Satellite Communications

Lecture 14: Multiple Access Techniques

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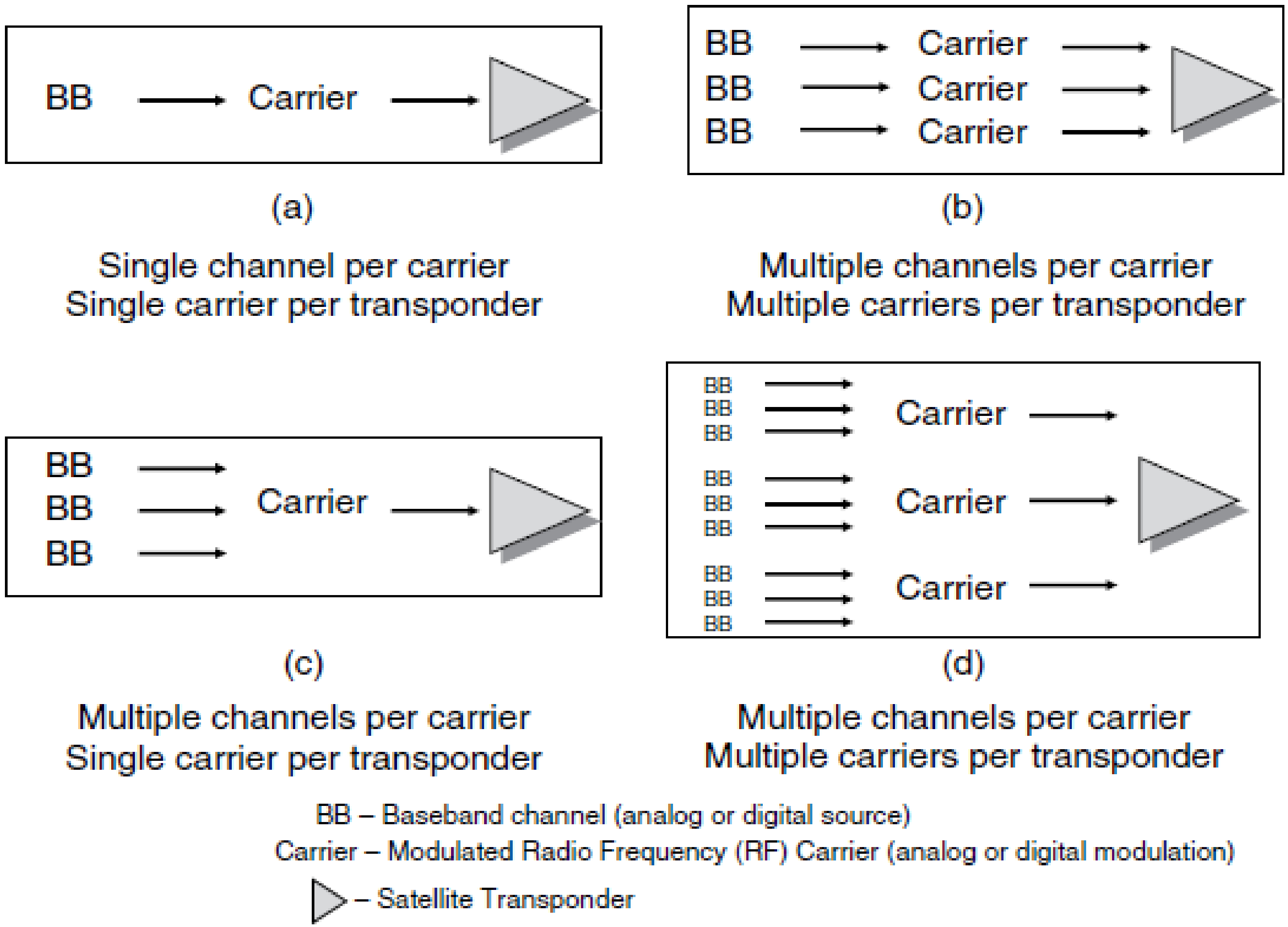
Goal of Multiple Access

- The goal of the MA process is to allow the communications network to respond to expected changes in user demand and adapt resources to provide the desired level of performance throughout high demand periods as well as average or limited demand conditions.
- The goal of optimizing several system attributes such as:
  - spectral efficiency;
  - power efficiency;
  - reduced latency;
  - increased throughput.

Access options in a satellite communications network

- Four basic multiple access configurations are identified in Figure



Multiple Access

- If the proportion of the resource (frequency, time, code) is allocated in advance, it is called ***PRE-ASSIGNED*** **MULTIPLE ACCESS** or ***FIXED*** **MULTIPLE ACCESS - FAMA**
- If the proportion of the resource is allocated in response to traffic conditions in a dynamic manner it is called ***DEMAND ASSIGNED*** **MULTIPLE ACCESS - DAMA**

Multiple Access Techniques

- Purpose: to allow several users to share the resources of the air interface in one cell
- The MA methods available to the satellite system designer can be categorized into three fundamental techniques, differentiated primarily by the domain used in the process:
  - FDMA - Frequency Division Multiple Access
  - TDMA - Time Division Multiple Access
  - CDMA - Code Division Multiple Access

Secondary Access Techniques

- Multiple access options are further defined by ***secondary access techniques***, which are usually implemented within one or more of the three fundamental access technologies introduced above. These secondary techniques include:
  - Demand Assigned Multiple Access (DAMA)
  - Space Division Multiple Access (SDMA)
  - Satellite Switched TDMA (SS/TDMA)
  - Multi-frequency TDMA(MF-TDMA).

Demand Assigned Multiple Access (DAMA)

- Demand assigned networks change signal configuration dynamically to respond to changes in user demand.
- FDMA or TDMA networks can be operated with:
  - pre-assigned channels, called ***fixed access*** (FA) or ***pre-assigned access*** (PA);
  - or they can be operated as an assigned-on-demand DAMA network.
- CDMA is a random access system by its implementation, so it is a DAMA network by design.

Space Division Multiple Access (SDMA)

- Space division multiple access refers to the capability to assign users to spatially separated physical links (different antenna beams, cells, sectored antennas, signal polarization, etc.), in addition to the MA inherent in the access method of implementation.
- It can be employed with any of the three basic MA techniques, and is an essential element of mobile satellite networks, which employ multibeam satellites, and may include frequency reuse and orthogonal polarized links to further increase network capacity.

Satellite Switched TDMA (SS/TDMA)

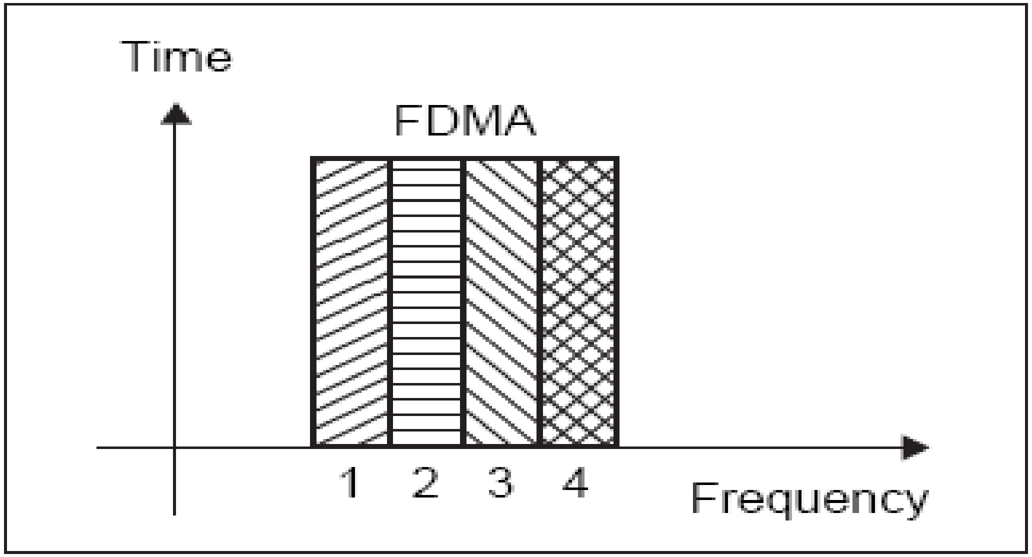
- Satellite switched TDMA employs sequenced beam switching to add an additional level of multiple access in a frequency translation satellite.
- The switching is accomplished at RF or at an intermediate frequency (IF) and is unique to satellite based systems.

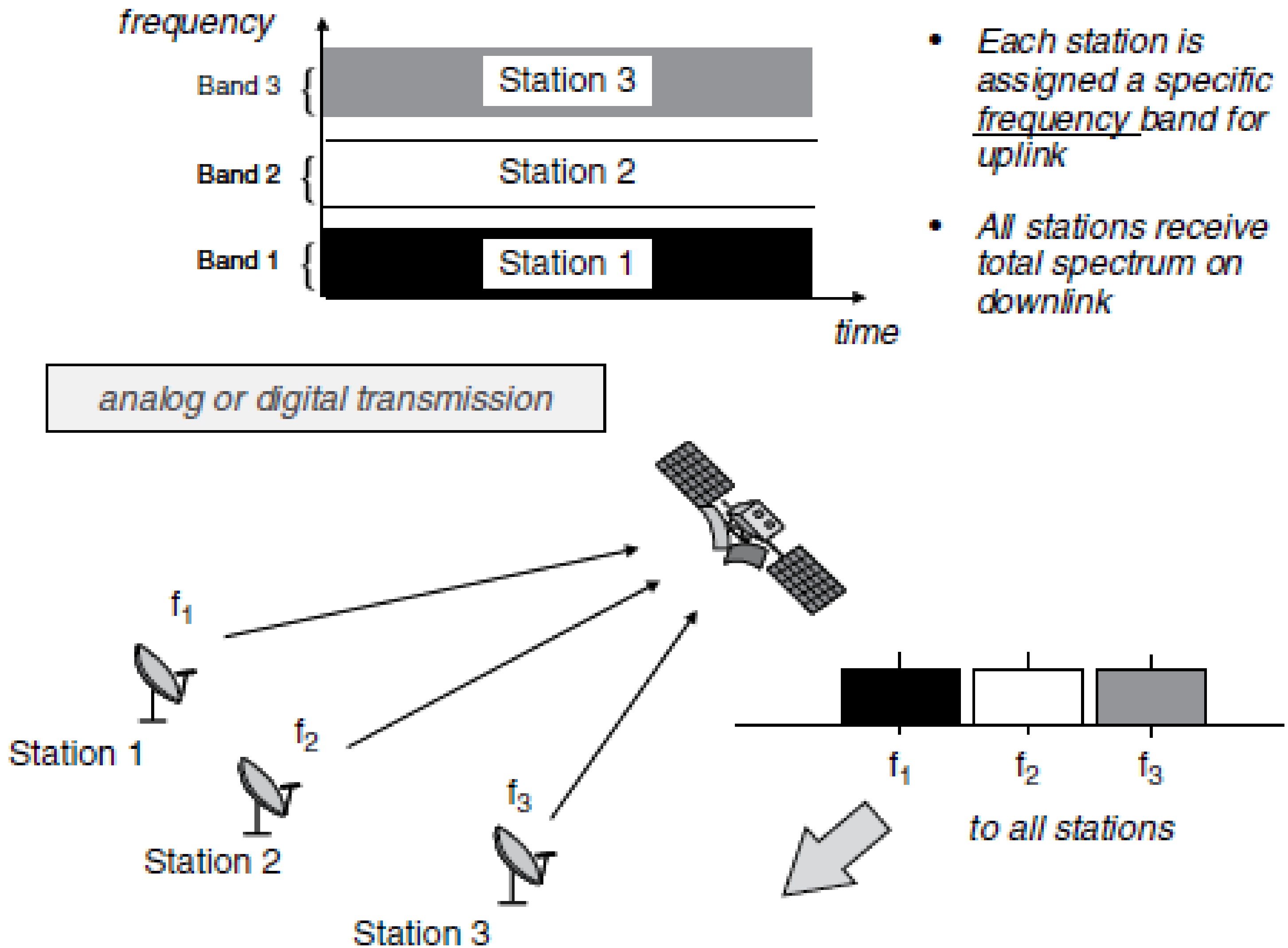
Multi-frequency TDMA(MF-TDMA)

- This technique combines both FDMA and TDMA to improve capacity and performance for broadband satellite communications networks.
- The broadband baseband signal is divided up in frequency band and each segment drives a separate FDMA carrier.
- The received carriers are then recombined to produce the original broadband data.

Frequency Division Multiple Access (FDMA)

- Satellite frequency is already broken into bands, and is broken in to smaller channels in Frequency Division Multiple Access (FDMA).
- Overall bandwidth within a frequency band is increased due to frequency reuse (a frequency is used by two carriers with orthogonal polarization).





Each station is assigned a specific frequency band for its uplink, f_1, f_2, and f_3, respectively.
Each ground station has exclusive use of its frequency band, or slot.
The frequency slot is either pre-assigned or can be changed on demand.
Frequency guard bands are used to avoid interference between the user slots.

- The number of sub-channels is limited by three factors:
  - Thermal noise (too weak a signal will be effected by background noise).
  - Intermodulation noise (too strong a signal will cause noise).
  - Crosstalk (cause by excessive frequency reusing).

Channel separation achieved by filters:

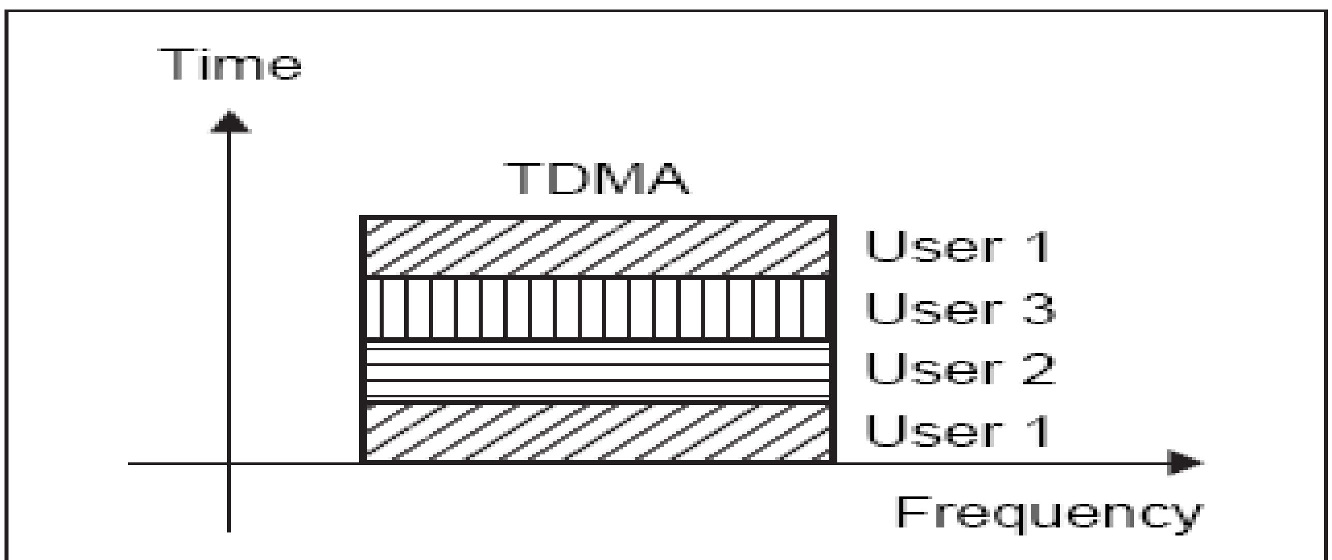
- Good selectivity
- Guard bands between channels

FDMA can be performed in two ways:

- **Fixed-assignment multiple access (FAMA):**
  - Each user is allocated a channel permanently, whether they use it or not.
  - Ideal for broadcast satellite communication.
- **Demand-assignment multiple access (DAMA):** The sub-channel allotment changes based on demand. Ideal for point to point communication.
  - Used to assign a bandwidth to clients that don't need to use it constantly.
  - It allows utilizing of one channel (frequency band, timeslot, etc.) by many users *at different times*.
  - This technology is mainly used by small clients, as opposed to *PAMA (Permanently Assigned Multiple Access)*.
  - DAMA is widely used in satellite communications, especially in VSAT systems, and military environment.

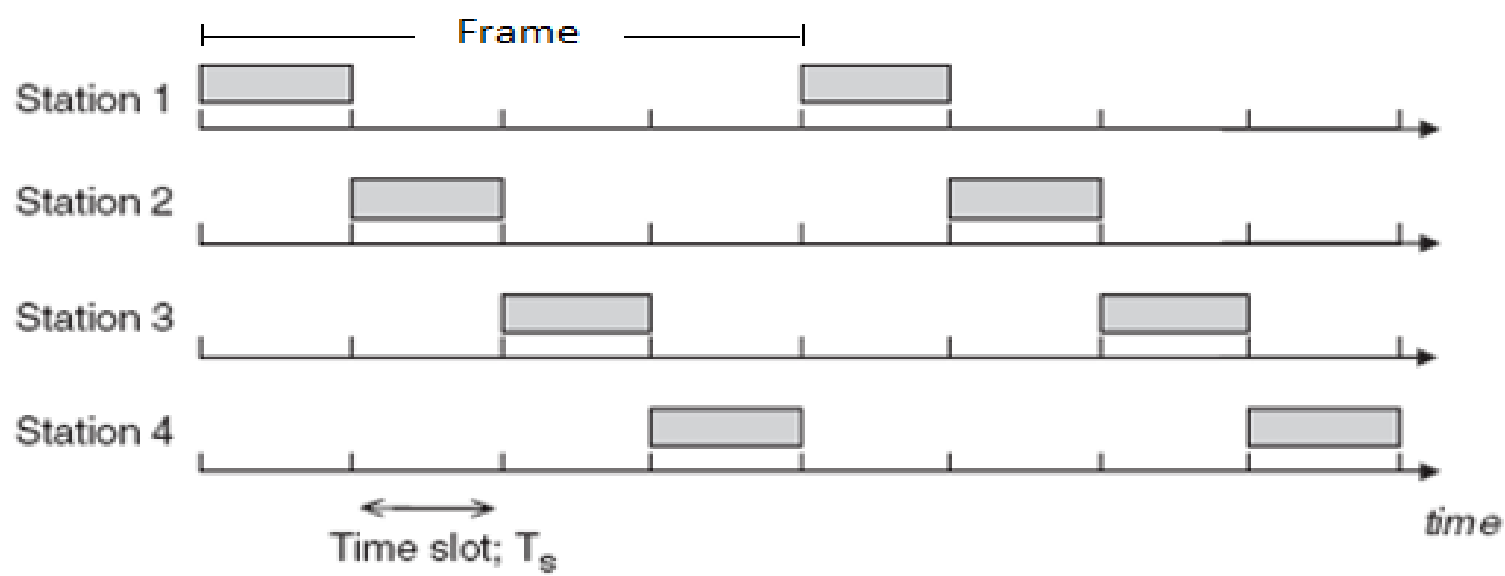
Time Division Multiple Access (TDMA)

- TDMA (Time Division Multiple Access) breaks a transmission into multiple time slots, each one dedicated to a different transmitter.
- TDMA is increasingly becoming more widespread in satellite communication.
- TDMA uses the same techniques (FAMA and DAMA) as FDMA does.

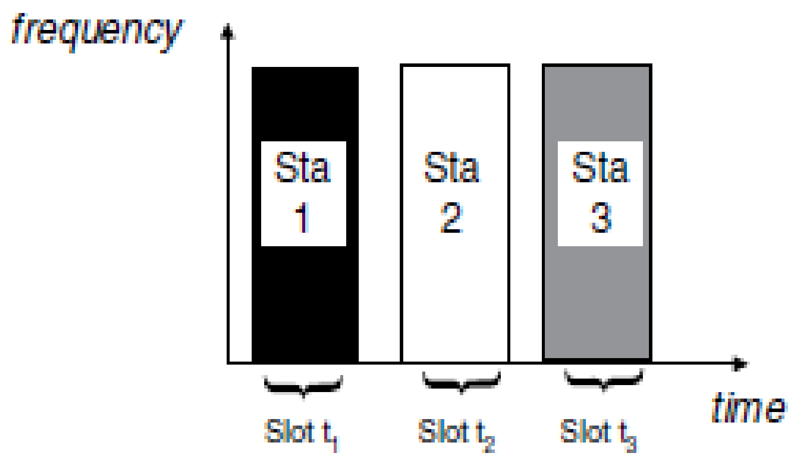


- With TDMA the multiple carriers are separated by TIME in the transponder, rather than by FREQUENCY as with FDMA, presenting only one carrier at any time to the transponder.
- Timeslots are repeated in frames.
- The satellite transponder operates with a saturated power output, providing the most efficient use of the available power.
- The time slot is pre-assigned or can be changed on demand.

TDMA time slot allocation

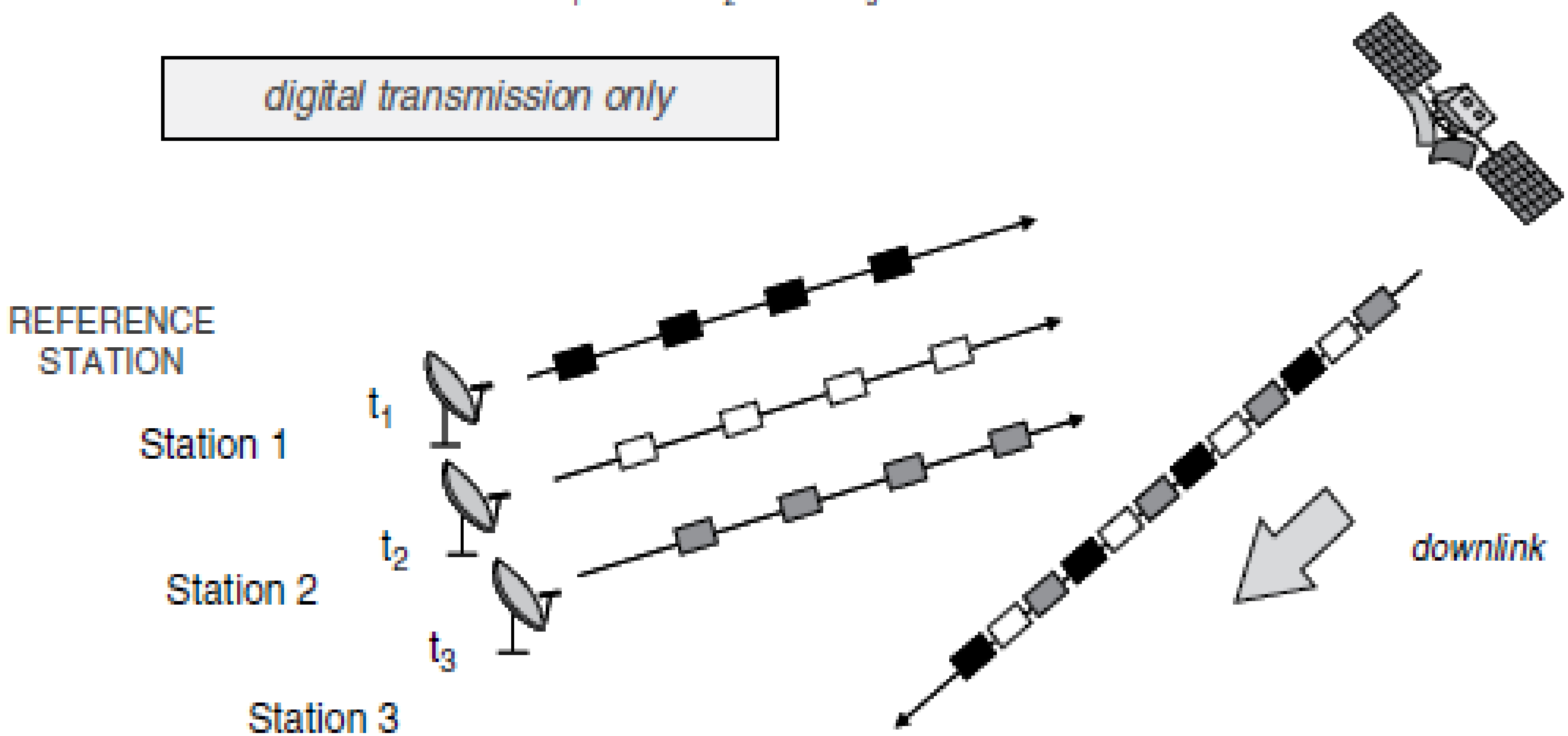


TDMA



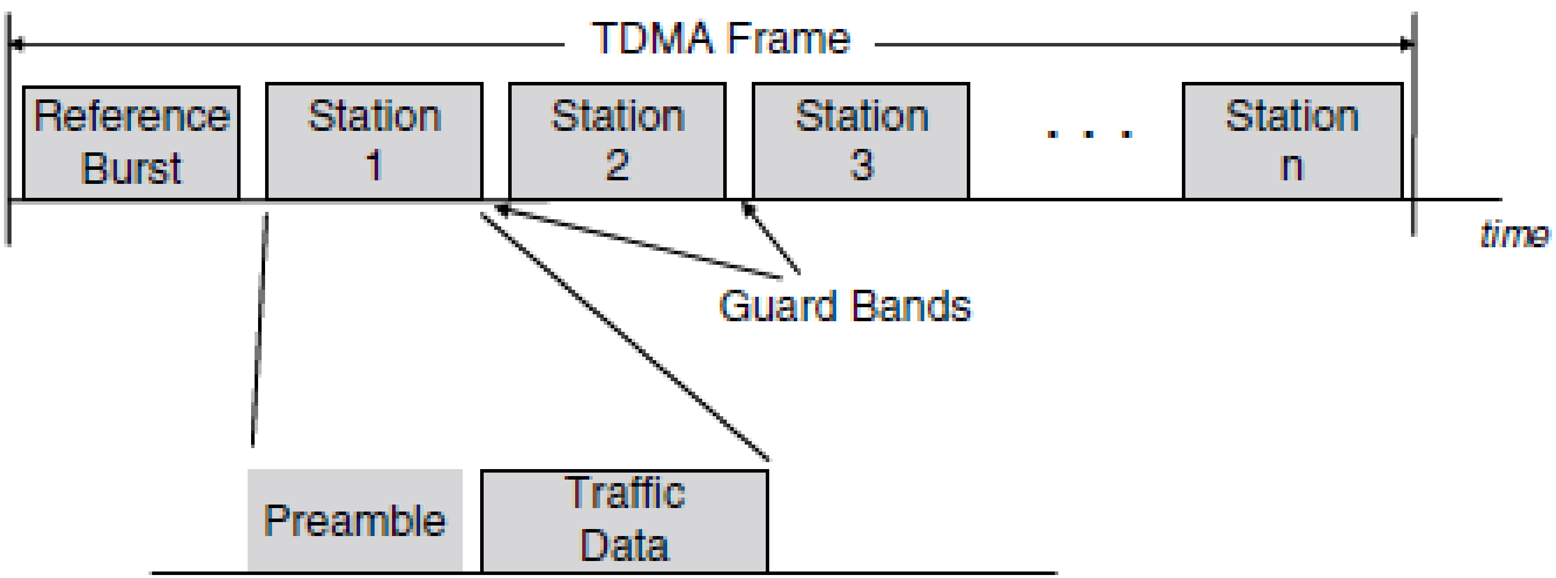
- *each station is assigned a specific uplink time slot for burst (packet)*
- *downlink transmission is interleaved set of all packets*

digital transmission only



TDMA frame

- The total time period that includes all traffic station bursts and network information is called the TDMA ***frame***.
- Typical frame times range from 1 to 20 ms. Each station burst contains a ***preamble*** and ***traffic data***.
- TDMA is most practical for digital data only.



TDMA frame structure

- Advantages of TDMA over FDMA.
  - Digital equipment used in time division multiplexing is increasingly becoming cheaper.
  - There are advantages in digital transmission techniques. Ex: error correction.
  - Lack of intermodulation noise means increased efficiency.
  - Each ground station has exclusive use of the full transponder bandwidth during its time slot.
  - TDMA offers a much more adaptive MA structure than FDMA regarding ease of reconfiguration for changing traffic demands.

TDMA Frame Efficiency

- The performance of a TDMA system can be evaluated by consideration of the TDMA ***frame efficiency***, η_F , defined as:

$$\eta_F = \frac{\text{Number of bits available for traffic}}{\text{Total number of bits in frame}}$$

or, in terms of the TDMA frame elements,

$$\eta_F = 1 - \frac{n_r b_r + n_t b_p + (n_r + n_t) b_g}{r_T t_F}$$

Where:

t_F = TDMA frame time, in s

r_T = total TDMA bit rate, in bps

n_r = number of reference stations

n_t = number of traffic bursts

b_r = number of *bits* in reference burst

b_p = number of *bits* in traffic burst preamble

b_g = number of *bits* in guard band

- Note that the frame efficiency is improved (increased) by:
  - a longer frame time, which increases the total number of bits; or
  - lowering the overhead (nontraffic bits) in the frame.
- The optimum operating structure occurs by providing the longest possible frame time with the lowest total number bits allocated to overhead functions.

TDMA Capacity

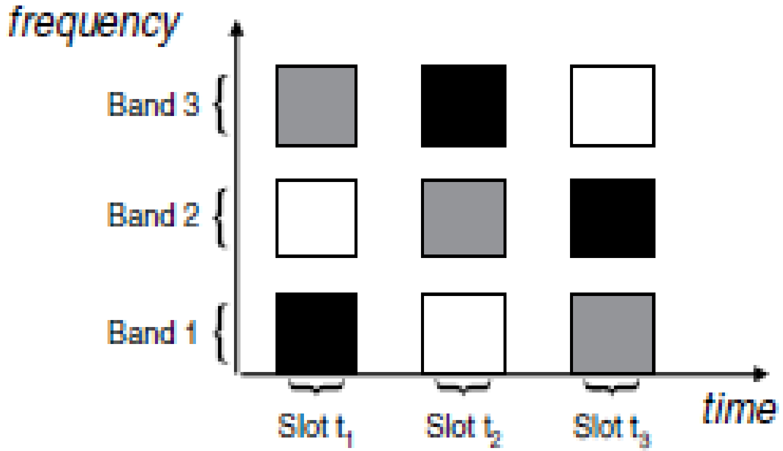
- The network channel capacity for a TDMA network is most often evaluated in terms of an ***equivalent voice-channel capacity***, n_c.
- This allows evaluation of capacity for any type of data source bit stream: voice, video, data, or any combination of the three.
- The equivalent voice channel capacity is defined as

$$n_C = \frac{\text{Available information bit rate, } r_i}{\text{Equivalent voice channel bit rate, } r_C} = \frac{r_i}{r_C}$$

- The available information bit rate, r_i, represents that portion of the total bit rate available for information (traffic), i.e., the total bit rate minus the bit rate allocated to overhead functions.
- The ***equivalent voice channel bit rate***, r_c, is usually defined as the standard PCM bit rate. **(r_c = 64 kbps)**

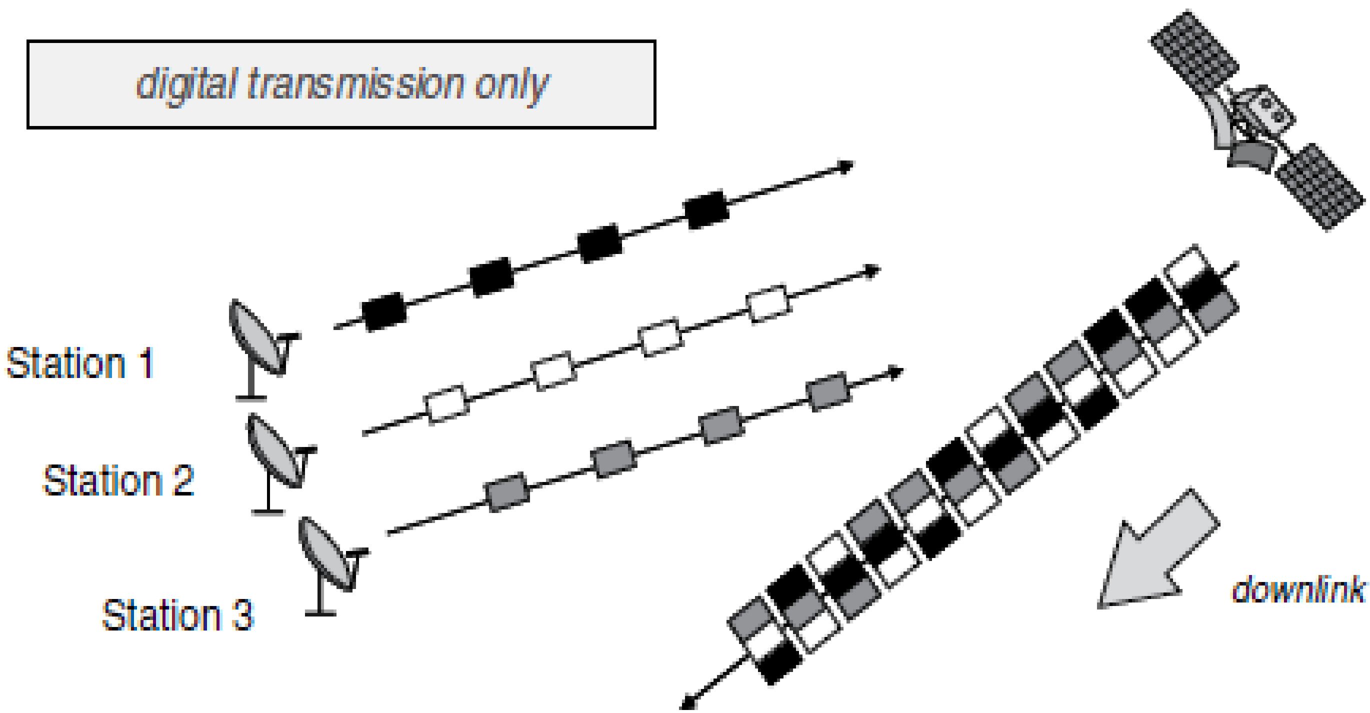
Code Division Multiple Access (CDMA)

- Each user is assigned a unique digital code (pseudo - random code sequence)
- Many users' communications can be transmitted simultaneously over the same frequency band
- Advantages:
  - very efficient use of spectrum
  - does not require frequency planning
- CDMA is the most complex technique to implement, requiring several levels of synchronization at both the transmission and reception levels.
- CDMA is practical for digital formatted data only, and offers the highest power and spectral efficiency operation of the three fundamental techniques.



- *a hybrid combination of FDMA and TDMA*
- *each uplink station is assigned time slot and frequency band in coded sequence*
- *downlink receiver must know code to detect*

digital transmission only



Code Division Multiple Access (CDMA)

CDMA Advantages over FDMA or TDMA

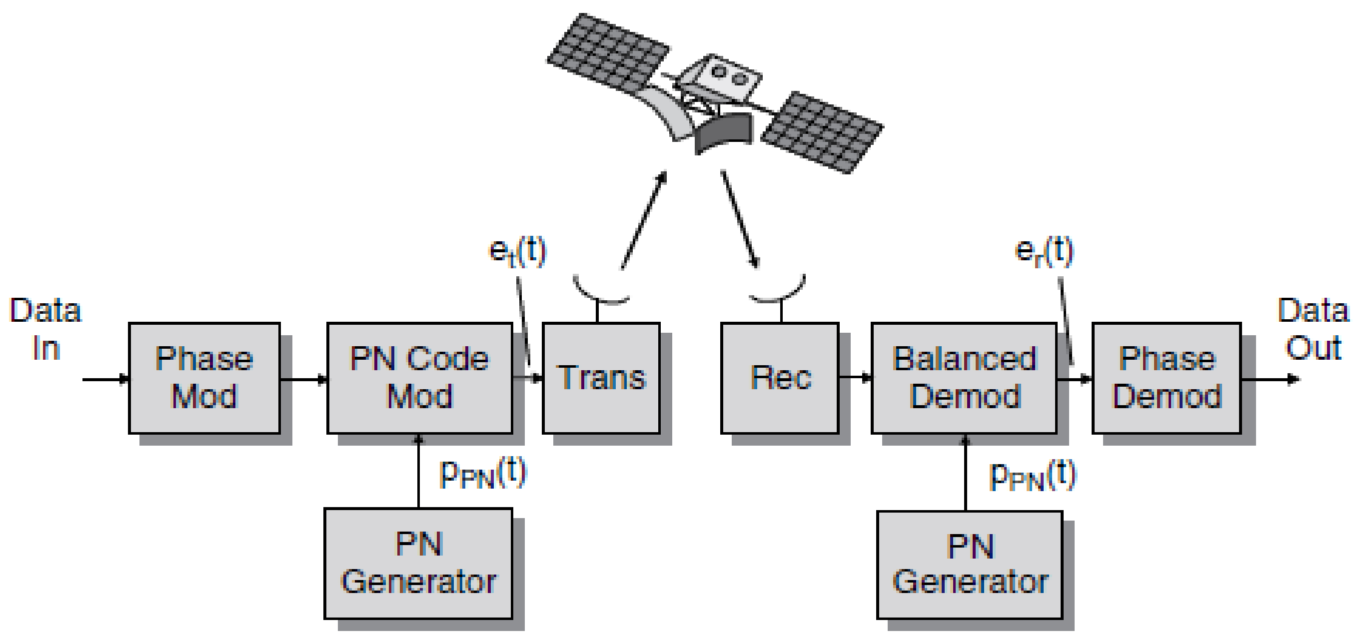
- **Privacy**. The code is distributed only to authorized users, protecting the information from others.
- **Spectrum Efficiency**. Several CDMA networks can share the same frequency band, because the undetected signal behaves as Gaussian noise to all receivers without knowledge of the code sequence.
- **Fading Channel Performance**. Only a small portion of the signal energy is present in a given frequency band segment at any one time, therefore frequency selective fading or dispersion will have a limited effect on overall link performance.
- **Jam Resistance**. Because only a small portion of the signal energy is present in a given frequency band segment at any one time, the signal is more resistant to intentional.

CDMA Approaches

- Code Division Multiple Access is often referred to as ***Spread Spectrum*** or ***Spread Spectrum Multiple Access*** (SSMA) because of the signal spreading characteristics of the process.
- Two basic approaches are used in CDMA for spectrum spreading, based on the data elements being acted upon by the PN sequence:
  - **Direct Sequence Spread Spectrum (DS-SS)**: The baseband signal sequence is acted upon by the PN sequence.
  - **Frequency Hopping Spread Spectrum (FH-SS)**: The transmission (carrier) frequency is acted upon by the PN sequence, producing a sequence of modulated data bursts with time varying pseudorandom carrier frequencies.

Direct Sequence Spread Spectrum

- A ***direct sequence spread spectrum*** (DS-SS) system spreads the baseband data bits with the PN sequence.
- In the most widely used satellite network implementation, a phase modulated baseband data stream is generated, then used to phase modulate an RF carrier with the PN spread signal.

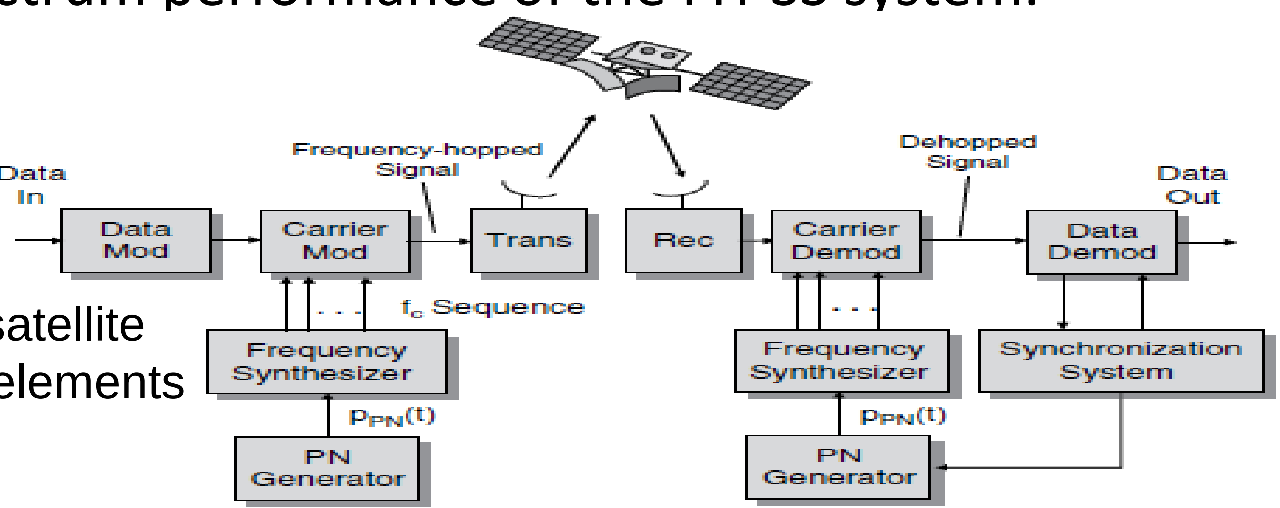


DS-SS satellite system elements

Frequency Hopping Spread Spectrum (FH-SS)

- Frequency hopping spreads the information data sequence across a broader band, producing the benefits of CDMA similar to the DS-SS approach.
- Two bandwidths are defined in FH-SS operation:
  - **Instantaneous Bandwidth**, b_{bb} – the baseband bandwidth of the channel used in the hopset.
  - **Total Hopping Bandwidth**, b_{rf} – the total RF bandwidth over which hopping occurs.
- The larger the ratio of b_{rf} to b_{bb} , the better the spread spectrum performance of the FH-SS system.

FH-SS satellite system elements



CDMA Processing Gain

- CDMA data recovery is possible because noise or other signals combine incoherently in the balanced demodulator (despreader) while the desired signal combines coherently.
- The ***processing gain*** or ***spreading ratio*** is defined as the ratio:

$$g_p \equiv \frac{b_{rf}}{r_b}$$

Where:

b_{rf} = spread spectrum RF bandwidth, in Hz.

r_b = transmission rate, in bps.

- The processing gain is a measure of the reduction in noise level produced by the spectrum spreading process.
- It is the improvement achieved by the 'despreading process' in the receiver demodulator correlator.
- This can be represented in link analysis form as:

$$\left(\frac{s}{n}\right)_{out} = \left(\frac{c}{n}\right)_{in} g_p$$

or in dB,

$$\left(\frac{S}{N}\right)_{out} = \left(\frac{C}{N}\right)_{in} + 10\log(g_p)$$

where

$\left(\frac{S}{N}\right)_{out}$ = output signal-to-noise ratio at the receiver correlator
$\left(\frac{C}{N}\right)_{in}$ = RF input carrier-to-noise ratio of the correlator

CDMA Capacity

- The CDMA capacity defines the maximum number of data channels that can be accommodated in a CDMA network for acceptable signal recovery.
- The capacity of the CDMA network:

$$M = \frac{g_p}{\left(\frac{e_b}{n_t}\right)}\left(1 - \frac{n_o}{n_t}\right)$$

where

g_p = processing gain of the CDMA network
$\left(\frac{e_b}{n_t}\right)$ = energy-per-bit to noise density for the data signal
n_o = thermal noise power density, in w/Hz n_t = total noise power density, $(n_o + n_j)$, in w/Hz

The capacity M gives the maximum number of channels that can be accommodated in a CDMA system. Acceptable performance is usually defined as the $\left(\frac{e_b}{n_t}\right)$ required to maintain a specified bit error rate for the specific modulation scheme and system parameters used in the CDMA network.