CDMA Mobile Communication & IS-95

Spread Spectrum Priniciples

- Does not attempt to allocate disjoint frequency or time slot resources
  - Instead, this approach allocates all resources to simultaneous users, controlling the power transmitted by each user to the minimum required to maintain a given SNR
- Each user employs a noise-like wideband signal occupying the entire frequency allocation
- Each user contributes to the background noise affecting all users, but to the least extent possible.

Spread Spectrum Priniciples

- This restriction on interference limits capacity, but because time and bandwidth resource allocations are unrestricted, the resulting capacity is significantly higher than the conventional system

Spread Spectrum PrinicIples

- Suppose each user use a wideband Gaussian noise carrier
- Suppose each user's transmission is controlled so that all signals received at the BS are of equal power
- Let P_s be the power of each user, and the background noise be negligible.
- Then the total interference power, I, presented to each user's demodulator is

$$I = (K-1)\,P_s \quad (1)$$ where K is the number of users

Spread Spectrum Priniciples

- Let’s say demodulator of each user operates at bit-energy-to-noise-density level of E_b/N_0.
- So the noise density received by each user’s demodulator is $N_0 = I/W$ (2), where W Hz is the bandwidth of the wideband noise carriers
- The received energy per bit is the received signal power divided by the data rate R (bits/s), i.e., $E_b = P_s/R$ (3)

Spread Spectrum Priniciples

- Combining (1), (2) and (3) we get

  $K - 1 = I/P_s = (W/R) / (E_b/N_0)$ (4)

- If W >> R then the capacity of the system can be large
  - i.e., transmission bandwidth should be much larger than the message bandwidth
- If E_b/N_0 is small, then also the capacity can be large. (since $E_b/N_0 \propto$ SNR, this means SNR should be as small as possible)

Code Division Multiple Access - CDMA

- Multiple users occupying the same band by having different codes is known as CDMA - Code Division Multiple Access system

Let

W - spread bandwidth in Hz

R = $1/T_b$ = Date Rate

S - received power of the desired signal in W

J - received power for undesired signals like multiple access users, multipath, jammers etc in W

E_b - received energy per bit for the desired signal in W

N_0 - equivalent noise spectral density in W/Hz

CDMA (contd…)

$$\frac{J}{S} = \frac{N_0 W}{E_b / T_b} = \frac{W T_b}{E_b / N_0} = \frac{W / R}{E_b / N_0}$$

$$\left(\frac{J}{S}\right)_{\max} = \frac{W / R}{(E_b / N_0)_{\min}}$$

What is the tolerable interference over desired signal power?

$$\left(\frac{J}{S}\right)_{\max} = \text{Jamming margin (db)} = \frac{W}{R}(db) - \left(\frac{E_b}{N_0}\right)_{\min}(db)$$

CDMA (contd…)

- In conventional systems $W/R \approx 1$ which means, for satisfactory operation $J/S < 1$

- Example Let $R = 9600$; $W = 1.2288$ MHz
  $(E_b/N_0)_{min} = 6$ dB (values taken from IS-95)
  Jamming margin (JM) = $10\log_{10}(1.2288*10^6/9.6*10^3) - 6$
  $= 15.1 \text{ dB} \equiv 32$

- This antijam margin or JM arises from Processing Gain (PG) = W/R = 128

- If $(E_b/N_0)_{min}$ is further decreased or PG is increased, JM can be further increased

CDMA (contd…)

- JM can be used to accommodate multiple users in the same band
- If $(E_b/N_0)_{min}$ and PG is fixed, number of users is maximized if perfect power control is employed.
- Capacity of a CDMA system is proportional to PG.

Spreading Codes

- A noise-like and random signal has to be generated at the transmitter.
- The same signal must be generated at the receiver in synchronization.
- We limit the complexity by specifying only one bit per sample, i.e., a binary sequence.

Desirable Randomness Properties

- Relative frequencies of "0" and "1" should be ½ (Balance property)

- Run lengths of zeros and ones should be (Run property):
  - Half of all run lengths should be unity
  - One - quarter should be of length two
  - One - eighth should be of length three
  - A fraction $1/2^n$ of all run lengths should be of length n for all finite n

Desirable Randomness Properties (contd…)

- If the random sequence is shifted by any nonzero number of elements, the resulting sequence should have an equal number of agreements and disagreements with the original sequence (Autocorrelation property)

PN Sequences

- A deterministically generated sequence that nearly satisfies these properties is referred to as a Pseudorandom Sequence (PN)
- Periodic binary sequences can be conveniently generated using linear feedback shift registers (LFSR)
- If the number of stages in the LFSR is r, $P \leq 2^r - 1$ where P is the period of the sequence

PN Sequences (contd…)

- However, if the feedback connections satisfy a specific property, $P = 2^r - 1$. Then the sequence is called a Maximal Length Shift Register (MLSR) or a PN sequence.
- Thus if r=15, P=32767.
- MLSR satisfies the randomness properties stated before

Randomness Properties of PN Sequences

- *Balance property* - Of the $2^r - 1$ terms, 2^{r-1} are one and $2^{r-1}-1$ are zero. Thus the unbalance is 1/P. For r=50; $1/P \cong 10^{-15}$
- *Run length property* - Relative frequency of run length n (zero or ones) is $1/2^n$ for $n \leq r-1$ and $1/(2^r - 1)$ for n = r
- One run length each of r-1 zeros and r ones occurs. There are no run lengths for n > r
- *Autocorrelation property* - The number of disagreements exceeds the number of agreements by unity. Thus again the discrepancy is 1/p

PN Sequences Specified in IS-95

- A "long" PN sequence (r =42) is used to scramble the user data with a different code shift for each user
- The 42-degree characteristic polynomial is given by:
  - $x^{42}+x^{41}+x^{40}+x^{39}+x^{37}+x^{36}+x^{35}+x^{32}+x^{26}+x^{25}+x^{24}+x^{23}+x^{21}+x^{20}+x^{17}+x^{16}+x^{15}+x^{11}+x^{9}+x^{7}+1$
- The period of the long code is $2^{42} - 1 \approx 4.4*10^{2}$ chips and lasts over 41 days

PN Sequences Specified in IS-95 (contd…)

- A short PN sequence (r = 15) is specific to a base station and its period is $(2^{15}-1)T_c$ = 27ms.
- Two “short” PN sequences (r=15) are used to spread the quadrature components of the forward and reverse link waveforms

Power Control in CDMA

- CDMA goal is to maximize the number of simultaneous users
- Capacity is maximized by maintaining the signal to interference ratio at the minimum acceptable
- Power transmitted by mobile station must be therefore controlled
  - Transmit power enough to achieve target BER: no less no more

Two factors important for power control

- Propagation loss
  - due to propagation loss, power variations up to 80 dB
  - a high dynamic range of power control required
- Channel Fading
  - average rate of fade is one fade per second per mile hour of mobile speed
  - power attenuated by more than 30 dB
  - power control must track the fade

Power Control in IS-95A

- At 900 MHz and 120 km/hr mobile speed Doppler shift =100Hz
- In IS 95-A closed loop power control is operated at 800 Hz update rate
- Power control bits are inserted (‘punctured’) into the interleaved and encoded traffic data stream
- Power control step size is +/- 1 dB
- Power control bit errors do not affect performance much

Rake Receiver

- Mobile station receives multiple attenuated and delayed replicas of the original signal (multipath diversity channels).
- Two multipath signals are resolvable only if their relative delay exceeds the chip period Tc
- Amplitudes and phases of multipath components are found by correlating the received waveform with multiple delayed versions of the signal (delay = nTc).
- Searcher performs the above task for up to 3 different multipath signals.
- 3 parallel demodulators (RAKE fingers) isolate the multipath components and the RAKE receiver combines them.

Handoff in CDMA System

- In GSM hard handoff occurs at the cell boundary
- Soft Handoff
  - Mobile commences Communication with a new BS without interrupting communication with old BS
  - same frequency assignment between old and new BS
  - provides different site selection diversity
- Softer Handoff
  - Handoff between sectors in a cell
- CDMA to CDMA hard handoff
  - Mobile transmits between two base stations with different frequency assignment

Soft Handoff- A unique feature of CDMA Mobile

Advantages

- Contact with new base station is made before the call is switched
- Diversity combining is used between multiple cell sites
  - Diversity combining is the process of combining information from multiple transmitted packets to increase the effective SNR of received packets
  - additional resistance to fading
- If the new cell is loaded to capacity, handoff can still be performed for a small increase in BER
- Neither the mobile nor the base station is required to change frequency

References

- Lee JS and Miller LM, CDMA System Engineering Handbook, Arttech Publishing House, 1998.
- Viterbi A, CDMA-Spread Spectrum Communication, Addison Wesley 1995.