Examinations : Mobile radio Communication

MODEL ANSWER and MARKING SCHEME

First Examiner: Dr. M. Gurcan **Paper Code E4.03, AS5, SO10, ISE4.3**

Second Marker : Dr. D. Ward **Question 1** **Page 1** ***out of 21***

1-a-i

$d_0 = 1$, $G_T = 1$, $G_R = 2$, $P_T = 10W$, $f = 900\ MHz$

$c = 3.10^8\ m/s$

$$\lambda = \frac{c}{\lambda} = \frac{3.10^8}{8.10^8} = 0.33\ m$$

$$P_{FSR}(d_0) = \frac{P_T G_T G_R \lambda^2}{(4\pi)^2 d_0^2} = \frac{10 \times 1 \times 2 \times 0.33}{(4\pi)^2\ 10^6} = 4.1795 \times 10^{-8}\ W$$

……

1-a-ii

$$e_{FSR} = \sqrt{\frac{P_{FSR} \times 2 \times \eta}{A_e}} \quad , \quad A_e = \frac{\lambda^2 G_R}{4\pi} = \frac{(0.33)^2\, 2}{4\pi} = 0.01733 m^2$$

$$|E_{FSR}| = \sqrt{\frac{4.1795 \times 10^{-8} \times 2 \times 377}{0.01733}} = 0.0426\ V/m$$

……

1-b

$$P_{FSR}(R_1) = 1.16\ 10^{-9}\ W$$

$$P_{am}(R_1) = P_{FSR}(R_1) \left| \frac{E(R_1)}{E_{FSR}(R_1)} \right|^2 = 1.16 \times 10^{-9} \times (0.238)^2$$

$$= 6.57 \times 10^{-11}\ W$$

$$\frac{\gamma}{6 P_{am}(D)} = 13\ dB \quad , \quad 6\ P_{am}(D) = 9.1\ 10^{-13}$$

$$\gamma = 6 .\ P_{am}(D)\ 10^{13/10} = 1.8157 \times 10^{-11}\ W$$

$$P_r(P_{am}(R_2) > \gamma) = 0.95 = 1 - \frac{1}{2\sqrt{\pi}} \exp\left\{ - \left(\frac{10 \log_{10} \frac{P_{am}(R_2)}{\gamma}}{\sqrt{2}\,\sigma} \right)^2 \right\}$$

$$10^{\frac{\sqrt{2}\,\sigma \sqrt{-\ln(0.05 \times 2\sqrt{\pi})}}{10}} .\ \gamma = P_{am}(R_2)$$

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1-b

Cont

$$P_{am}(R_2) = 10^{\frac{2 \times 3 \times 1.315}{10}} \times 1.8157 \times 10^{-11}$$

$$= 6.56\ 10^{-11}\ W.$$

$$\left(\frac{R_1}{R_2}\right)^4 = \frac{P_{am}(R_2)}{P_{am}(R_1)} \quad , \quad P_{am}(R_1) = 6.57 \times 10^{-11}\ W$$

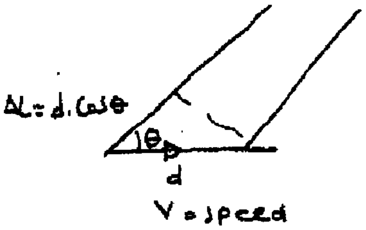
$$R_2 = R_1 \sqrt[4]{\frac{P_{am}(R_1)}{P_{am}(R_2)}} = R_1 \sqrt[4]{\frac{6.57 \times 10^{-11}}{6.56 \times 10^{-11}}}$$

$$R_2 = R_1 \times 1.0003 = R_1$$

$$\boxed{R_2 = R_1 = 6\ km.}$$

....

1-c



$d = V . \Delta t$

$\Delta L = d . \cos\theta = V . \Delta t . \cos\theta$

$\Delta \phi = \frac{2\pi}{\lambda} . \Delta L = \frac{2\pi}{\lambda} V . \Delta t . \cos\theta$

$\frac{\Delta \phi}{\Delta t} = 2\pi f_d = \frac{2\pi}{\lambda} . V . \cos\theta$

Frequency of received signal

$f = f_c + f_d$,

Electric field $E_d = E_0 \cos(2\pi f_c t) = R_e(E_0 \exp(j 2\pi f_c t))$

Total field is given by addition of N electric fields

$E_n = re\left[E_0 C_n \exp(j 2\pi f_n t) \exp(j 2\pi f_c t)\right]$

$E_T = r_e\left[E_0 \exp(j 2\pi f_c t) \sum_{n=1}^{N} C_n \exp(j 2\pi f_n t)\right]$

let $g(t) = \sum_{n=1}^{N} C_n \exp(j 2\pi f_n t) = X + jY$

$X = \sum C_n \cos(2\pi f_n t)$

$Y = \sum C_n \sin(2\pi f_n t)$, $\sum C_n^2 = 1$, $|g(t)| = R$

$|g(t)| = \sqrt{x^2 + y^2}$, $\langle R^2 \rangle = \langle X^2 \rangle + \langle Y^2 \rangle$

$\langle X^2 \rangle = \langle Y^2 \rangle = \frac{1}{2}$, $f(x) = \frac{1}{\sqrt{\pi}} \exp(-x^2)$, $f(Y) = \frac{1}{\sqrt{\pi}} \exp(-Y^2)$

$f_{X,Y}(x,y) = f_X(x) . f_Y(y) = \frac{1}{\pi} \exp(-(x^2 + y^2)) = \frac{1}{\pi} \exp(-R^2)$

$f_{R,\theta}(R,\theta) = R\, f_{X,Y}(x,y) = \frac{R}{\pi} \exp(-R^2)$

$f_R(R) = \int_{-\pi}^{\pi} f_{R,\theta}(R,\theta)\, d\theta = 2R \exp(-R^2)$

1-d

$$P_e(X_R)=\int_0^\infty \frac{1}{2}\exp(-X_A)\cdot\frac{1}{X_R}\exp\left(-\frac{X_A}{X_R}\right)dX_A$$

$$=\frac{1}{2X_R}\int_0^\infty \exp\left(-X_A\left(1+\frac{1}{X_R}\right)\right)dX_A$$

$$=\frac{1}{2X_R}\,\frac{-1}{1+\frac{1}{X_R}}\,\exp\left(-X_A\left(1+\frac{1}{X_R}\right)\right)\Big|_0^\infty$$

$$=\frac{1}{2(X_R+1)}$$

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2-a-i

offered load is $G = k_{opt} \cdot \frac{N}{S}$

where S is estimate, N is real number of back-logged users. The re-transmission probability is made equal to $q_r = S$. If S is equal to N system operates at the optimum offered load. When G is higher than k_{opt} S and hence q_r is systematically increased to bring the operating point back to k_{opt}. In the light traffic region we do the opposite.

2-a-ii

We do not know the real number of back-logged users. we therefore need to guess what the back-logged user number is.

2-a-iii

As $dG = \frac{dn - G\,ds}{S_{k+1}}$ and $S_k \gg 1$ we consider

joint drift equation

$$dj = dn - G \cdot ds$$

when $dj = 0$, the system settles at that point we make sure that the root of $dj = 0$ is at the optimum ~~to~~ offered load. We also make

$$dj > 0 \text{ for } G < k_{opt}$$

and

$$dj < 0 \text{ for } G > k_{opt}.$$

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2-b

$d\dot{j} = dn - G.ds$ where $dn = \lambda - G.\exp(-G)$

$ds = u_c - (u_0 - u_c)\exp(-G) + (u_1 - u_c)G.\exp(-G)$

for $G = 0$ $G.ds = 0$ and $dn = \lambda$

$\therefore$ $d\dot{j}(G=0) = \lambda$ as λ has values $0 < \lambda < \exp(-1)$

$d\dot{j}(G) > 0$ for $G = 0$.

$$\lim_{G\to 0} d\dot{j} = \lim_{G\to\infty} dn - \lim_{G\to\infty} G.ds$$

where $\lim_{G\to\infty} dn = 0$ and $\lim_{G\to\infty} ds = \infty$ for $u_c > 0$

$$\therefore \lim_{G\to\infty} d\dot{j} = -\infty$$

As $dJ(G=0) > 0$ and $\lim_{G\to\infty} d\dot{j}(G) = -\infty$ $\therefore$ $d\dot{j}(G) = 0$ has at least one root. At the roots of $dJ = 0$ we have no corrections applied to G hence it is a settling point.

2-c

If $d\dot{j}(G) = 0$ has three roots the dJ curve will have the following characteristics

2-d

$$d_u = \frac{1600}{20000} = 0.08 \text{ users}/m^2$$

$$N_A = \pi R^2 \rho_a d_u = (450)^2 \pi \times 0.12 \times 0.08$$

$$= 6107 \text{ users.}$$

$$\lambda = \frac{N_A}{3600} = 1.696 \text{ users/s}$$

$$\lambda_T = 0.1 \times 1.696 \text{ user/slot}$$

$$= 0.1696 \text{ users/slot.}$$

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3-a

A correlator is used to obtain channel impulse response. Using optimum filter theory

$$w_{opt} = R^{-1} P$$

coefficients for the equaliser are obtained. Where R matrix elements are obtained using

$$r(i) = \sum_{m=0}^{M} h_{m+i} h_m \quad \text{for } i \geqslant 1 \text{ and}$$

$$r(0) = \sum_{m=0}^{M} h_n^2 + \frac{N_0}{2}$$

P is the time reversed channel impulse response

Channel impulse response introduces intersymbol interference. An equaliser removes the interference coming from adjacent symbols.

3-b,i

a linear equaliser tries to make the combined channel & equaliser transfer function equal to an impulse. When there are spectral nulls in the spectrum, linear equaliser enhances noise.

3-b,ii

A decision-feedback filter uses decisions made previously to remove the tail part of the combined channel and feedforward filter response. The feed forward filter makes

3-b-ii

the combined channel + fff response a minimum phase impulse response. As the information in the feedback filter is free from noise, it introduces less noise than linear equaliser.

....

3-b-iii

Maximum likelihood receiver matches the received sequence to one of the expected transmitted sequences. As a result it uses all the received signal energy and hence has the best signal to noise ratio performance

....

3-c

For Narrow band

Desired SNR $= 13\text{dB} \Rightarrow X_D(R_2) = 10^{13/10} = 19.95$

$X_D(R_2) = a \cdot X_R(R_1) \Rightarrow X_R(R_1) = \frac{1}{a} X_D(R_2)$

$X_R(R_1) = \frac{1}{0.0228} 19.95 = 875$

$\frac{3N^2}{2} = 875 \quad \Rightarrow N = 24$

Nearest $N = 28$ for $i = 4$, $j = 2$

Total number of channels $= N \times 20 = 560$ channels

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3-c cont

For wideband system

$X_D(R_2) = C_o\, X_R(R_2)$

$X_R(R_2) = \frac{1}{C_o} X_D(R_2) = \frac{1}{0.8}\, 19.95 = 24.94$

$X_R(R_1) = X_R(R_2)\left(\frac{R_2}{R_1}\right)^4 = 24.94\ (0.97)^4$

$X_R(R_1) = 22$

$\frac{3N^2}{2} = 22 \implies N = 3.83$, Newest $N=4$

Number of channels per cell $= \frac{\text{Total channels}}{N}$

$= \frac{560}{4} = 140$ chanels.

as opposed to 20 channels for the narrow band system.

…………………………………………………………………

3-d

$MSE = 1 - [-0.0094 \quad 0.0477 \quad 1.081][0.169 \ 0.507 \ 0.895]^T$

$= 1 + 1.5886 \cdot 10^{-3} - 0.0241839 - 0.91369$

$= 1.0015886 - 0.9378739 = 0.0637$

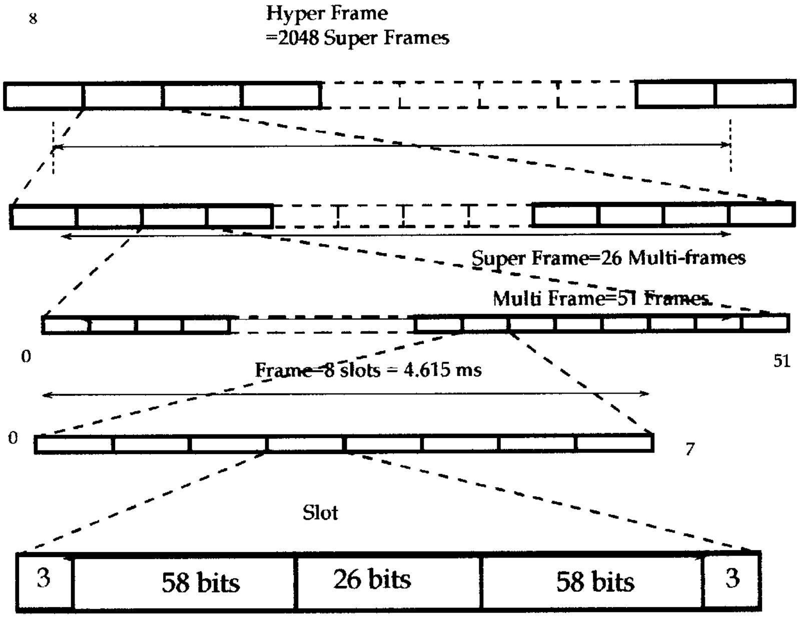
$SNR = \frac{1}{MSE} - 1 = \frac{1}{0.0637} - 1 = 14.69858$

$SNR_{20,047} = 10 \log_{10} 14.69858 = 11.673$ dB

$-10 \log_{10} C_o = 13 - 11.673 = 1.327246$ dB.

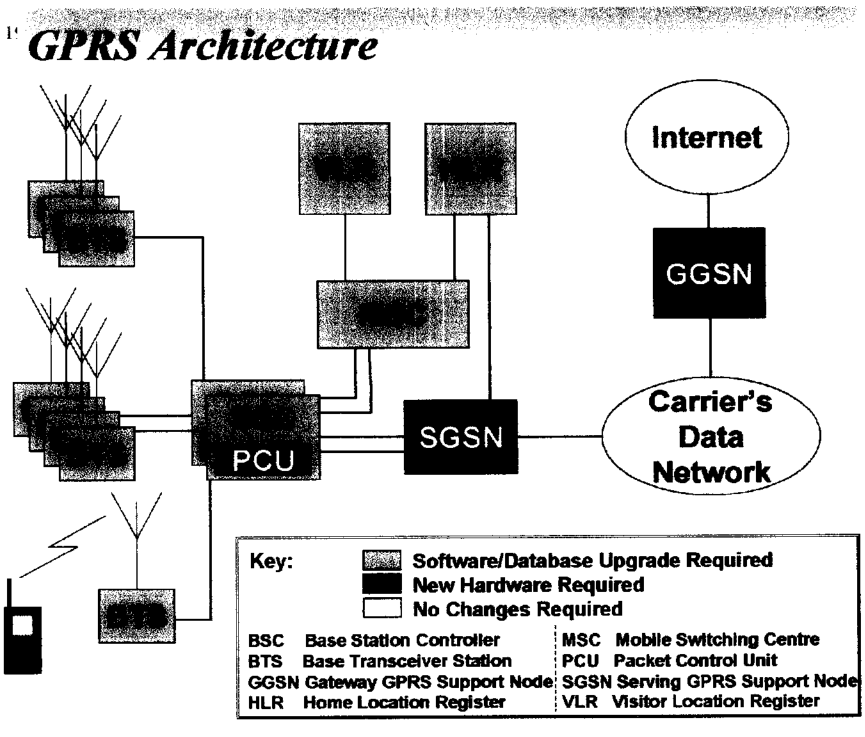
$\boxed{C_o = 0.736}$

4-a-i


8
Hyper Frame
=2048 Super Frames
Super Frame=26 Multi-frames
Multi Frame=51 Frames
0
51
Frame=8 slots = 4.615 ms
0
7
Slot
3
58 bits
26 bits
58 bits
3

……

4-a-ii


GPRS Architecture
Internet
GGSN
Carrier's Data Network
SGSN
PCU
BTS
Key:
Software/Database Upgrade Required
New Hardware Required
No Changes Required
BSC Base Station Controller
BTS Base Transceiver Station
GGSN Gateway GPRS Support Node
HLR Home Location Register
MSC Mobile Switching Centre
PCU Packet Control Unit
SGSN Serving GPRS Support Node
VLR Visitor Location Register

4-b

GPRS defines a set of new logical radio channels.

Packet Common Control Channel (PCCCH). This consists of

- Packet random Access channel
- Packet paging channel
- Packet access grant channel
- Packet notification channel

Packet Broadcast Control Channel

Packet Data Traffic channel is used for data transfer

……………………………………………………………

4-c-i

Transmissions from a single source are separated by channelisation codes, i.e. downlink connections within one sector and the dedicated physical channel in the uplink from one terminal. The spreading/channelisation codes of UTRA are based on the Orthogonal Variable Spreading Factor (OVSF) technique,

The use of OVSF codes allows the spreading factor to be changed and orthogonality between different spreading codes of different lengths to be maintained. The codes are picked from the code tree, which is illustrated in Figure In case the connection uses a variable spreading factor, the proper use of the code tree also allows despreading according to the smallest spreading factor. This requires only that channelisation codes are used from the branch indicated by the code used for the smallest spreading factor.

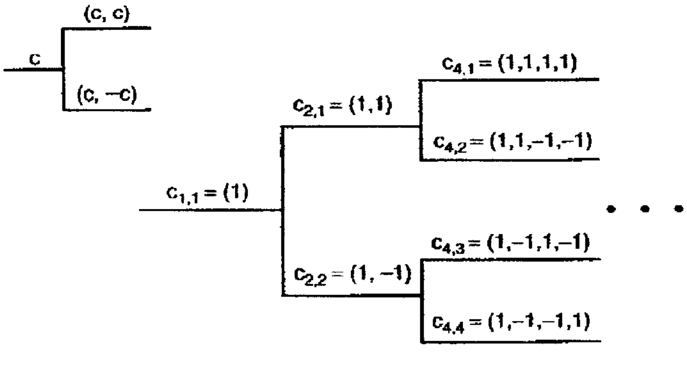


Figure Beginning of the channelisation code tree

There are certain restrictions as to which of the channelisation codes can be used for a transmission from a single source. Another physical channel may use a certain code in the tree if no other physical channel to be transmitted using the same code tree is using a code that is on an underlying branch, i.e. using a higher spreading factor code generated from the intended spreading code to be used. Neither can a smaller spreading factor code on the path to the root of the tree be used. The downlink orthogonal codes within each base station are managed by the radio network controller (RNC) in the network.

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4-c-ii **Up link Modulation**

In the uplink direction there are basically two additional terminal-oriented criteria that need to be taken into account in the definition of the modulation and spreading methods. The uplink modulation should be designed so that the terminal amplifier efficiency is maximised and/or the audible interference from the terminal transmission is minimised.

Discontinuous uplink transmission can cause audible interference to audio equipment that is very close to the terminal, such as hearing aids. This is a completely separate issue from the interference in the air interface. The audible interference is only a nuisance for the user and does not affect network performance, such as its capacity. With GSM operation we are familiar with the occasional audible interference with audio equipment that is not properly protected. The interference from GSM has a frequency of 217 Hz, which is determined by the GSM frame frequency. This interference falls into the band that can be heard by the human ear. With a CDMA system, the same issues arise when discontinuous uplink transmission is used, for example with a speech service. During the silent periods no information bits need to be transmitted, only the information for link maintenance purposes, such as power control with a 1.5 kHz command rate. With such a rate the transmission of the pilot and the power control symbols with time multiplexing in the uplink direction would cause audible interference in the middle of the telephony voice frequency band. Therefore, in a WCDMA uplink the two dedicated physical channels are not time multiplexed but I-Q/code multiplexing is used.

The continuous transmission achieved with an I-Q/code multiplexed control channel is shown in Figure Now, as the pilot and the power control signalling are maintained on a separate continuous channel, no pulsed transmission occurs. The only pulse occurs when the data channel DPDCH is switched on and off, but such switching happens quite seldom.

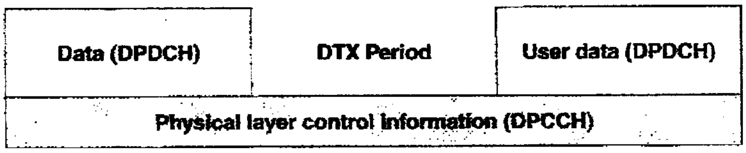


Figure Parallel transmission of DPDCH and DPCCH when data is present/absent (DTX)

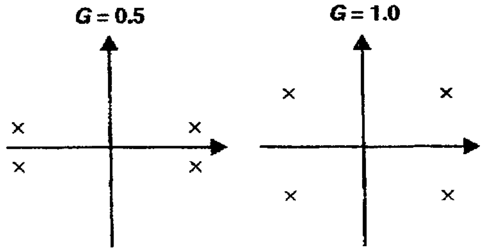
4-c-ii

cont.

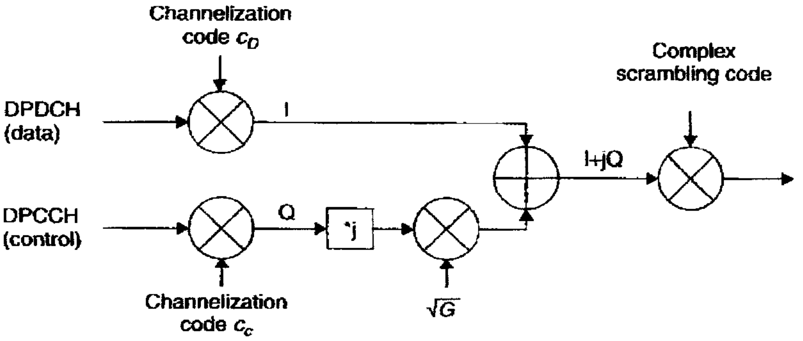
The average interference to other users and the cellular capacity remain the same as in the time-multiplexed solution. In addition, the link level performance is the same in both schemes if the energy allocated to the pilot and the power control signalling is the same.

For the best possible power amplifier efficiency, the terminal transmission should have as low peak-to-average (PAR) ratio as possible to allow the terminal to operate with a minimal amplifier back-off requirement. mapping directly to the amplifier power conversion efficiency, which in turn is directly proportional to the terminal talk time. With the I-Q/code multiplexing, called also dual-channel QPSK modulation, the power levels of the DPDCH and DPCCH are typically different, especially as data rates increase and would lead in extreme cases to BPSK-type transmission when transmitting the branches independently. This has been avoided by using a complex-valued scrambling operation after the spreading with channelisation codes.

The signal constellation of the I-Q/code multiplexing before complex scrambling is shown in Figure The same constellation is obtained after descrambling in the receiver for the data detection.



By using the spreading modulation solution shown in Figure the transmitter power amplifier efficiency remains the same as for normal balanced QPSK transmission in general. The complex scrambling codes are formed in such a way that the rotations between consecutive chips within one symbol period are limited to ±90°. The full 180° rotation can happen only between consecutive symbols. This method further reduces the peak-to-average ratio of the transmitted signal from the normal QPSK transmission.

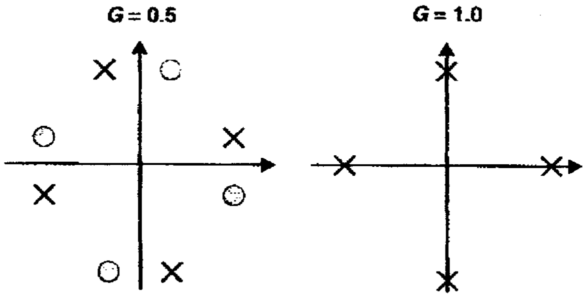


4-c-ii

cont.

The efficiency of the power amplifier remains constant irrespective of the power difference G between DPDCH and DPCCH. This can be explained with Figure which shows

the signal constellation for the I-Q/code multiplexed control channel with complex spreading. In the middle constellation with $G = 0.5$ the possible constellation points are only circles or only crosses during one symbol period. Their constellation is the same as for the rotated QPSK. Thus the signal envelope variations with complex spreading are very similar to QPSK transmission for all values of G . The I-Q/code multiplexing solution with complex scrambling results in power amplifier output back-off requirements that remain constant as a function of the power difference between DPDCH and DPCCH.



4-c-ii

cont

Down link dedicated transport channel

The spreading factor for the highest transmission rate determines the channelisation code to be reserved from the given code tree. The variable data rate transmission may be implemented in two ways:

- In case TFCI is not present, the positions for the DPDCH bits in the frame are fixed. As the spreading factor is also always fixed in the Downlink DPCH, the lower rates are implemented with Discontinuous Transmission (DTX) by gating the transmission on/off. Since this is done on the slot interval, the resulting gating rate is 1500 Hz. As in the uplink, there are 15 slots per 10 ms radio frame; this determines the gating rate. The data rate, in case of more than one alternative, is determined with Blind Transport Format Detection (BTFD) which is based on the use of a guiding transport channel or channels that have different CRC positions for different Transport Format Combinations (TFCs). For a terminal it is mandatory to have BTFD capability with relatively low rates only, such as with AMR speech service. With higher data rates also the benefits from avoiding the TFCI overhead are insignificant and the complexity of BTFD rates starts to increase.
- With TFCI available it is also possible to use flexible positions, and it is up to the network to select which mode of operation is used. With flexible positions it is possible to keep continuous transmission and implement the DTX with repetition of the bits. In such a case the frame is always filled as in the uplink direction.

4-c-ii

Down link Shared Channel

Transmitting data with high peak rate and low activity cycle in the downlink quickly causes the channelisation codes under a single scrambling code to start to run out. To avoid this problem, basically two alternatives exist: use of either additional scrambling codes or common channels. The additional scrambling code approach loses the advantage of the transmissions being orthogonal from a single source, and thus should be avoided. Using a shared channel resource maintains this advantage and at the same time reduces the downlink code resource consumption. As such resource sharing cannot provide a 100% guarantee of

available physical channel resource at all times, its applicability in practice is limited to packet-based services.

As in a CDMA system one has to ensure the availability of power control and other information continuously, the Downlink Shared Channel (DSCH) has been defined to be always associated with a Downlink Dedicated Channel (Downlink DCH). The DCH provides, in addition to the power control information, an indication to the terminal when it has to decode the DSCH and which spreading code from the DSCH it has to despread. For this indication two alternatives have been specified: either TFCI based on a frame-by-frame basis or higher layer signalling based on a longer allocation period.

The small difference from the downlink DCH spreading codes is that spreading factor 512 is not supported by DSCH. The DSCH also allows mixing terminals with different data rate capabilities under a single branch from the code resource, making the configuration manageable with evolving terminal capabilities. The DSCH code tree was illustrated in Figure in connection with the downlink spreading section.

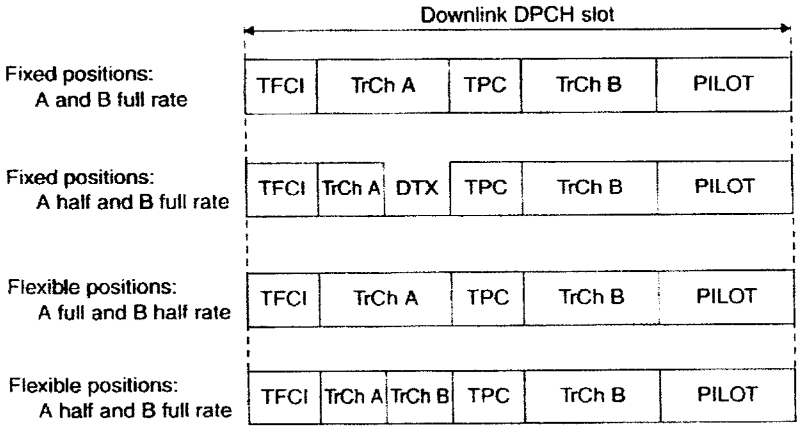


Figure Flexible and fixed transport channel slot positions in the downlink

4-c-ii

cont.

With DSCH the user may be allocated different data rates, for example 384 kbps with spreading factor 8 and then 192 kbps with spreading factor 16. The DSCH code tree definition allows sharing the DSCH capacity on a frame-by-frame basis, for example with either a single user active with a high data rate or with several lower-rate users active in parallel. The DSCH may be mapped to a multicode case as well; for example, three channelisation codes with spreading factor 4 provide a DSCH with 2 Mbps capability.

In the uplink direction, such concerns for code resource usage do not exist, but there is the question how to manage the total interference level and in some cases the resource usage on the receiver side. Thus an operation similar to DSCH is not specified in the uplink in UTRA FDD.

The physical channel carrying the DSCH is the Physical Downlink Shared Channel (PDSCH). The timing relation of the PDSCH to the associated downlink Dedicated Physical Channel (DPCH) is shown in Figure The PDSCH frame may not start before three slots after the end of the associated dedicated channel frame. This ensures that buffering requirements for DSCH reception do not increase compared to the other buffering needs in the receiver.

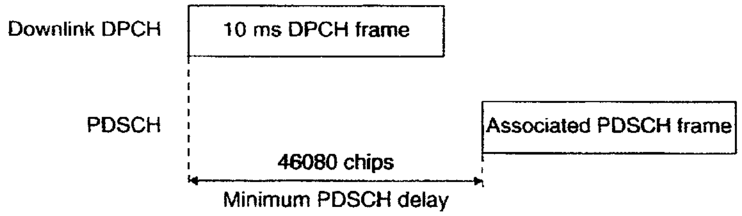
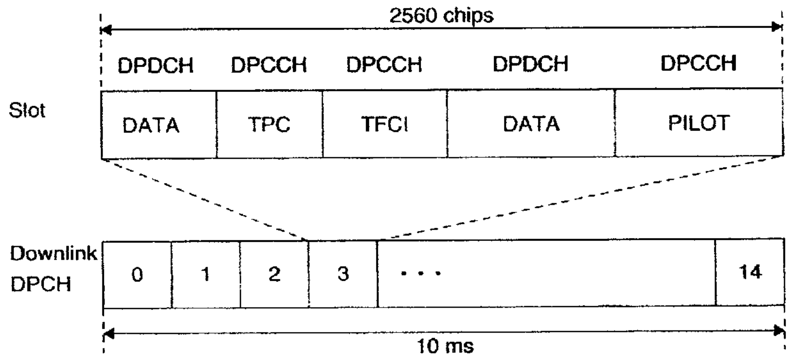


Figure PDSCH timing relation to DPCH

4-c-iii

In the downlink the spreading factors range from 4 to 512, with some restrictions on the use of spreading factor 512 in the case of soft handover. The restrictions are due to the timing adjustment step of 256 chips in soft handover operation, but in any case the use of a spreading factor of 512 for soft handover is not expected to occur very often. Typically, such a spreading factor is used to provide information on power control, etc., when providing services with minimal downlink activity, as with file uploading and so on. This is also the case with the CPCH where power control information for the limited duration uplink transmission is provided with a DPCCH with spreading factor 512. In such a case soft handover is not needed either.



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Down Link multiplexing

The multiplexing chain in the downlink is mainly similar to that in the uplink but there are also some functions that are done differently.

As in the uplink, the interleaving is implemented in two parts, covering both intra-frame and inter-frame interleaving. Also the rate matching allows one to balance the required channel symbol energy for different service qualities. The services can be mapped to more than one code as well, which is necessary if the single code capability in either the terminal or base station is exceeded.

There are differences in the order in which rate matching and segmentation functions are performed. Whether fixed or flexible bit positions are used determines the DTX indication insertion point. The DTX indication bits are not transmitted over the air; they are just inserted to inform the transmitter at which bit positions the transmission should be turned off. They were not needed in the uplink where the rate matching was done in a more dynamic way, always filling the frame when there was something to transmit on the DPDCH.

The use of fixed positions means that for a given transport channel, the same symbols are always used. If the transmission rate is below the maximum, then DTX indication bits are used for those symbols. The different transport channels do not have a dynamic impact on the rate matching values applied for another channel, and all transport channels can use the maximum rate simultaneously as well. The use of fixed positions is partly related to the possible use of blind rate detection. When a transport channel always has the same position regardless of the data rate, the channel decoding can be done with a single decoding 'run' and the only thing that needs to be tested is which position of the output block is matched with the CRC check results. This naturally requires that different rates have different numbers of symbols.

With flexible positions the situation is different since now the channel bits unused by one service may be utilised by another service. This is useful when it is possible to have such a transport channel combination that they do not all need to be able to reach the full data rate simultaneously, but can alternate with the need for full rate transmission. This allows the necessary spreading code occupancy in the downlink to be reduced. '

The use of blind rate detection is also possible in principle with flexible positions, but is not required by the specifications. If the data rate is not too high and number of possible data rates is not very high, the terminal can run channel decoding for all the combinations and check which of the cases comes out with the correct CRC result.

4-c-iv

Cont

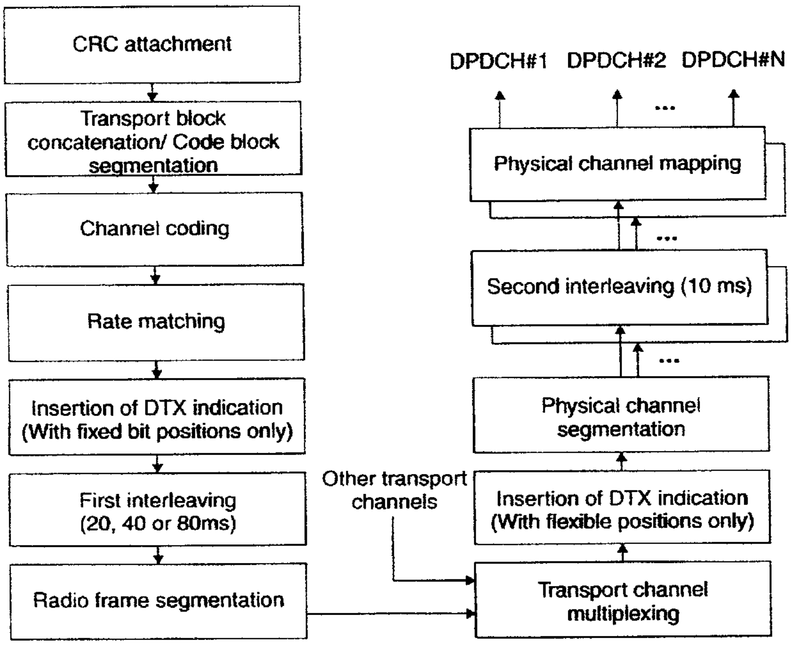

Figure Downlink multiplexing and channel coding chain