E4.03
AS5
SO10
ISE4.3

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2004

MSc and EEE/ISE PART IV: MEng and ACGI

MOBILE RADIO COMMUNICATION

Tuesday, 18 May 10:00 am

Time allowed: 3:00 hours

Corrected Copy

There are FOUR questions on this paper.

Answer THREE questions.

All questions carry equal marks

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : M.K. Gurcan
Second Marker(s) : D.B. Ward

Special Instructions for Invigilators: None

Information for candidates:

1. a) In a narrow-band cellular radio system, the transmitter and receiver antennae have heights of 40m and 3m respectively. The cell radius is 2km. The system transmits at 1800 MHz. If the received free-space power, at a reference distance $d_0 = 1\,\text{km}$, is equal to 1 microwatt and the total interfering signal area-mean power at the cell boundary is measured to be 0.07 microwatt, what is the cluster size of the radio system? [10]

b) For the knife-edge geometry in Figure 1.a, the Fressnel-Kirchoff diffraction parameter is given by

$$\upsilon = \alpha\sqrt{\frac{2\,d_1\,d_2}{\lambda(d_1+d_2)}},$$

~~$\lambda = 0.166$ m~~

$\lambda = 0.333$ m

10.28

10.29

both λ values acceptable

10.35

where λ is the wavelength and $\phi = \frac{\pi}{2}\upsilon^2$ is the phase difference between the signals arriving over the direct line-of-sight and the diffracted paths. It is also assumed that $d_1, d_2 >> h$, and also $h >> \lambda$.

Given the geometry shown in Figure 1.b, and using the diffraction gain $G_d(dB) = 20\log\left(\frac{0.225}{\upsilon}\right)$, determine the loss due to knife-edge diffraction. [10]

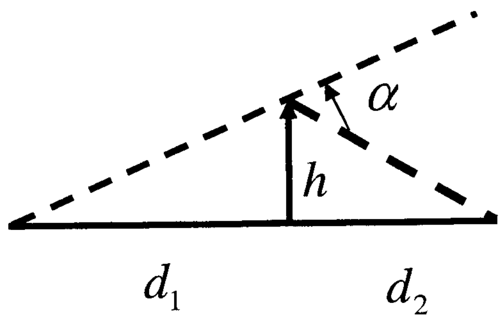

Figure 1.a: Knife edge geometry

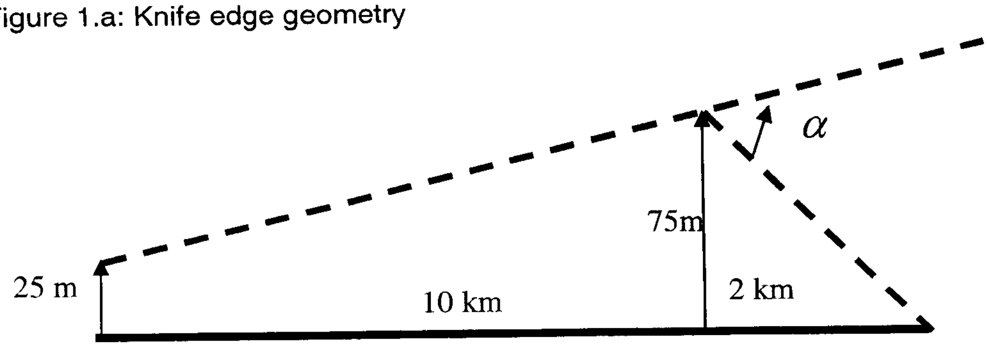

Figure 1.b: Diffraction Model for problem 1.b

2. a) Using relevant capacity equations, explain the rationale behind building the following radio systems and progressively moving to the next generation

   i) the narrowband radio systems, [4]

   ii) wideband radio systems based on equalisation principles, [4]

   iii) wideband radio systems based on wideband code-division-multiple-access (W-CDMA) principles. [4]

b) Describe the Signal-to-Noise calculation principle for decision-feedback, and partial-response-decision-feedback equalisers using the spectral factorization technique. [8]

3. a) Consider the third generation wideband UTRA/FDD radio system and describe the following common physical channels:

i) the Primary and Secondary Synchronization Channels (SCH), [4]

ii) the Primary Common Control Physical Channel (PCCPCH) and [3]

iii) the Secondary Common Control Physical Channel (S-CCPCH). [4]

b) Consider the third generation wideband UTRA/FDD radio system and describe how the three-step cell search principle is used for each cell to identify the primary and secondary scrambling codes from the family of scrambling codes generated at the output of the following Gold code encoder. [9]

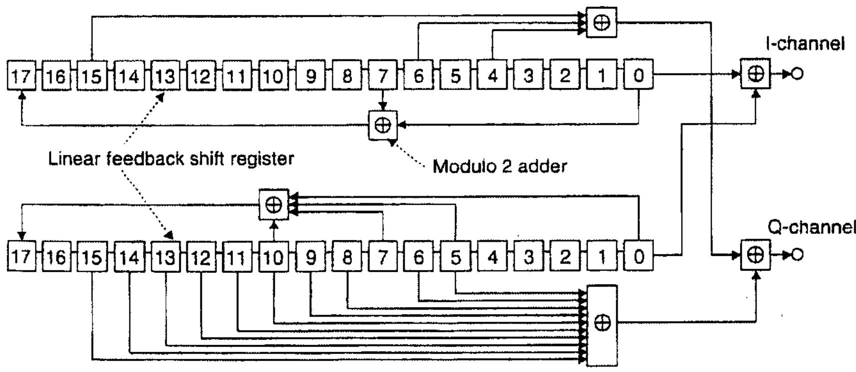

Figure 3.1 Configuration of Gold Code encoder.

4. a) In connection with the third generation wideband UTRA/FDD radio system, it is assumed that a 4.1 kbps speech service and 64 kbps video service is to be transmitted simultaneously on the uplink (UL) using the FDD transmission scheme. The parameters used in this transmission are shown in Table 4.1. Show the mapping of several multimedia services to the UL dedicated physical data channel in the FDD mode. [10]

	Service 1, DCH#1	**Service 2, DCH#2**
Transport Block Size	640 bits	164 bits
Transport Block Set Size	4 * 640 bits	1 * 164 bits
TTI	40 ms	40 ms
Bit Rate	64 kbps	4.1 kbps
CRC	16 bits	16 bits
Coding	Turbo Rate: 1/3	Convolutional Rate: 1/3

Table 4.1 parameters for the multimedia communication link.

b) In connection with the third generation wideband UTRA/FDD radio system, describe

i) the Random Access Channel operation and [5]

ii) the acquisition detection over the Acquisition Indicator Channel, [5]

for uplink packet transfers.

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1.a 10

$$P_{am}(R) = P_{FSR}(d_0)\left(\frac{d_0}{R}\right)^2 \cdot \left(\frac{4\pi}{\lambda} \frac{h_1 h_2}{R}\right)^2$$

$$P_{am}(R) = P_{FSR}(d_0) \cdot (d_0)^2 \left(\frac{4\pi}{\lambda}\right)^2 \frac{h_1^2 \cdot h_2^2}{R^4}$$

$d_0 = 1\,\cancel{km} = 10^3\,m$

$P_{FSR}(d_0) = 1.10^{-6}\,W$

$\cancel{d}R = 2 \cdot 10^3\,m$

$$\lambda = \frac{3 \cdot 10^8}{18 \cdot 10^2 \cdot 10^6} = \frac{3}{18} = 0.166\,m$$

$h_1 = 40\,m$, $h_2 = 3\,m$

$$P_{am}(R) = 10^{-6} \cdot (10^3)^2 \left(\frac{4\pi}{0.166}\right)^2 \frac{(40)^2 \cdot (3)^2}{(2 \cdot 10^3)^4}$$

$= 5.1576$ micro watt

$$\frac{P_{am}(R)}{6 \cdot P_{am}(D)} = \frac{5.1576 \cdot 10^{-6}}{7 \cdot 10^{-8}} = 73.6797$$

$$\frac{3N^2}{2} = 73.6797$$

$N^2 = 49.1198$

$\boxed{N = 7}$

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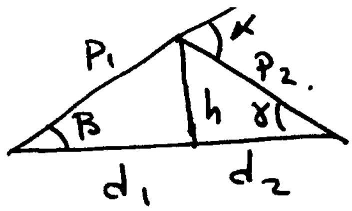
1.b



10

$$d_1+d_2 = \sqrt{P_1^2-h^2} + \sqrt{P_2^2-h^2} = P_1\sqrt{1-\sin^2\beta} + P_2\sqrt{1-\sin^2\gamma}$$

$$= P_1\sqrt{\left(1-\frac{\sin^2\beta}{2}\right)^2} + P_2\sqrt{\left(1-\frac{\sin^2\gamma}{2}\right)^2}$$

$$= P_1\cdot\left(1-\frac{\sin^2\beta}{2}\right) + P_2\left(1-\frac{\sin^2\gamma}{2}\right)$$

$$= P_1+P_2 - P_1\cdot\frac{\sin^2\beta}{2} - P_2\cdot\frac{\sin^2\gamma}{2}$$

$$= P_1+P_2 - \frac{h}{2}\cdot\sin\beta - \frac{h}{2}\sin\gamma$$

$\therefore$

$$\Delta = P_1+P_2-d_1-d_2 = \frac{h}{2}\left(\sin\beta+\sin\gamma\right)$$

$$= \frac{h}{2}\left(\frac{h}{d_1}+\frac{h}{d_2}\right)$$

as $\sin\beta = \tan\beta = \frac{h}{d_1}$, $\sin\gamma = \frac{h}{d_2} = \tan\alpha$

$$\Delta: \frac{h^2}{2}\left(\frac{1}{d_1}+\frac{1}{d_2}\right) = \frac{h^2}{2}\frac{(d_1+d_2)}{d_1\cdot d_2}.$$

$\tan\alpha = \alpha$, also $\alpha = \beta+\alpha$

$$\therefore \quad \alpha = \frac{h}{d_1}+\frac{h}{d_2} = \frac{h(d_1+d_2)}{d_1\cdot d_2}$$

$$h = \alpha\cdot\frac{d_1\cdot d_2}{d_1+d_2}.$$

1.b continued

$$\Delta = \frac{h^2}{2} \cdot \frac{d_1+d_2}{d_1 \cdot d_2} = \frac{\alpha^2}{2}\left(\frac{d_1 \cdot d_2}{d_1+d_2}\right)^2 \cdot \frac{d_1+d_2}{d_1 d_2}$$

$$\Delta = \frac{\alpha^2}{2} \frac{d_1 \cdot d_2}{d_1+d_2}$$

$$v = \sqrt{\frac{4\Delta}{\lambda}} \quad \text{as} \quad \phi = \frac{2\pi}{\lambda} \cdot \Delta = \frac{\pi}{2} \cdot v^2$$

$$v = \alpha\sqrt{\frac{2}{\lambda} \cdot \frac{d_1 \cdot d_2}{d_1+d_2}} = h \cdot \sqrt{\frac{2}{\lambda} \frac{d_1+d_2}{d_1 \cdot d_2}}$$

$$\beta = \tan^{-1}\left(\frac{75-25}{10000}\right) = 0.2865^\circ$$

$$\gamma = \tan^{-1} \frac{75}{2000} = 2.15^\circ$$

$$\alpha = \beta+\gamma = 2.434^\circ = 0.0424 \text{ rad.}$$

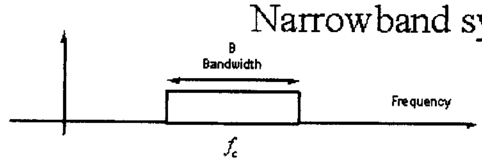
$$v = 0.0424\sqrt{\frac{2}{1/3} \frac{10000 \times 2000}{10000+2000}} = 4.24$$

$$G_d\,(dB) = 20 \log\left(\frac{0.225}{v}\right) = -25.5\text{ dB.}$$

$$\boxed{G_d(dB) = 25.5 \text{ dB.}}$$

2.a

Narrowband system capacity



$B = R_s$ ← Symbol rate

Because of bandlimited transmission

$$C_{NB} = B\log_2\left(1 + R_0^2 \frac{P_{am}(R)}{6\,P_{am}(D)}\right)$$

Capacity per user

K_{NB} = number frequencies in a cell

N = number of cells in a cluster

M = number of channels in a cluster

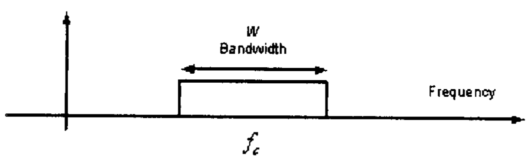
$$N^2 = \frac{2}{3} SNR_{channel} = \frac{2}{3\;R_0^2}\; SNR_{in}$$

$$K_{NB} = \frac{M}{N} = M\sqrt{\frac{3\;R_0^2}{2\;SNR_{in}}}$$

Narrowband System capacity

$$C_{T,NB} = K_{NB}\;C_{NB} = M\sqrt{\frac{3R_0^2}{2\;SNR_{in}}}\;\;B\;\;\log_2\left(1 + R_0^2\,\frac{P_{am}(R)}{6\;P_{am}(D)}\right)$$ 4

Wideband TDMA system capacity



$W = R_s$ ← Symbol rate

Because of bandlimited transmission

$B = \frac{T_1}{T} W$ symbol Rate bandwidth per user

Capacity per user

$$C_{WB} = \frac{T_1}{T} W \log_2\left(1 + C_0 \frac{P_{am}(R)}{5\,P_{am}(D)}\right)$$

$$= B\log_2\left(1 + C_0 \frac{P_{am}(R)}{6\,P_{am}(D)}\right)$$

K_{WB} = number of frequencies in a cell

N = number of cells in a cluster

M = number of channels in a cluster

$$N^2 = \frac{2}{3} SNR_{channel} = \frac{2}{3\;C_0}\; SNR_{in}$$

$$K_{WB} = \frac{M}{N} = M\sqrt{\frac{3\;C_0}{2\;SNR_{in}}}$$

Wideband System Capacity

$$C_{T,WB} = K_{WB}\;C_{WB}$$

$$= M\sqrt{\frac{3C_0}{2\;SNR_{in}}}\;\;B\;\;\log_2\left(1 + C_0\,\frac{P_{am}(R)}{6\,P_{am}(D)}\right)$$ 4

2.a cont

Capacity with Load balancing for WCDMA

$$SNR_{in} = \frac{W}{R} \frac{P_i h_i}{(P_T - P_i)\alpha h_i + I + N_0}$$

$$R = \frac{W}{SNR_{in}} \frac{P_i h_i}{(P_T - P_i)\alpha h_i + I + N_0}$$

$$C_{WCDMA} = \frac{T_2}{T} R = \frac{T_2}{T} \frac{W}{SNR_{in}} \frac{P_i h_i}{(P_T - P_i)\alpha h_i + I + N_0}$$

k_{WCDMA} = number of channels in the WCDMA cell

$$C_{T,WCDMA} = k_{WCDMA} C_{WCDMA} = k_{WCDMA} \frac{T_2}{T} \frac{W}{SNR_{in}} \frac{P_i h_i}{(P_T - P_i)\alpha h_i + I + N_0}$$ 4

Total capacity for CDMA system

Rationale and Strategy for 3G WCDMA

- Rationale
  - Load balancing works for wideband TDMA
  - Load balancing worked for 2G and 2.5 GSM and GPRS systems.
  - New services will be introduced. Wideband TDMA system is circuit switched and not very suitable for packet based services.
  - Load balancing when used with CDMA systems can provide packet based services.
- Strategy
  - Use load balancing in downlink resource allocation for MAI reduction in WCDMA systems for 3G

2.b cont

Transmitted signal power spectrum 8

$$S_v = g(z)\, g^*(1/z^*) = A_v^2\, G_v(z)\, G_v(1/z^*)$$

$$g(z) = \sum_{i=0}^{Q} g_i z^{-i} = A_v \prod_{i=1}^{Q}\left(1 - c_k z^{-1}\right)$$

$$G_v(z) = \prod_{i=1}^{Q}\left(1 - c_k z^{-1}\right) \qquad |c_k| \le 1$$

$$A_v^2 = \exp\left(\frac{T}{2\pi}\int_{-\frac{\pi}{T}}^{\frac{\pi}{T}} \ln\left(S_v\left(\exp^{j\omega T}\right)\right) d\omega\right)$$

Signal power spectrum at the input of the equaliser and also its geometric mean

- **The signal power spectrum at the input of the equaliser is given in terms of**
  - **the transmitted signal spectrum**
  - **Channel spectrum**
  - **Noise variance**
- **By suing spectral factorization we can get the geometric mean for the signal at the input of the equaliser**

Signal power spectrum at the input of equal

$$S_Y = S_v\, HH^* + S_N = A_Y^2 G_Y(z)\, G_Y^*(1/z^*)$$

$$G_Y(z) = \prod_{i=1}^{Q}\left(1 - c_k z^{-1}\right) \qquad |c_k| \le 1$$

$$A_Y^2 = \exp\left(\frac{T}{2\pi}\int_{-\frac{\pi}{T}}^{\frac{\pi}{T}} \ln\left(S_Y\left(\exp^{j\omega T}\right)\right) d\omega\right)$$

2.b cont

We show that

- **Asymptotic value for the equaliser mean square error is given in terms of**
  - **the transmitted signal geometric mean,**
  - **the noise variance, and**
  - **The geometric mean of the signal at the input of the equaliser**
- **We show that the SNR at the output of the equaliser of at the input of the receiver is given in terms of**
  - **the geometric mean of the transmitted signal**
  - **Mean square error at the output of the equaliser**

SNR at the output of the equaliser

$$\xi^2 = E\left(\varepsilon^2\right) = E\left(ee^*\right) = \frac{A_v^2}{A_Y^2}\frac{N_0}{2}$$

$$SNR_{DFE\ OUT} = \frac{Desired\ signal\ power}{\xi^2} - 1$$

$$= \frac{A_v^2}{\xi^2} - 1$$

$$SNR_{in} = SNR_{DFE\ out} = \frac{2\ A_Y^2}{N_o} - 1$$

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3a The core network is organised as follows

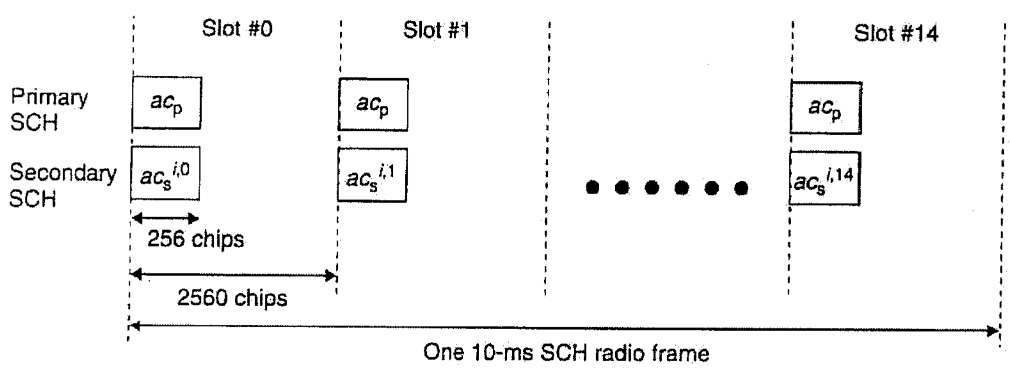
Primary and secondary synchronization channels 4

Synchronization CHannel (SCH)

SCH is a downlink physical channel used for cell search. SCH consists of two subchannels: Primary SCH (P-SCH) and Secondary SCH (S-SCH). Figure shows the frame structure of SCH.

P-SCH is used in step 1 of cell search, so that the UE can establish slot synchronization with the cell. P-SCH is spread by a 256-chip-long code called the Primary Synchronization Code (PSC). PSC referred to as c_p in Figure is transmitted once in each slot. PSC is common to all cells in the system.

S-SCH is used in step 2 of cell search, so that the UE can establish frame synchronization with the cell, and find the scrambling code group to which the cell belongs. S-SCH is spread by a 256-chip-long modulated code called the Secondary Synchronization Code (SSC), which changes every 15 slots. There are 64 patterns of the 15-slot-cycle SSC, and the scrambling code group used in the same cell corresponds to the pattern at a one-to-one ratio. In Figure , SSC is referred to as $c_s^{i,k}$, in which i represents the scrambling code group number (1–64) and k stands for the slot number (0–14). S-SCH and P-SCH are transmitted simultaneously.

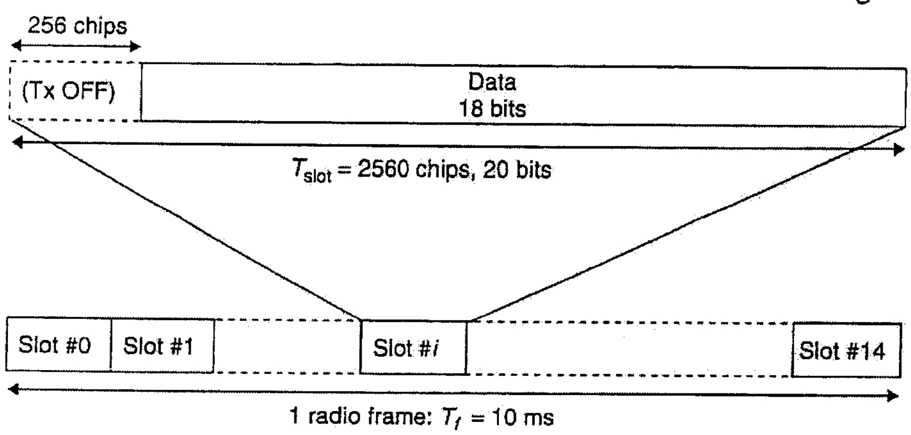


3.a cont

Primary Common Control Physical CHannel (P-CCPCH) 3

P-CCPCH is a fixed rate (30 kbps, $SF = 256$) downlink physical channel for transmitting BCH.

Figure shows the frame configuration of P-CCPCH. It is different from downlink DPCH in that it does not transmit Pilot, TPC or TFCI. P-CCPCH is not transmitted during the first 256 chips of each slot. Instead, the SCH is transmitted during this period.



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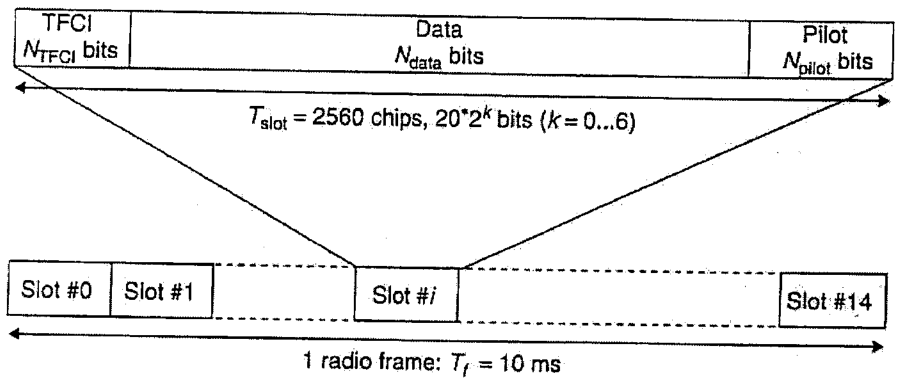
3.a cont

Secondary Common Control Physical CHannel (S-CCPCH)

S-CCPCH is a physical channel for transmitting FACH and PCH. There are two types of S-CCPCH: with TFCI and without TFCI. Figure shows the frame structure of S-CCPCH. 1

The number of bits inside the downlink S-CCPCH frame is determined by the parameter k. k corresponds to SF of the physical channel: $SF = 256/2^k$. SF may have a value between 256 and 4.

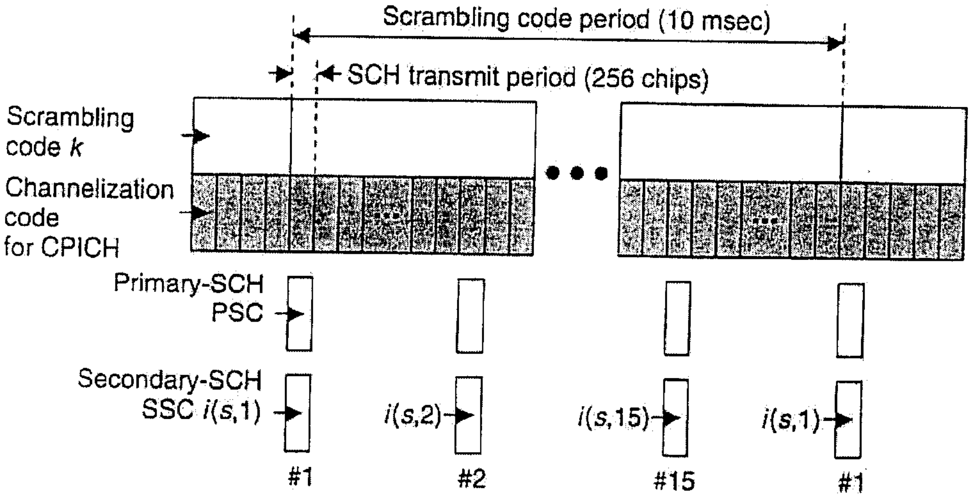


3b

Three-Step Cell Search

Figure shows the configuration of transmission frames in CPICH and Synchronization CHannel (SCH) used for three-step cell search. In the 256-chips-long zone in the header of each slot, the Primary Synchronization CHannel (Primary-SCH) and the Secondary Synchronization CHannel (Secondary-SCH) are code-multiplexed with CPICH for transmission. (P-CCPCH is transmitted to parts excluding the first 256-chips-long part in each slot.) SC is a spreading code used for spreading SCH. There are two types of SC, both of which have a code length of 256: Primary Synchronization Code (PSC), which is used for spreading Primary-SCH, and Secondary Synchronization Code (SSC), for spreading Secondary-SCH[9]. As described later, an MF is used to detect Primary-SCH. As the circuit would become bulkier if a 256-tap MF is used for the direct detection of PSC correlations, 256-chip code sequences are generated through the iteration of 16 modulation patterns with minimal autocorrelation peaks based on time-shifted, 16-chips-long 5

3.b



orthogonal code sequences. Assuming that C_{PSC} represents PSC, C_{PSC} is defined by the equation below as a complex code sequence in which the real part and the imaginary part are equal.

$$C_{PSC} = (1 + j)x < a, a, a, -a, -a, a, -a, -a, a, a, a, -a, a, -a, a, a >$$

in which $a = \{x_1, x_2, x_3, \ldots, x_{16}\}$

$$= \{1, 1, 1, 1, 1, 1, -1, -1, 1, -1, 1, -1, 1, -1, -1, 1\}.$$

Assuming that the jth symbol in the nth row of the Hadamard matrix is $h_n(j)$ and the jth symbol of common sequence Z is $z(j)$, $C_{SSC,k}$ is represented by the following equation.

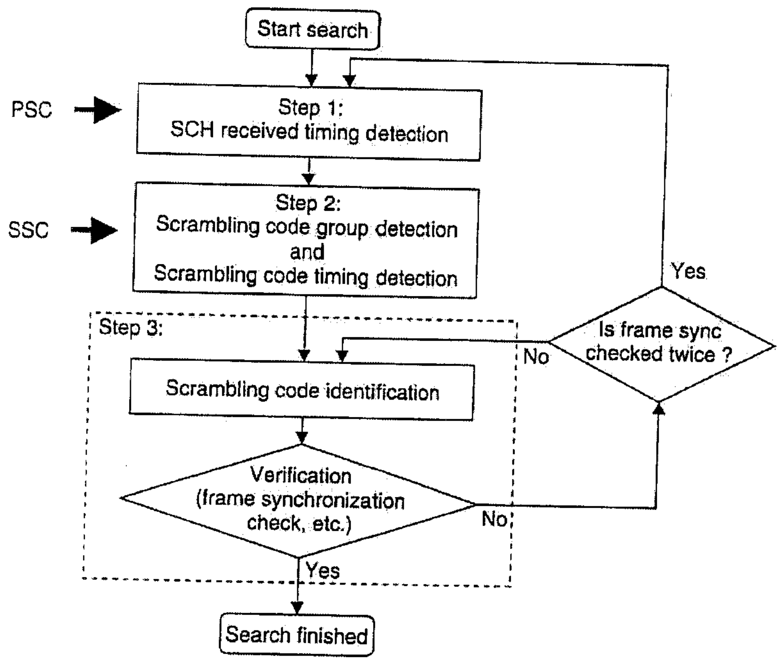
$$C_{SSC,k} = (1 + j)\times < h_n(0) \times z(0), h_n(1) \times z(1), h_n(2) \times z(2) \cdots h_n(255) \times z(255), >,$$

in which $Z = \{b, b, b, -b, b, b, -b, -b, b, -b, b, -b, -b, -b, -b, -b\}$,

and $b = \{x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, -x_9, -x_{10}, -x_{11}, -x_{12}, -x_{13}, -x_{14}, -x_{15}, -x_{16}\}$

3-b continued

In Steps 1 and 2, the correlation value of Primary-SCH and Secondary-SCH are time-averaged with T_1 and T_2, respectively, to calculate the maximum correlation peak excluding the impact of instantaneous fading fluctuations.



Step 1

$$\psi_1(t) = \frac{1}{256T_c}\int_0^{256T_c} r(t-\mu)\cdot c_{psc}(256T_c-\mu)\,d\mu$$

$$\overline{\Psi}_1(\tau) = \frac{1}{15N_1}\sum_{n=n_1}^{n_1+N_1-1}\sum_{m=0}^{14}|\psi_1(\tau,m,n)|^2$$

Step 2

$$\psi_2(x,\hat{\tau},m,n) = \frac{1}{256T_c}\int_0^{256T_c} r(\hat{t}-\mu)\cdot c_{ssc,x}(256T_c-\mu)\,d\mu$$

$$\overline{\Psi}_2(s,m) = \frac{1}{15N_2}\sum_{n=n_2}^{n_2+N_2-1}\sum_{k=0}^{14}|\psi_2(i(s,k),\hat{\tau},(m+k)\ \mathrm{mod}15,n)|^2$$

3 b cont

$$\overline{\Psi}_2(s,m) = \frac{1}{15N_2}\left|\sum_{n=n_2}^{n_2+N_2-1}\sum_{k=0}^{14}\psi_2[i(s,k),\hat{\tau},(m+k)\bmod 15,n]\right.$$

$$\left.\times\,\xi^*[\hat{\tau},(m+k)\bmod 15,n]\right|^2$$

Step 3

MS identifies the scrambling code by detecting the correlation between the reception signal and the candidate scrambling codes in the scrambling code group detected with reference to the frame timing detected in Step 2 and by determining the threshold level. Assuming that $L(\hat{s},i)$ stands for the index of the ith scrambling code in group $\hat{s}$, correlation detection is performed on scrambling code $L(\hat{s},i)$ using CPICH on the basis of H_3 symbol length for each scrambling code. The correlation output power is represented by the following equation.

$$\Psi_3(L(\hat{s},i),\hat{\tau},\hat{m},n) = \frac{1}{H_3}\sum_{j=1}^{H_3}\left|\frac{1}{256T_c}\int_{256jT_c+\hat{\tau}}^{256(j+1)T_c+\hat{\tau}} r(t+\eta)\cdot c_{L(\hat{s},i),0}\right.$$

$$\left.\times\,(\eta+\hat{m}T_{\text{slot}}+nT_{\text{Frame}}-\hat{\tau})\,d\eta\right|^2$$

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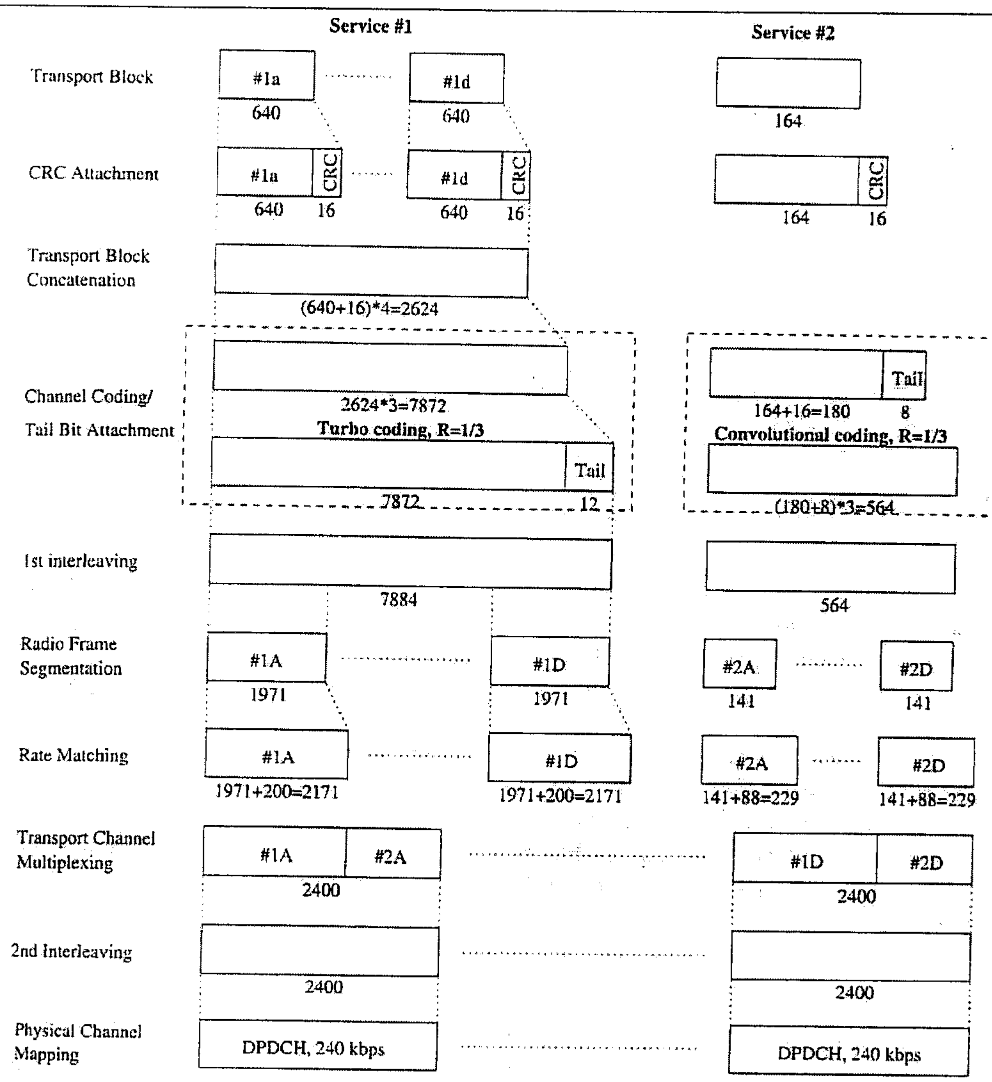
4.a



10

4.b *Physical Random Access CHannel (PRACH)* + Common packet Chan.

Random access transmission is based on a slotted ALOHA approach with fast acquisition indication. Specifically, UE transmits the preamble by random access before sending the message part. When it receives an acquisition indication corresponding to the preamble from the network, UE sends the message part. 4+2

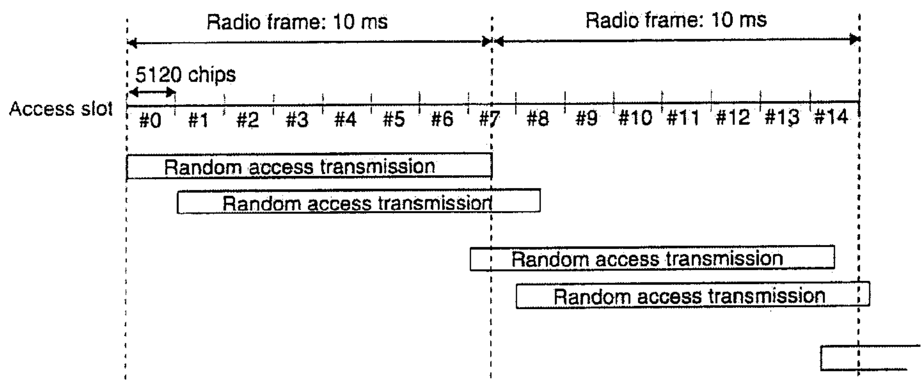
UE starts the transmission of RACH from a number of predetermined time-offsets, called access slots. There are 15 access slots per 2 frames, which are spaced 5120 chips apart. Figure shows the number of access slots and their spacing. Access slots that can be used are specified by the higher layer.

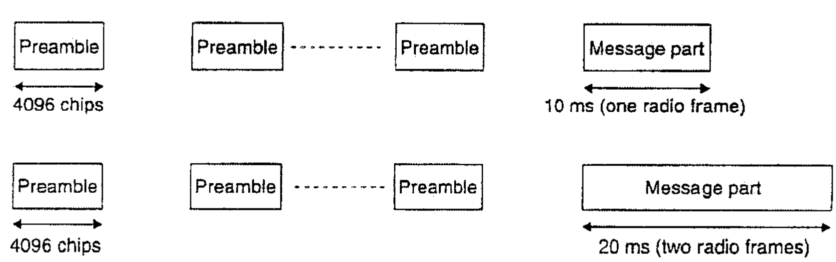
Figure illustrates the configuration of PRACH. Random access transmission consists of one or more preambles (4096 chips) and a message (10 ms or 20 ms).

The length of the message part and the arrangement between signature and the access slot are predetermined by the higher layer.

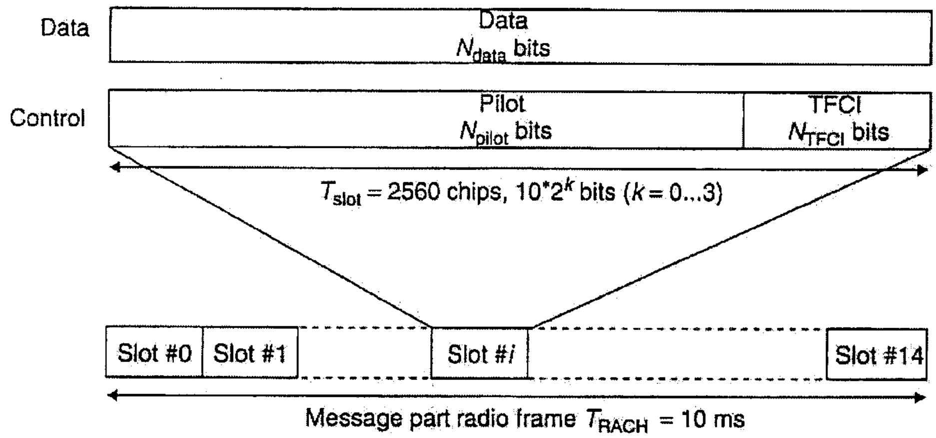
Figure 3... shows the radio frame configuration of the random access message part. The message part radio frame of length 10 ms is divided into 15 slots, each consisting of 2560 chips. Each slot consists of a data part that transmits Layer 2 information and a control part that transmits Layer 1 control information (pilot bits and TFCI). The data part and the control part are transmitted in parallel with each other through I/Q multiplexing. The 20-ms-long message part consists of two consecutive message part radio frames.

The data part consists of $10*2^k$ bits ($k = 0, 1, 2, 3$), which corresponds to the Spreading Factor ($SF = 256, 128, 64, 32$).





4.b



Acquisition Indicator CHannel (AICH)

AICH is a downlink physical channel used for random access control, and transmits the Acquisition Indicator (AI) in the preamble of PRACH. 4

Acquisition Indicator AI_S corresponds to the signature S of PRACH.

Figure shows the frame structure of AICH, which consists of a repeated sequence of 15 consecutive access slots. Each access slot consists of 40 bits. The first 32 bits are the AI part, and the remaining 8 bits are not transmitted.

In Figure , $a_0, a_1, \ldots, a_{31}$ is determined by the following equation.

$$a_j = \sum_{S=0}^{15} \mathrm{AI}_s b_{s,j}$$

In the equation, AI_S indicates the response to the preamble reception of Signature (S): ACK = +1, NACK = −1, and nonreception = 0. $b_{s,j}$ is the Signature pattern of AICH corresponding to the Signature(s) received in the preamble, and consists of 32 bits. There are 16 patterns according to the Signature of the preamble.