Mid-Semester Test

Instructor: B. Sainath, 2210A, Electrical and Electronics Eng. Dept., BITS Pilani.

Course No./Title : G522/Advanced Satellite Communication DATE: Oct. 4^{th}, 2016. Test duration: 90 Mins.

Max. points: 30.

Part I: Solve/Answer the following.

Q. 1. [5 points] Read the following traffic model carefully before attempting to answer questions.

- Each user generates packets according to a Poisson process with an average arrival rate equal to λ packets per unit time.
- The packets are stored in a buffer and served at an average rate μ.
- Average load to the system is simply the ratio of average arrival rate to the average service rate.

Consider a satellite packet communication system. In it, link transmission rate is R bps and is equal to channel capacity. It uses FDMA mode and there are N users.

a. What is the expression for the channel capacity assigned for each user ? [0.5 point]

b. Assume that average packet length is L bytes. What is the average service rate of FDMA channel ? [0.5 point]

c. Write down the expression for average load (ρ) (also called traffic intensity) for each channel ? [0.5 point]

Assuming constant packet length model, the packet delay for the FDMA ($T_{d,\text{FDMA}}$) channel which include roundtrip delay RTD is given by

$$T_{d,FDMA} = \frac{2-\rho}{2\mu(1-\rho)} + RTD. \tag{1}$$

d. Consider a FDMA system of 400 users sharing a satellite channel with capacity of $R = 25.6$ Mbps. Assume that each user generate a constant-length packet of 1250 bytes according to a Poisson process at a rate of 3 packets per second.

(i). Compute the channel capacity assigned for each user ? [0.5 point]

(ii). Compute the average service rate of each FDMA channel in packets per second. [0.5 point]

(iii). Compute the average packet delay for each user when RTD $= 270$ ms. (Hint: Use (1)) [1 point]

Assuming an exponentially distributed packet length, the packet delay for the FDMA ($T_{d,\text{FDMA}}$) channel which include roundtrip delay RTD is given by

$$T_{d,FDMA} = \frac{1}{\mu(1-\rho)} + RTD. \tag{2}$$

(i). Compute the average packet delay for each user when RTD $= 270$ ms. (Hint: Use (2)) [1 point]

(ii). In which model latency is more ? [0.5 point]

Q. 2. [4 points] A satellite transponder has a bandwidth of 36 MHz. Earth stations use root-raised-cosine (RRC) filters with roll-off factor of 0.2. What is the maximum bit rate that can be sent through this transponder with

a). 8-PSK [1 point] b). 64-QAM [1 point] c). Compute spectral efficiency for both a) and b). [2 points]

Q. 3. [5 points] Describe the following in <u>two</u> sentences with appropriate illustrations.

a). Intermodulation (IM) noise in FDMA. b). Processing gain in direct sequence spread spectrum. c). TDMA frame efficiency. d). Sun transit outage. e). Doppler shift in LEO satellite system.

Q. 4. [5 points] (a). State <u>two</u> differences between a geosynchronous satellite and a geostationary satellite orbit ? [1 point]

(b). The orbital period of a geostationary satellite is 23 hours, 56 minutes, and 4.1 seconds. It is called a sidereal day. What is the velocity (in KM/Sec) of a geostationary satellite in its orbit? Note: Assume the average radius of the earth is $6,378.137$ KM and orbital height equal to $35,786.03$ KM. [1 point]

(c). A geostationary transfer orbit (GTO) has an apogee of 35786.03 KM and a perigee of 270 KM.

(i). What is the size of semimajor axis ? [1 point]

(ii) Assuming the eccentric anomaly equal to zero, what was the eccentricity of the GTO? [1 point]

(iii) What was the period of the GTO? [1 point]

Note: Kepler's constant has the value 3.986004418×10^5 km^3/s^2.

Q. 5. [7 points] Consider TDMA frame structure and burst structure shown in Figure 1 and Figure 2. Note that the guard interval is present between any two successive bursts. Consider the following parameters:

- The TDMA frame length is 15 ms and the TDMA burst bit rate is 90 Mbps.
- There are 10 stations. Each station transmits 2 traffic bursts for a total of 20 traffic bursts in frame plus 2 reference bursts.

- The length of carrier and clock recovery sequence is 352 bits.
- The length of the unique word is 48 bits and the order wire channel has 510 bits.
- The management channel has 256 bits, the service channel has 24 bits, and the transmitting timing channel has 320 bits.
- The Guard time is assumed to be 64 bits.

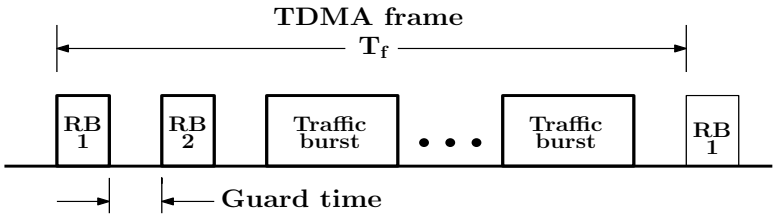

Fig. 1: TDMA frame of duration T_f; RB: reference burst.

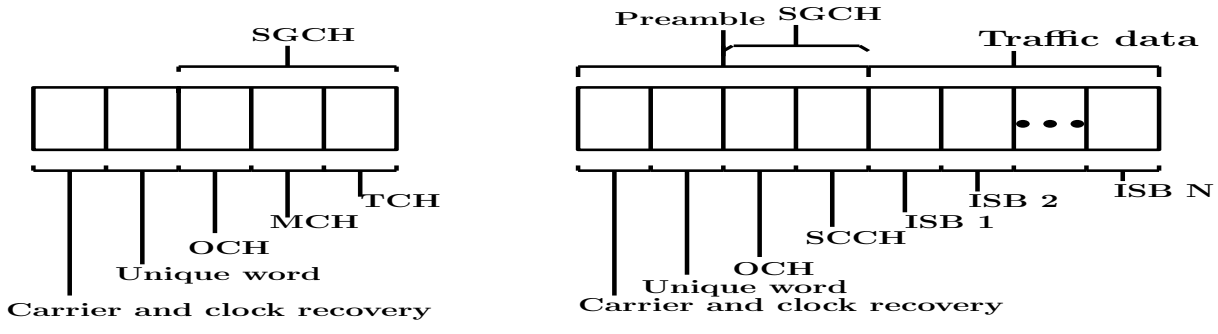

Fig. 2: TDMA burst structure. (Left) Reference burst and (right) traffic burst.

Compute the following:

a). Number of bits in the reference burst preamble. b). Number of bits in the traffic burst preamble.

c). The total number of overhead bits. d). Total number of bits in the frame.

e). TDMA Frame efficiency.

Consider 8-bit PCM encoded voice. Each voice channel has a data rate of 64 Kbps.

f). Compute number of bits in a frame. g). Compute Maximum number of PCM voice channels carried in a frame.

Part-II: True or False (4 points)

Note: Each question carries $\frac{1}{2}$ point. Just indicate 'T/F' ('T' for True statement; 'F' for false statement.).

1) Interaction between ionized particles and electromagnetic waves causes rotation of polarization of the waves.
2) Rain attenuation is inversely proportional to satellite link frequency.
3) Two key properties of maximal length sequences are high cross-correlation and low autocorrelation.
4) In TDMA, we can operate transponder closer to saturation and use error correction coding of digital data, smaller earth station antennas can be used.
5) Spot beam can be received by transmitters anywhere within coverage zone whereas zone beam or narrow beam has only limited coverage.
6) When an orbiting body crosses the reference plane from south to north, it is said to be at descending node of the orbit.
7) Slotted ALOHA protocol delivers less maximum throughput than pure ALOHA protocol.
8) During full eclipse, satellite receives no power from its solar array and it must operate entirely from its batteries.

□ END OF QUESTION PAPER □

Answers

Part I

Q. 1. ans. (a). The expression for the channel capacity assigned for each user = $\frac{R}{N}$ bps.

(b). Average service rate of FDMA channel = $\frac{R}{NL}$ packets per second.

(c). Average load (ρ) (also called traffic intensity) for each channel = $\frac{\lambda}{\mu}$ i.e. packet arrival rate (λ) $\times$ service time ($\left(\frac{1}{\mu}\right)$).

(d). (i). The channel capacity assigned for each user = 64 Kbps.

(ii). The average service rate of each FDMA channel in packets per second = 6.4 packets per second.

(iii). The average packet delay for each user when RTD $= 270$ ms is equal to 495 ms.

Exponentially distributed packet length model:

(i). Average packet delay for each user is 564 ms.

(ii). Latency is high in exponentially distributed packet length model.

Q. 2. ans. a). $R_b = 90$ Mbps.

b). $R_b = 180$ Mbps.

c). Spectral efficiency (bit rate per bandwidth) when 8PSK is employed is equal to 2.5 bps/Hz.

Spectral efficiency when 64-QAM is employed is equal to 5.0 bps/Hz.

Q. 3. ans. (a). Intermodulation noise in FDMA:

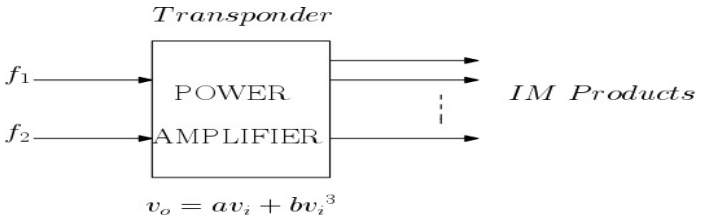

Fig. 3: IM products at the output of transponder.

When multiple carriers pass through a transponder, the nonlinear effects of power amplifiers cause intermodulation (IM) products among these carriers. These beat frequencies produce additional frequency components at the output that can interfere with the desired carriers and produces intermodulation noise.

(b). Processing gain in DSSS

In a spread spectrum communication system, the 'processing gain' G is defined as the ratio of the spread (or RF) bandwidth R_c to the unspread (or baseband) bandwidth R_b which can be mathematically expressed as $G = \frac{R_c}{R_b} = \frac{T_b}{T_c}$. It is usually expressed in decibels (dB).

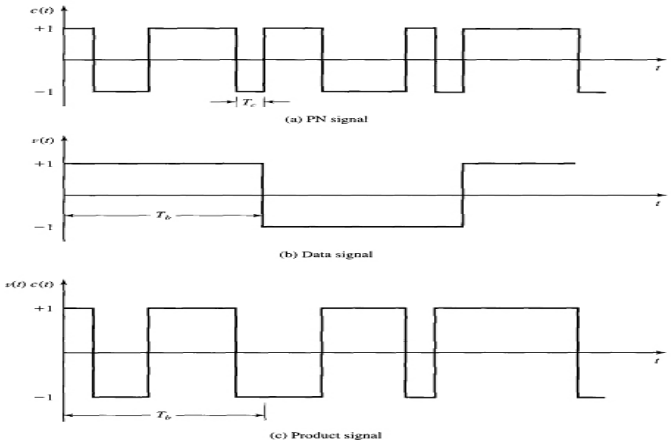

Fig. 4: Signals in spread direct sequence spectrum.

(c). TDMA frame efficiency:

The TDMA frame efficiency is defined as

$$\eta = 1 - \frac{T_o}{T_f},$$

where T_f is the frame duration and T_o is the overhead portion of the frame.

If there are 'N' bursts in a frame, then T_o can be expressed as

$$T_o = NT_g + \sum_{j=0}^{N} T_{pj},$$

where T_g is the guard time between bursts and T_{pj} is the preamble of burst j.

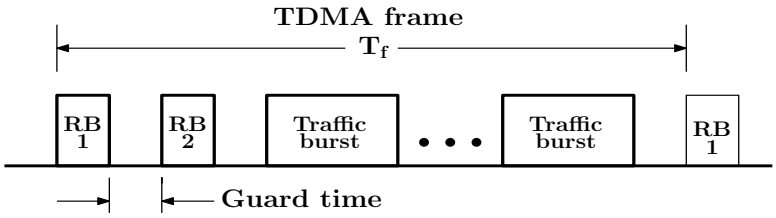

Fig. 5: TDMA frame of duration T_f; RB: reference burst.

(d). Sun transit outage: ES antenna receives not only signal from satellite but also noise temperature transmitted by sun. If noise temperatures are too high, sun transit outage or fade occurs.

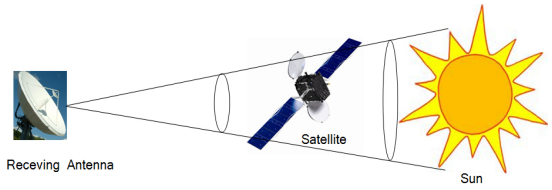

Fig. 6: Sun transit outage illustration

(e). In LEO, high velocity satellite causes significant Doppler shift. Frequency of transmitter on a satellite moving towards an ES appears to be increased by $\frac{v}{\lambda}$.

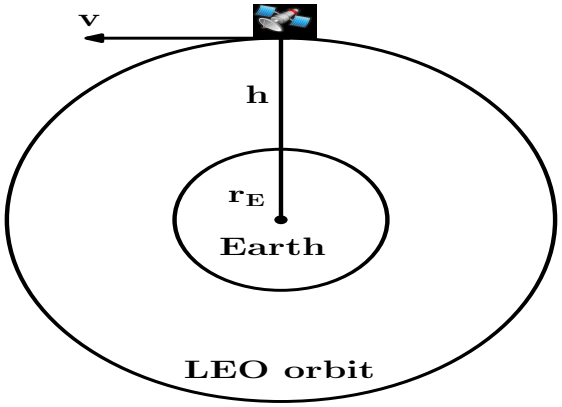

Fig. 7: Illustration of Doppler in LEO orbit.

Q. 4. ans. (a). A geostationary satellite orbit makes zero inclination with equatorial plane and is perfectly circular (eccentricity is zero). The geostationary satellite remains apparently stationary in orbit as viewed from the surface of the earth. A geosynchronous satellite orbit is not in the equatorial plane and may or may not be in circular orbit.

(b). The velocity of a geostationary satellite is 3.0747 KM/sec.

(c). (i). The semimajor axis $a = \frac{2re+hp+ha}{2} = 24,406.152$ KM

(ii). When the eccentric anomaly $E = 0$, we have $r_0 = r_e + h_p = a(1-e)$. Solving, we get $e = 0.728$.

(iii). The orbital period $T = 37,945.47102$ seconds = 10 hrs 32 mins 25.5 seconds.

Q. 5. ans. a). Number of bits in the reference burst preamble = (carrier and clock recovery bits) + (unique word bits) + (order wire channel bits) + (management channel bits) + (transmit timing channel bits) = 352 + 48 + 510 + 256 + 320 = 1486 bits.

b). Number of bits in the traffic burst preamble = (carrier and clock recovery bits) + (unique word bits) + (order wire channel bits) + (service channel bits) = 352 + 48 + 510 + 24 = 934 bits.

c). Let 'n' denote the number of bursts. Total number of overhead bits = (n $\times$ guard time bits) + (total preamble bits) = $(22 \times 64) + ((2 \times 1486) + (20 \times 934))$ = 23060 bits.

d). Total number of bits in the frame = frame duration $\times$ burst bit rate = 1.35×10^6 bits.

e). Frame efficiency = $1 - \frac{23060}{1.35 \times 10^6}$ = 0.9829 or 98.29%.

f). PCM encoded voice: Each voice channel has a data rate of 64 Kbps. Therefore, number of bits in 15 ms frame is 64 Kbps $\times$ 15 ms = 960 bits.

g). Maximum number of PCM voice channels carried in a frame = $\lfloor 0.9829 \times \frac{1.35 \times 10^6}{960} \rfloor \approx 1382$.

Part II

1. T 2. F 3. F 4. T
5. F 6. F 7. F 8. T