EEE6430/443

Solution to Question 1

(a)

Normal burst (not to scale):

T 3	57 bits coded data	S 1	26 bits training sequence	S 1	57 bits coded data	T 3	G 8

156.25 bits = 576.56us

T = tail bits, S= stealing flags depicting data type, G = guard period

Logical control channels that map onto a normal burst:
Broadcast **C**ontrol **CH**annel (**BCCH**) informs the MS about specific system parameters such as Cell Id (identifies the cell), **L**ocal **A**rea **C**ode (**LAC**) (identifies the area or cell group to which the cell belongs), **M**obile **N**etwork **C**ode (**MNC**) identifies the system operator (e.g. Cellnet, Orange etc.). It also gives the frequencies of neighbouring cells.

The **C**ommon **C**ontrol **CH**annels (**CCCH**) support the establishment of a dedicated link between the MS and BTS. There are several types of CCCH:
i) **A**ccess **G**rant **CH**annel (**AGCH**) is used to inform the MS which dedicated channel it should use, and is a response by the BTS to the mobile's RACH message. The BTS also informs the MS what timing advance it should use on the AGCH, based on the time of arrival of the random access burst.
ii) **P**aging **CH**annel (**PCH**) is used by the BTS to call mobiles.

The **S**tandalone **D**edicated **C**ontrol **CH**annel (**SDCCH**) is intended for the transfer of signalling information between MS and BTS.

There are also associated control channels:
(i) **S**low **A**ssociated **C**ontrol **CH**annel (**SACCH**) is always used in association with either a traffic channel or SDCCH. If a BTS assigns a traffic channel, there will always be an SACCH assigned with it. The purpose of the SACCH is to maintain the link, by allowing the radios to have their own 'conversation'. In the downlink direction, the BTS transmits system information parameters and instructs the MS to use a specific timing advance or power level. In the uplink direction the MS reports the results of measurements on neighbouring cells, which assist the network in making hand over decisions.

ii) **F**ast **A**ssociated **C**ontrol **CH**annel (**FACCH**) can carry the same information as the SDCCH. The difference is that the SDCCH exists on its own, whereas the FACCH replaces all or part of a traffic channel. If during a call there is the need for a large amount of signalling (e.g. the mobile switches from one cell to another), then the FACCH appears in the place of a traffic channel, indicating its presence with stealing flags.

(b)

The mobile transmits 3 time slots after the BTS to reduce the complexity of the required isolation between the transmit and receive circuits in the compact mobile transceiver.

(i)Since from (a) each time slot is of $576.56\mu s$ duration, the mobile will transmit

$$\Delta t = 3 \times 576.56 - TA\mu s \quad (1)$$

after the start of the received *BTS* burst. TA is the time advance which the mobile uses to compensate for the propagation delay between it and the BTS, so that its burst arrives at the BTS at the beginning of the particular time slot. Each increment of the TA is one bit period of $3.69\mu s$, hence

$$TA = 63 \times 3.69 = 232.47\mu s \qquad (2)$$

Thus the mobile starts its transmit burst

$$\Delta t = 3 \times 576.56 - 232.47 = 1497.21\mu s \ (3)$$

after the start of the *BTS* transmit burst.

(ii) From the BTS's perspective, the mobile burst is received on time, 3 timeslots after the BTS transmits, since that is what the TA is designed to ensure, so

$$\Delta t = 3 \times 576.56 = 1729.68\mu s$$

(c)

The TA is related to the distance d between the mobile and BTS by

$$TA = \frac{2d}{c} \qquad (3)$$

where c denotes the speed of light (and radio waves). Hence

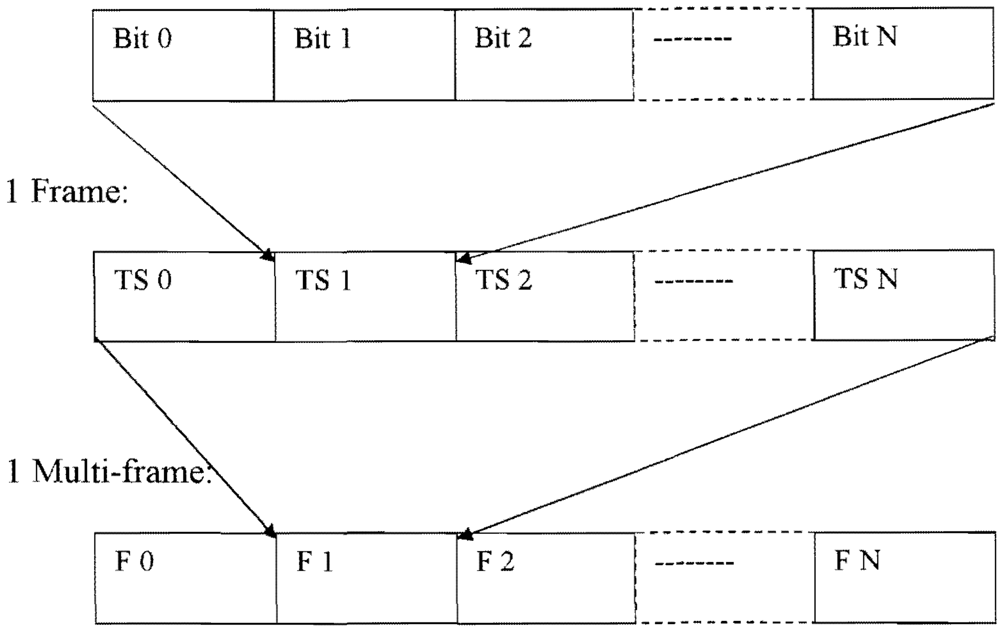
$$d = \frac{63 \times 3.69 \times 300}{2} m = 34.87 km \qquad (4).$$

The significance of this particular value of TA is that it is the maximum permissible within the GSM protocol. If the mobile moves any further from the BTS then it will not be possible to advance the mobile's transmission time to compensate for this, and data will be lost meaning the call will fail.

Solution to Question 2

(a)

1 Burst:



GSM	TETRA
Bit: N = 155.25	Bit: N = 509
Normal burst duration = 576.56us	Burst duration = 14.17ms
TS: N = 7	TS: N = 3
Frame length = 4.61ms	Frame length = 56.67ms
F: N = 25 (Traffic), N = 50 (Control)	F: N = 16 (Traffic), F 17 = Control
GMSK @ 271kbps	QPSK @ 36kbps
Channel B/W = 200kHz	Channel B/W = 25kHz
Designed for public cellular telephony	Designed for professional mobile radio applications
Not suitable for emergency services due to latency in call establishment ~a few seconds	Very fast call initiation ~300ms
No direct mode operation, only handset -> BTS -> handset	Direct mode operation supported, handset -> handset

(b)

The TETRA time waveform can be represented by:

$$(f(t) * \delta_T(t-nT)) \times e^{j\omega_c t} \quad (2.1)$$

where $f(t)$ is a Rect function of amplitude A (this assumes no amplitude tailoring on the burst to reduce the bandwidth) and width equal to the $TDMA$ burst duration $\tau = 14.2 \times 10^{-3} s$, $\delta_T(t-nT)$ is a delta function pulse train with period equal to the frame period $T = 56.7 \times 10^{-3} s$, and where $\omega_c = 2\pi \times 390 \times 10^6\, rads^{-1}$ is the carrier frequency. The signal spectrum is given by the Fourier transform of (2.1), as

$$(F(\omega) \times \omega_o \delta(\omega - n\omega_o)) * \delta(\omega - \omega_c) \quad (2.2).$$

Here,

$$F(\omega) = A \int_{-\tau/2}^{\tau/2} cos(\omega t)dt = A\tau Sa(\frac{\omega\tau}{2}) \quad (2.3)$$

and

$$\omega_o = 2\pi f_o = \frac{2\pi}{T} \quad (2.4).$$

The first null in the spectral envelope therefore occurs at

$$\frac{\omega\tau}{2} = \pi, so\ f = \frac{1}{\tau} = 70.4Hz \quad (2.5)$$

and the first side-lobe at (approx)

$$\frac{\omega\tau}{2} = \frac{3\pi}{2}, so\ f = \frac{3}{2\tau} = 105.6Hz \quad (2.6)$$

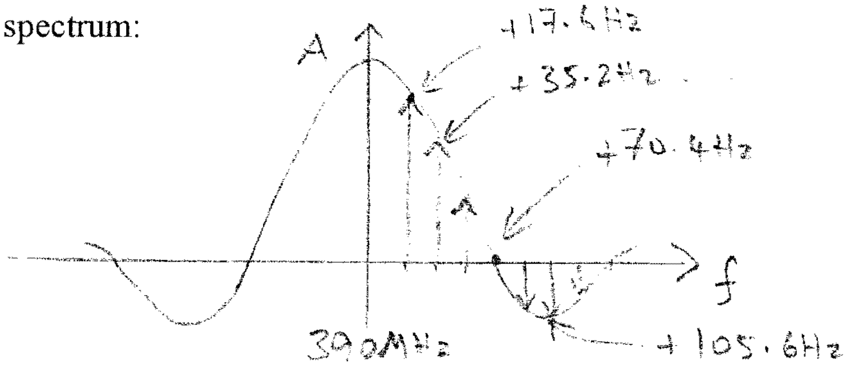
whose relative height compared with the main lobe is

$$20log_{10}(1/(3\pi/2)) = -13.5dB \quad (2.7).$$

Finally, the actual spectral harmonics occur at f_o intervals, where

$$\omega_o = \frac{2\pi}{56.7 \times 10^{-3}}, so\ f_o = 17.6Hz \quad (2.8).$$

Hence the spectrum:



(c) The spectral harmonics spaced at 17.6Hz intervals due to the TDMA framing could induce low frequency intermodulation products at $17.6n$ Hz in non-linear media such as the brain, which may be biologically significant.

Solution to Question 3

(a)

Fast power control is required in WCDMA systems, since without it a single overpowered mobile could block an entire cell, or a mobile close to the base station could block those further away. This does not happen in GSM because each user is assigned a discrete physical channel in a FDMA/TDMA system, rather than all calls being on the same frequency as in the case of 3G. The optimum strategy for maximising capacity therefore is to equalize the received power per bit from all mobile stations. Whereas open loop power control can be used to provide a coarse initial power setting for a mobile (as in GSM), the only effective solution for 3G is fast closed loop power control. Here the base station performs frequent estimates of the Signal to Interference Ratio (SIR) on the uplink pilot bits on every slot of the DPCCH, and instructs the mobile to adjust its power to achieve a target SIR on the downlink TPC bits. This measure-command-react cycle is executed at a rate of 1500Hz for each mobile station and thus operates faster than any path loss change. The basic step size is *1dB*. The near-far problem of one strong signal blocking weaker ones is not so important in the downlink direction since there is usually only one base station transmitting to a mobile. However closed loop power control is still used to provide additional signal power to mobiles on the edge of cells.

(b)

There are two main effects of multi-path propagation:

(i) The signal energy may arrive at the receiver at clearly distinguishable time intervals. The delay profile extends typically from $1-2\mu s$ in urban areas due to reflections off buildings, to as long as $20\mu s$ due to hill reflections in rural regions. Since the WCDMA chip duration at *3.84Mcps* is $0.26\mu s$, then if the delay of a reflected signal is at least of the order of this value, bit cancellation could occur. The WCDMA Rake receiver can take advantage of this however, by separating out the two signals and then coherently combining them to obtain multi-path diversity gain. Since free space radio waves travel at $300m/\mu s$, the minimum reflected path length difference required for multi-path diversity is about *78m*, which is achievable in small cells. Clearly if the chip rate is lower, the minimum path length increases and it becomes harder to achieve such diversity gain in small cells. In GSM which uses a type of FSK modulation, the bit rate is *271kbps* with a bit duration of $3.69\mu s$, meaning that the path length difference to cause a delay of one bit is *~1.1km* and Rake reception is not appropriate therefore. However bit cancellation is less likely with GSM.

(ii) For a particular reflected path, there will be additional tiny path length changes as the mobile moves. At a frequency of *2GHz* for instance the wavelength is *15cm*, and therefore if there is a direct-reflected path length difference of $(2n+1)\times 7.5cm$ signal cancellation (destructive interference) will occur, whilst signal enhancement (constructive interference) will occur for $2n\times 7.5cm$ path difference. Clearly the mobile will move through many signal peaks and troughs very quickly therefore. This fast or Rayleigh type fading makes error free reception of data bits very difficult, and occurs both in GSM/FSK and WCDMA/QPSK modulation. Equalisation and phase compensation can be applied to minimise destructive interference between fingers in Rake reception for WCDMA, and equalisation used to reconstruct the anticipated signal spectrum in GSM. Frequency diversity gain can be achieved in GSM networks using frequency hopping which ameliorates fading in GSM signals through alteration of wavelength, and space diversity gain can be obtained using two receive antennas placed several wavelengths apart.

(c)

(i) A path length difference of $0.52025\mu s$ corresponds to ~two bit periods in the WCDMA protocol, meaning that direct and reflected paths can be differentiated into separate Rake fingers for processing.

(ii) The same path length difference only corresponds to *~0.14* of a GSM bit period, and therefore bit level demodulation should still be possible with some equalisation. However $0.52025\mu s$ corresponds to a path difference of *156.075m*, which is an odd number of half wavelengths, meaning Rayleigh type fading will be evident, and frequency and space diversity gain techniques may be required to ameliorate this.

(d)

As the mobile moves away from the BTS, transmit power will be increased by fast closed loop power control (i) and slower open loop control (ii). Optimum combination of changing multi-path signals will be maintained using dynamic Rake reception (i) and frequency hopping and space diversity gain and equalisation (ii). A soft(er) (i) or hard handover (i)+(ii) to another cell may be negotiated when the signal level drops significantly. The time advance will also increase to maintain bit synchronisation (ii).

Solution to Question 4

(a)

The processing gain is generally defined as

$$G_p = \frac{W}{R} \qquad (1)$$

where W denotes the chip rate of the spreading code and R the data rate. It can be thought of as a 'pay off' for deliberately increasing the signal bandwidth in WCDMA systems.

(b)

For a particular user j, the energy per user bit divided by the noise spectral density is given by

$$E_j = G_{p_j} \frac{P_j}{P_t - P_j} \qquad (2)$$

where P_j is the received signal power from user j and P_t the total received wideband power including thermal noise in the BTS.

Rearranging and factoring (2) yields

$$P_j = \frac{E_j}{E_j + G_{pj}} P_t = L_j P_t \qquad (3)$$

where the load factor of one connection is

$$L_j = \frac{E_j}{E_j + G_{pj}} \qquad (4).$$

The total received interference from N users, excluding the thermal noise P_n can then be written

$$P_t - P_n = \sum_{j=1}^{N} P_j = \sum_{j=1}^{N} L_j P_t \qquad (5).$$

The noise rise due to user activity is then

$$\frac{P_t}{P_n} = \frac{1}{1 - \eta_{ul}} \qquad (6)$$

where

$$\eta_{ul} = \sum_{j=1}^{N} L_j \qquad (7)$$

is the uplink load factor, and through (4) is the same as eq (4.1) in the question. Thus when η_{UL} approaches unity, the noise rise approaches infinity, and the system has reached its pole capacity.

(c)

If $N=10$ users are all uploading data at $R_j = 96 \times 10^3\,bps$, with $W = 3.84 \times 10^6\,cps$ for 3G WCDMA and $E=1.5dB$, then (7) can be written

$$\eta_{ul} = \sum_{j=1}^{N} \frac{E_j}{E_j + G_{pj}} = \frac{NE}{E + G_p} \qquad (8)$$

where

$E = 1.41, G_p = 40$

so

(i)

$$\eta_{ul} = \frac{10 \times 1.41}{1.41 + 40} = 0.34 \qquad (9)$$

(ii)

from (6)

$$\frac{P_t}{P_n} = \frac{1}{1 - 0.34} = 1.52 = 1.8dB \qquad (10)$$

(iii)

The pole capacity of the cell is reached when $\eta_{ul} = 1$ and the noise rise is then infinite from (6), and thus from (8)

$$\eta_{ul} = \frac{NE}{E + G_p} = 1 \qquad (11).$$

The pole capacity is given by NR, and so we need an expression for this from (11). Rewriting (11) using (1) gives

$$\frac{NRE}{RE + W} = 1 \qquad (12)$$

so

$$NR = \frac{RE + W}{E} \qquad (13).$$

thus

$$NR = \frac{96 \times 10^3 \times 1.41 + 3.84 \times 10^6}{1.41} = 2819kbps \qquad (14)$$