Introduction to Satellite Communications

Multiple Access

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Agenda

- ***Multiple Access Concept***
- ***FDMA***
- ***TDMA***
- ***CDMA***
- ***On Board Processing***

Source Material:

- Pratt & Bostian Chapter 6, plus updated material

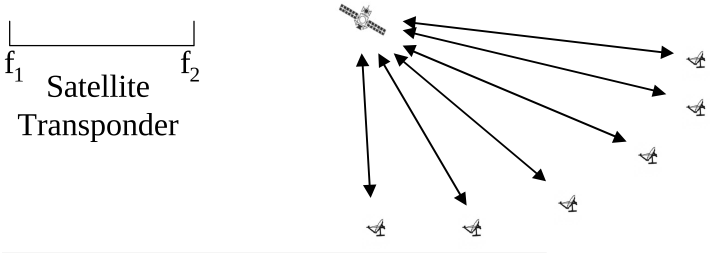
Acknowledgements:

•Dr. Jeremy Allnutt course notes (*With professor's permission*).

Multiple Access Concept

MULTIPLE ACCESS - 1

- THE PROBLEM:
  HOW DO WE ***SHARE*** ONE TRANSPONDER BETWEEN SEVERAL EARTH STATIONS?



IT IS AN OPTIMIZATION PROBLEM

MULTIPLE ACCESS - 2

- NEED TO OPTIMIZE
  - – Satellite capacity (revenue issue)
  - – Spectrum utilization (coordination issue)
  - – Interconnectivity (multiple coverage issue)
  - – Flexibility (demand fluctuation issue)
  - – Adaptability (traffic mix issue)
  - – User acceptance (market share issue)
  - – Satellite power
  - – Cost

Very, **VERY**, rarely a simple optimum; nearly always a trade-off exercise

HOW DO YOU SEPARATE USERS?

- LABEL THE SIGNAL IN A UNIQUE WAY AT THE TRANSMITTER

– UNIQUE FREQUENCY SLOT	***FDMA***
– UNIQUE TIME SLOT	***TDMA***
– UNIQUE CODE	***CDMA***

- RECOGNIZE THE UNIQUE FEATURE OF EACH SIGNAL AT THE RECEIVER

CHANNEL RECOGNITION?

- **FDMA**
  - – BAND PASS FILTER EXTRACTS SIGNAL IN THE CORRECT FREQUENCY SLOT
- **TDMA**
  - – DE-MULTIPLEXER “GRABS” SIGNAL IN THE CORRECT TIME SLOT
- **CDMA**
  - – DE-SPREADER OR DE-HOPPER EXTRACTS SIGNAL WITH THE CORRECT CODE

Direct Sequence

Frequency-Hopped

MULTIPLE ACCESS - 3A

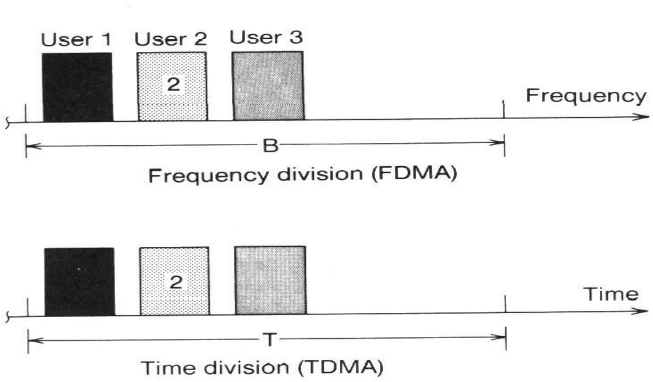


Fig. 6.1 (top part) in text

MULTIPLE ACCESS - 3B

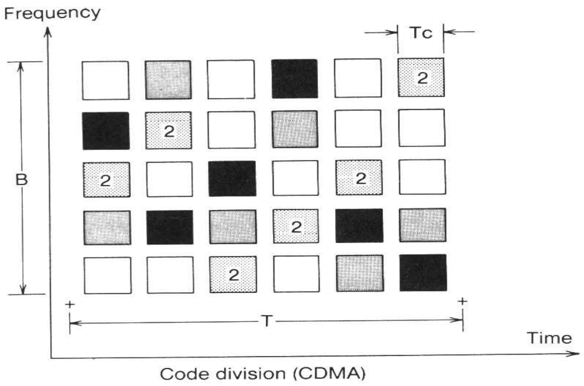


Fig. 6.1 (bottom part) in text

MULTIPLE ACCESS - 4

- If the proportion of the resource (frequency, time, code) is allocated in advance, it is called ***PRE-ASSIGNED*** **MULTIPLE ACCESS** or ***FIXED*** **MULTIPLE ACCESS**
- 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**

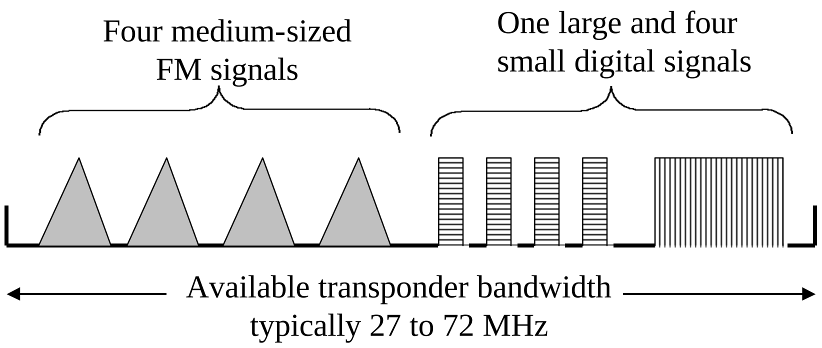
FDMA

FDMA

- SHARE THE FREQUENCY
  - – TIME IS COMMON TO ALL SIGNALS
- DEVELOP A ***FREQUENCY PLAN*** FROM USER CAPACITY REQUESTS
- TRANSPONDER LOADING PLAN USED TO MINIMIZE ***IM*** PRODUCTS

TRANSPONDER LOADING PLAN ⇨

FDMA TRANSPONDER LOADING PLAN



IMPORTANT TO CALCULATE INTERMODULATION PRODUCTS

INTERMODULATION

- INTERMODULATION
  - WHEN TWO, OR MORE, SIGNALS ARE PRESENT IN A CHANNEL, THE SIGNALS CAN “MIX” TOGETHER TO FORM SOME UNWANTED PRODUCTS
  - WITH THREE SIGNALS, ω_1, ω_2 AND ω_3, PRESENT IN A CHANNEL, IM PRODUCTS CAN BE SECOND-ORDER, THIRD-ORDER, FOURTH-ORDER, ETC.

ORDER OF IM PRODUCTS

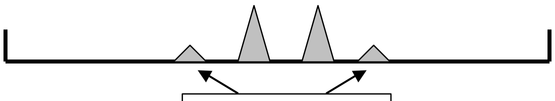
IM PRODUCT ORDER

- Second-order is $\omega_1 + \omega_2$, $\omega_2 + \omega_3$, $\omega_1 + \omega_3$
- Third-order is $\omega_1 + \omega_2 + \omega_3$, $2\omega_1 - \omega_2$, $2\omega_2 - \omega_1$..
- Usually, only the **odd-order** IM products fall within the passband of the channel
- Amplitude <u>reduces</u> as order <u>rises</u>
- Only **third-order IM products** are usually important

3-IM products very sensitive to small signal changes. Hence, IM 'noise' can change sharply with output amplifier back-off

IM EXAMPLE

- There are two 10 MHz signals at 6.01 GHz and 6.02 GHz centered in a 72 MHz transponder
- 2-IM product is at 12.03 GHz
- 3-IM products are at [2(6.01) - 6.02] = 6.00 and [2(6.02) - 6.01] = 6.03 GHz



3-IM products

FDMA LIMITATIONS

- Intermods cause C/N to fall
- Back-Off is needed to reduce IM
- Parts of band cannot be used because of IM
- Transponder power is shared amongst carriers
- Power balancing must be done carefully
- Frequencies get tied to routes

Patterned after terrestrial analog telecoms and so does not confer the full benefit of satellite "broadcast" capabilities

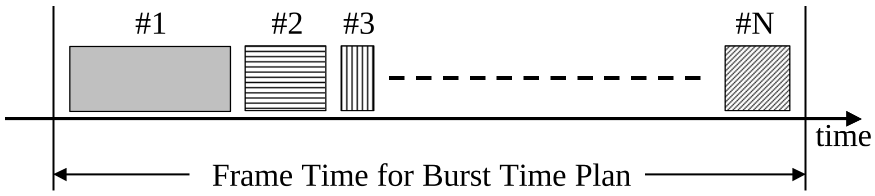
TDMA

TDMA

- SHARE THE TIME
  - – FREQUENCY IS COMMON TO ALL SIGNALS
- DEVELOP A ***BURST TIME PLAN*** FROM USER CAPACITY REQUESTS
- LARGE SYSTEM BURST TIME PLANS CAN BE COMPLICATED AND DIFFICULT TO CHANGE

BURST TIME PLAN

BURST TIME PLAN



USERS OCCUPY A SET PORTION OF THE FRAME ACCORDING TO THE BURST TIME PLAN

NOTE: (1) GUARD TIMES BETWEEN BURSTS

(2) LENGTH OF BURST $\propto$ BANDWIDTH ALLOCATED

TDMA - 1

- **THE CONCEPT**:
- Each earth station transmits ***IN SEQUENCE***
- Transmission bursts from many earth stations arrive at the satellite
  IN AN ORDERLY FASHION and
  IN THE CORRECT ORDER

TDMA - 2

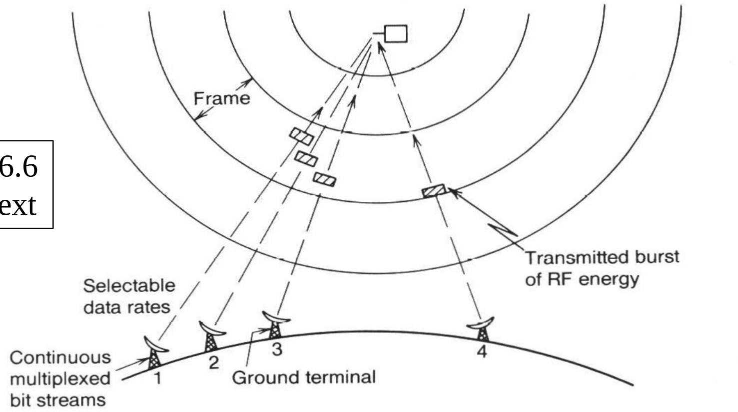


Figure 6.6 in the text

NOTE: Correct timing accomplished using ***Reference Transmission***

TDMA - 3

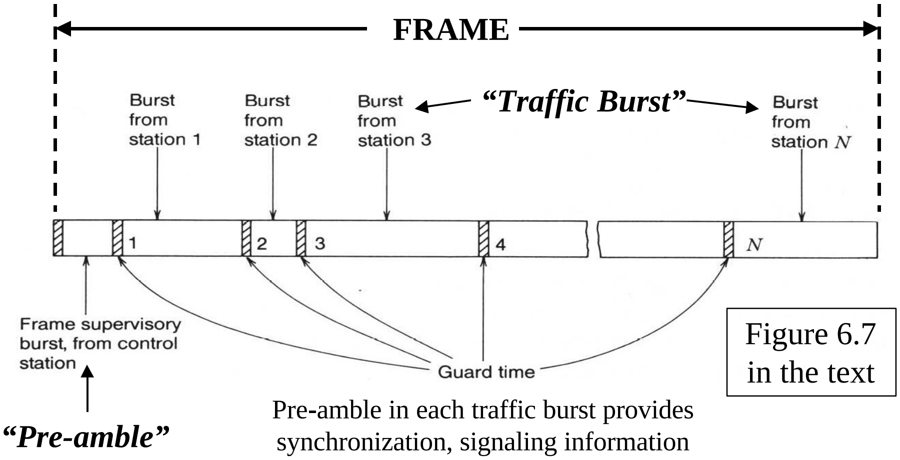


Figure 6.7 in the text

Pre-amble in each traffic burst provides synchronization, signaling information (e/s tx, e/s rx, etc.), and data

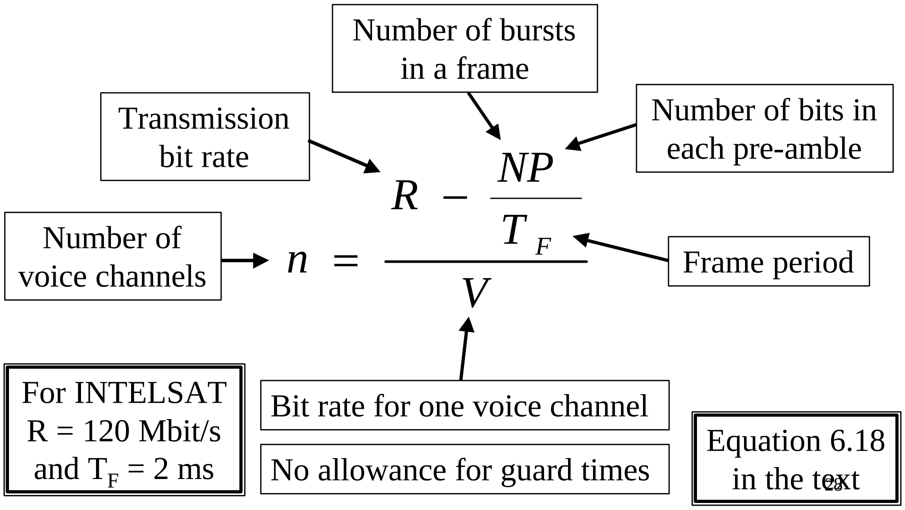
TDMA - 4

- Timing obtained by
  - organizing TDMA transmission into frames
  - each e/s transmits once per frame such that its burst begins to leave the satellite at a specified time interval before (or after) the start of a reference burst
- Minimum frame length is 125 μs
  - 125 μs ≡ 1 voice channel sampled at 8 kHz

TDMA - 5

- Reference burst(s) and pre-amble bits are system overhead and earn no revenue
- ***Traffic bits*** earn the revenue
- Need to minimize system overhead
- Complicated system trade-off with number of voice (or data) channels, transmission bit rate, number of bursts, etc.

TDMA - 6



$$n = \frac{R - \frac{NP}{T_F}}{V}$$

Number of bursts in a frame

Transmission bit rate

Number of bits in each pre-amble

Number of voice channels

Frame period

Bit rate for one voice channel

No allowance for guard times

For INTELSAT R = 120 Mbit/s and T_F = 2 ms

Equation 6.18 in the text

TDMA - 7

- PROBLEM
  - Delay time to GEO satellite is ~ 120 ms
  - TDMA Frame length is 125 μs to 2 ms
  - There could be almost 1000 frames on the path to the satellite at any instant in time

- **Timing** is therefore ***CRUCIAL*** in a TDMA system

LONG TDMA FRAMES

- To reduce overhead, use longer frames
  - 125 μs frame: 1 Word/Frame
  - 500 μs frame: 4 Words/Frame
  - 2000 μs frame: 16 Words/Frame

2000 μs = 2 ms = INTELSAT TDMA standard

NOTE: 1 Word is an 8-bit sample of digitized speech, a "terrestrial channel", at 64 kbit/s

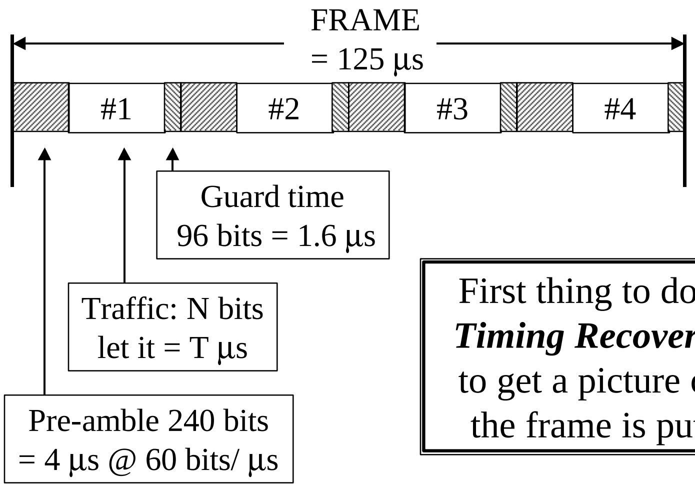
8 kHz × 8 bits = 64 kbit/s

TDMA EXAMPLE - 1

- Transponder bandwidth = 36 MHz
- Bit rate (QPSK) 60 Mbit/s = 60 bits/µs
- Four stations share transponder in TDMA using 125 µs frames
- Pre-amble = 240 bits
- Guard time = 1.6 µs

Assuming no reference burst we have →

TDMA EXAMPLE - 2



FRAME
= 125 µs

Guard time
96 bits = 1.6 µs

Traffic: N bits
let it = T µs

Pre-amble 240 bits
= 4 µs @ 60 bits/ µs

First thing to do: draw the ***Timing Recovery Diagram*** to get a picture of the way the frame is put together

TDMA EXAMPLE - 3

- WITH THE TDMA EXAMPLE
  - – (a) What is the transponder capacity in terms of 64 kbit/s speech channels?
  - – (b) How many channels can each earth station transmit?
- ANSWER
  - – (a) There are four earth stations transmitting within the 125 μs frame, so we have

TDMA EXAMPLE - 4

- 125 μs frame gives
  $125 = (4\times4\ \mu s) + (4\times1.6\ \mu s) + (4\times T\ \mu s)$

Four earth stations, 4 μs pre-amble,
1.6 μs guard time, T μs traffic bits

This gives $T = (125 - 16 - 6.4)/4 = 25.65\ \mu s$
60 Mbit/s $\equiv 60$ bits/μs, thus $25.65\ \mu s = 1539$ bits
Hence channels/earth station $= 1539/8 = 192(.375)$

8 bits/word for a voice channel

TDMA EXAMPLE - 5

- (a) What is the transponder capacity in terms of 64 kbit/s speech channels?

  Answer: 768 (64 kbit/s) voice channels

- (b) How many channels can each earth station transmit?

  Answer: 192 (64 kbit/s) voice channels

TDMA EXAMPLE - 6

- What happens in the previous example if we use an INTELSAT **2 ms** frame length?
  $2\ \text{ms} = 2{,}000\ \mu\text{s} = 4\times 4 + 4\times 1.6 + 4\times T$

  Therefore, $T = 494.4\ \mu\text{s}$
  and, since there are 60 bits/μs (60 Mbit/s),
  we have $T \Rightarrow 29{,}664$ bits

Remember we have 128 bits for a satellite channel

TDMA EXAMPLE - 7

- With 128 bits for a satellite channel we have
  Number of channels/access = 29,664/128
  = 231(.75)
- Capacity has increased due to less overhead

  125 μs frame ⇒ 192 channels/access
  2 ms frame ⇒ 231 channels/access

TDMA SYNCHRONIZATION

- Start-up requires care!!
- Need to find accurate range to satellite
  - Loop-back (send a PN sequence)
  - Use timing information from the controlling earth station
- Distance to satellite varies continuously
  - Earth station must monitor position of its burst within the frame ***AT ALL TIMES***

TDMA SUMMARY - 1

- ADVANTAGES
  - No intermodulation products (if the full transponder is occupied)
  - Saturated transponder operation possible
  - Good for data
  - With a flexible Burst Time Plan it will optimize capacity per connection

TDMA SUMMARY - 2

- DISADVANTAGES
  - Complex
  - High burst rate
  - Must stay in synchronization

CDMA

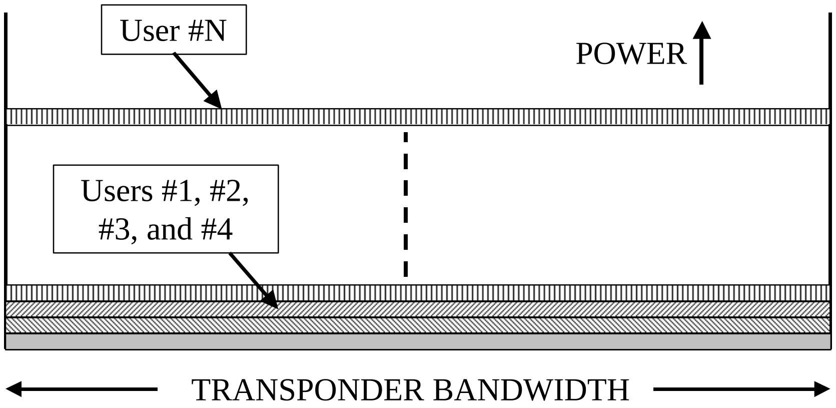
CDMA - 1

- SHARE TIME **AND** FREQUENCY
  - SEPARATION OF SIGNALS IS THROUGH THE USE OF UNIQUE CODES
- EACH USER IS ASSIGNED A CODE
  - STATION 1 ⇒ CODE 1
  - STATION 2 ⇒ CODE 2
- RECEIVER SEARCHES FOR CODES
- CODE RATE >> DATA RATE

CDMA - 2

- SYSTEM OPERATOR - OR INDIVIDUAL PAIRS OF USERS - ASSIGN UNIQUE SPREADING OR HOPPING CODES TO EACH DUPLEX LINK
- CDMA IS A SOLUTION FOR SEVERE INTERFERENCE ENVIRONMENTS, USUALLY AT A CAPACITY LOSS COMPARED WITH TDMA AND FDMA

CDMA - 3



CODE DIVISION MULTIPLE ACCESS - ***CDMA***

- ALL USERS SHARE THE **SAME TIME *AND* FREQUENCY**
- SIGNALS ARE SEPARATED BY USING A UNIQUE CODE
  - Codes must be “orthogonal” so that ***User A*** does not respond to a code intended for ***User B***
  - Codes are usually <u>**very long**</u> : PN sequence, Gold, or Kasami codes

CDMA - 1

- CDMA CAN BE ONE OF THREE TYPES
  - Direct Sequence (Spread Spectrum)
    - Occupies full bandwidth all the time
  - Frequency Hopping
    - A pair of frequencies (one for “1” and one for “0”) hop over the full bandwidth randomly
  - A hybrid of Direct Sequence and Frequency Hopping

We will concentrate on Direct Sequence ⇨

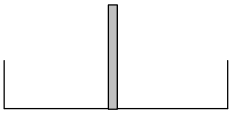
DIRECT SEQUENCE CDMA - 1

- Multiply the information stream (the data) by a high speed PN code
- Use two codes: one for a “1” and one for a “0”
- 1 data bit ⇒ many “Chips” →
  e.g. 2.4 kbit/s ⇒ 1 Mbit/s

The Chip Rate is essentially the code rate from the PN sequence generator

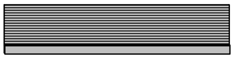
The “Spreading factor” is ≈ 400, can think of this as coding gain

DIRECT SEQUENCE CDMA - 2

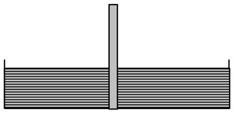


Narrow-band data

Narrow-band data “spread” over the full bandwidth

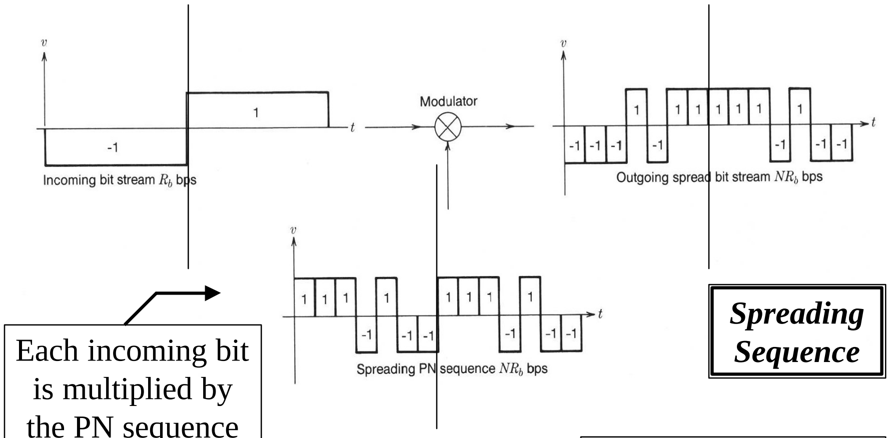


Other spread signals added, filling up the channel with many noise-like signals



De-spreading process brings the wanted channel out of the noise

DIRECT SEQUENCE CDMA - 2

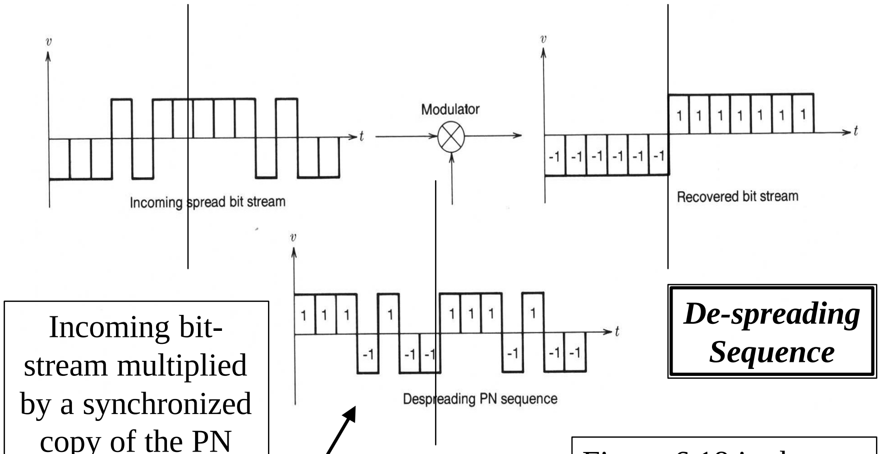


Each incoming bit is multiplied by the PN sequence

Spreading Sequence

Figure 6.16 in the text

DIRECT SEQUENCE CDMA - 3



Incoming bit-stream multiplied by a synchronized copy of the PN sequence

De-spreading Sequence

Figure 6.18 in the text

CDMA SPECTRUM

Other users in channel just look like noise

- FLAT - usually **below** the noise
- Code must be **compressed** (de-spread) to raise the signal above the noise
- Receiver must synchronize to a code sequence **which is below the noise**
- Requires the use of a correlator, a generator, and ….. ***patience***

Takes a while to “pull in”

CDMA APPLICATIONS

- MILITARY
  - Anti-Jam (AJ)
  - Low Probability of Intercept (LPI)
- COMMERCIAL
  - VSATs (due to wide beams)
  - GPS
  - Microwave Cellular Systems

On Board Processing

SATELLITE REQUIREMENTS - 1

- LEO SYSTEM
  - Adapt to rapid movement of the satellite which causes
    - rapid change in pathlength (time of arrival and power balancing problems)
    - rapid change in look-angle (multi-path and blockage environment problems)
    - rapid change in Doppler spread (spectrum broadening)

SATELLITE REQUIREMENTS - 2

- GEO SYSTEM
  - – Adapt to long path length to satellite which causes
    - Large path loss (low EIRP and/or capacity problem)
    - Long delay (protocol problem requiring an emulation or “spoofing” procedure)
    - Large satellite antenna footprint (frequency re-use problem)

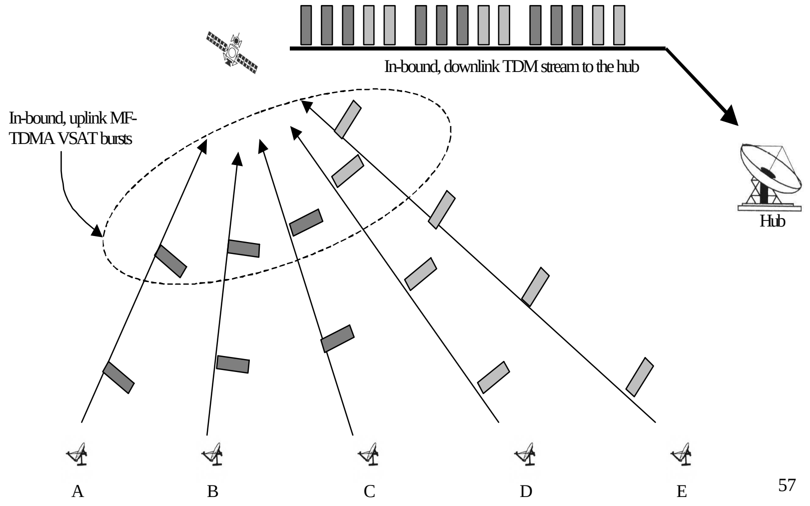
Both GEO and LEO systems now make use of extensive OBP technological approaches

OBB APPROACHES

- Receive aggregate uplink channel(s)
- Detect each (narrow-band) uplink signal
- Process each uplink signal so that
  - – errors removed
  - – address read
- Repackage signals into a large TDM stream
- Transmit TDM stream

MF-TDMA approach is emerging as the “way to go”

MF-TDMA INTERNET S/C



MF-TDMA ADVANTAGES

- Relatively narrow-band uplink
- Detection of signal at satellite enables
  - U/L power control to be exercised
  - On-board routing of traffic
  - Error detection and correction of the u/l signals
- TDM downlink enables relatively easy capture of desired return signal at the terminal