the primary cell scrambling code.

Using the same Access Slot timing as the PRACH, mobiles send Access Preambles (AP) until an acknowledgement is seen in the Access Preamble Acquisition Indicator Channel (AP-AICH). The mobile then sends one more AP for Collision Detection Verification and expects a Collision Detection message in the Collision Detection Indicator Channel (CD-ICH). Optionally, the CD-ICH can carry an orthogonally coded second channel shown as Channel Assignment Indicator Channel (CA-ICH) which may direct the mobile to a PCPCH other than the one where access was attempted.

AP-AICH, CD-ICH (+CA-ICH) and CSICH can all share the code resource used by the AICH by effective time multiplexing.

The beginning of the uplink PCPCH transmission can optionally consist of 8 slots of power control preamble to help establish an appropriate power level for the message part which follows. The message part is of variable length (determined by higher layers) and consists of data and control parts in parallel.

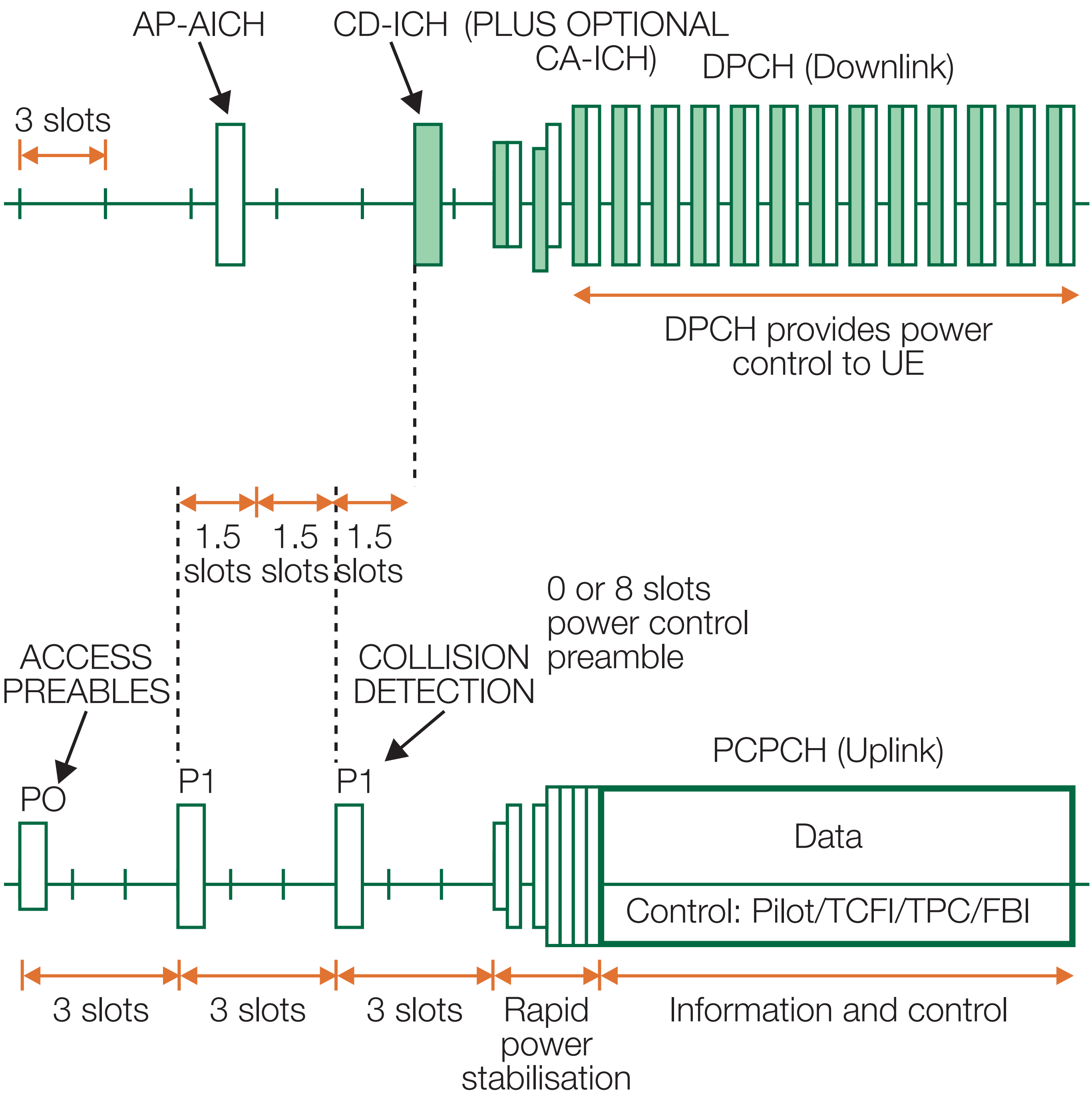


Fig. 25 – PCPCH Access and Data Transfer

7.2.3 Physical Downlink Shared Channel (PDSCH)

The physical downlink shared channel is allocated to a single UE on a frame by frame basis, with variable spreading factors taken from the same branch of the OVSF code tree to ease dynamic re-allocation. A single UE can be allocated multiple PDSCH with the same spreading factor or different UEs can use the same frame with different spreading factors (i.e. OVSF codes).

Each PDSCH is always associated with a DPCH carrying associated signalling. This will indicate, through the TFCI (or higher layer signalling) transport parameters relating to the PDSCH.

PDSCH Fields

Slot Format	Channel Bit Rate (kbit/s)	Channel Symbol Rate (ksps)	SF	Bits/ Frame	Bits/ Slot	N_{data}
0	30	15	256	300	20	20
1	60	30	128	600	40	40
2	120	60	64	1,200	80	80
3	240	120	32	2,400	160	160
4	480	240	16	4,800	320	320
5	960	480	8	9,600	640	640
6	1,920	960	4	19,200	1,280	1,280

PDSCH Slot and Frame Structure

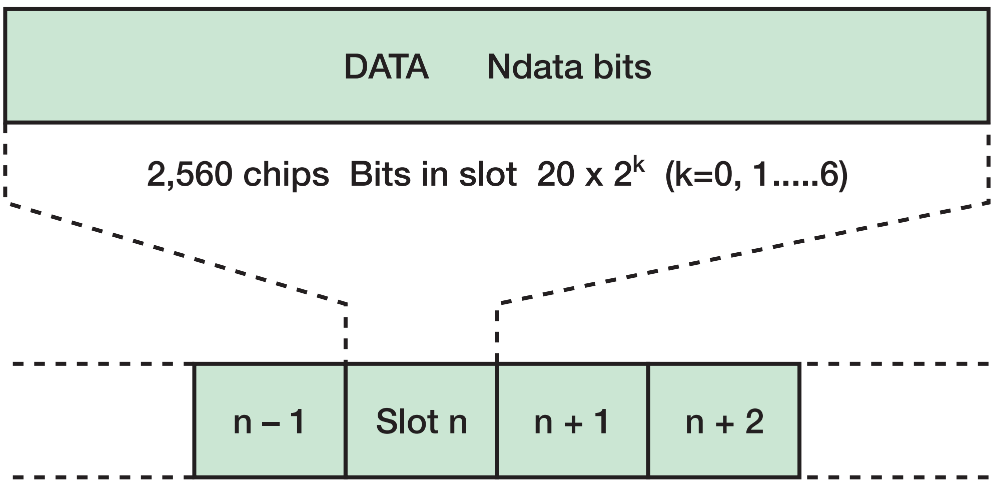


Fig. 26 – PDSCH Format

7.3 AICH, AP-AICH, CSICH, CD/CA-ICH and CPICH

There are a number of other downlink physical channels which have no mapping to higher layers, but which are applicable only in FDD mode. These are:

AICH – Acquisition Indication Channel, used by the UTRAN to indicate back to the mobile whether a random access attempt has succeeded (requested via the uplink RACH transport channel). In common with RACH itself, it is a mandatory requirement for system operation.

AP-AICH – Access Preamble Indication Channel, identical to AICH but used to indicate whether the UTRAN has successfully received a request for access to the CPCH transport channel, which is used for bursty packet user data.

Three further channels also relate to AP-AICH, being relevant specifically to access to the CPCH transport channel:

CSICH – CPCH Status Indication Channel, used to indicate the availability of each physical channel related to CPCH transport channel access. CSICH utilises the unused part of the AICH channel.

CD-ICH and CA-ICH – Collision Detection & Channel Assignment Indication Channels, used to indicate the success of a collision detection operation and the status of the channel assignment respectively. These two channels are sent in parallel to the terminal.

Finally there is:

CPICH – Common Pilot Channel
This is a mandatory channel, used for cell phase and time reference, and for channel estimation for the common channels (and occasionally for the dedicated channels). Channel estimation refers to the conditions of interference and reception quality.

In fact, there is both a Primary and a Secondary CPICH, P-CPICH and S-CPICH respectively, which differ in their usage and the limitations on their physical features.

P-CPICH is used as the reference for the downlink channels SCH, P-CCPCH, AICH and PICH. The same channelisation code is always used and is scrambled using the primary scrambling code, of spreading factor 256. One P-CPICH exists in each cell, and is broadcast over the entire cell.

The importance of P-CPICH is in measurements for handover and cell selection/re-selection. Reducing the power applied to the channel causes some of

- physical Layer only
- FDD only
- downlink only
- no power control

	mandatory	usage
AICH (Acquisition Indication)	✓	indicate success of random access
AP-AICH (Access Preamble Indication)	✗	indicate success of access to CPCH
CSICH (CPCH Status Indication)	✗	indicate availability of physical channels for CPCH
CD-ICH (Collision Detection Indication)	✗	indicate collision detection during CPCH access
CA-ICH (Channel Assignment Indication)	✗	indicate status of channel assignments for CPCH
CPICH (Common Pilot)	✓	channel estimation, cell phase & time reference for common channels, for handover

Fig. 27 – FDD Only Physical Channels

the terminals to hand over to other cells, while increasing it invites terminals to handover into the cell, or to use that cell as their initial access.

S-CPICH may be used as a reference for the S-CCPCH and the Downlink Dedicated Physical Channel, which carries the dedicated transport channel DCH. It will use an arbitrary channelisation code of spreading factor 256, and is scrambled by either the primary or a secondary scrambling code. It may be transmitted over only part of a cell, and hence used with beam forming antennas for hot-spots or high density traffic areas.

- physical Layer only
- FDD only
- downlink only
- no power control

	mandatory	usage
AICH (Acquisition Indication)	✓	indicate success of random access
AP-AICH (Access Preamble Indication)	✗	indicate success of access to CPCH
CSICH (CPCH Status Indication)	✗	indicate availability of physical channels for CPCH
CD-ICH (Collision Detection Indication)	✗	indicate collision detection during CPCH access
CA-ICH (Channel Assignment Indication)	✗	indicate status of channel assignments for CPCH
CPICH (Common Pilot)	✓	channel estimation, cell phase & time reference for common channels, for handover

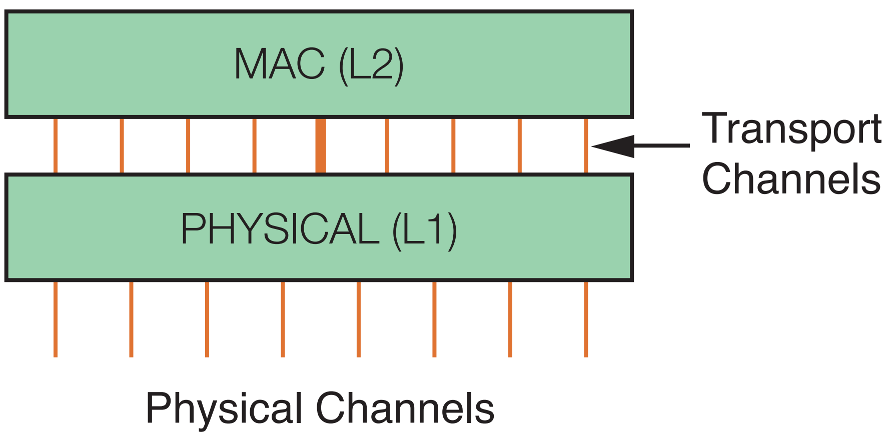


Fig. 27 – FDD Only Physical Channels

7.3.1 The Acquisition Indicator Channel (AICH) and AP-AICH

The AICH is used to acknowledge successful receipt, at the Node B, of an access preamble from a UE. The preamble carries one of 16 signatures and the AICH acknowledges the signature of a specific UE by transmitting a corresponding signature pattern from the table in figure 28. Up to 16 signatures can be acknowledged simultaneously.

The AICH consists of 15 consecutive access slots (AS) lasting 20 ms before repeating and its start is offset by 1.5 Access Slots from the PRACH as seen earlier. It is transmitted at full power.

Each AS lasts for 5120 chips but the final 1024 are not transmitted. The 4096 chips spread 32 real-valued symbols, A_0 to A_{031}.

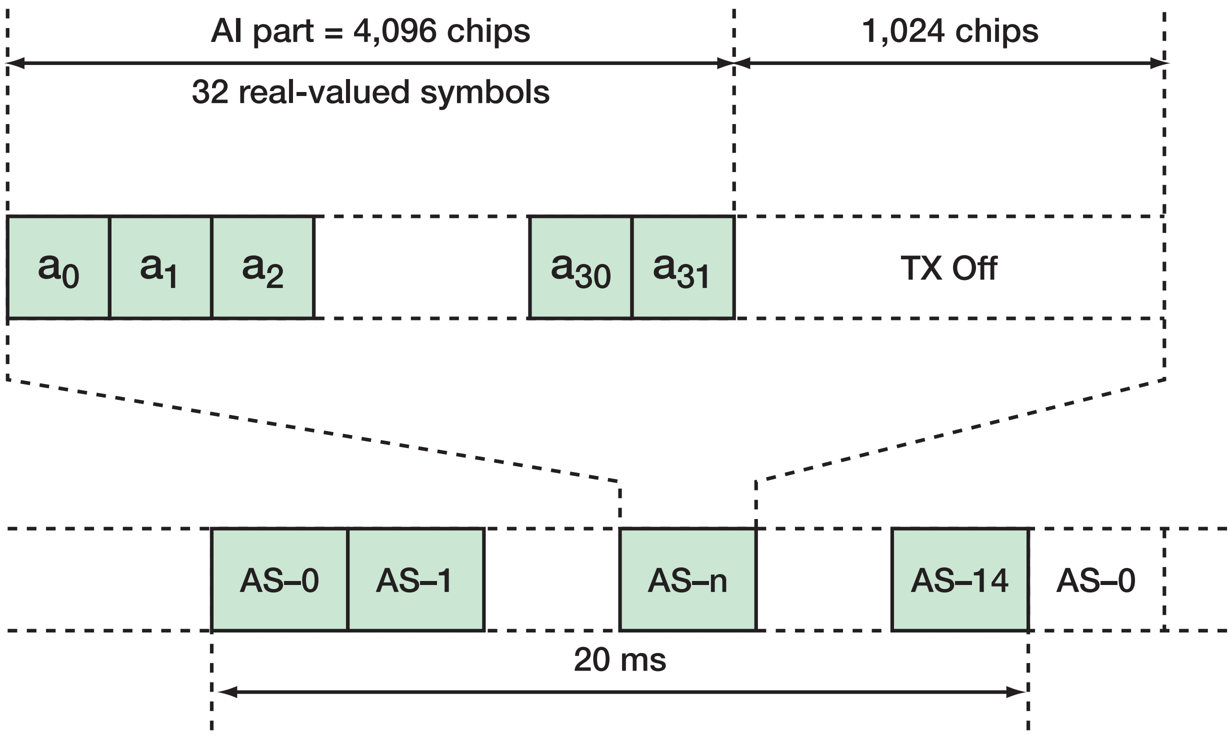
The symbols are given by:

$$a_j = \sum_{s=0}^{s=15} AI_s \, b_{s,j}$$

The Acquisition Indicators multiplying the patterns may take the following value:

1 = signature acknowledged
-1 = signature not acknowledged
0 = no response

The Access Preamble Acquisition Indicator Channel (AP-AICH) used to control PCPCH access uses identical timing and coding principles as the AICH above, and normally shares the same channelisation code.



AICH Signature Patterns

S	$b_{s,0}, b_{s,1} \cdots b_{s,31}$
0	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1	1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1
2	1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1
3	1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1
4	1 1 1 1 1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 1 1 1 1 1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1
5	1 1 –1 –1 1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 1 1 –1 –1 1 1 –1 –1 –1 –1 1 1 –1 –1 1 1
6	1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 1 1 1 1 1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 1 1 1 1
7	1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 1 1 –1 –1 1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 1 1 –1 –1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1
9	1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1
10	1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1
11	1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1
12	1 1 1 1 1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 –1 1 1 1 1 1 1 1 1
13	1 1 –1 –1 1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 –1 –1 1 1 1 1 –1 –1 1 1 –1 –1
14	1 1 1 1 –1 –1 –1 –1 –1 –1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 1 1 1 1 –1 –1 –1 –1
15	1 1 –1 –1 –1 –1 1 1 –1 –1 1 1 1 1 –1 –1 –1 –1 1 1 1 1 –1 –1 1 1 –1 –1 –1 –1 1 1

- Each signature (S) multiplied by +1, –1 or 0

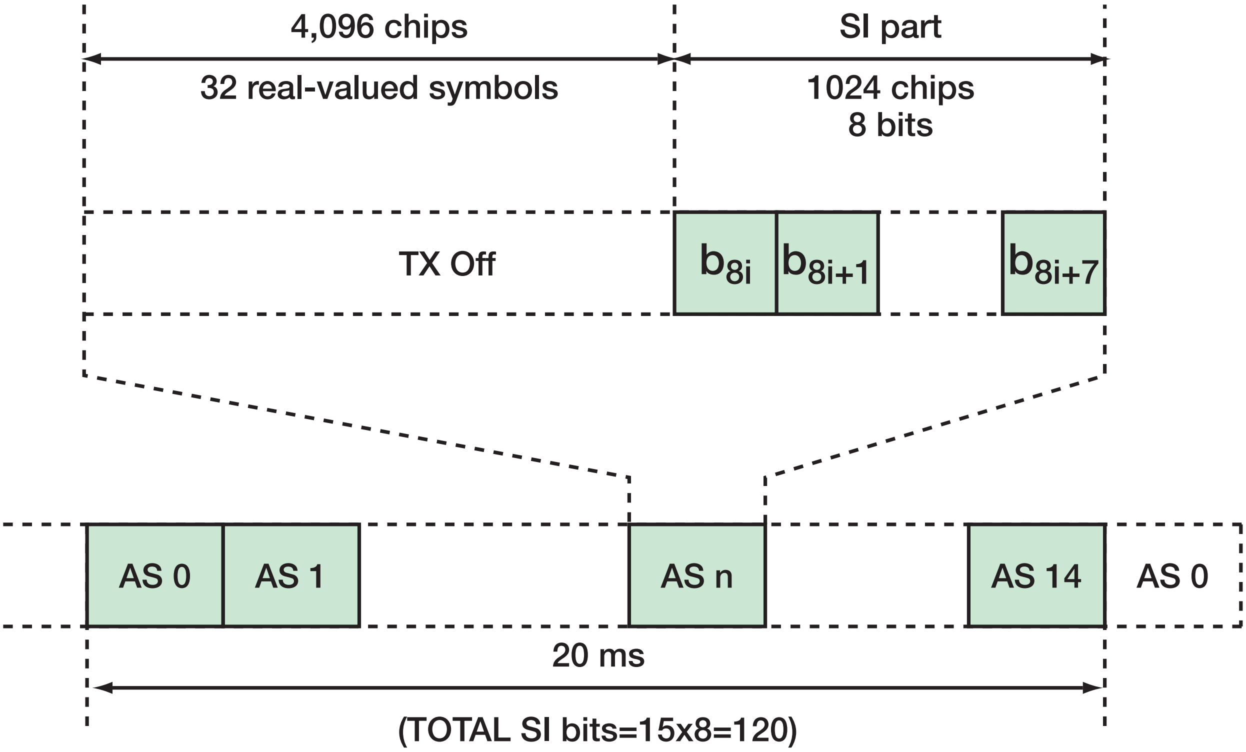
Fig. 28 – Acquisition Indicator Channel (AICH)

7.3.2 CPCH Status Indication Channel (CSICH)

The CSICH is structured as 15 access slots (2 radio frames) in the same way as the AICH and utilises the last 1024 chips as the CSICH. Thus the timing is complementary to that in the AICH, allowing them to share the same physical channel. CSICH spreading factor is 256.

This means that the status indication (SI) part equates to 8 bits, giving a total of 8 x 15 = 120 bits throughout the 20 ms cycle.

These are used to indicate the status of the associated CPCH in the cell. If relevant bits for the channel are set to -1, the channel is available (SI = 1) and if set to +1, the channel is not available (SI = 0).



Number of SI per frame (N)	SI_n = 1	SI_n = 0
N=1	hb_0, ..., b_{119}j= h–1, –1, ..., –1j	hb_0, ..., b_{119}j= h+1, +1, ..., +1j
N=3	hb_{40n}, ..., b_{40n+23}j= h–1, –1, ..., –1j	hb_{40n}, ..., b_{40n+39}j= h+1, +1, ..., +1j
N=5	hb_{25n}, ..., b_{24n+23}j= h–1, –1, ..., –1j	hb_{24n}, ..., b_{24n+23}j= h+1, +1, ..., +1j
N=15	hb_{8n}, ..., b_{8n+7}j= h–1, –1, ..., –1j	hb_{8n}, ..., b_{8n+7}j= h+1, +1, ..., +1j
N=30	hb_{4n}, ..., b_{4n+3}j= h–1, –1, –1, –1j	hb_0, ..., b_{119}j= h+1, +1, +1, +1j
N=60	hb_{2n}, ..., b_{2n+1}j= h–1, –1j	hb_{2n}, ..., b_{2n+1}j= h+1, +1j

AS = Access Slot

Fig. 29 – CSICH Structure and Coding

7.3.3 CPCH Collision Detection/Channel Assignment Indicator Channel (CD/CA-ICH)

This carries collision detection (CD) indicators and may optionally carry channel assignment (CA) indicators in parallel using orthogonal coding. The general structure, timing and principle are the same as AICH (and a common channelisation code can be used for both AICH and CD/CA-ICH). The CDI/CAI part comprises 32 real-valued symbols a_{30} – a_{31} (spreading factor = 256).

If channel assignment is not active, a_{30} to a_{31} are given by

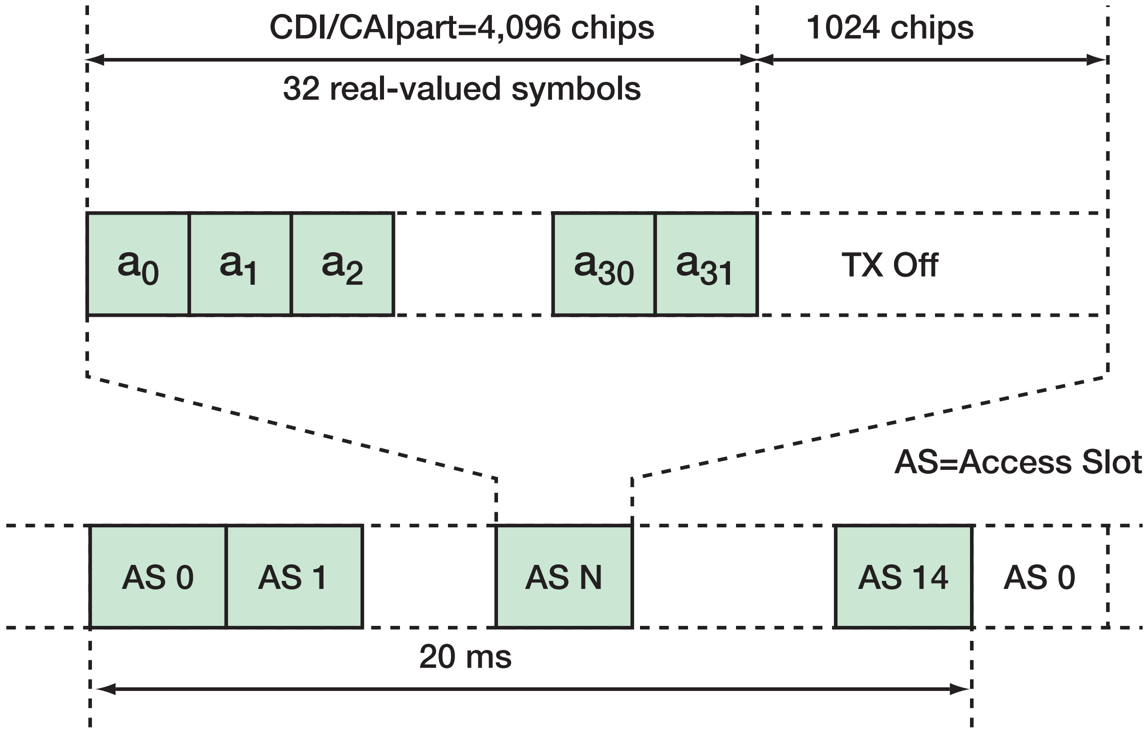
$$a_j = \sum_{s=0}^{s=15} CDI_s \, b_{s,\,j}$$

Where CDI corresponds to CD preamble signatures transmitted by the mobile. CDI can take the values +1 or 0 and the sequences for b_{s0} – b_{s31} are the same as the AICH signatures seen in figure 27.

If channel assignment is active

$$a_j = \sum_{s=0}^{s=15} CDI_i \times b_{si,\,j} + \sum_{k=0}^{k=15} CAI_k \times b_{sk,\,j}$$

Where si and sk relate to the indexes i and k in the table which indicate signature numbers, 5. CDI_i and CAI_k can take the values +1/0 or -1/0 as illustrated.



UE transmitted CD Preamble	CDI	Signature S_i	Ch. Assign. Index k	CAI_k	Signature S_k
0	+1/0	1	0	+1/0	0
1	–1/0		1	–1/0	
2	+1/0	3	2	+1/0	8
3	–1/0		3	–1/0	
4	+1/0	5	4	+1/0	4
5	–1/0		5	–1/0	
6	+1/0	7	6	+1/0	12
7	–1/0		7	–1/0	
8	+1/0	9	8	+1/0	2
9	–1/0		9	–1/0	
10	+1/0	11	10	+1/0	6
11	–1/0		11	–1/0	
12	+1/0	13	12	+1/0	10
13	–1/0		13	–1/0	
14	+1/0	15	14	+1/0	14
15	–1/0		15	–1/0	

Fig. 30 – CD/CA-ICH Structure

7.3.4 Common Pilot Channel (CPICH)

All UMTS cell radiate a primarily common pilot channel across the whole cell (P-CPICH) which acts a phase reference for SCH, P-CCPCH, AICH, PICH, AP-AICH, CD/CA-ICH, CSICH and S-CCPCH. It is also the default reference for a DPCH.

Optionally, cells can radiate one or more secondary common pilot channels (S-CPICH) over the whole cell or within a sub-cell with the aid of beam-forming antennas to cover traffic hotspots. S-CPICH can act as a phase reference for S-CCPCH and DPCH.

The P-CPICH has a rate of 30 kbps and a fixed spreading factor of 256 and carries a pre-defined sequence spread with the primary scrambling (Gold) code planned for the cell. It is radiated with greater weighting than other channels and because it is used by mobiles for cell selection and handover measurements, changing its weighting will affect the effective cell size.

The S-CPICH can use any arbitrary channelisation code and optionally a different scrambling code.

If downlink transmit diversity is in use at the Node B, the CPICH is radiated from both antennas with the same codes but modulation symbols on the two antennas are varied as shown in figure 31. The pattern for antenna one is used if no transmit diversity is employed.

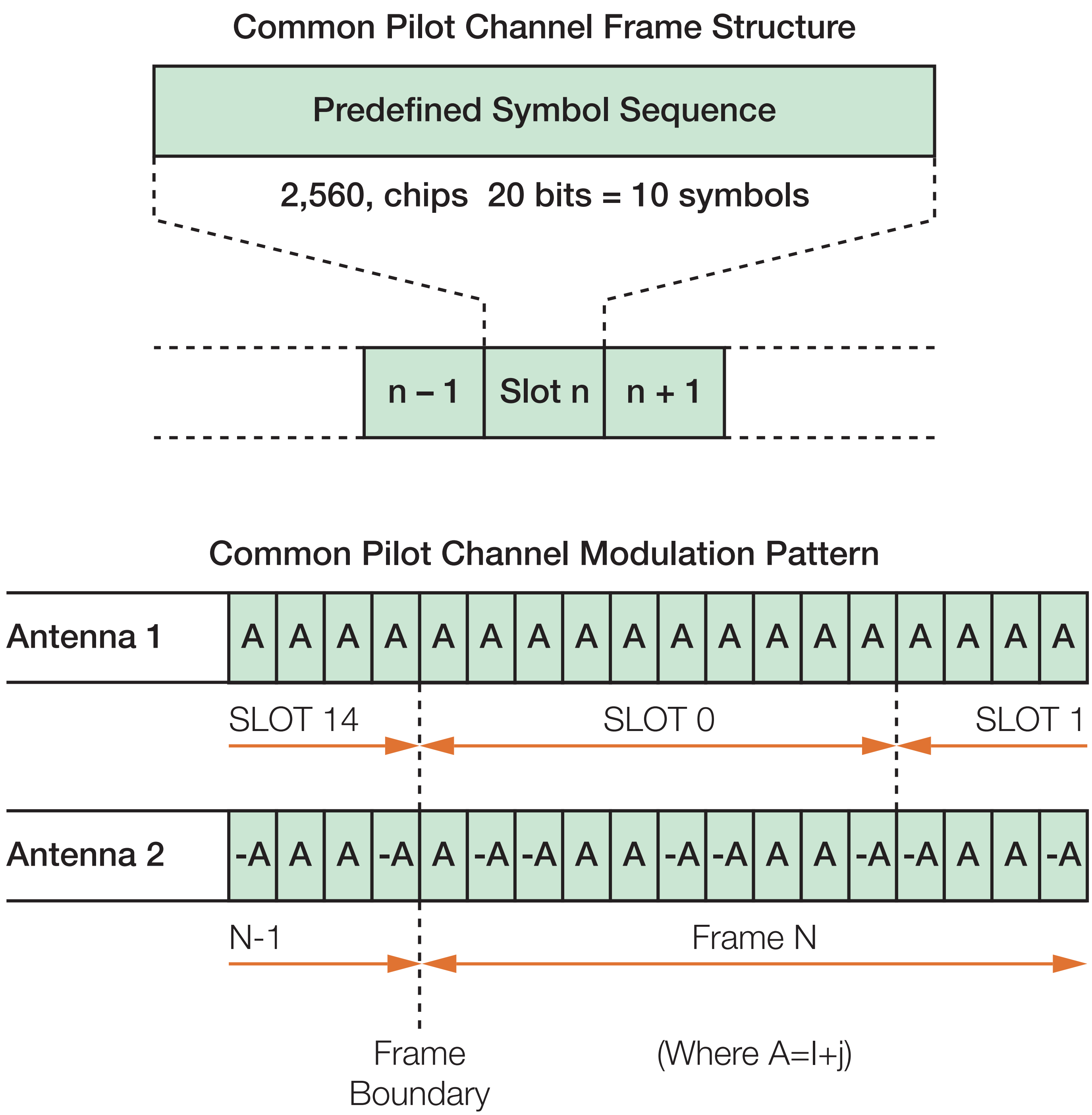


Fig. 31 – CPICH Structure and Modulation

7.4 Mapping Transport Channels onto Physical Channels

All Transport Channels map directly onto a specific physical channel, except in the case of the transport channels FACH (forward access channel) and PCH (Paging Channel), which are both mapped to share the single S-CCPCH (Secondary Common Control) Physical Channel.

Applicability to uplink, downlink, FDD and TDD modes of operation therefore follow that for the transport channels.

DPDCH and DPCCH, which carry the DCH dedicated transport channel, including the user data, are the only channels which can apply in every combination of modes and direction.

PRACH must exist for uplink FDD & uplink TDD, in order to carry the RACH transport channel. PCPCH may exist in uplink FDD, and PUSCH in uplink TDD, in order to carry the transport channels CPCH and USCH respectively.

In the downlink, SCCPCH, PCCPCH will always apply to both TDD & FDD, and carry the paging and broadcast transport channels, PCH and BCH respectively. SCCPCH additionally carries the FACH transport channel.

PDSCH may apply in either TDD or FDD downlink, where the DSCH transport channel is being used.

In addition to channels mapped directly from the transport channels, the downlink of both FDD and TDD will include the mandatory physical layer channels SCH and PICH.

In FDD mode only, the downlink will also include the unmapped physical layer channels AICH and CPICH, which are mandatory, plus AP-AICH, CSICH, CD-ICH and CA-ICH, which may apply if the mobile terminal requests access to the CPCH transport channel.

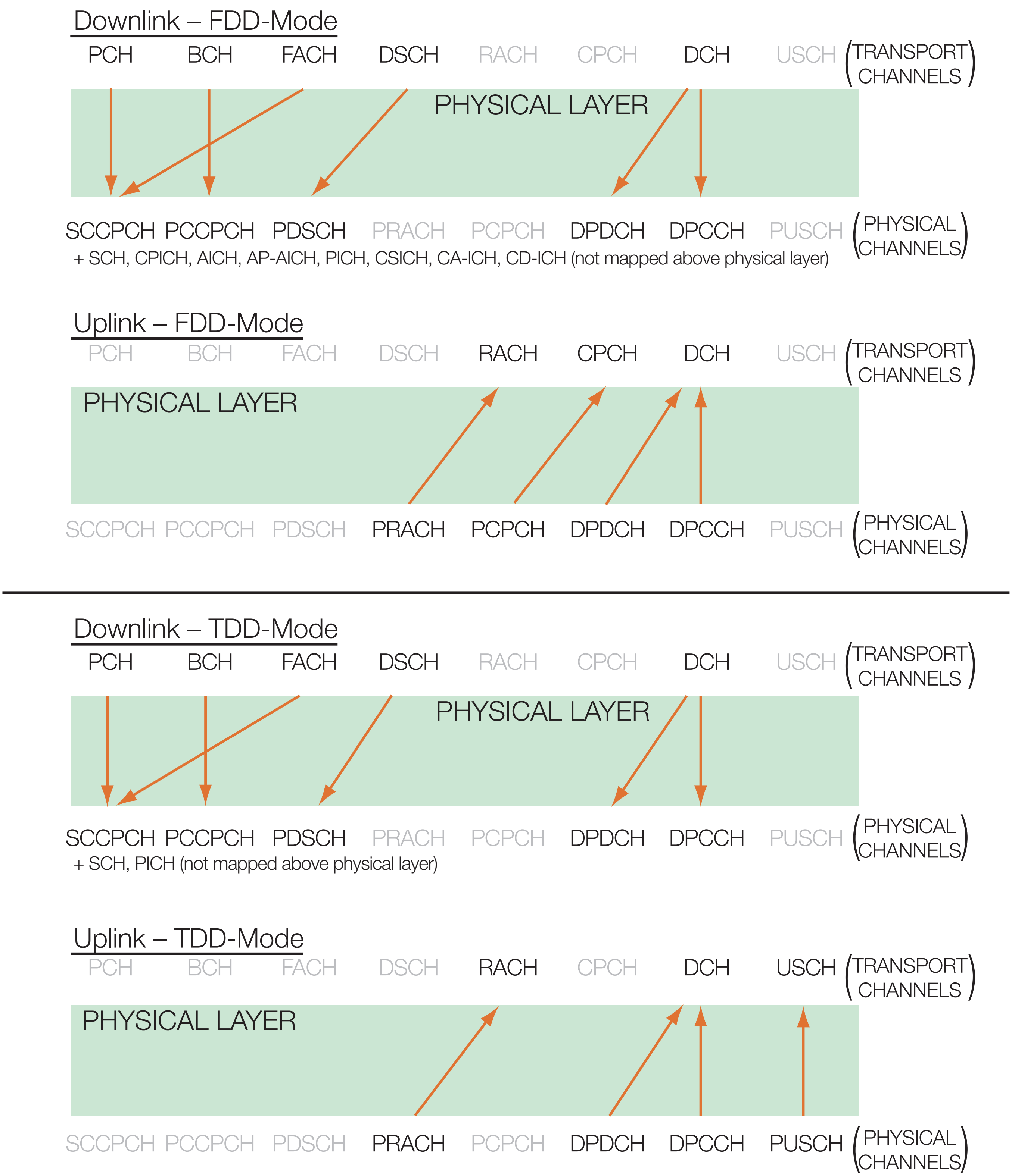


Fig. 32 – Mapping Between Transport and Physical Channels

7.5 Downlink Timing for Physical Channels

Downlink physical channel timing is shown in figure 33.

Primary and secondary SCH are aligned with each other an with the start of each time slot. Similarly, the CPICH,P-CCPCH and PDSCH are aligned with the 10ms radio frames.

S-CCPCH are offset by a multiple of 256 chips (T_{SCCPCH}) from the P-CCPCH. Different S-CCPCH can have different offsets, selected from 150 available offsets, i.e. T_{SCCPCH} = k x 256 chips.

PICH timing (T_{PICH}) is set at 7680 chips prior to the corresponding S-CCPCH frame carrying the associated PCH transport channel.

Access slot 0 is aligned with the start of P-CCPCH frames with (SFN modulo 2) = 0. Access slots are used by the PRACH, AICH, AP-AICH and CD/CA-ICH.

DPCH timing may be different for different DPCHs where the offsets are a multiple of 256 chips, i.e. T_{DPCH} = n x 256 chips.

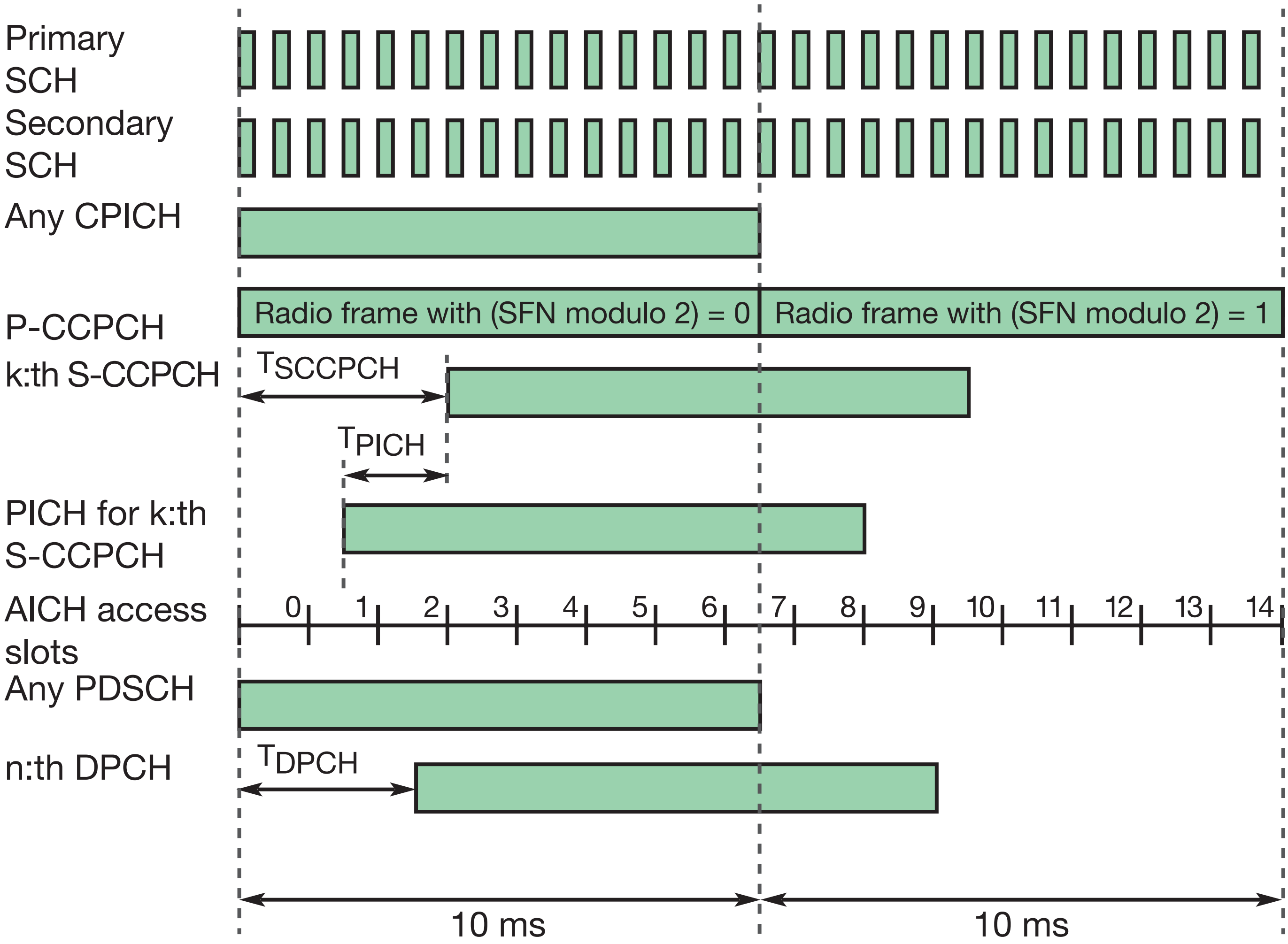


Fig. 33 – Radio Frame Timing and Access Slot Timing of Downlink Physical Channels

7.6 Uplink Timing for Physical Channels

The UE takes its timing from the observed downlink. However, in a multipath environment the UE will always use the first detected path as a reference and will offset its timing by 1024 chips from this reference. The delay as perceived by the UTRAN will be a total comprised of the 1024 chips plus the propagation delay. This information can be utilised for the Location Service (LCS).

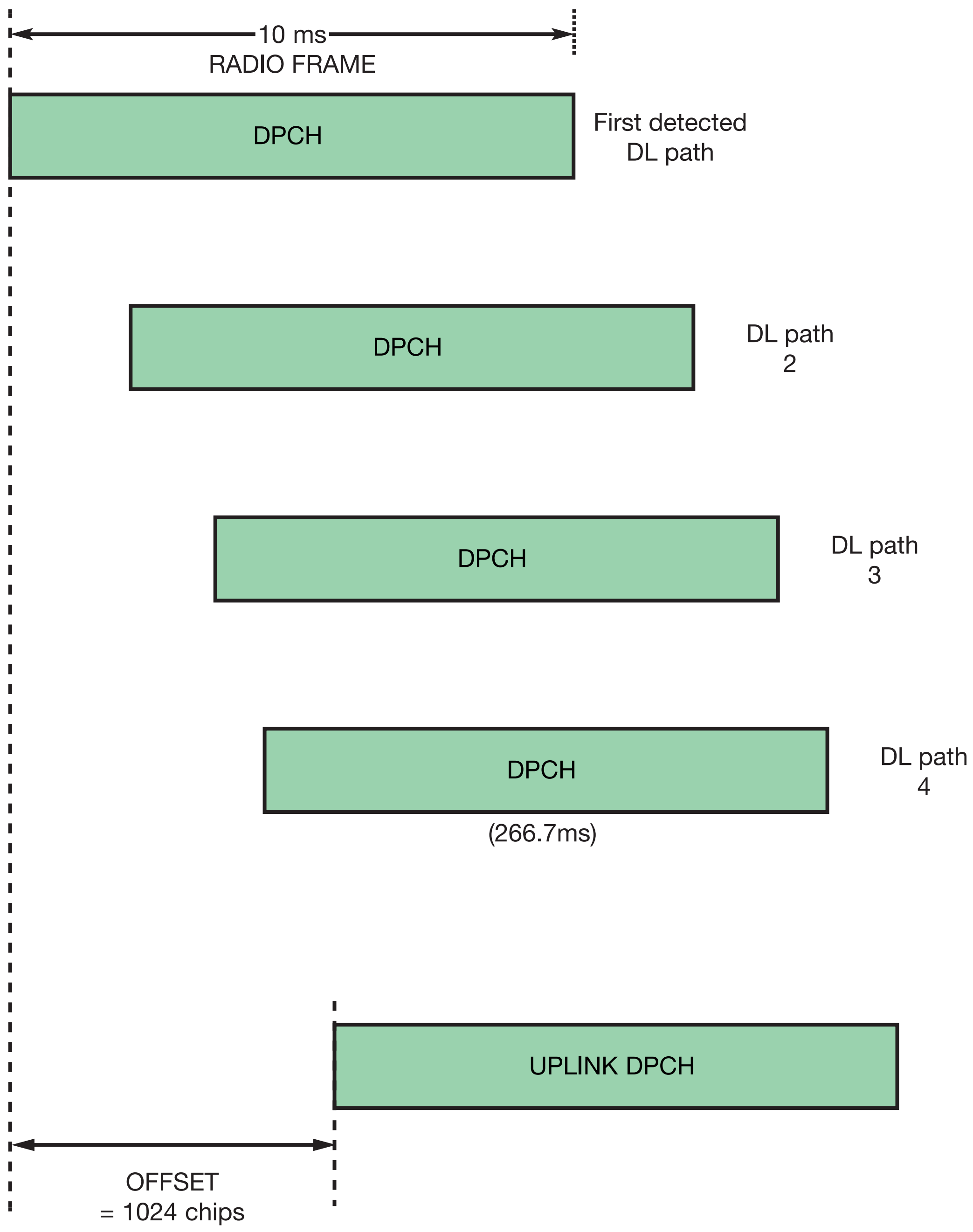


Fig. 34 – Uplink DPCH Timing

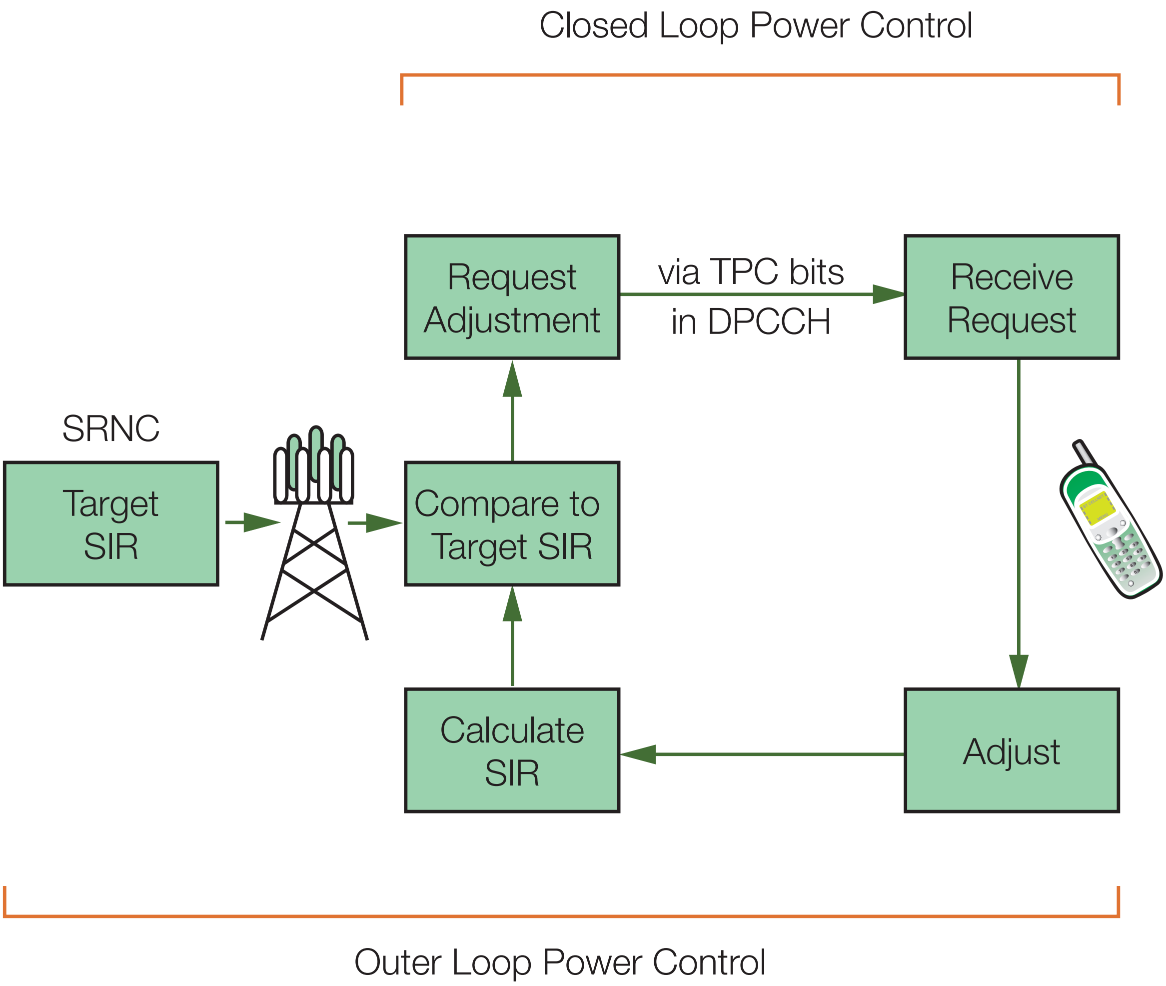
7.7 Power Control

7.7.1 Uplink Power Control

According to the QoS, the SRNC will set a target SIR for the uplink. The Node B will check uplink SIR against the target and try to keep the uplink on target by issuing power commands to the UE via the TPC bits in the DPCCH. The UE processes TPC bits to produce the factor TPC_cmd, which can take the values 1, 0 or -1. The UE is also, via higher layer signalling, given a power step size, Δ_{TPC} of either 1dB or 2dB (also ΔRP-PC of 3dB) and then computes the ordered power change Δ_{DPCCH} as shown in figure 35. 1500 (fifteen per 10ms radio frame) power control commands can then be implemented per second.

There may need to be a difference between the power level of the DPCCH and DPDCH parts of the uplink signal to maintain the modulation envelope. Power changes as computed above are applied to the DPCCH and then the level of the DPDCH is set in proportion using two factors β_C and β_D (which are sent to the UE in higher layer signalling).

Outer loop power control is initiated by the SRNC, which may change the target SIR periodically in order to maintain QoS. This could be triggered, for example, by the UE increasing its speed.



- UE Power Change $\Delta_{DPCCH} = \Delta_{TPC} \times TPC\_cmd$
- Δ_{TPC} = 1dB or 2dB ($\Delta_{RP\text{-}TPC}$ = 3dB)
- TPC_cmd = +1, 0 or -1

Fig. 35 – Uplink Closed Loop and Outer Loop Power Control

7.7.1.1 Processing TPC Bits from a Single Channel

If the UE is not in soft handover, it needs only to process one set of TPC bits per time slot to compute TPC_cmd. The UTRAN will indicate which of two algorithms the UE should employ.

Algorithm 1 requires that TPC bits be interpreted as 1 or 0 and mapped directly to +1 and -1 as TPC_cmd values. 1500 power commands occur per second.

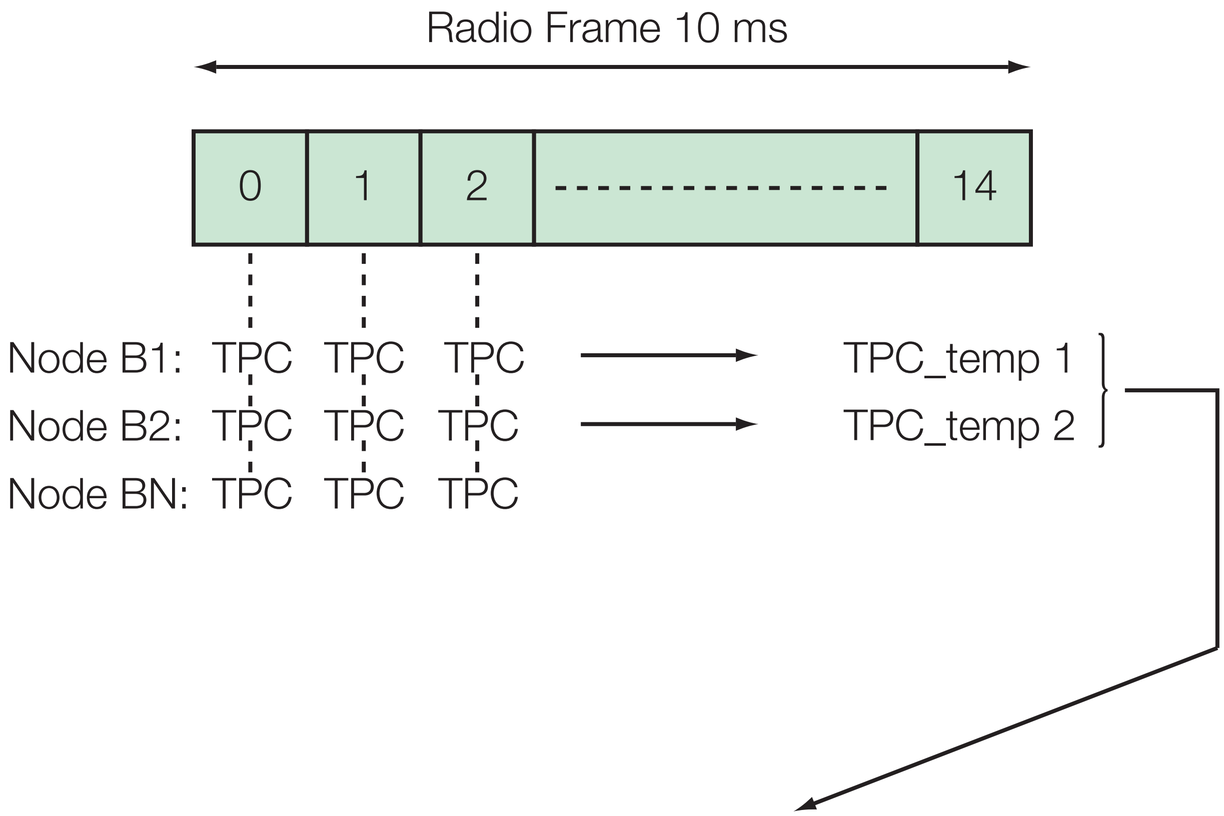
Algorithm 2 looks at five consecutive sets of TPC bits over five slots. For the first four, TPC_cmd is set to 0 regardless of the state of the TPC bits. Once the TPC bits in the fifth slot have been received, all five slots are then considered. If and only if all five slots are 1 or 0 will TPC_cmd be set to +1 or -1. It is otherwise set to 0. This results in 3 power commands per frame (300 per second).

7.7.1.2 Processing TPC Bits from Multiple Channels

When engaged in an N way soft handover, the UE must combine N sets of TPC bits to compute a value for TPC_cmd. Once again, there are two possible algorithms.

Algorithm 1 requires that, on a per slot basis, the value of TPC_cmd be set to +1 only if all TPC bits from every Node B is 1. Otherwise, it is set to -1. This results in 1500 commands per second.

Algorithm 2 requires that for each Node B in the active set, TPC bits are considered over periods of three time slots to produce a value called TPC_temp (whose value is set to +1 or -1 only if all TPC bits were 1 or 0 respectively, otherwise it is set to 0). All values of TPC_temp must then be used to compute the final value for TPC_cmd according to the conditions shown in figure 34. The result is 500 commands per second.



$$\text{TPC\_cmd} = +1 \text{ if } \frac{1}{N}\sum_{i=1}^{N} \text{TPC\_temp}_i > 0.5$$

$$\text{TPC\_cmd} = -1 \text{ if } \frac{1}{N}\sum_{i=1}^{N} \text{TPC\_temp}_i < -0.5$$

Otherwise, TPC_ cmd = 0

Fig. 36 – Algorithm 2 (Multiple Channels)

7.7.2 Closed Loop Downlink Power Control

In this case, the UE is issued a target SIR for the downlink (by higher layer signalling from the UTRAN) against which it compares the actual downlink SIR. Uplink TPC bits in the DPCCH are used to indicate power commands to the Node B. This can be done every slot (using DPC_mode 0) or every three slots (using DPC_mode 1), resulting in either 1500 or 500 commands per second.

The UTRAN will thus calculate a new downlink power level every slot (DPC_mode 0) or three slots (DPC_mode 1). The TPC bits of 1 or 0 are once again mapped to a power command P_{TPC} which can take the value +1 or -1. If the maximum power has been reached and another increase is ordered, however, P_{TPC} takes the value 0. Power steps can be 0.5, 1, 1.5 or 2dB.

7.7.2.1 Power Difference between DL DPCCH and DPDCH

Once again, there will be a difference between the power levels of the DPCCH and DPDCH parts of the downlink signal. In this case, power control is applied equally to both DPDCH and DPCCH and then the relative proportions are set using three independent variables called PO1, PO2 and PO3 as illustrated in figure 37.

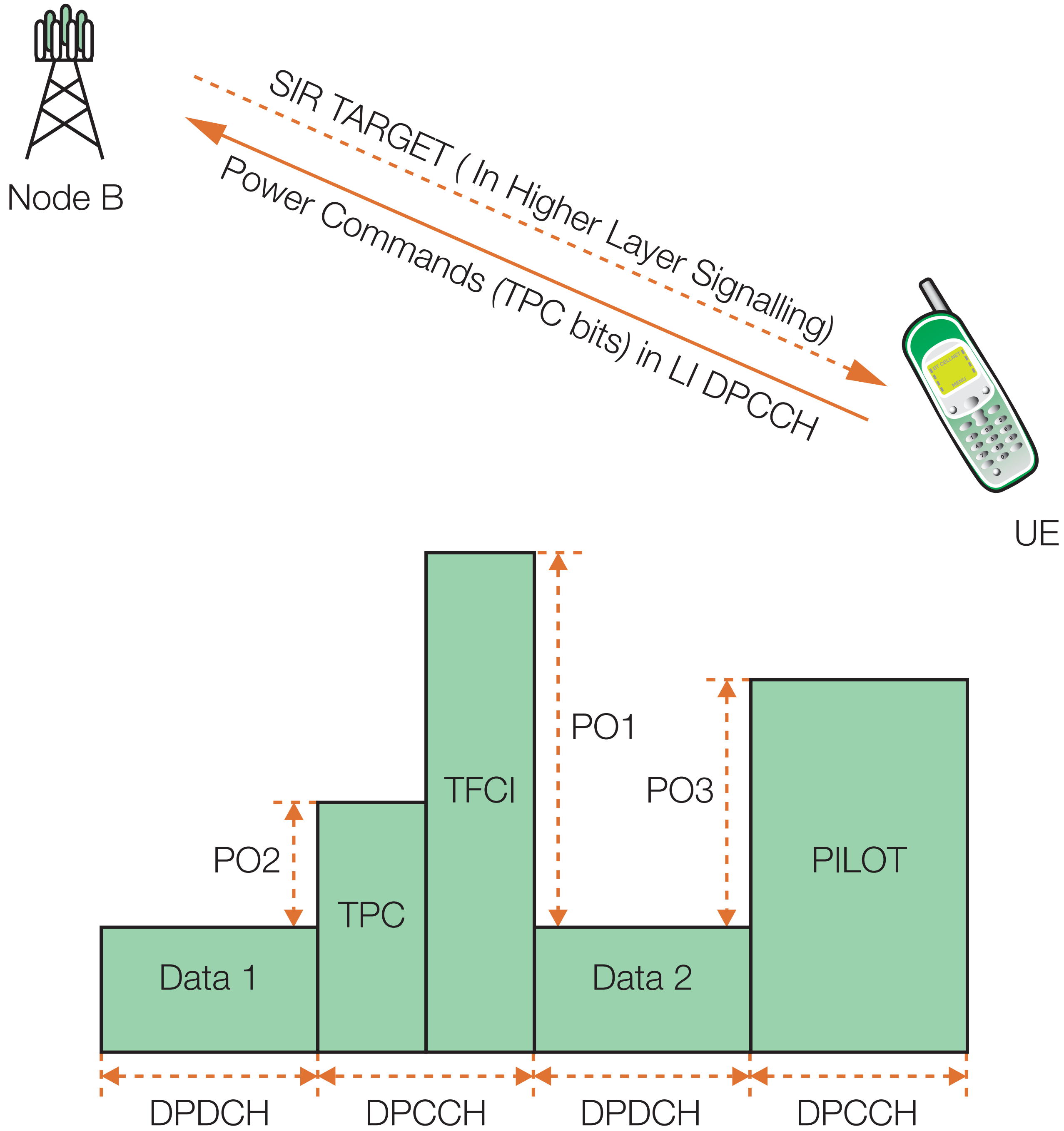


Fig. 37 – Closed Loop Downlink Power Control

7.8 Layer 1 Data Transfer Formats

7.8.1 Transport Blocks

A transport block is the basic unit of data transfer between physical (L1) and MAC (L2) layers and comprises a MAC PDU (protocol data unit). A cyclic redundancy checksum (CRC) is added to each transport block as it arrives at the physical layer. A number of transport blocks can be grouped into a transport block set. These are passed to the same transport channel at the same time and must be of equal size. The TTI is the transmission time interval over which the transport block set is passed to the transport channel and will be a multiple of 10ms (radio frame duration). This also constitutes the interleaving period for the transport block set.

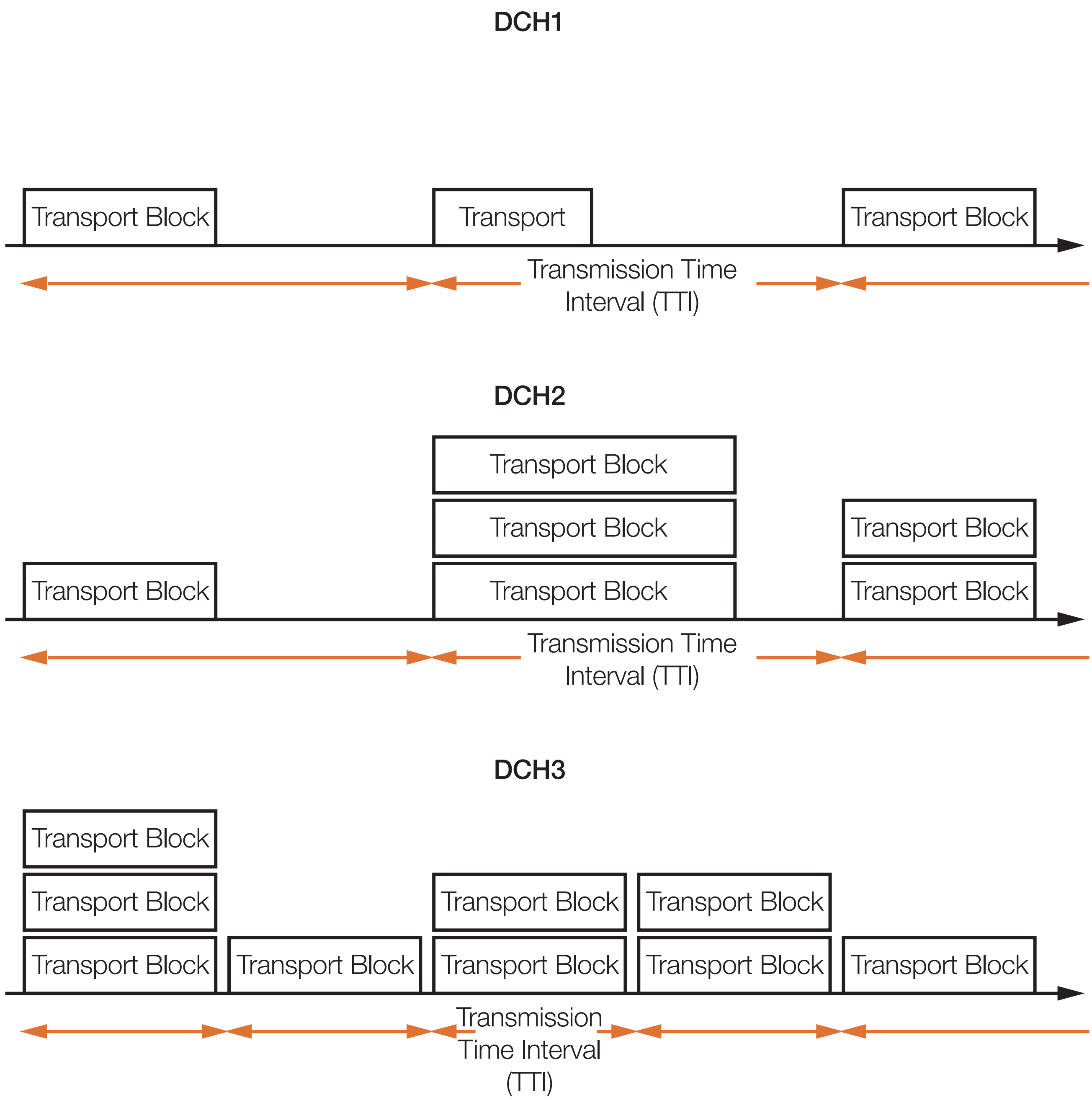


Fig. 38 – Transport Blocks and TTI

7.8.2 Transport Format

For each transport channel, one or more transport formats (in terms of transport block description, transport block set description, TTI and description of error protection) will be defined. For a fixed-rate service only one transport format need be defined.

A transport format set is the list of available transport formats for the related transport channel. TTI and error correction for all transport formats within a set will be the same. The data rate of the channel can be changed from one TTI to the next either by changing the transport block size alone, or changing it together with the transport block set size and this is done by swapping between different transport formats within the set defined for that transport channel. The specific transport format for the channel is defined by a Transport Format Indicator (TFI).

The physical layer will multiplex individual transport channels together to form a Coded Composite Transport Channel (CCTRCH). The specific combination of transport formats comprising the CCTRCH is defined by a Transport Format Combination Indicator (TFCI). The Transport Format Combination Set (TFCS) defines which combinations of transport sets are applicable.

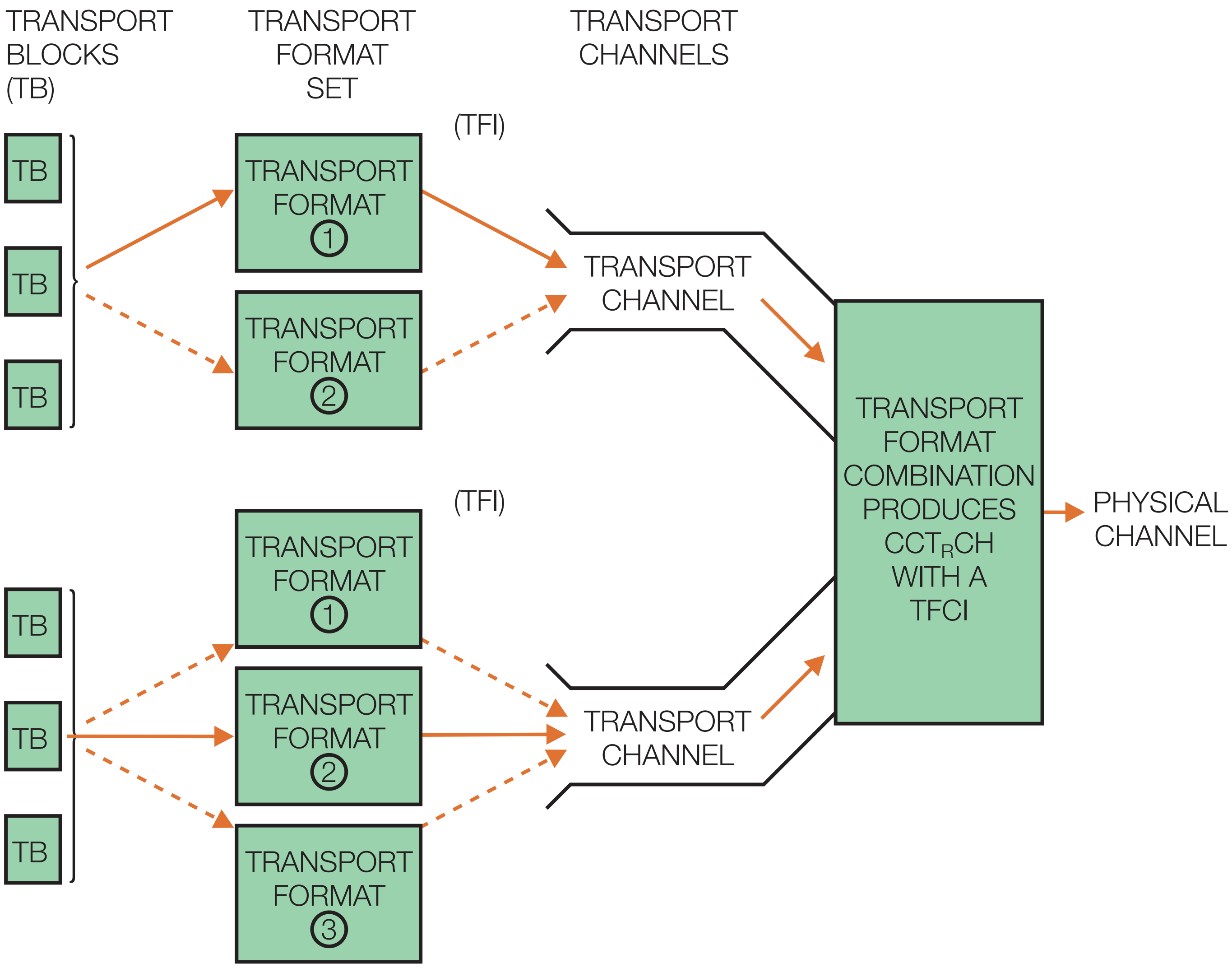


Fig. 39 – Transport Channel Contribution

8. TRANSPORT CHANNEL CODING AND MULTIPLEXING

8.1 Overall Process

Figure 40 illustrates the overall process of coding and multiplexing of transport channels on to physical channels. Note that some processes are applicable to both links, whilst other apply to only one direction and may also depend on the service being delivered.

A cyclic redundancy checksum (CRC) of 0, 8, 12, 16 or 24 bits may be added for error detection. Transport blocks may then be concatenated before channel coding.

Channel coding provides forward error correction (FEC) capabilities. The techniques used are 1/2-rate or 1/3-rate convolutional coding or a combination of 1/3-rate convolutional coding enhanced by turbo-coding.

Both uplink and downlink undergo rate matching, which matches block size to radio frames. It can be achieved by repeating bits, or puncturing bits, in the encoded blocks. For the uplink, rate matching is carried out after interleaving and radio frame segmentation. UL radio frame equalisation is similar to rate matching but involves the addition of padding to blocks.

Two stages of block interleaving (a structured re-ordering of bits within the block) are carried out to reduce the impact of interference and fading over the radio link.

Transport channels may be multiplexed together and for TTI values exceeding 10ms are segmented to fit within 10ms frames.

The CCTrCH may be mapped in the physical layer to a number of physical channels.

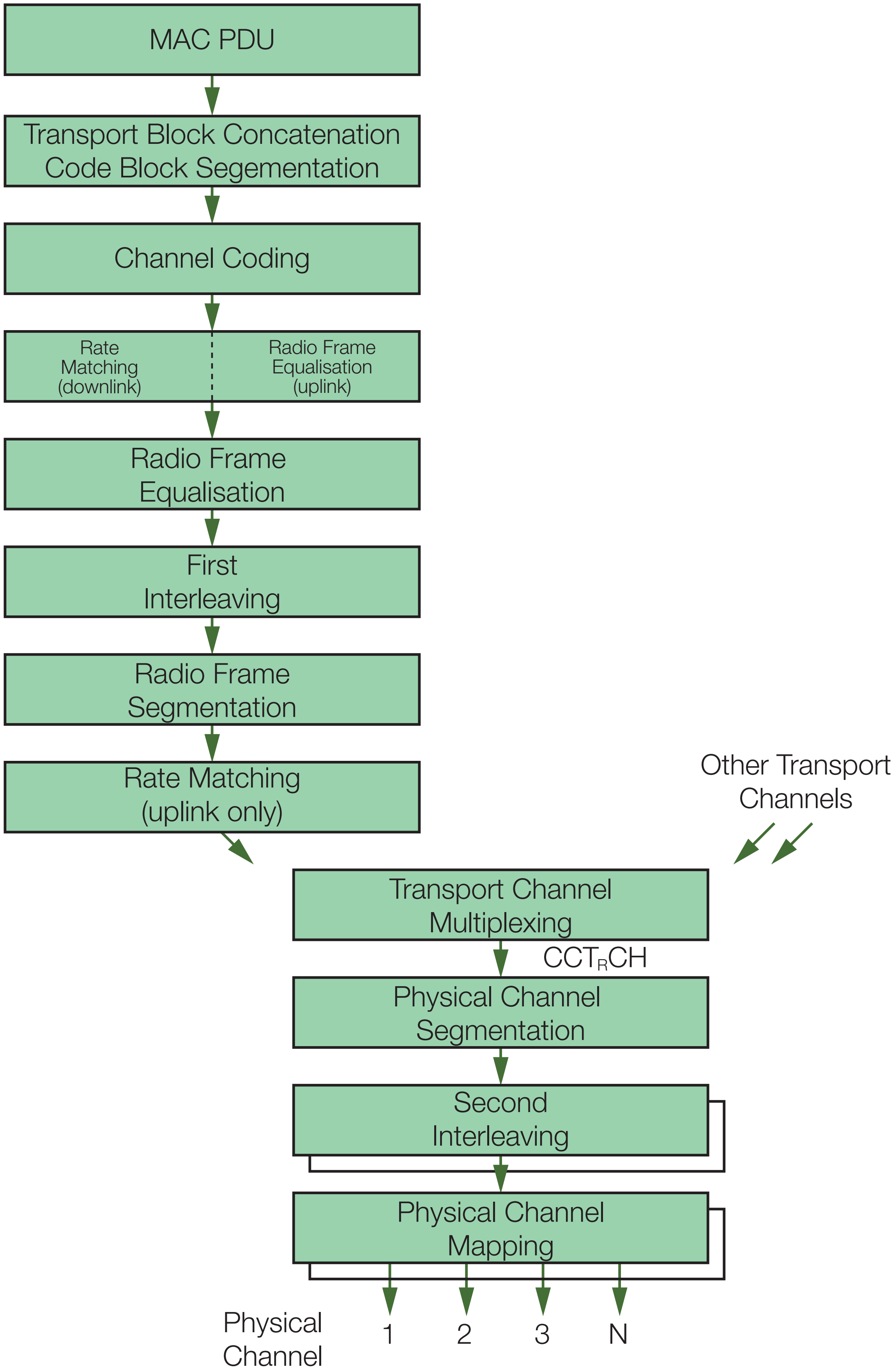


Fig. 40 – Physical Layer Multiplexing (uplink example)

8.2 Forward Error Correction (FEC)

Forward error correction provides for error detection and, within limits, correction without re-transmission of data over the radio link. This is especially important for real-time services where time for re-transmission is extremely limited or non-existent. The complexity of the code used to provide FEC determines its resilience to errors. The code adds an overhead in proportion to complexity.

Codes commonly used for FEC (and in UMTS) are convolutional codes, possibly enhanced by turbo coding. Half rate and one-third rate coders can be used according to error protection levels required.

A simple half-rate convolutional coder is shown in figure 41, consisting of two bistable storage elements and two points of modulo-2 addition. There are two output bits for every input bit (i.e. bit rate is doubled) and the coder is therefore termed half-rate. It is also said to have a constraint length of 3, because up to 3 bits can be combined to produce an output bit.

The coder trellis shows all possible outputs from the coder for every state and every input combination.

Increasing the constraint length or the coder rate (e.g. to one-third rate) improves the performance but brings bigger overheads in terms of processing load and increased bit-rate.

Turbo-coding offers increased resilience, significantly in excess of that offered by convolutional coding alone.

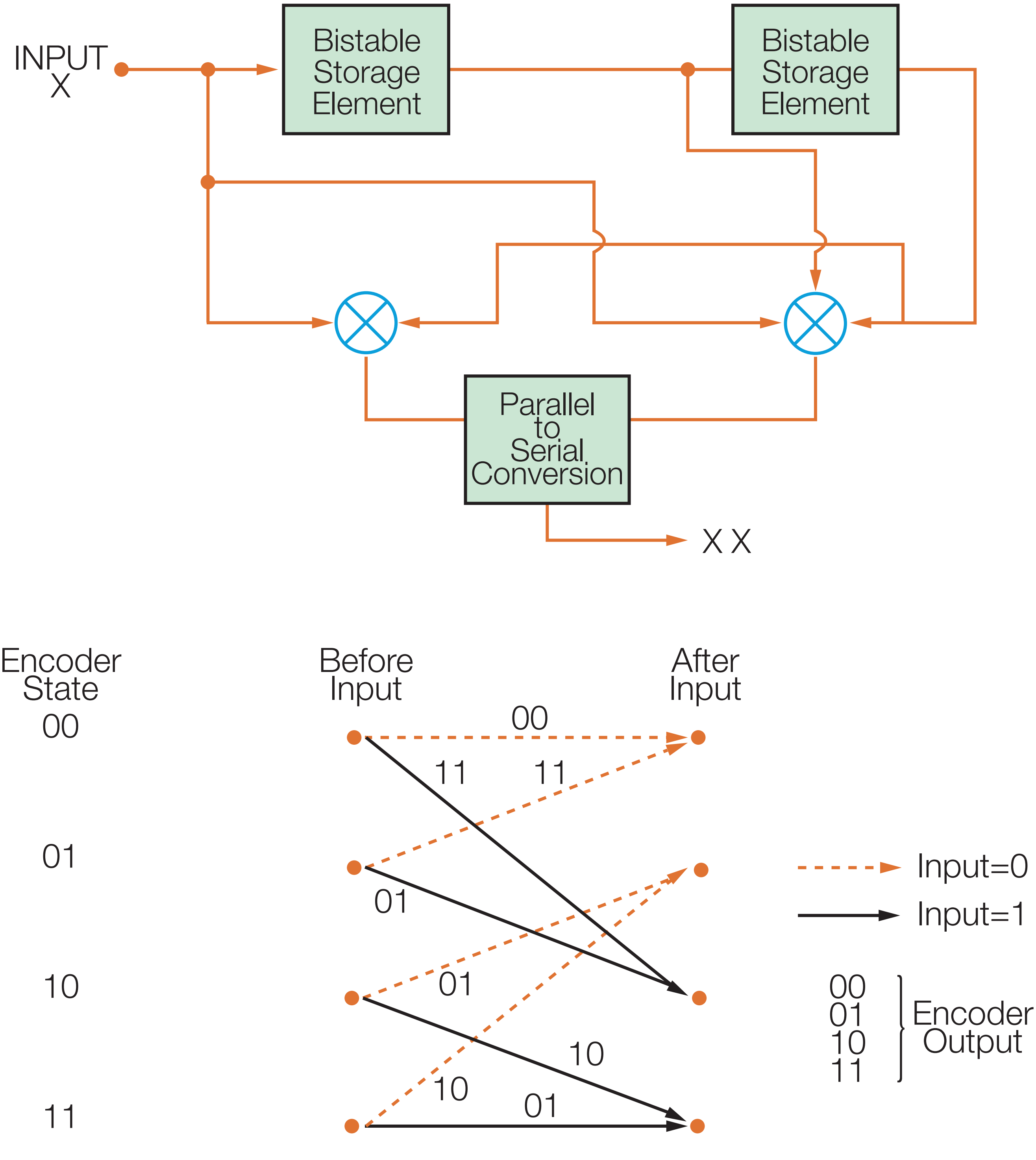


Fig. 41 – Half-Rate Convolutional Codes and Trellis

8.2.1 Trellis Decoding and Error Detection

The decoder is identical in principle to the encoder and starts the decoding process in a known state of 00. This is achieved by prefixing the transmitted data with suitable resetting or flushing bits on a frame by frame basis. The decoder then makes a series of attempts to trace all possible parts through the trellis and for each path to generate a corresponding coder output sequence. These sequences are then compared with the received sequence to identify that with the least number of discrepancies. On the basis of maximum likelihood (ML) that is then assumed to be the correct transmitted sequence.

Possible paths through the trellis grow rapidly and to minimise delays and processing load, some paths must be abandoned at an early stage.

Exercise
Figure 42 illustrates the decoding of the received sequence 10 00 10 00 00. Decoding has been started with broken lines for 0 and solid lines for 1. Pairs of bits indicate coder outputs and bracketed figures indicate cumulative discrepancies. One unlikely path has already been terminated at ⊗.

Complete the path(s), select the most likely and hence suggest the most probable transmitted bit pattern.

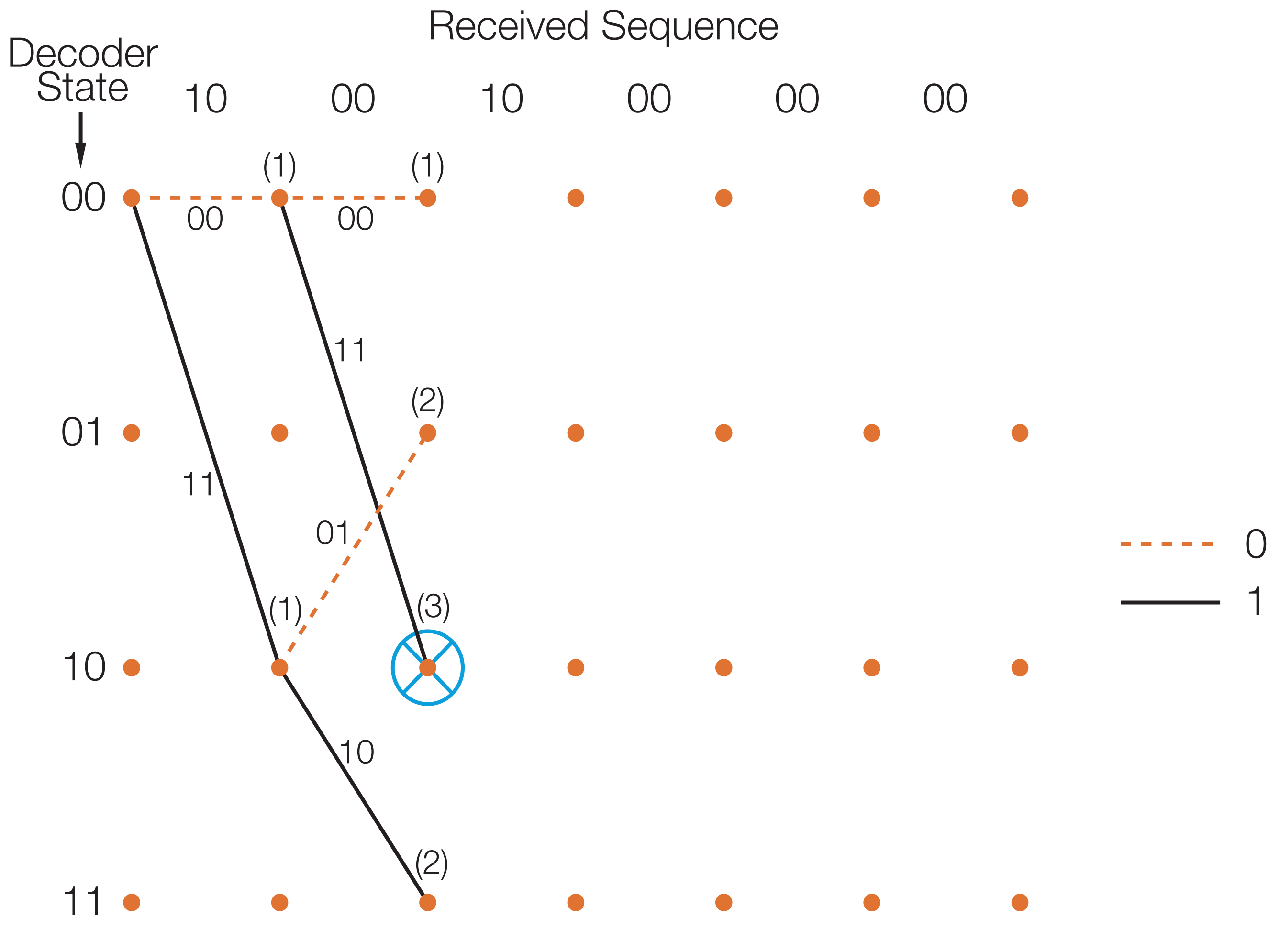


Fig. 42 – Trellis Decoding

9. OVERVIEW OF TDD MODE

TDD mode uses many of the same principles and timing as FDD mode but is a hybrid of TDMA and CDMA. Mobiles are assigned resource units to suit the required QoS. A resource unit (shown in figure 43) is defined in terms of a frequency, time slot and channelisation code. Changes of bit rate can be accommodated with relatively fine granularity by increasing or reducing allocated resource units.

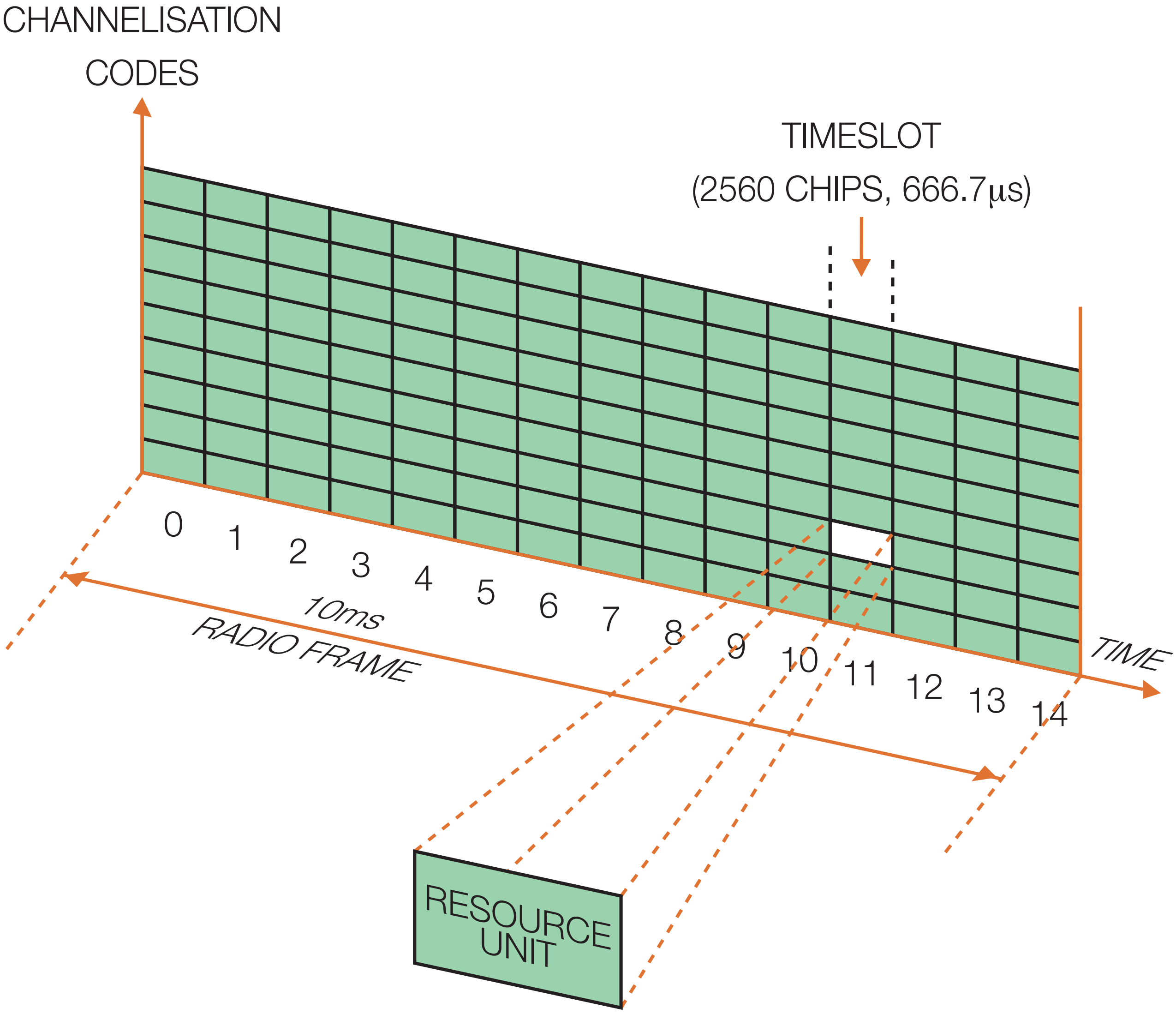
9.1 TDD Codes

TDD uses OVSF spreading codes with spreading factors 16, 8, 4, 2 and 1 for the uplink and either 16 or 1 for the downlink. Scrambling codes are short (16 chip) codes taken from a total of 128 different orthogonal sequences. Chip rate options are 3.84 Mcps and under Release 4, a lower rate of 1.28 Mcps (3.84/3) for lower capacity applications.

Multiple users are therefore separated by code in the same time slot and possibly by time slot as well.

For the uplink, a physical channel can consist of a single channelisation code and variable spreading (1 to 16). Multicode operation is also possible for higher rates.

For the downlink, spreading factors are limited to 1 or 16 and different rates are supported by assigning more or fewer codes with one of these fixed spreading factors.



- OVSF Channelisaton Codes
- Short 16 chip scrambling codes
- 3.84 or 1.287 Mcps

Fig. 43 – TDD Resource Unit

9.2 TDD Tx/Rx Switching

The radio frame can be operated with either multiple or a single switching point(s) in terms of uplink/downlink operation.

The ratio of uplink to downlink slots can easily be varied to provide differing degrees of asymmetry, as shown in figure 44.

Neighbouring TDD Node Bs are required to be synchronous because of the transmit/receive switching in order to control interference.

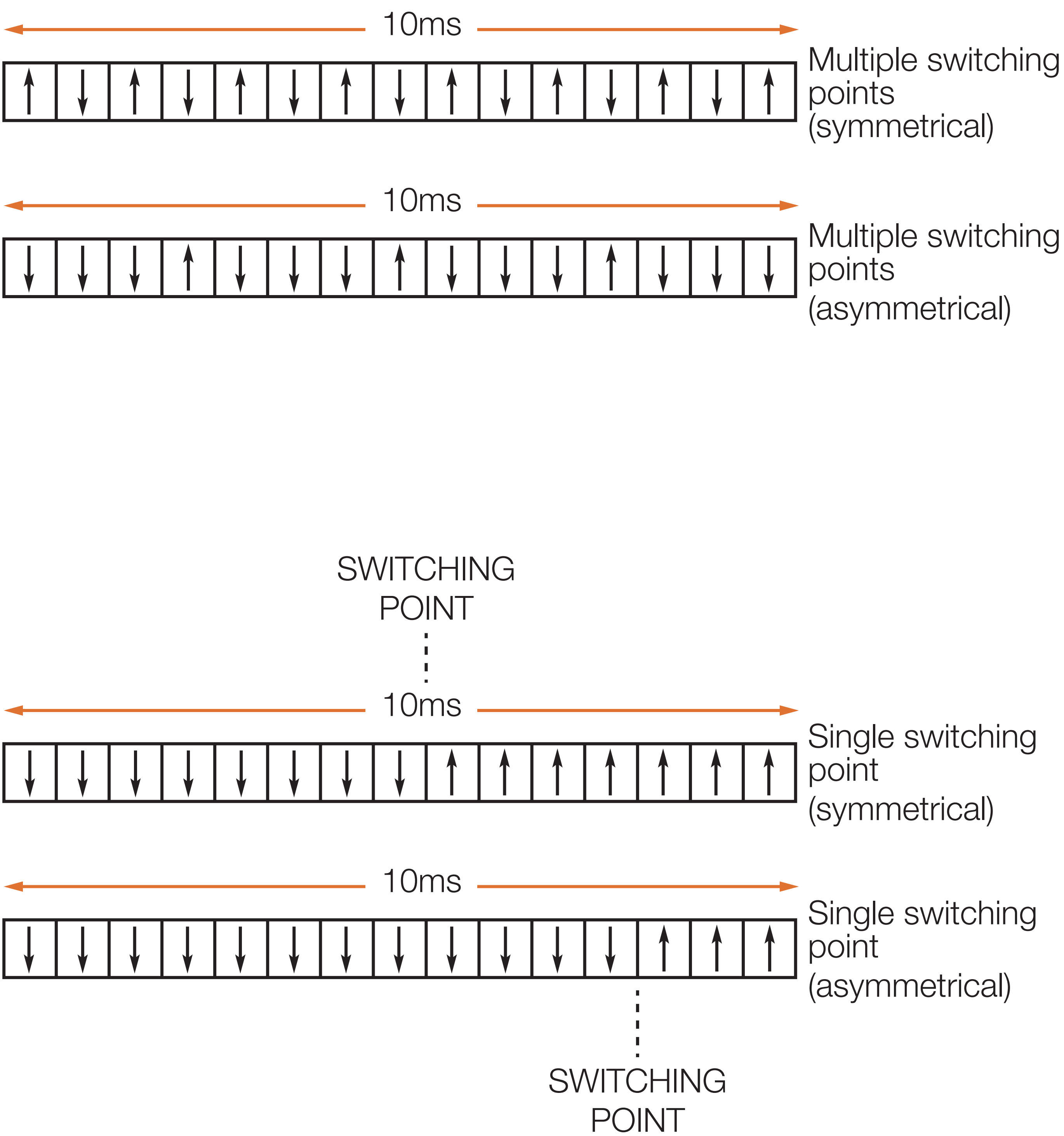


Fig. 44 – TDD Switching

9.3 TDD Bursts

Transmission of data within a resource unit is carried out in bursts. Several burst types are defined (figure 45 illustrates two) and the type employed will depend on QoS, logical channel and number of active users in the time slot.

In general, bursts consist of payload areas for data symbols, a midamble and a guard period (GP). The number of data symbols depends on spreading factor – for example in burst type 1, 61 data symbols corresponds to SF 16 and 976 data symbols to SF 1.

The midamble provides a training sequence/pilot function for channel estimation and synchronisation.

The GP provides for the effects of propagation delay, which limit the range of TDD cells to a nominal 3.75 km unless an optional timing advance feature is employed. However, it is envisaged that the majority of TDD cells will be used for low-mobility indoor or outdoor short range (micro) cells, providing high data rate hotspot coverage.

Burst type 1 can be used independently of the number of users in a time slot. Burst type 2 can be used in the uplink, provided there are fewer than four active users. It can be used in the downlink independently of the number of users.

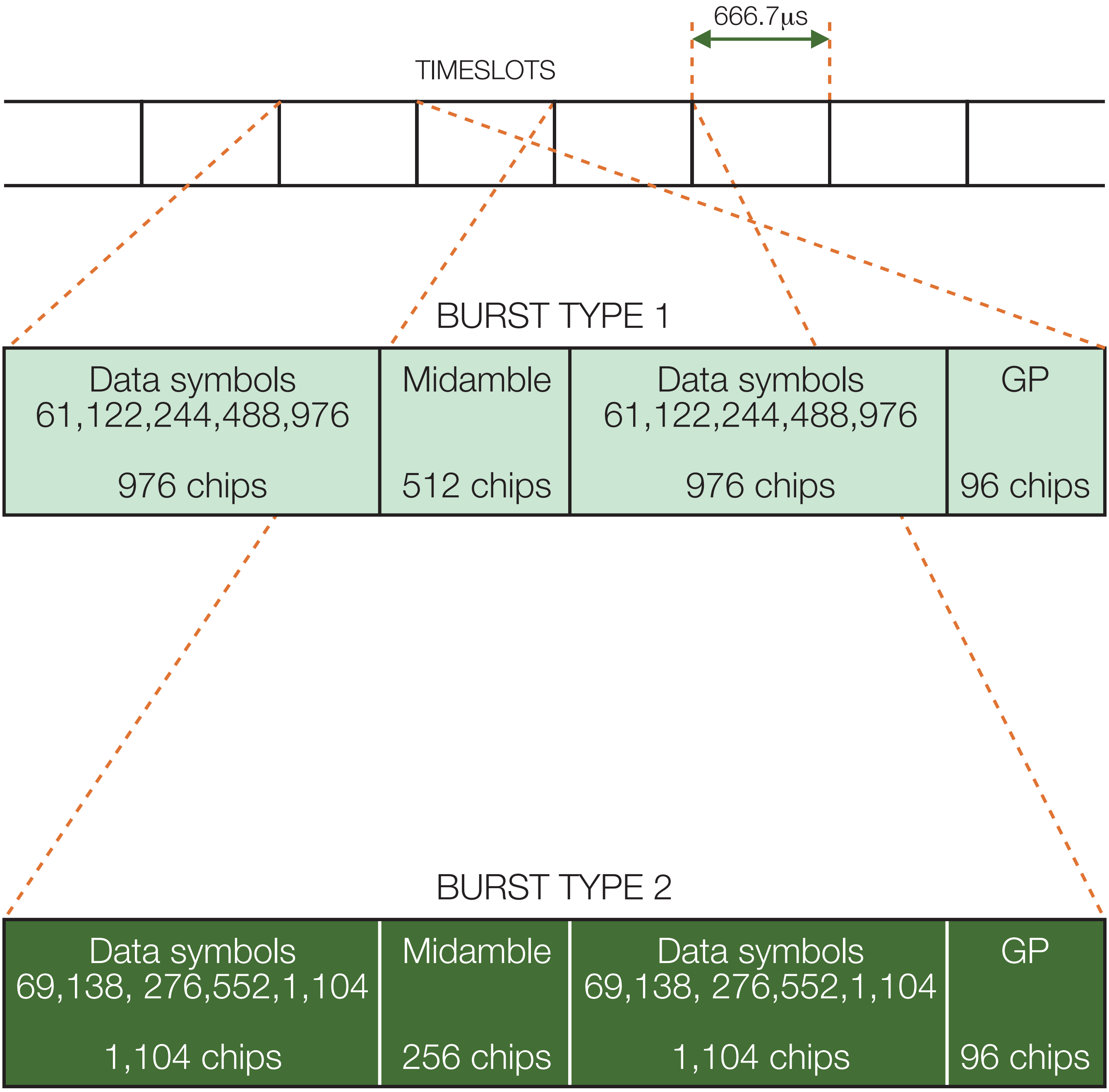


Fig. 45 – TDD Burst Types 1 and 2