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**Section 10: Multiple user access for wireless communications**

Multiple access schemes allow many users to share a given amount of radio bandwidth. Frequency division multiple access (FDMA) time-division multiple access (TDMA) and code division multiple access (CDMA) are the three main techniques available. CDMA is a type of "spread spectrum multiple access" technique. To these techniques we must add "space division multiple access" meaning that the same band-width is re-used in different places far enough apart (or shielded by mountains or high buildings) such there is no significant transmission from one place to the other. We can also add "packet radio (PR)" as a form of time division multiplexing where the bandwidth, or some of, is requested for a short time slot only when a packet of data is ready to be transmitted.

It is useful to define wireless systems as being narrow-band or wide-band. Narrow-band systems are such that the bandwidth used by a single channel for transmission is low with respect to the coherence bandwidth ( $B_C$  Hz) of the channel. Wide-band systems have the transmission bandwidth much higher than  $B_C$ . The coherence bandwidth is a measure of the range of frequencies over which the channel fading can be considered flat i.e. all spectral components within this range are received with approximately equal gain and delay imposed by the channel and its multi-path effects. If there is fading, all frequencies in this range will suffer approximately the same amount of attenuation. Two sinusoids with frequency separation much greater than the  $B_C$  Hz will be affected quite differently by the channel. The coherence bandwidth is often assumed to be proportional to  $1/\sigma_t$  where  $\sigma_t$  is the " r.m.s. delay spread", i.e. a measure of the spread of delays occurring due to multi-path propagation. Typically  $B_C \approx 0.2 / \sigma_t$  though the exact definition of  $B_C$  (i.e. how flat is acceptable as flat fading), and hence the constant (0.2) seems to vary in the literature. A typical delay-spread measurement in a large city with lots of reflections from buildings would be of the order of 1 to 10 microsecond for a 900 MHz wireless system (about 0.3  $\mu$ s inside the buildings). A **coherence bandwidth** of 30 kHz would allow an analogue mobile phone system with 30 kHz channels to work without the need for an equaliser. However a 900 MHz GSM system with 200 kHz bandwidths for the digital transmission of speech and data would require equalisation.

**FDMA** divides up the available bandwidth by assigning an individual frequency band to each channel. The American analogue "AMPS" cellular mobile telephone system divides a 70 MHz band (824 to 894 MHz) into 1664 channels, each of 30 kHz, with 10 kHz "guard-bands" between each channel (leaving some spare bandwidth). The 1664 are split into 832 reverse and 832 forward channels each pair of forward and reverse channels being separated by a fixed frequency separation. Each cellular carrier is allocated 416 channels and must use space division multiplexing to allow a large number of users to use these channels. FDMA is usually implemented with narrow-band channels for which equalisation is not needed

**TDMA** uses an available frequency band by transmitting a high frequency bit-stream containing data from many users. Each user is allocated a cyclically repeating time slot within the bit-stream. Therefore digital encoding and transmission techniques must be used. Transmissions from different users are interlaced into a repeating frame structure. Each frame has a number of "preamble" bits for synchronisation purposes, the bit-stream containing data from all the users, and then a few "tail bits" to terminate the frame. GSM cellular systems use 25 MHz bands (in the frequency range 890 to 960 MHz) for the forward and reverse links split into 200 kHz channels (by frequency division multiplexing) each of which supports eight 24.7 kb/s speech channels (with spare capacity) interleaved in a 270.833 kbits/second bit-stream. GSM transmits 270,833 b/s in each 200 kHz sub-band by a form of binary FSK known as MSK with Gaussian pulse shaping. Adaptive equalisation is usually needed since the 200 kHz bandwidth is higher than the coherence bandwidth and hence frequency selective fading will occur within some or all of the 200kHz channels. There are 250 such channels thus allowing the system to accommodate 1000 (potentially interfering) users each with a 24.7 kb/s forward channel and a 24.7kb/s reverse channel. The use of space division multiplexing (cellular radio) increases this number.

**SSMA** ("spread spectrum multiple access" techniques use transmitters which spread the information over a bandwidth several orders of magnitude wider than would be needed with ordinary PSK, FSK or ASK. While this may seem inefficient, it is done in such a way that many users can transmit simultaneously over the same very wide frequency band, their transmissions being separable at a receiver. There are two main types of SSMA: "frequency hopped" (FH) and "direct sequence" (DS). The latter is also known as "code division multiple access" (CDMA).

**FH-MA** ("frequency hopping multiple access") can be applied to transmission schemes such as PSK by varying the carrier frequencies in a pseudo-random fashion within a wide-band channel. The data to be transmitted is split into blocks each of equal duration, and each is transmitted and received with a different carrier frequency. If the rate of hopping is greater than the symbol rate it is said to be "fast hopping". If the rate is less than or equal to the symbol rate this is "slow hopping". The choice of frequencies must be made according to a known pseudo random sequence and synchronised at transmitter and receiver. FHMA provides security and also considerable immunity to fading since the effect of deep fades at particular frequencies will be spread out among all users each being degraded for just a short period of time (until he "hops" onto another carrier). The effect of the short duration degradation can be minimised by error coding or "diversity" transmissions.

**CDMA** is achieved by multiplying a base-band signal not by a sinusoidal carrier but instead by a very large bandwidth signal called a "spreading signal". The base-band signal represents the data stream to be transmitted (e.g. a 24.7 kb/s digitised speech channel). The spreading signal is created in digital form by generating a pseudo-random sequence of bits at a very high sampling rate called the "chip-rate". The chip rate will be many orders of magnitude higher than the data-rate (e.g. 24.7 kb/s for the data and 1228.8k chips per second for the spreading signal; a factor of about 50). The

multiplication is done digitally where each data bit modulates about 50 pseudo random "chips". The stream of chips is transmitted as a very wide-band signal. The receiver, knowing the chip sequence can recover each data bit by a cross-correlation process. CDMA has the advantages of a "soft" capacity limit; i.e. as more and more users start to share the same bandwidth, the quality of signal received will degrade slowly. The effects of multi-path fading are substantially reduced because of the spreading. However power control is a difficulty with CDMA due to the well known "near-far" problem (see Rappaport page 406).

**Packet radio** access techniques as used by wireless networks have possibly many users attempting to access a single channel in an uncoordinated (or minimally co-ordinated) way. Access occurs in short bursts for each user, and techniques for detecting or avoiding collisions (as on wired networks) are needed.

### **CSMA with Collision Detection and/or Collision Avoidance**

With earlier forms of wired Ethernet (e.g. 10BASE-2 or "thin Ethernet") where all hosts are connected to a single coaxial cable acting as a "bus", all users had to compete for access to this bus according to a set of carrier sensing multiple access (CSMA) protocols. These involved:

- Collision avoidance (CSMA/CA) by sensing the channel to determine whether there is a signal present from another device before attempting a transmission, and waiting until it is clear.
- Collision detection (CSMA/CD) while transmitting to determine whether another device is transmitting at the same time and rendering the transmission useless. This can happen when two devices find the channel clear and start to transmit at once.

If a collision is detected, further collisions are avoided by a 'random back-off' mechanism whereby each device involved in the collision selects a random delay and waits this amount of time before retransmitting.

One important difference between wireless LAN medium access protocols and the Ethernet strategy is that unlike an Ethernet device, a wireless LAN device cannot listen while it is transmitting so that "collision detection" (CSMA/CD) is not possible. Wireless LANs must rely on CA mechanisms.

A form of priority for different packet types is introduced by forcing each device to wait for a period of time after finding the radio channel free. Different delays are enforced for different packet types. The two most important for IEEE802.11b/g are 'short' and 'distributed' inter-frame spacing (SIFs and DIFs). Important packets only have to wait for the shorter 'SIFS' time and hence gain access to the network before less important packets required to wait for 'DIFS'.

### **The 'hidden node' problem**

The "hidden node" problem occurs with a wireless LAN when two devices A and B say, are in range with a third device, C, but out of range with each other. If A transmits to C and B cannot sense or detect this transmission, B may start transmitting also thus causing a collision with A's message and rendering it useless.

In some cases, maybe for short messages, we may choose to take a chance and allow such "hidden node" collisions to occur from time to time relying on retransmissions (with randomised time delays or back-off as normally used with Ethernet) to achieve corrected transmissions.

In other cases it is safer to use a "request-to send/clear-to send (RTS/CTS) protocol between devices before any of them starts a transmission. The RTS/CTS protocol requires the sending device to send a short RTS (request to send) control packet and to receive a short CTS (clear to send) control packet before attempting a transmission. The CTS is sent to tell just one device that it may transmit and to tell all other devices to stay quiet for a period of time. Other devices stay quiet by setting their 'network allocation vectors' NAVs for a specified period of time. RTS/CTS packets can also collide with other hidden node transmissions, but they are made to very short to minimise this occurrence.