## SOLUTION TO EEE443/6430 (2009) QUESTION 1

**(a)**

| 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

Structure of a normal burst.

A *normal burst* in *GSM* can be transmitted from the mobile to the BTS or vice-versa. The *tail bits* are used as a guard time to cover the periods of uncertainty in power ramping, and are always set to zero. The *guard period* allows for the ramping down of the current burst power, and simultaneously the next burst ramps its power up in this time. No data is transmitted in this period. The *coded data* portions contain the actual information to be relayed, either signalling data used to allow the network and mobile to exchange link control information, or traffic data such as coded speech. The type of data is indicated by the *stealing flags*, which allow the receiver to correctly route the information (e.g. to speech decoders or to frequency control circuits). The *training sequence* is a fixed bit sequence known to both transmitter and receiver. It is used to compensate for signal distortion due to multi-path fading. The *equaliser* in the receiver compares the received training sequence with what it knows it should be, and then adjusts its own filter characteristics to correct the received sequence. These filter characteristics will then also be effective in correcting the remaining unknown coded data.

The logical channels that are mapped onto the burst are *Traffic CHannels* (*TCH)*, *Broadcast Control CHannels* (*BCCH*), *Common Control CHannels* (*CCCH*) and *Dedicated Control CHannels* (*SDCCH, SACCH, FACCH*).

**(b)**

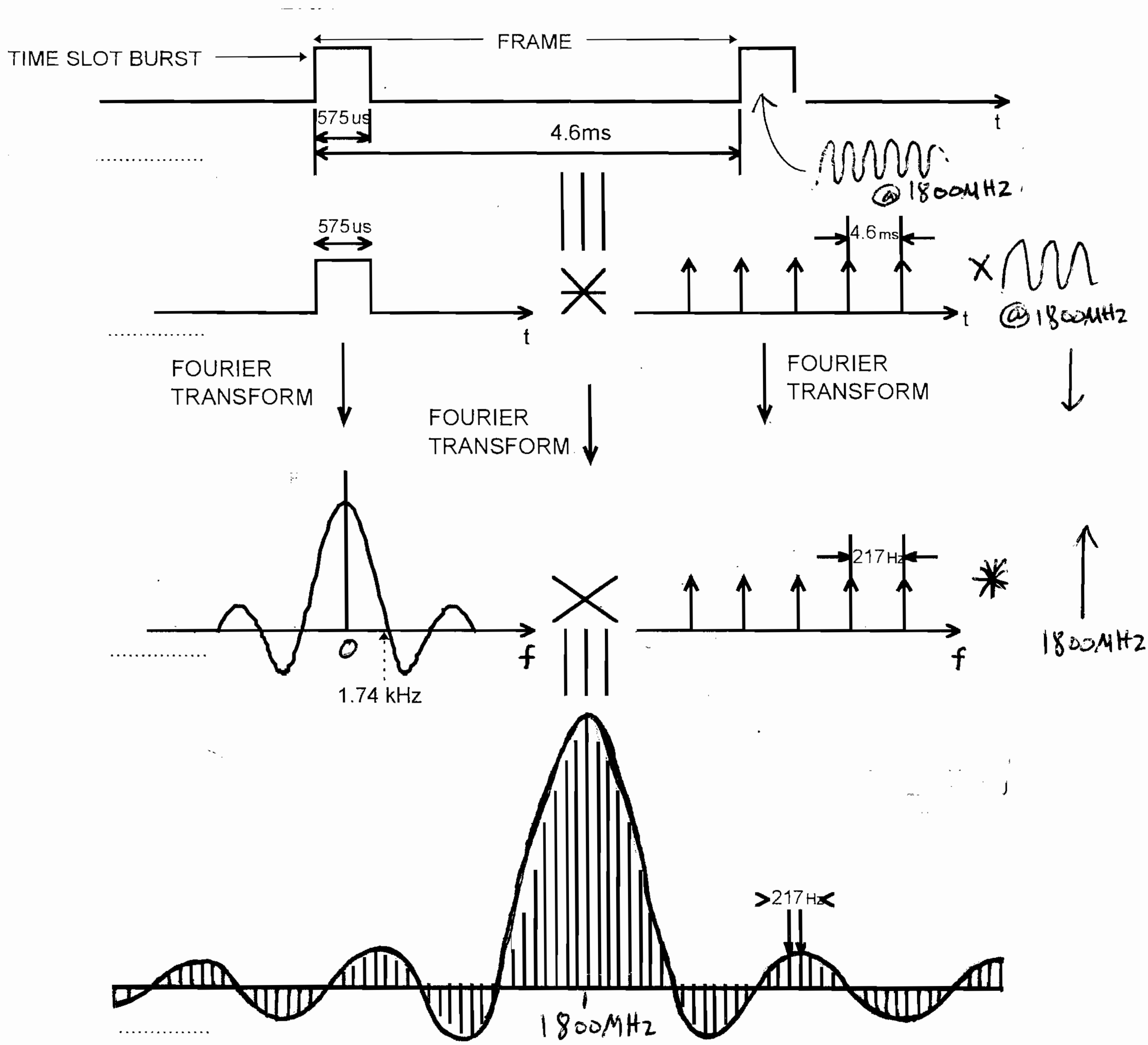
Since all bits are set equal in the burst, the spectrum is given by

$$\left[F(f)\times\delta_{f_o}(f)\right]*\delta(f-f_c) \qquad (1)$$

where

$$F(f)=A\int_{-\frac{\tau}{2}}^{\frac{\tau}{2}}e^{-j2\pi ft}dt=A\tau Sa(\pi f\tau) \quad (2),$$

$\tau=.575ms$ is the burst duration, $f_c=1800MHz$ and $\delta_{f_o}(f)$ is a series of delta functions in frequency separated by the reciprocal of the burst repetition period $T=4.6ms$, so that $f_o=217Hz$. Hence the spectrum:




**(c)**

The 'buzzing' noise is caused by the frequency components being separated by $217Hz$. When these are present in a non linear medium such as audio amplifier circuitry they produce low frequency inter-modulation products of $n \times 217Hz$.

## SOLUTION TO EEE443/6430 (2009) QUESTION 2

**(a)**

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

88 Bit = 324.72 µs

Structure of a random access burst.

The random access burst is so called because the *MS* transmits this type of burst at random times, and only when a mobile is trying to gain initial access to the system. The long guard period compared to a normal burst 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 ($300m/\mu s$). 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. Once a successful access attempt has been made, the *BTS* then instructs the phone to *time advance* its transmissions by $n \times 3.69\mu s$, ($n = 0$ *to 63* depending on the distance) so that the *BTS* actually receives data at the beginning of the time slot allocated to the *MS*.

**(b)**

The $TA = n$ therefore includes distance information about the *MS* and *BTS*. Thus

$$\frac{2d}{c} = n \times 3.69\mu s \quad (1)$$

so

$$d = n \times 553.5\, m \quad (2)$$

Hence if $n=20$ then $d=11.07\ km$. Assuming the clock recovery is with respect to keeping the majority of a bit within the expected receive epoch, then each non-zero *TA* distance estimate has an error of $\pm 277m$ .

The *RA* bit sequence must get back to the *BTS* while it is still 'listening out' for an *RA* attempt. This listening period is basically $68 \times 3.69\mu s \approx 251\mu s$. Thus

$$\frac{2d_{max}}{c} \approx 251 \quad (3)$$

so

$$d_{max} \approx 251 \times 150 = 37.65km \quad (4)$$

Hence an *MS* will not be able to access a cell, even with a good signal path, if it is further than about *37km* away. With an analogue system, access will be possible at any distance so long as the propagation between *MS* and *BTS* is adequate.

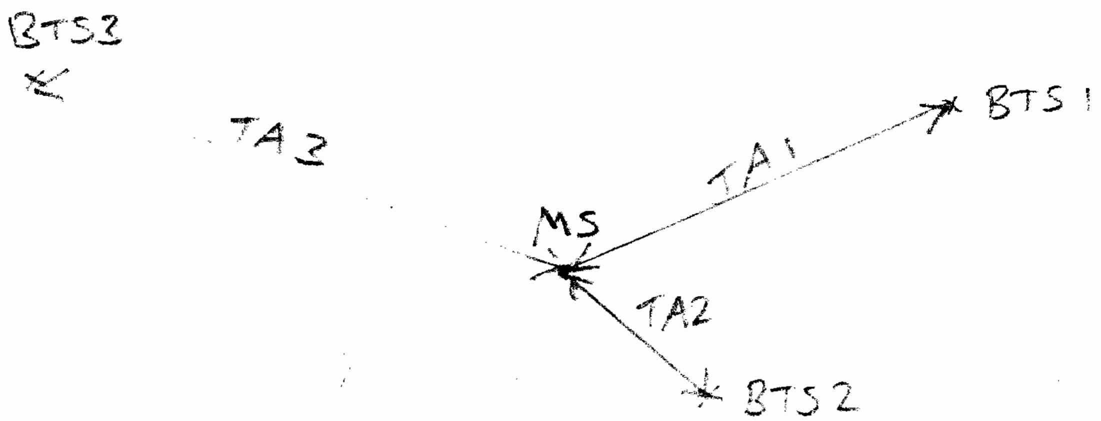
**(c)**

Using appropriate software, upon request, the *MS* could make *RA* attempts to several strong *BTS's*. The network will have location information about each *BTS*, and could therefore correlate each *TA* with the respective *BTS*, and thus triangulate the *MS* position. The accuracy of this location finding would be dependent on several factors:

(i) The number and spatial distribution of *BTS's* used

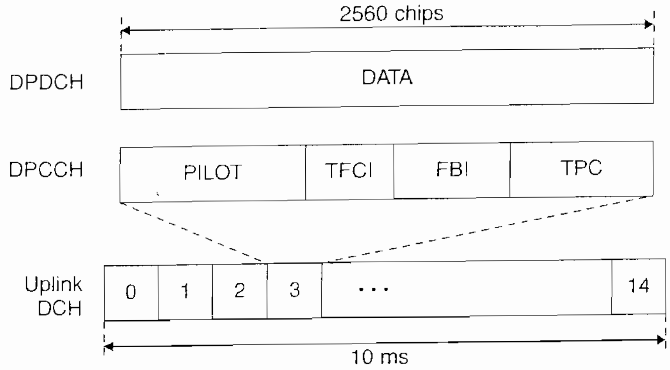
(ii) The accuracy of the bit sampling at the *BTS*. For example, one sample per bit would produce an error bar of $\pm 277m$ for each *BTS*.

*GPS* derived data is more accurate, but requires a *GPS* receiver built into the *MS*. The satellite platform means that the *GPS* signal can become unreliable in wooded areas and buildings etc., where a *GSM* signal may still get through.

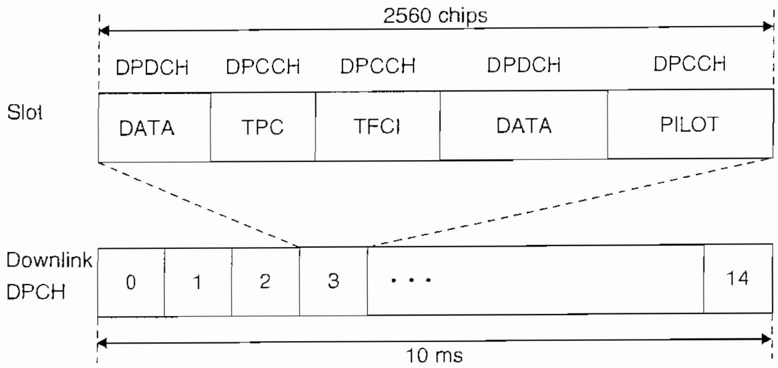


**SOLUTION TO EEE443/6430 (2009) QUESTION 3**

**(a)**




Uplink dedicated channel structure

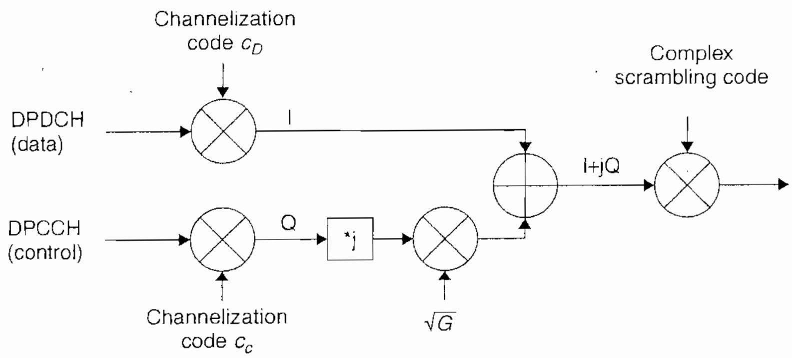



Downlink Dedicated Physical Channel (Downlink DPCH) control/data multiplexing

The *Dedicated Physical Data CHannel* (*DPDCH*) carries user payload data, such as speech for a particular call, whereas the *Dedicated Physical Control CHannel* (*DPCCH*) carries control information for that call. The *DPDCH* data rate may vary on a frame by frame basis, which is informed on the *DPCCH* via the *Transport Format Combination Indicator* (*TFCI*). The *Pilot* bits are used for channel estimation in the receiver. The *Transmission Power Control* (*TPC*) bits carry commands on the downlink for the *MS* power control and the *FeedBack Information* (*FBI*) bits are used for relaying the received *BTS* quality on the uplink, providing closed loop transmission diversity. If *TFCI* is not present, then lower data rates are implemented with *Discontinuous Transmission* (*DTX*), by gating slots at a rate of *1500Hz* (1/slot period).

**(b)**

The *DPDCH* and *DPCCH* are spread using channelisation codes running at *3.84Mcps*, and are subsequently scrambled at the same rate. In the uplink direction, the handset transmits using dual channel *QPSK* modulation, also called *I-Q* Code multiplexing, where the control and data channels are transmitted as orthogonal (*IQ*) data streams.




I-Q/code multiplexing with complex scrambling

This is to maintain a more even signal level during *DTX* periods to minimise the generation of audio frequency intermodulation products caused by pulsed transmission, as is evident when a *GSM* handset is placed near audio equipment for example. The two channels are also transmitted with a 4-bit power difference on the uplink. Since this is not an issue for *BTS* transmissions, the downlink uses normal *QPSK* where the control and data streams are time-multiplexed. The scrambling codes are used to differentiate between terminals in the uplink, and cells in the downlink, whereas the channelisation codes differentiate data and control channels in the uplink and terminals in the downlink. Variable spreading factors are used for the *DPDCH* channelisation codes between *4 - 256* (*512* in downlink), dependent on the data channel bit rate, whereas the *DPCCH* uses a fixed spreading factor of *256*. When higher data rates are needed, up to *6* parallel code channels are used, raising the channel bit rate up to a maximum of *5760kbps*.

**(c)**

(I) Uplink *DPDCH*:

(i) Symbol rate $= 3.84 \times 10^6 / 32 = 120kbps$

(ii) Bit rate = *120kbps*

(iii) Max user data rate *~60kbps* (approx. half bit rate)

(II) Downlink *DPCH*:

(i) Symbol rate = *120kbps*

(ii) Bit rate = *240kbps*

(iii) Max user data rate *~120kbps* (approx. half bit rate)

**SOLUTION TO EEE443/6430 (2009) QUESTION 4**

**(a)**

| Feature | 3G | GSM |
|---|---|---|
| Carrier spacing | 5MHz | 200kHz |
| Frequency reuse factor | 1 | 1-18 |
| Power control frequency | 1500Hz | < 2Hz |
| Frequency diversity | Inherent in 5MHz bandwidth | Frequency hopping |
| Packet data | Load based packet scheduling | Time slot based scheduling with GPRS |
| Downlink transmit diversity | Supported for improving downlink capacity | Not supported by the standard |

**(b)**

Frequency diversity is employed to help combat the effects of multipath fading on the carrier.

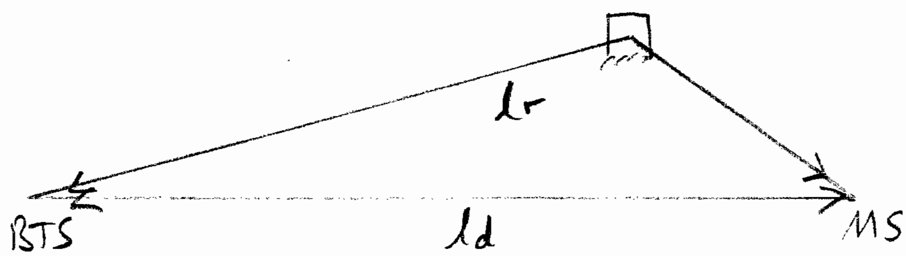
Spectral components of digital signals propagate as

$$S(t,\ell) = A\cos(\phi) \qquad (1)$$

where

$$\phi = \frac{2\pi}{\lambda}(ct - \ell) \qquad (2)$$

and $\lambda, \ell$ denote the wavelength and path length respectively. Consider a direct path between *MS* and *BTS* $\ell_d$ and an effective indirect path $\ell_r$ due to reflection off a building (including any phase change at reflection).




The spectral component at time *t* is then received as

$$S(t,\ell) = A_d\cos(\phi_d) + A_r\cos(\phi_r) \quad (3).$$

If

$$\phi_r - \phi_d = \frac{2\pi}{\lambda}(\ell_r - \ell_d) = (2n+1)\pi \qquad (4)$$

then there will be partial cancellation (a fading null) of this spectral component (complete cancellation if $A_d = A_r$).

For such cancellation therefore

$$(\ell_r - \ell_d) = (2n+1)\frac{\lambda}{2} \qquad (5)$$

and clearly if the wavelength varies slightly then the equality in (5) no longer holds and the degree of cancellation is ameliorated.

Thus in *GSM* systems, the frequency of each *4.6ms* frame is cyclically rotated through about *5* channels, called frequency hopping, so that any severe fading null will only prevail for a fraction of the total transmission time. Such hard switched frequency changes are required because the *200kHz* spectral bandwidth of the signal does not contain enough wavelength diversity to significantly affect any fading nulls.

In *3G* however, the total signal bandwidth of *5MHz* is wide enough to accommodate sufficient wavelength diversity to shift fading nulls. In other words, if one spectral component of the digital waveform is cancelled, there will be others at different frequencies that are not, thus helping to preserve the data.

**(c)**

At *2GHz* the wavelength is

$$\lambda = \frac{c}{f} = 15cm \qquad (6)$$

Thus the path length difference is

$$(\ell_r - \ell_d) = \frac{150.075}{.15} = 1000.5\lambda \qquad (7).$$

At *2.005GHz*

$$\lambda = \frac{c}{f} = 14.96cm \qquad (8)$$

so

$$(\ell_r - \ell_d) = \frac{150.075}{.1496} = 1003.18\lambda \qquad (9).$$

If both paths were received with equal amplitude there would be complete signal cancellation at *2GHz* since the effective path length difference is an odd number of half wavelengths and therefore the direct signal is in anti-phase with the scattered signal. However at *2.005GHz* the direct and scattered signals are no longer in anti-phase, so a resultant signal would be received.

In reality, the scattered signal would probably be weaker than the direct, so there would be a resultant received signal at the handset at *2GHz*, but the *2.005GHz* signal would still be stronger.