EEE6430/443 Solutions 2007

Q1

(a)

The energy per user bit divided by the noise spectral density is given by

$$(E_b / N_o)_j = G_{Pj} \frac{P_j}{P_t - P_j} \qquad (1)$$

where P_j is the received signal power from user j, P_t the total received wideband power including thermal noise in the BTS, and where the processing gain of user j is

$$G_{Pj} = \frac{W}{\upsilon_j R_j} \qquad (2)$$

with chip rate W, bit rate R_j and activity factor υ_j. Rearranging (1) and (2) yields

$$P_j = \frac{1}{1 + \dfrac{W}{(E_b / N_o)_j \upsilon_j R_j}} P_t = L_j P_t \qquad (3)$$

where L_j is the load factor of one connection,

$$L_j = \frac{1}{1 + \dfrac{W}{(E_b / N_o)_j \upsilon_j R_j}} \qquad (4)$$

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

$$\Delta N = \frac{P_t}{P_n} = \frac{1}{1 - \eta_{UL}} \qquad (6)$$

where

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

is the uplink load factor. Thus when η_{UL} approaches unity, the noise rise approaches infinity, and the system has reached its pole capacity. So far we have assumed no interference from users of adjacent cells. Let

$i =$ (interference from users of adjacent cells)/(interference from users of own cell)

then the load factor of (7) is modified as

$$\eta_{UL} = (1+i)\sum_{j=1}^{N} L_j \qquad (8)$$

Hence Equation (1.1) in the question is shown on substituting (4) into (8).

(b)

If $N=9$ users are all uploading data at $R_j = 144\times 10^3\,bps$, with $W = 3.84\times 10^6\,cps$ and $\upsilon_j = 1$ for data, then with the other given values (8) becomes

$$\eta_{UL} = (1+0.65)\frac{1}{1+\dfrac{3.84\times 10^6}{1.41\times 144\times 10^3\times 1}}\times 9 = 0.75 \qquad (9)$$

Thus from (6) the noise rise is

$$\Delta N = \frac{1}{1-0.75} = 4 = 6dB \qquad (10)$$

(c)

Rewriting (8) for N equal users at uplink pole capacity gives

$$\eta_{UL} = (1+i)\frac{NR}{R+\dfrac{W}{(E_b/N_o)v}} = 1 \qquad (11)$$

where NR is the total data throughput, which is the pole capacity. Thus,

$$NR = \left(R+\frac{W}{(E_b/N_o)v}\right)\frac{1}{(1+i)} = 1735kbps \qquad (12)$$

Q2
(a)

Mobile transmitter:
Max mobile transmit power $P_m \approx 0.125W = 21dBm$
Mobile antenna gain $G_m \approx 2dBi$
Body loss $L_b \approx 3dB$
Equivalent Isotropic Radiated Power $EIRP = P_m + G_m - L_b = 20dBm$

BTS receiver:
Receiver thermal noise density $\eta_t \approx -174dBm/Hz$
Receiver noise figure $\eta_f \approx 5dB$
Receiver bandwidth $B \approx 3.84MHz$
Receiver noise power $N_o = \eta_t + \eta_f + 10\log_{10}(B) = -103.2dBm$
Interference margin $I \approx 3dB$
Chip rate $R_c = 3.84Mcps$
Data rate $R_d = 12.2kbps$
Processing Gain $G_p = 10\log_{10}(\frac{R_c}{R_d}) = 25dB$
Required $\frac{E_b}{N_o} = 5dB$
Required receiver sensitivity (for this $\frac{E_b}{N_o}$) $S = N_o + I + \frac{E_b}{N_o} - G_p = -120.2dBm$

BTS antenna:
Antenna gain $G_b \approx 18dBi$
Cable/connector loss $L_c \approx 2dB$

Propagation:
Fading margin $F \approx 7dB$
Soft handover gain $G_h \approx 3dB$
In-car loss $L_c \approx 8dB$

Allowed propagation loss: $EIRP - S + G_b - L_c - F + G_h - L = 144.2dB$

(b)

The gain of an antenna G is related to its 'plane wave' absorption area A through

$$A = \frac{\lambda^2 G}{4\pi} \qquad (1)$$

Typically a 3G BTS antenna will have a gain of $\sim 18dBi$ at a frequency of $2162.2MHz$ corresponding to $\lambda = 0.139m$, hence

$$A \approx 0.1m^2 \qquad (2)$$

The power absorbed by this virtual aperture is then

$$P = AP_d = 0.1 \times 10^{-10} = 10^{-11} W = -80dBm \quad (3)$$

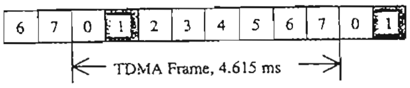
where P_d denotes the power density of the incident plane wave. Now not all of this power will reach the receiver, due (i) to cable/connector loss (*~2dB*), and (ii) to re-radiation of some of the received power by the antenna itself (*~3dB*). Thus the final received power will be a few dB's less than *-80dBm*, say ~ *-85dBm*.

(c)

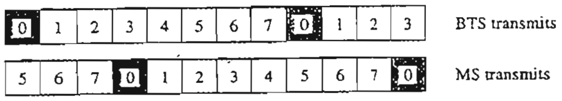
The link between a BTS and MS must be reciprocal. Potentially the BTS will have higher transmit power available plus a more sensitive receiver than the MS, but these must be balanced to ensure that the link remains reciprocal and each station can hear the other with similar *S/N*. For instance, it's no use if the BTS turns its transmit power up to increase the range of a cell if it can't hear the MS over this increased range. Most BTS's have mast-head receive preamplifiers attached to their antennas. This extra sensitivity on receive can allow the BTS to use a higher transmit power than the MS whilst still maintaining a reciprocal link, thereby increasing coverage in a cell. Assuming capacity is not the main concern, then if cell coverage can be increased the number of BTS's can be reduced, providing considerable cost savings for the network. In rural, sparsely populated regions, the anticipated traffic density will be relatively low, whilst the area to be covered will be relatively large, and increasing cell size becomes a desirable option. Super-cooled mast head preamplifiers would enable highly sensitive reception with a very low noise figure, thereby facilitating cells with increased range, and thus fewer BTS's would be required to cover a given region. The cost saving in reducing the number of BTS's would have to be balanced against the installation and maintenance cost of the cryogenic equipment etc., but an increase in receiver sensitivity of ~ *3dB* would reduce the required BTS density by ~ *30%*, assuming signal power density falls by *6dB* per doubling of distance.

Q3

(a)



TDMA frame.



Time-division duplex in the GSM system.

The *MS* transmits ~3 timeslots after it receives the burst from the *BTS* (neglecting the time advance) to enable less stringent specifications for its duplexer. If the *MS* were to transmit concurrently with the *BTS* then its receiver would need a very selective high pass filter to stop it being desensitised by the transmit burst, which would increase cost.

(b)

(i)

Type	T	Coded Data	S	Training Sequence	S	Coded Data	T	GP
Number of Bits	3	57	1	26	1	57	3	8.25

148 Bit = 546.12 μs

A *normal burst* is the most common burst in *GSM*, which is transmitted either from the base or mobile station in one time slot. Such a burst comprises:
Three *tail bits* at the beginning and end of each burst. The tail bit time covers the periods of uncertainty during the ramping up and down of power bursts, and these bits are always set to zero.
Two blocks of *57* bit *coded data* which contain information such as coded speech etc.
Two *stealing flag* bits which indicate to the decoder in the receiver whether the incoming burst is carrying signalling data which are 'housekeeping' messages the radios use to maintain the link between themselves, or whether the burst contains user data (e.g. speech).
A *26* bit *training sequence* is used to compensate for distortion caused by multi-path fading for example. This is a sequence known to the receiver, a priori, and the *equaliser* in the radio compares what it actually receives with what it knows the training sequence should look like. It then adjusts its filter characteristics to compensate for any distortion in the received sequence. This same filtering is then applied to the rest of the frame, where the actual bit pattern is not known, hence cleaning up the signal.
The *guard period* is a length of time ($30.4\,\mu s$) when no data are transmitted.

(ii)

Type	T	Synchronization Seq.	Coded Data	T	GP
Number of Bits	8	41	36	3	68.25

88 Bit = 324.72 μs

The *random access burst* is so called because the *MS* transmits this type of burst at random times, and only when the mobile is trying to gain initial access to the system. The long *guard period* allows for propagation delay between the MS and BTS. The

MS will be synchronised to the data stream from the BTS when it is idling on standby. It will know the timing of the random access time slot, and when required the MS will start transmitting when it thinks this time slot starts. However, in reality the time slot has already started (i.e. the BTS has started listening for random access bursts) *d/c* seconds ago, where *d* is the distance between the BTS and MS, and *c* is the propagation velocity of radio waves ($3\times 10^{8}\,ms^{-1}$). It will also take *d/c* seconds for the MS transmission to reach the BTS, meaning that the access request will be received at the BTS *2d/c* seconds after the listening period starts. For a successful access attempt, the 88 bits must be received at the BTS, and to compensate for the propagation delays, the BTS actually listens for a time longer than is required to receive these, i.e. for an extra *guard period* corresponding to 68.25 bits. This therefore defines a maximum distance from which an MS can successfully access a BTS, i.e.:

$$\frac{2d}{c} \le 3.69\times 10^{-6}\times 68.25 \qquad (1)$$

so $d \le 37.8km$. Once a successful access attempt has been made, the BTS then instructs the phone to *time advance* its transmissions by

$$n\times 3.69\mu s \approx \frac{2d}{c} \qquad (2)$$

($n = 0$ *to* 63 depending on the distance) so that the BTS actually receives data at the beginning of the time slot allocated to the MS.

(c)

If there was 'zero' distance between the BTS and handset, then as previously mentioned the handset will transmit *3* timeslots after the BTS burst. The BTS uses timeslot *4*, and therefore the downlink BTS burst to this particular handset starts at

$$\Delta t_1 = 4\times 576.6\mu s \qquad (3)$$

after the beginning of the frame (frame starts at timeslot *0*). The handset will then start its reply burst at

$$\Delta t_2 = 3\times 576.6\mu s \qquad (4)$$

after this, and thus at

$$\Delta t_1 + \Delta t_2 = 7\times 576.6 = 4.0362ms \qquad (5)$$

after the beginning of the BTS downlink frame. However there is a $TA=30$, which means the handset advances its transmission by

$$\Delta t_3 = 30\times 3.69 = 0.1107ms \qquad (6)$$

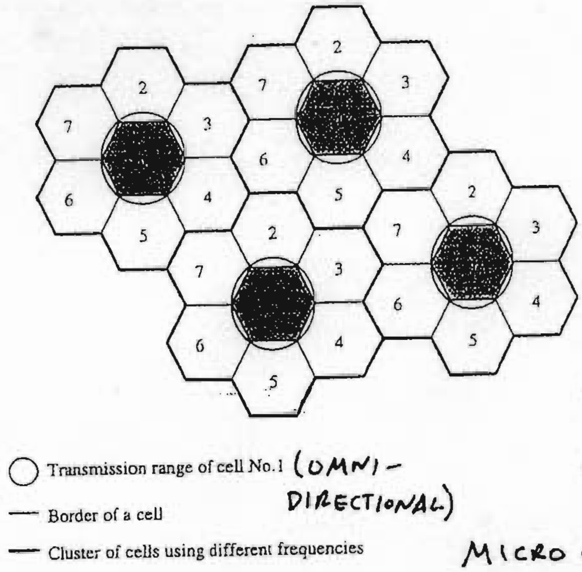
From the BTS point of view, the TA is there to compensate for any propagation delay, so the answer to **(i)** is given by (5) as

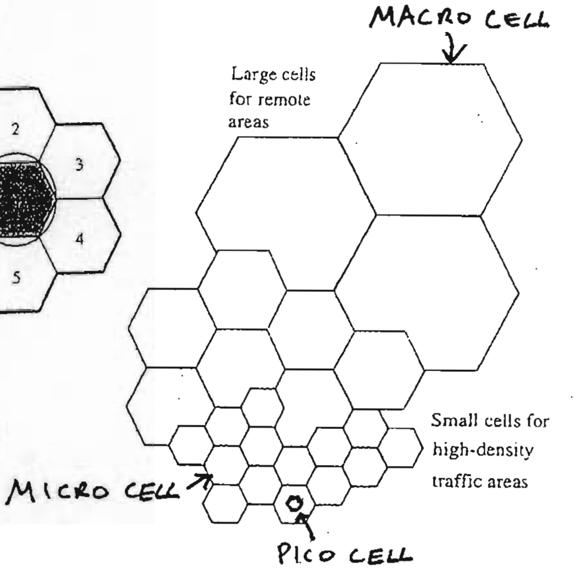
$$\Delta t_1 + \Delta t_2 = 4.0362ms \ (7)$$

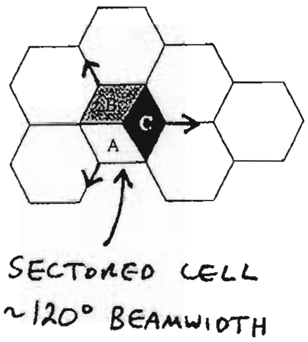
(ii) However from the handset point of view, the BTS downlink frame will start $\Delta t_3 / 2$ later, and the handset will start sending its burst Δt_3 earlier to compensate for the propagation delay at the BTS. Thus at the handset the time between the start of the received BTS downlink frame and its uplink frame is

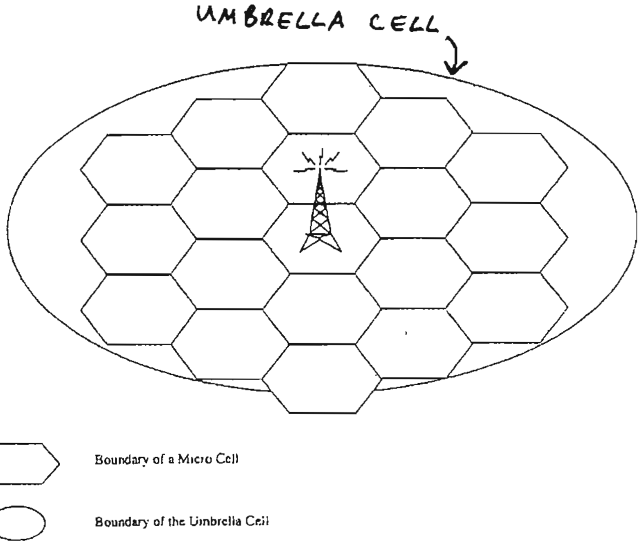
$$\Delta t_4 = \Delta t_1 + \Delta t_2 - \frac{3\Delta t_3}{2} = 3.87015ms \qquad (8)$$

Q4
(a)









Macro Cell: Typically deployed in rural areas and in the countryside to provide wide area coverage of *~5km* or more radius. Transmitter power may be *~10-20W* with antenna gain *~16-19dBi* giving an **E**quivalent **I**sotropic **R**adiated **P**ower (**EIRP**) of *~26-29dBW*. Could be omni-directional but most probably sectored and using space diversity gain on receive since size of a triangular antenna gantry not a problem. This is because the BTS most likely uses an existing TV mast or communications tower to mount the antenna platform on. Relatively low traffic density would be expected in the area covered, and call capacity limited. Trunking of calls to the mobile switching centre probably via a microwave link to the local telephone exchange.

Micro Cell: Typically used in urban areas and city centres where high traffic density is expected. Coverage of each cell less than ~*1km*, and could be a little as a few hundred metres along a street with an *EIRP* of ~*16-19dBW*. Could still be sectored, or may just use a single 'plank' antenna, or two fed in parallel for more omni-directional coverage. Will only use space diversity for increased gain if a gantry is mounted on the roof of a building for example. If the BTS uses a pole (similar to a lamp post) on the street as the antenna mast, then space diversity is not possible due size limitations on the antennas. However polarization and frequency diversity gains could still be used. Due to the increased number of cells in a given area, the call capacity is significantly increased in such urban areas. Can also be used to provide extra capacity in areas already covered by macro cells. BTS's probably hard-wired to the switch.

Pico Cell: Used to provide coverage in buildings, shopping arcades, railway stations etc., where signals from external BTS's may be attenuated. BTS may be just a 'box' on the wall, housing the transceiver unit and antenna.

Umbrella Cell: Area coverage cell duplicating coverage of several micro cells. Used for fast moving mobiles who would incur frequent handovers between micro cells, thereby degrading QoS and increasing network signalling load. Sited to cover motorways for example, and used according to Doppler frequency shift ($\propto$ speed) on mobile signal.

Sectored Cell: The most common BTS antennas are 'plank' arrays of vertically stacked elements backed by a groundplane. As such they inherently have a $\sim 120^o$ azimuthal radiation pattern, lending themselves to a 3 sectored cell configuration. They could be mounted along the sides of a triangular gantry, or as a back-to-back cluster on the top of a pole. Assuming a fundamental limit on the number of traffic channels that can be coupled into a single antenna, plus the fact that sectored cells allow frequency re-use within shorter distances due to their directional radiation, then sectoring increases call capacity by allowing up to three cells at one BTS site. Sectoring also allows the network to have more precise location information about the mobile, which can be used for mobile internet data services, such as finding your nearest petrol station etc.

(b)

The bit rate of a GSM signal is $1/\tau = 270kbps$, whereas the chip rate of a 3G WCDMA transmission is $1/\tau = 3.84Mbps$, where τ denotes the bit period. Therefore a delay of τ in the reflected path (with respect to the direct path) from handset to BTS will potentially cause bit cancellation if the two signals are of comparable strengths. This delay corresponds to an extra reflected path length difference of $c\tau$ where $c = 3 \times 10^8 m/s$. Thus $c\tau|_{GSM} = 1.1km$ and $c\tau|_{3G} = 78m$. In a city centre, reflection off nearby buildings etc. will almost always cause significant path length differences of much less than *1.1km*, but differences of ~*78m* are quite likely however.

Rake reception could be used to compensate for this delay so that both direct and reflected path signals could be added coherently with correct time synchronization. The direct and reflected path signals would each be assigned a Rake finger, and delays and phase discrepancies between the two equalized before combining.