CHAPTER 10
Multiple Access Systems

10.1 Communication Resource Conservation:

The basic task in communication systems is to economize the use of communication resources, namely, time and bandwidth. This is done by availing the resources to multiple users. There are two terms, multiplexing and multiple access. Multiplexing usually means combining the needs of different users in a fixed infrastructure providing sharing of the resources based on the user's varying needs. Whereas multiple access usually means the efficient serving of a large number of users with a variety of bit rates and duty cycles. There are different ways for multiple access.

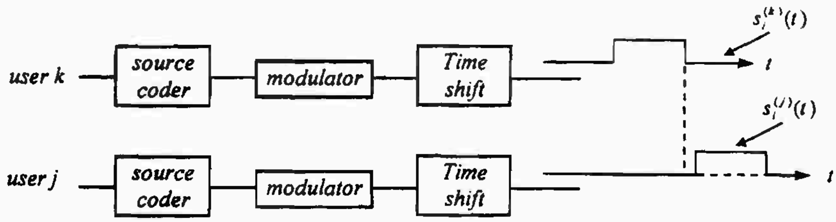
1. Frequency division FDMA: allocating subbands of frequencies for different users.
2. Time division TDMA: periodically sampling multiple users, i.e, randomly accessing the resource.
3. Code division CDMA: specification of a set of orthogonal or nearly orthogonal spread spectrum codes for multiple users, each using the full channel bandwidth.
4. Space division SDMA: multiple beam frequency reuse: spot beam antennas are used to propagate radio signals in different directions using the same frequency band.
5. Polarization division PDMA: (dual polarization frequency reuse): orthogonal polarizations are used to separate signals based on polarization allowing for reuse of the same frequency band.
6. Orthogonal frequency division OFDMA: a technique for transmitting data in parallel by using a large number of modulated carriers with sufficient frequency spacing so that the carriers are orthogonal to reduce multipath interference errors.

The key to all multiplexing and multiple access schemes is orthogonality. In TDM, we have (Fig. 10.1),

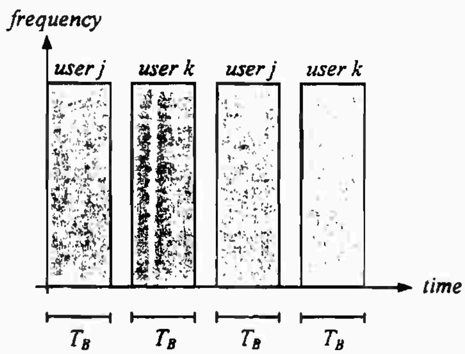
$$\int_{-\infty}^{\infty} x_k(t)\, x_j(t)\, dt = \begin{cases} A & k = j \\ 0 & otherwise \end{cases} \qquad (10-1)$$

Similarly in FDM, we have (Fig. 10.2)

$$\int_{-\infty}^{\infty} X_k(f)\, X_j(f)\, df = \begin{cases} A & i = j \\ 0 & otherwise \end{cases} \qquad (10-2)$$



(a)



(b)

Fig. (10.1) TDMA

a) concept *b) frequency time chart*

10.2 FDMA:

Communication satellites are located in geostationary orbits (chapter 11). Satellite systems are made up of repeaters (or transponders). The up link (earth to satellites) transmissions are amplified, frequency shifted and retransmitted on the down link (satellite to earth) without any modulation or demodulation in the transponder. Satellite communication uses C band (4.6 Hz for the up link and $4GHz$ carrier for the down link). Each satellite has $500MHz$ wide spectral assignment. Each satellite has 12 transponder with bandwidth $36MHz$ each. The most common $36MHz$ transponders operate in an FDM/FM/FDMA multidimension link mode. Telephone signals (each $4kHz$ spectrum) are *FDM 'ed* to form a multi channel composite signal. The composite signal is *FM ed* onto a carrier and transmitted to the satellite. Subdivisions of the $36MHz$ transponder bandwidth is assigned to different, users, each accessing an allocated bandwidth. No synchronization is required. Each channel is independent of other channels.

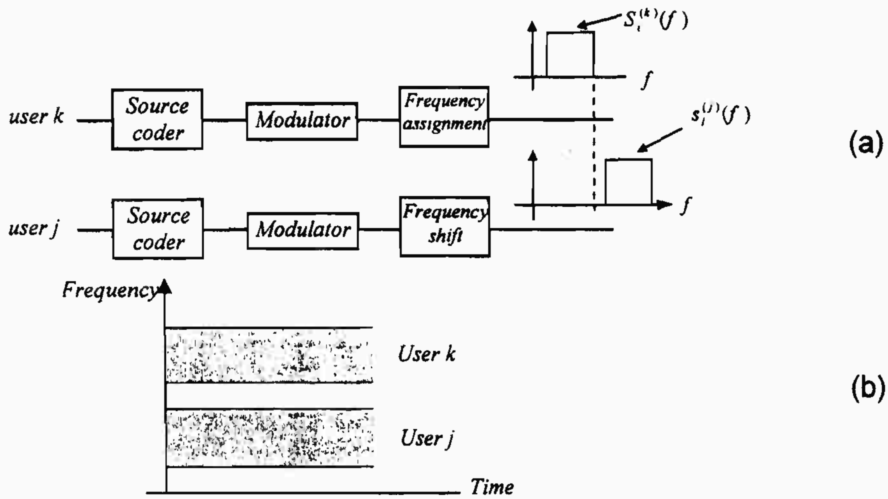


Fig. (10.2) FDMA

a) Concept *b) frequency time domain*

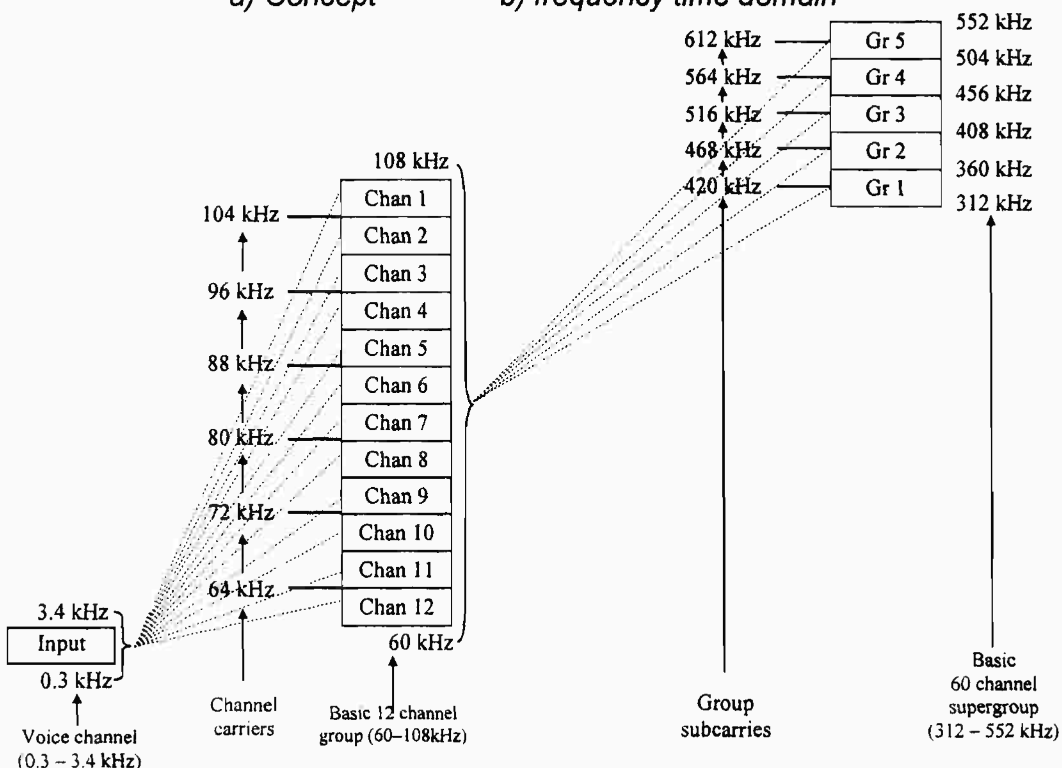


Fig. (10.3) Modulation plan for FDM

10.3 TDMA:

Here, the communication channel is shared by assigning each of M users the full spectrum for a short duration of time called time slots separated by band called guard times acting as buffer zones to reduce interference. Time is segmented into intervals called frames. Each frame is further partitioned into time slots. The frame structure repeats. Fixed TDMA assignment constitutes slots that periodically appear during each frame time. Each earth station transmits its data in bursts, timed so as to arrive at the receiver within its preassigned time slot. When the bursts, are received by the satellite transponder they are retransmitted on the downlink bursts for other stations. A receiving station detects and demultiplexes the appropriates bursts and feeds the information to the intended user (Fig. 10.4).

The multiplexing operation consists of providing each source with a time slot (Fig. 10.4a). The demultiplexing consists of deslotting the information. The multiplexer and demultiplexer are synchronized with each user. The message comprises a preamble part and a data part.

The preamble consists of synchronization, addressing and error control sequences (Fig. 10.4b). The fixed assignment TDMA scheme is efficient when the time slots are always filled (heavy traffic). However, for bursts or sporadic traffic the fixed assignment scheme is wasteful. In Fig. (10.5), there are four slots per frame, each slot is preassigned to users A , B , C and D, respectively. Fig. (10.5a) shows an activity profile. During the first frame time, user C has no data to transmit. During the second frame time, user B has none. During the third frame time, user A has none. In a fixed assignment TDMA scheme all of the slots within a frame are preassigned. If the user has no data his slot is empty or waste time slot.

Packet switching compresses data by eliminating the waste time slots, hence, conserving capacity. Such systems, also called statistical multiplexers or concentrators.

We may use a hybrid of TDMA and FDMA. In Fig. (10.1) the frequency resource is divided into frequency bands. In Fig. (10.2) the communication resource is divided into time slots. We may alternately organize the communication channel allowing for the assignment of a frequency band for a prescribed period of time. Such a multiple access scheme is called combined FDMA / TDMA. Let us assume an equal access opportunity of the total bandwidth B among M user groups or classes so that M frequency bands of width $B/M\ Hz$ are available to their assigned group. Similarly, for the assignment of time slots, the time axis is portioned into time frames each of duration T, and the frames are partitioned into N slot times each of duration T/N . We assume that the users are time synchronized and that the assigned slots are located periodically within the frames.

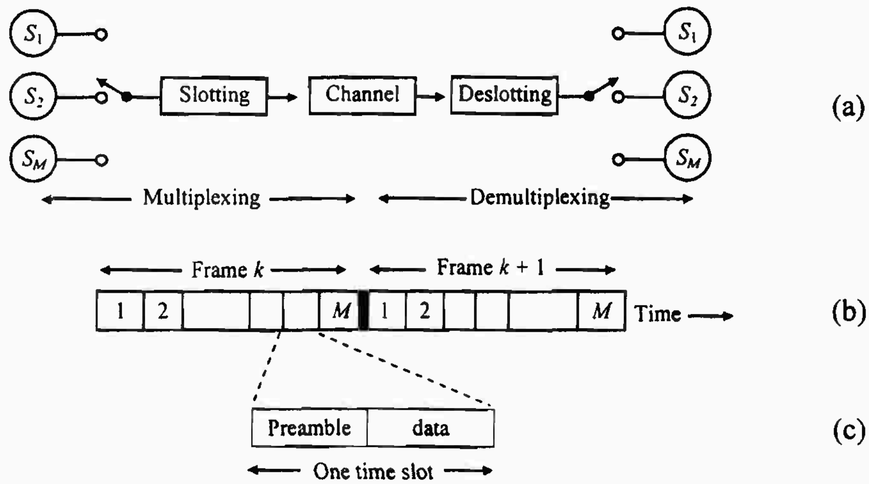


Fig. (10.4) Fixed assignment TDMA

a) multiplexing and demultiplexing.
b) structure message.
c) each slot consists of a structure preamble part and a data part

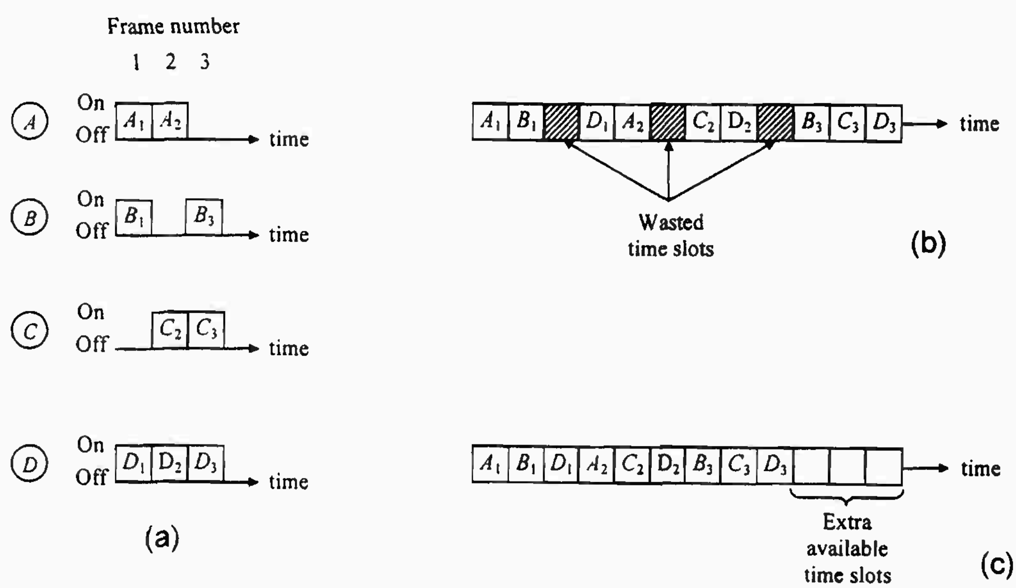


Fig. (10.5) Packet switching

a) activity profile *b) fixed assignment TDM* *c) TDM packet switching*

A slot is uniquely determined as the m^{th} slot within the n^{th} frame (Fig. 10.6).
We may define a time slot (n, m) as n^{th} frame and m^{th} slot

$$\text{slot }(n, m) = nT + \frac{(m-1)T}{N} \le t \le nT + \frac{mT}{n} \qquad (10-3)$$
$$n = 0, 1, \ldots$$
$$m = 1, 2, \ldots N$$

The domain of the unit signal is the intersection of the time slot (n, m) and the frequency band j. Assume that a modulation (coding) system is chosen so that the full bandwidth B of the channel can support R_b bit/s. In any frequency band of width $B/M\ Hz$, the associated bandwidth is R_b/M bits/s. FDMA would provide M band each with a bandwidth of $1/M$ of the full bandwidth of the channel. TDMA would provide the full system bandwidth of each of the N slots, where the duration of each slot is $1/N$ of the frame time. In Fig. (10.7a), the system bandwidth is divided into M orthogonal frequency bands. Hence, each of the M sources m $(1 \le m \le M)$ can simultaneously transmit at a bit rate of R_b/M bit/s.

In Fig. (10.7b), the frame is divided into M orthogonal time slots. Hence, each of the M sources bursts its transmission at R_b bit/s, i.e., M times faster than the equivalent FDMA user for $(1/M)^{th}$ the time. In both cases, the source transmits information at an average rate of R_b/M bits/s.

Let the information generated by each of the sources be b-bits grouped in packets. In FDMA, the b bits packets are transmitted in T seconds over each of the M channels. Therefore, the total bit rate required is

$$R_{FD} = M\frac{b}{T} \quad bits/s \qquad (10-4)$$

In the case of TDMA, the b bits are transmitted in T/M seconds from each source. The bit rate required is

$$R_{TD} = \frac{b}{(T/M)} \quad bits/s \qquad (10-5)$$

Thus,

$$R_{FD} = R_{TD} = R_b = Mb/T \qquad (10-6)$$

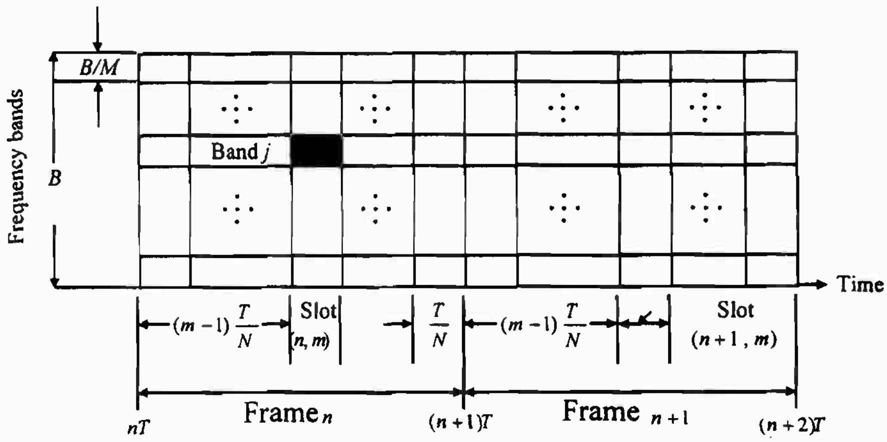


Fig. (10.6) Combined TDMA / FDMA channelization

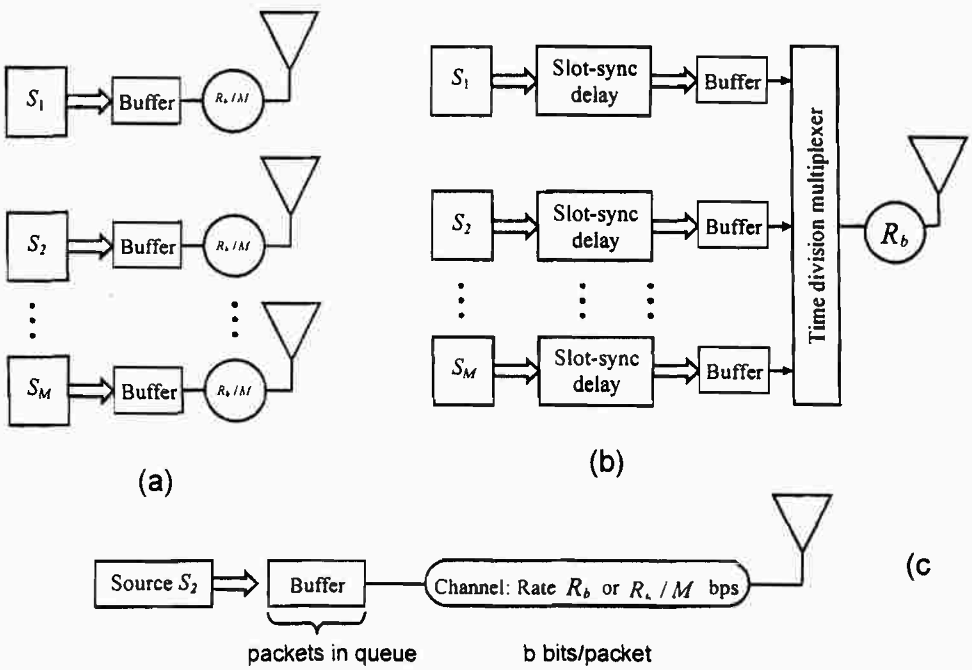


Fig. (10.7) FDMA / TDMA equivalence

a) FDMA: M orthogonal bands

b) TDMA M orthogonal time slots (one packet / time slot)

c) Packet (representation /b bits /packet)

Thus, both systems require the same full channel data rate R_b bits/s. if we have M bands and N time slots, then in a combined FDA/TDA system each slot has time T/N containing b bits, then each user transmits at a rate $\frac{b}{(T/N)} = \frac{bN}{T}$.

The total data rate of transmission R_b for combined TDMA and FDMA,

$$R_b = \frac{M\ N\ b}{T} \qquad (10-7)$$

The total number of users

$$M\ N = \frac{R_b\ T}{b} \qquad (10-8)$$

The number of frames

$$N = \frac{R_b\ T}{M\ b} \qquad (10-9)$$

The number of bands

$$M = \frac{R_b\ T}{N\ b} \qquad (10-10)$$

Multiple access schemes are called fixed assignment when a station has periodic access to the channel independent of its actual use. By comparison dynamic assignment (demand assignment) multiple accesses (DAMA) means that a given station accesses the channel only when it requests so. DAMA becomes more efficient when use is light. By using DAMA and buffers traffic becomes more cost effective.

Ex. 10.1 (case study)

Compare TDMA and FDMA delay time

Solution

For the analysis of message delay, let us assume that in the case of FDMA, the system bandwidth is again divided into N orthogonal bands, and in the case of TDMA the frame is divided into N orthogonal time slots. It is assumed that the cannel is 100% utilized, so that all bands or slots are filled with packets, neglecting any over band costs such as guard bands or guard times. The message delay Δt, for zero waiting is

$$\Delta t = t_w + \tau \qquad (10-11)$$

where t_w is the average packet waiting time prior to transmission and τ is the packet transmission time. In FDMA, each packet is sent over a T second interval so

$$\tau_{FD} = T \qquad (10-12)$$

From eqn. (10 – 5),

$$\tau_{TD} = \frac{T}{N} = \frac{b}{R_b} \qquad (10-13)$$

Fig. (10.8) shows the bit streams for FDMA and TDMA. For TDMA, we have sources S_1, S_2 .. S_M . Each source has samples sent every T seconds. For example, source S_1 has sample S_{11} , S_{12} .. S_{1k} .. $S_{1,k+1}$ .. Source S_M has packet S_{m1} , S_{m2} .. S_{mk} , $S_{m,k+1}$. In the k^{th} TDMA frame, we must transmit packets, S_{k1} , S_{Mk} within the frame time. The packets must be ready, but there must be waiting time before transmission that varies from packet to another. Packet S_{mk} will start at $(m-1)T/N$ seconds $(1 \le m \le N)$ after the packet generation instant. The average waiting time t_w that a TDMA packet undergoes before transmission is given by

$$t_w\big|_{TD} = \frac{1}{N}\sum_{m=1}^{N}(m-1)\frac{T}{N} \qquad (10-14)$$

$$= \frac{T}{N^2}\sum_{m'=0}^{N-1} m'$$

$$= \frac{T}{N^2}\frac{(N-1)N}{2}$$

$$= \frac{T}{2}\left(1-\frac{1}{N}\right) \qquad (10-15)$$

The maximum waiting time $\hat{t}_w$ is given by

$$\hat{t}_w = T\left(\frac{N-1}{N}\right)$$

$$= T\left(1-\frac{1}{N}\right) \qquad (10-16)$$

From eqn. (10 – 11),

$$\Delta t_{FD} = T \qquad (10-17)$$

$$\Delta t_{TD} = \frac{T}{2}\left(1-\frac{1}{N}\right)+\frac{T}{N} \qquad (10-18)$$

$$= \frac{T}{2} - \frac{T}{2}\times\frac{1}{N} + \frac{T}{N} + \frac{T}{2} - \frac{T}{2}$$

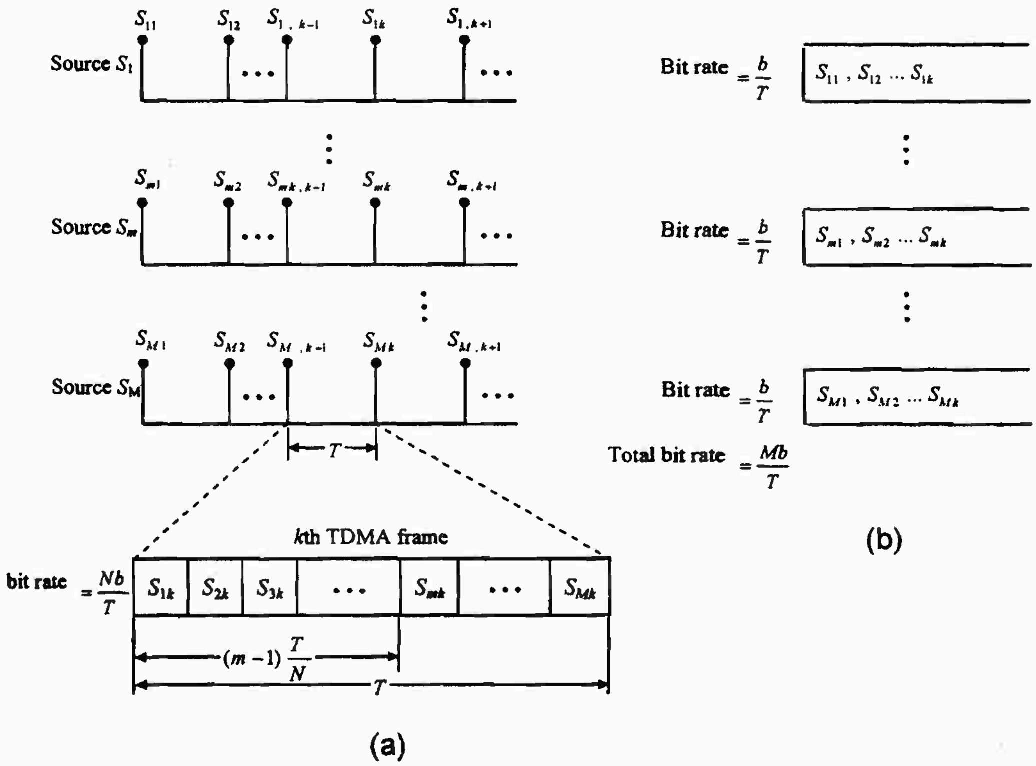


Fig. (10.8) Channelization

a) TDMA *b) FDMA*

$$= T - \frac{T}{2}\left(1 - \frac{1}{N}\right)$$

$$= \Delta t_{FD} - \frac{T}{2}\left(1 - \frac{1}{N}\right)$$

$$= \Delta t_{FD} - \frac{Nb}{2R_b}\left(1 - \frac{1}{N}\right)$$

$$= \Delta t_{FD} - \frac{b}{2R_b}(N-1) \qquad (10-19)$$

We may alternatively rewrite eqn. (10 – 18) as

$$\Delta t_{TD} = \frac{T}{2}\left[1 + \frac{1}{N}\right] = \Delta t_{FD} \times \frac{1}{2}\left[1 + \frac{1}{N}\right] \qquad (10-20)$$

$$\frac{\Delta t_{FD}}{\Delta t_{TD}} = \frac{2}{1+\frac{1}{N}} \tag{10 – 21}$$

Thus,

$$2 > \frac{\Delta t_{FD}}{\Delta t_{TD}} > 1 \tag{10 – 22}$$

We conclude that TDMA is superior to FDMA from the message delay point of view.

10.4 CDMA:

CDMA is the hybrid of FDMA and TDMA. Fig. (10.9) shows FH-CDMA. At each time slot, the frequency bands are reassigned such as to fully utilize the spectrum in a way similar to musical chairs. In time slot 1, signal 1 occupies band 1 signal 2 occupiers band2, and signal 3 occupies band 3. During time slot 2 the order is changed and so on.

Fig. (10.10) shows the frequency hopping mechanism. At each frequency hop time, the PN generator feeds a code sequence to the frequency hopper which synthesizes one of the allowable hop frequencies. There are two steps: data modulation (MFSK) and frequency hopping (carrier hopping). This hybrid CDMA has advantages over TDMA or FDMA in terms of privacy. In case of fading where part of the spectrum suffers attenuation, instead of one user being affected all the time the degradation is distributed among all users part of the time. Also, CDMA provides jamming resistance. In CDMA, there is no need for time coordination among the various users.

In Intelsat many FM carriers from various earth stations access the satellite simultaneously. Long distance calls originating in country A enter the telephone exchange and are multiplexed into a supergroup of 12 voice circuits each. Country A transmits the supergroup on a single FM carrier f_A. Each group within the super group has been preassigned to an earth station in country A for telephone traffic destined to countries B through F. These countries receive the signal on frequency f_A. The received signal is demodulated and demultiplexed at the destination country selecting only those 12 channels preassigned to it. This is called preassigned multidestination FDM / FM / FDMA or multichannel per carrier (MCPC). If the transponder uses a 36 MHz bandwidth in a single carrier then 900 channels per transponder can be supported at 4 kHz each.

TDMA is now widely used. One disadvantage in the implementation of TDMA is the need for providing precise synchronization among the participating earth stations.

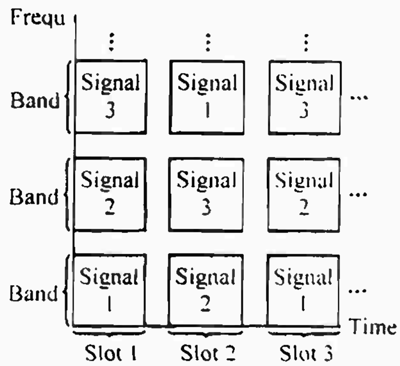


Fig. (10.9) FH CDMA

We note that with TDMA there is only one carrier present in the microwave source, hence distortion caused by interference is eliminated.

There are two digital telephony standards for PCM frame structures in operation. The North American standard is called T - carrier. It is built around the 193 bit frame (Fig. 10.11a). There are 24 channels, each containing an 8 bit voice sample. Also, there is one bit per frame with alternating value (1010) from frame to frame, used for frame alignment. Since a voice grade telephone channel has a bandwidth of 4 kHz, the Nyquist sampling rate is 8000 samples/s. This basic PCM frame-called the Nyquist frame - containing 24 voice samples from 24 different message sources has a frame rate of 8000 frames/s (duration of 125 μs). Thus, the basic T carrier bit rate is 193 bits/frame $\times$ 8000 frame/s $= 1.544\ Mb/s$.

The European standard is built around a 256 bit frame shown (Fig. 10.11b). There are 30 message channels, each containing an 8 bit voice sample. Also one 8 bit time slot is used for frame alignment and another 8 bit time slot is used for signaling addressing information. The bit rate in the European system is 256 bits/frame $\times$ 8000 frames/s $= 2.048\ Mb/s$.

At the transmitting earth station the continuous low rate data stream enters one of a pair of buffers (Fig.10.12a). When one buffer is filling at the low rate ($1.544\ Mb/s$ or $2.048\ Mb/s$) the other is emptying at the burst rate ($120.832\ Mb/s$). The buffers alternate function at each TDMA frame. The time of application of the high rate clock is controlled so that the traffic burst is transmitted with proper interval to arrive at the satellite in its assigned position in the TDMA frame. At the receiving station a received traffic burst is routed to one of a pair of expansion buffers (Fig. 10.12b) when one buffer is filling at the high rate the other is emptying at the desired output rate.

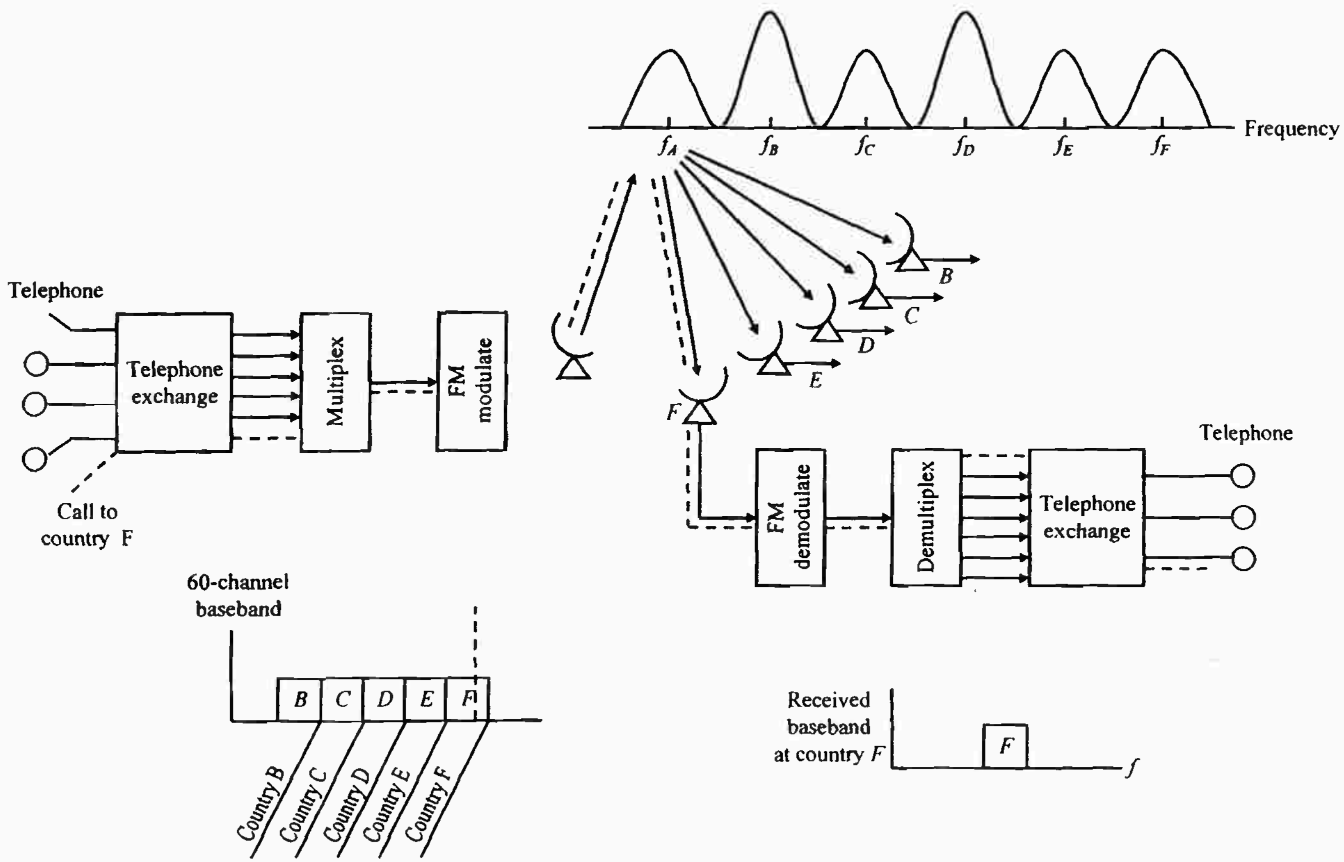


Fig. (10.10) Multi destination FDM/FM carriers

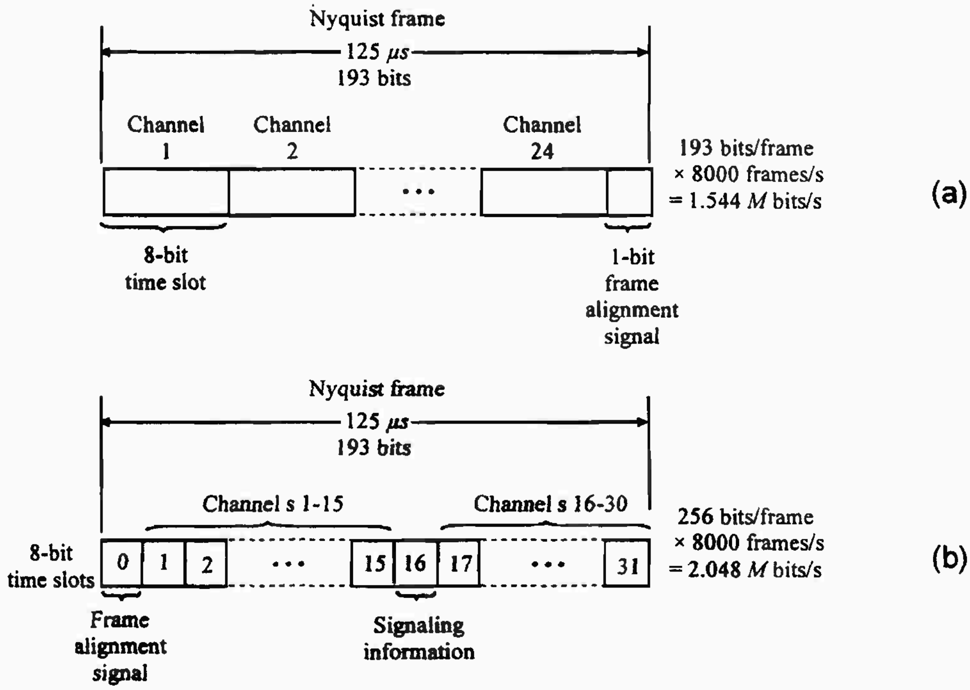
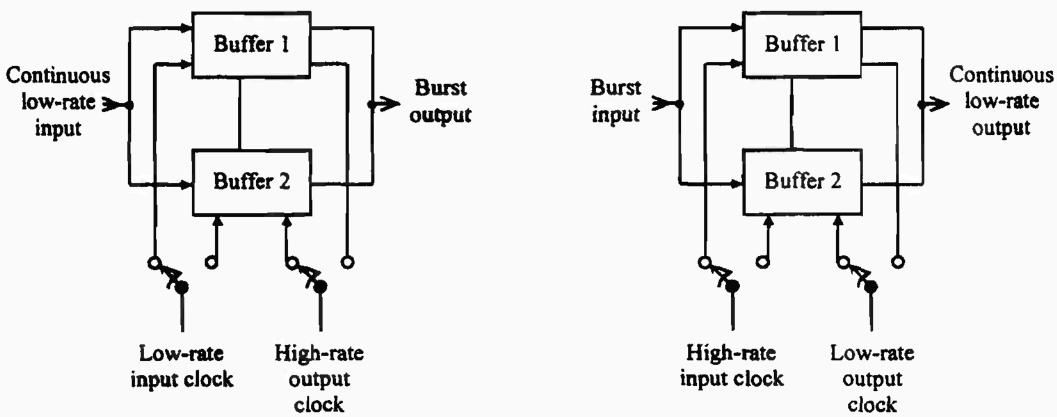


Fig. (10.11) PCM Multiplex frame structure

a) T carrier PCM multiplex *b) European PCM Multiplex*



(a) (b)

Fig. (10.12) Burst compression and expansion buffers

a) Compression at the transmitter *b) expansion at the receiver*

Ex. 10.2 (case study)

Design high rate TDMA in European system for 16 frames for 30 terrestrial channels with 8 bits of framing and 8 bits of signaling.

Solution:

Consider sixteen Nyquist frames of the European PCM Multiplex format shown in Fig. (10.13a). Each frame contains an 8 bit sample from each of 30 terrestrial channels with 8 bits of framing and 8 bits of signaling information. The TDMA frame duration is

16 Nyquist frames $\times 125\ \mu s$ / Nyquist frames $= 2\ ms$

Within this $2\,ms$ frame are maintained

16 Nyquist frames $\times 256$ bits / Nyquist frames $= 4096\ bits$

A user's low rate data stream can share the communication resource with similar streams from other users by bursting the transmission at a much faster rate than the rate at which it is generated. Fig. (10.13b) shows a $2\ ms$ high rate TDMA frame.

The frame begins with a reference burst $RB1$ emitted by a reference station. The burst contains information necessary to enable other stations to precisely position their message traffic bursts in the frame. There may be a second burst $RB2$ for reliability followed by a sequence of traffic slots. The traffic slots may be preassigned or may be assigned according to DAMA.

The PCM multiplex signal with a bit rate of $R_b = 2.048\ Mb/s$ and a frame duration of $T = 2\,ms$, compressed by a factor of 59 and transmitted using QPSK modulation at is burst rate of $R_T = 120.832\ Mb/s$ (symbol rate of $60.416\ M\,sym/s$). The duration of the traffic data field T_{tr} in the high rate TDMA form is given by

$$T_{tr} = \frac{R_b T}{R_T} = \frac{2.048\times 10^6 \times 2\times 10^{-3}}{120.832\times 10^6} = 33.9\ \mu s$$

To obtain the total duration of a traffic burst, the time used for the preamble must be added. If the preamble contains S_p symbols, then assuming QPSK modulation, the total length of the traffic burst in symbols/s

$$S_T = \frac{R_b T}{2} + S_p$$

The burst time duration is

$$T_l = \frac{2\,S_l}{R_T}$$

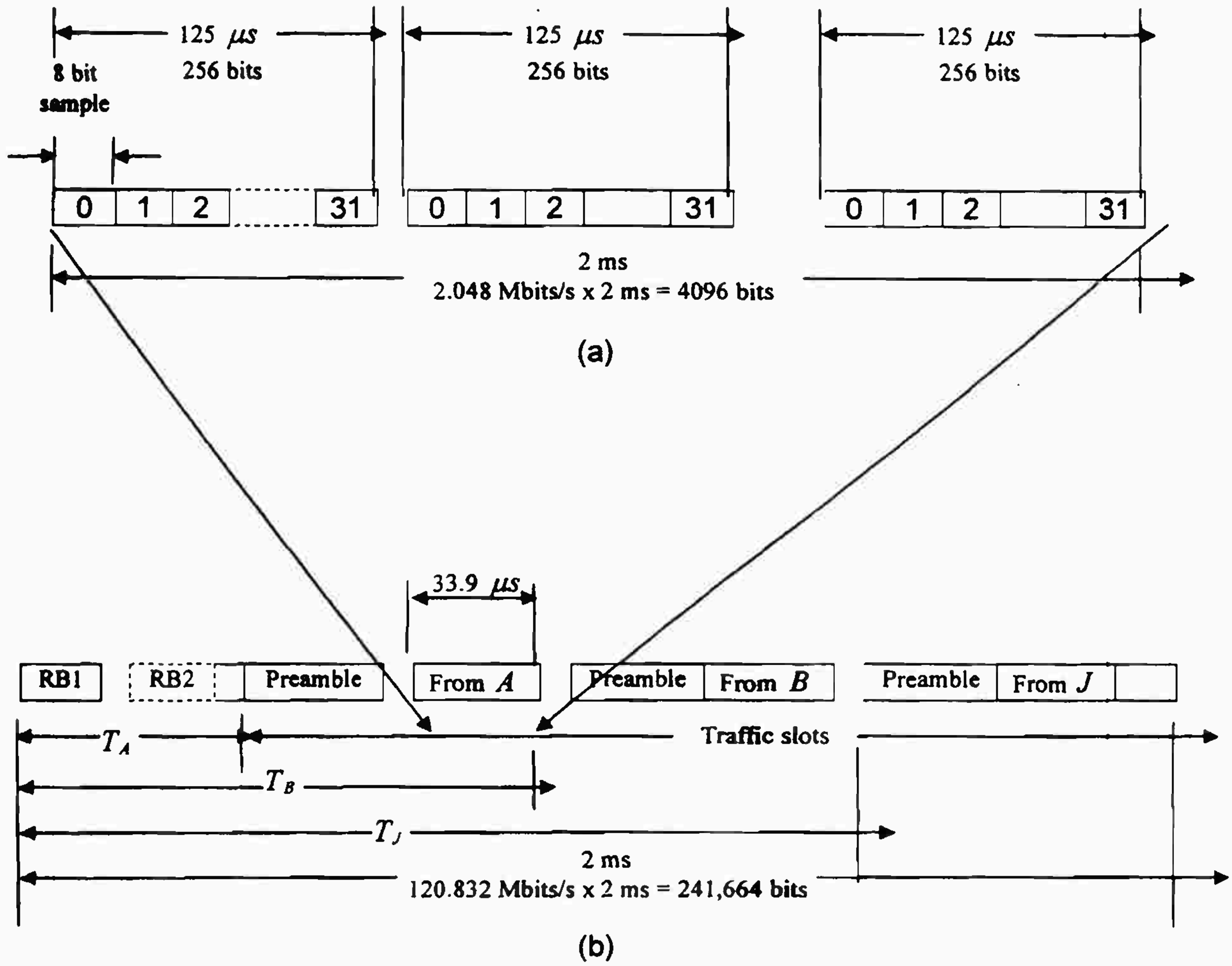


Fig. (10.13) Intelsat digital transmission European standard
a) Terrestrial PCM multiplex. *b) High rate frame.*

If the preamble contains 300 symbols

$$S_T = \frac{2.048\times10^6\times2\times10^{-3}}{2}+300$$

$$= 2348 \text{ Symbols}$$

$$T_T = \frac{2\times2348}{120.832\times10^6} = 38.9\ \mu s$$

Problems

1. Two users wish to share a communication channel. One user sends $+x(t)$ to indicate bit 1 and $-x(t)$ to indicate bit 0. The second user sends $+y(t)$ to indicate bit 1 and $-y(t)$ to indicate bit 0. Determine if the two users can share the same channel without interference.

2. Design high rate TDMA for North American system assuming 24 channels $\times 8$ bits $+1$ frame alignment bit, 16 Nyquist frames data rate of $1.544\ Mb/s$, and burst rate $R_T = 120.832\ Mb/s$.

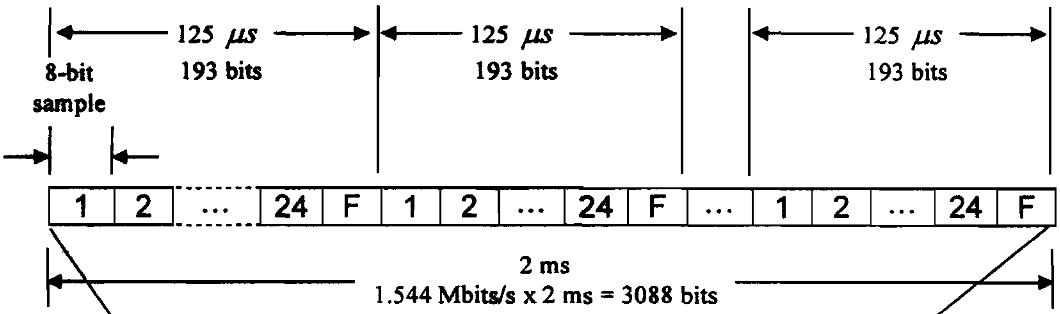
3. The frame length of TDMA system is $2ms$. If QPSK symbol rate $60.136\ M$ baud is used and all traffic bursts are of equal length, determine
   a) The maximum number of earth stations that can be served (N).
   b) The frame efficiency. Assume the overheard to be $1200+712\ N$ bits.

4. Calculate the frame efficiency for the above problem.

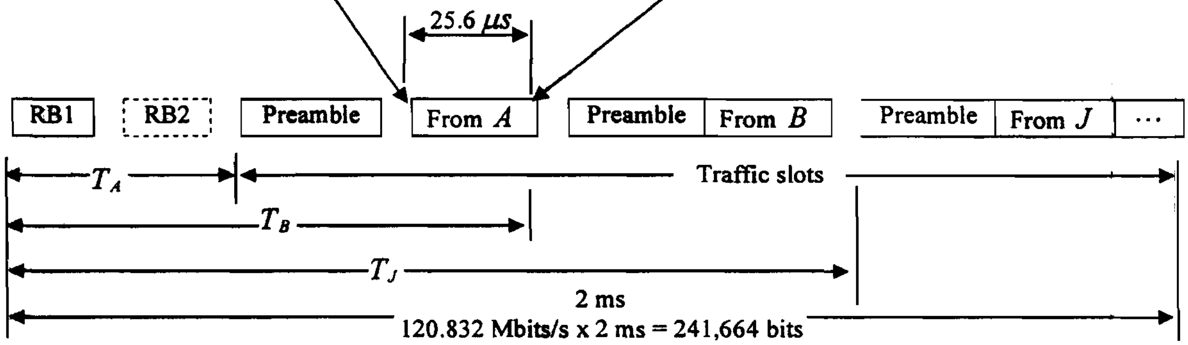
5. For standend $64\ kb/s$ PCM voice transmission what would be the TDMA voice channel capacity of the system in prob. 4.? Calculate the number of samples from each voice channel to be transmitted per frame assuming 8 bit sample.

6. A communication system is used for voice signal transmission. It employs an 8 PSK modulation scheme with a spectral efficiency $3.356\ b/s\,Hz$. Assuming one burst per frame for a frame period of $2\ ms$,determine the maximum number of voice channels if the total number of guard and preamble bits is 680 and bandwidth $36\ MHz$.

7. Compute the maximum number of voice channels for a TDMA system specified as one burst per frame, frame period $2.5ms$, modulation $QPSK$, efficiency $2.2 b/s\,Hz$ guarded preamble bits 700.


125 μs
193 bits
8-bit
sample
125 μs
193 bits
125 μs
193 bits
1
2
...
24
F
1
2
...
24
F
...
1
2
...
24
F
2 ms
1.544 Mbits/s x 2 ms = 3088 bits

(a)


25.6 μs
RB1
RB2
Preamble
From A
Preamble
From B
Preamble
From J
...
T_A
Traffic slots
T_B
T_J
2 ms
120.832 Mbits/s x 2 ms = 241,664 bits

(b)

Prob. (10.2)

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