Department of Electrical Engineering
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ELEG 5663 Communication Theory
Ch. 11 Multiplexing and Multiple Access

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OUTLINE

- **Introduction**
- **Multiple access techniques**
  - FDMA, OFDMA
  - TDMA
  - CDMA
  - SDMA/PDMA

INTRODUCTION

- **Communication resource**
  - The time and frequency that is available for communication signaling associated within a given system
  - The time and frequency can be considered as a two dimensional plane
    - Time as the x-axis, and frequency as the y-axis
  - Sharing communication resource ➔ Sharing areas on the plane.
- **Multiple Access**
  - Multiple users share the communication resource
  - Two types of multiple access
    - 1. The allocation of communication resources among users are fixed.
    - 2. The allocation of communication resources among users are dynamically allocated based on the needs of the users.
  - Objective
    - Design efficient resource sharing technique such that
      - 1. the total throughput (data rate) is maximized.
      - 2. No area on the time-frequency plane is wasted.

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INTRODUCTION

- **There are three ways to improve communication throughput**
  - 1. Increase EIRP or reduce system loss to improve E_b / N_0 at receiver (Link analysis)
  - 2. Provide more channel bandwidth.
  - 3. Make the allocation of the communication resource more efficient (multiple access)
- **Basic multiple access types**
  - 1. Frequency division (FD): specified sub-band or frequency are allocated.
  - 2. Time division (TD): specified time slots are allocated.
  - 3. Code division (CD): users use mutually orthogonal code
  - 4. Space division (SD): use beam antennas pointing to different direction.
  - 5. Polarization division (PD): orthogonal polarization are used to separate signals.
  - 6. The combination of the above schemes
    - E.g. FDMA/TDMA, CDMA/TDMA, CDMA/FDMA

INTRODUCTION

- **Various signals sharing the communication resource (CR) should not create unmanageable interference to each other**
  - The signal on one CR channel should not significantly increase the probability of error in another channel.
  - Possible solutions for multiple access
    - Orthogonal time domain waveforms used by different users. (TDMA)

$$\int_{-\infty}^{+\infty} x_i(t)x_j(t)dt = K\delta_{ij}$$

    - Orthogonal frequency domain waveforms used by different users (FDMA)

$$\int_{-\infty}^{+\infty} x_i(f)x_j(f)df = K\delta_{ij}$$

OUTLINE

- Introduction

- **Multiple access techniques**
  - FDMA, OFDMA
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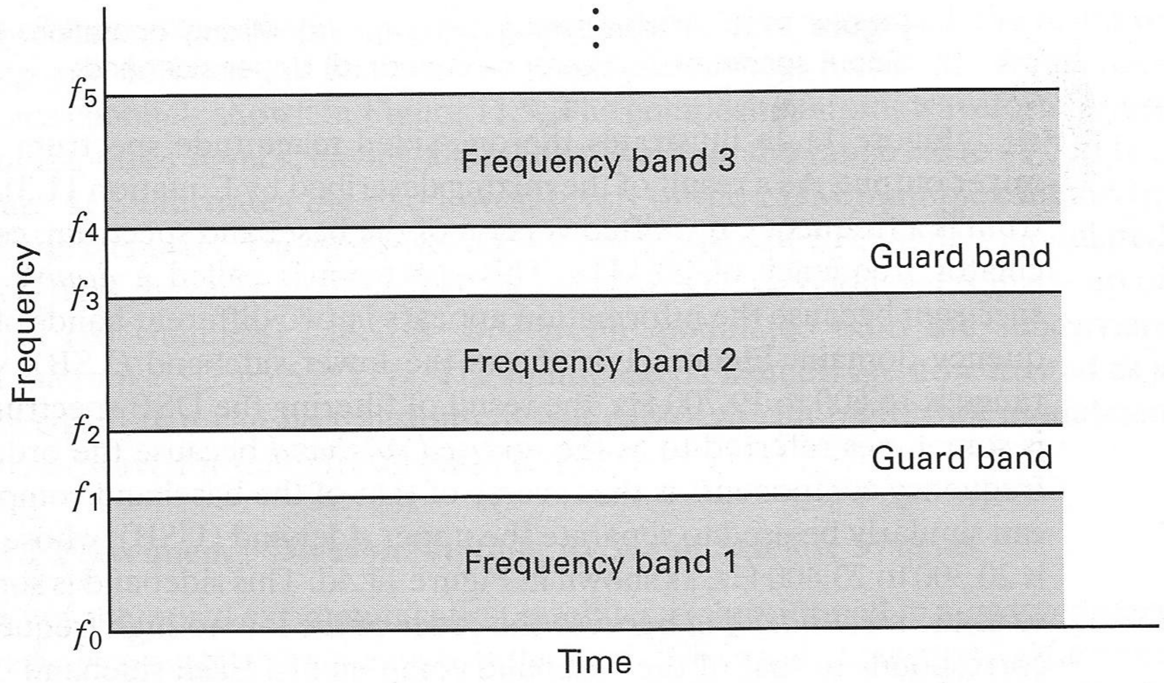
MULTIPLE ACCESS: FDMA

- **Frequency division multiple access (FDMA)**
  - Allocate different frequency bands to different users.
  - Ideally, there is no overlapping between the frequency bands.
  - Guard band: a buffer zone between adjacent channels to reduce adjacent channel interference.



MULTIPLE ACCESS: OFDMA

- **Orthogonal Frequency Division Multiple Access (OFDMA)**
  - Mutually orthogonal frequency domain signals are used by different users.
    - The signal from each user spreads the entire spectrum ➔ There is significant frequency domain overlapping among signals from different users.
    - The signals from different users are orthogonal.
  - Orthogonal signal set

$$\psi_k(t) = \frac{1}{\sqrt{T}} e^{j2\pi f_k t}, k = 1, 2, \cdots, N$$

$$\int_0^T \psi_i(t)\psi_k^*(t) = \delta_{ik}$$

  - Signal transmitted by the k-th user

$$x_k(t) = s_k \psi_k(t)$$

  - Signal at the receiver

$$r(t) = \sum_{k=1}^{N} s_k \psi_k(t) + n(t)$$

  - The detection of the m-th user

MULTIPLE ACCESS: OFDMA

- **The minimum frequency space between carriers**

$$f_{k+1} - f_k = \frac{1}{T}$$

MULTIPLE ACCESS: OFDMA

- **OFDMA with minimum frequency spacing**
  - Orthogonal signal sets

$$\psi_k(t) = \frac{1}{\sqrt{T}} e^{j2\pi \frac{k}{T} t}, k = 0, 1, \cdots, N-1, \qquad t \in [0, T]$$

  - Received signal

$$r(t) = \frac{1}{\sqrt{T}} \sum_{k=1}^{N} s_k e^{j2\pi \frac{k}{T} t} + n(t)$$

- **OFDM**
  - Orthogonal Frequency Division Multiplexing
  - If $s_0, s_1, \cdots, s_{N-1}$ belong to the same user, the scheme is called OFDM
  - A new modulation scheme that has been widely accepted by many standards.
  - Advantage: robust against ISI.

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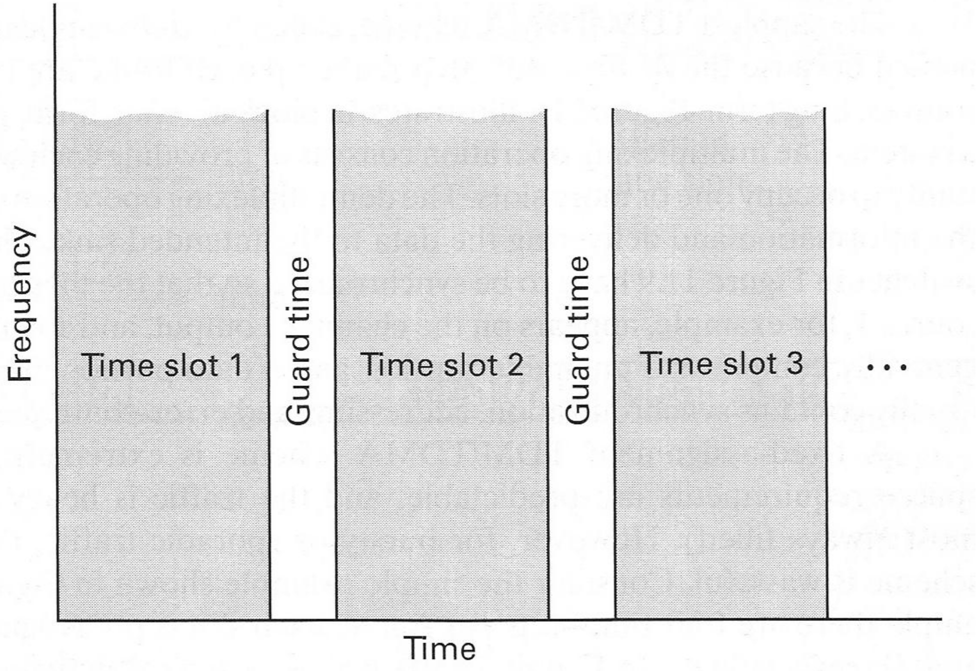
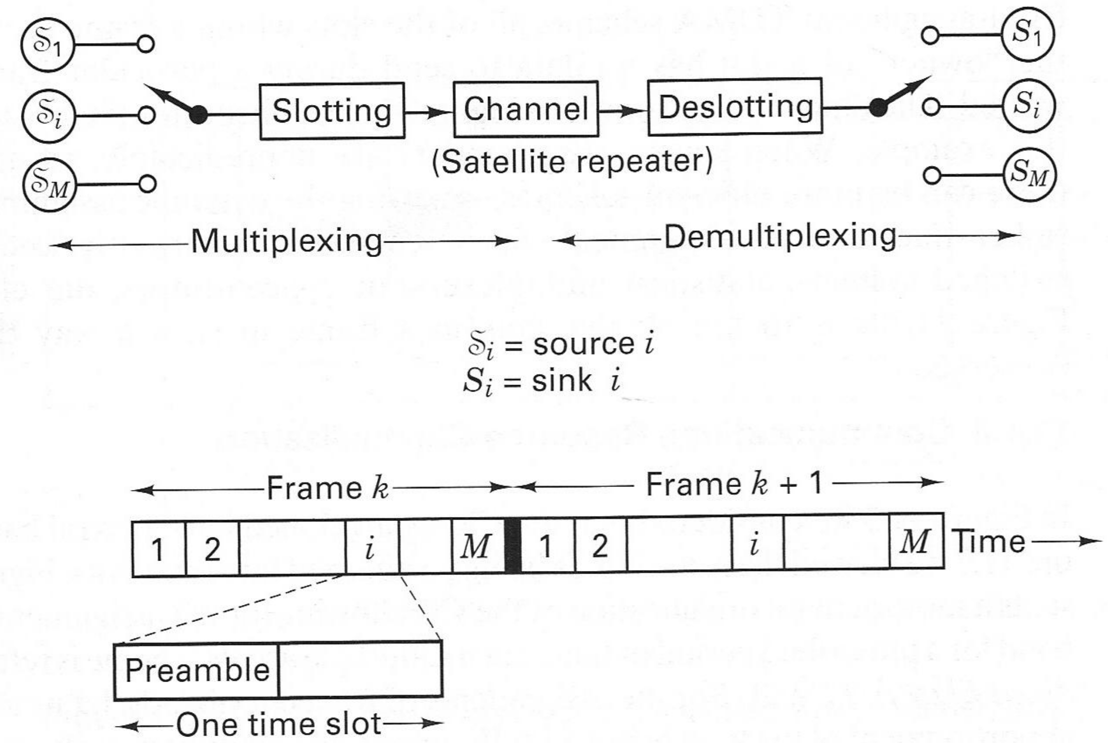
MULTIPLE ACCESS: TDMA

- **Frame and slots**
  - Frame: time is segmented into short intervals
  - Slot: Each frame is further divided into slots.
- **Time division multiple access (TDMA)**
  - Different users are assigned different time slots.
  - Can only be used in digital communication systems.



MULTIPLE ACCESS: TDMA

- **Fixed-assignment TDMA**
  - Each user is assigned one or more fixed time slots
  - Efficient when the data from users are heavy.
  - Inefficient when the data from users are bursty (sporadic)



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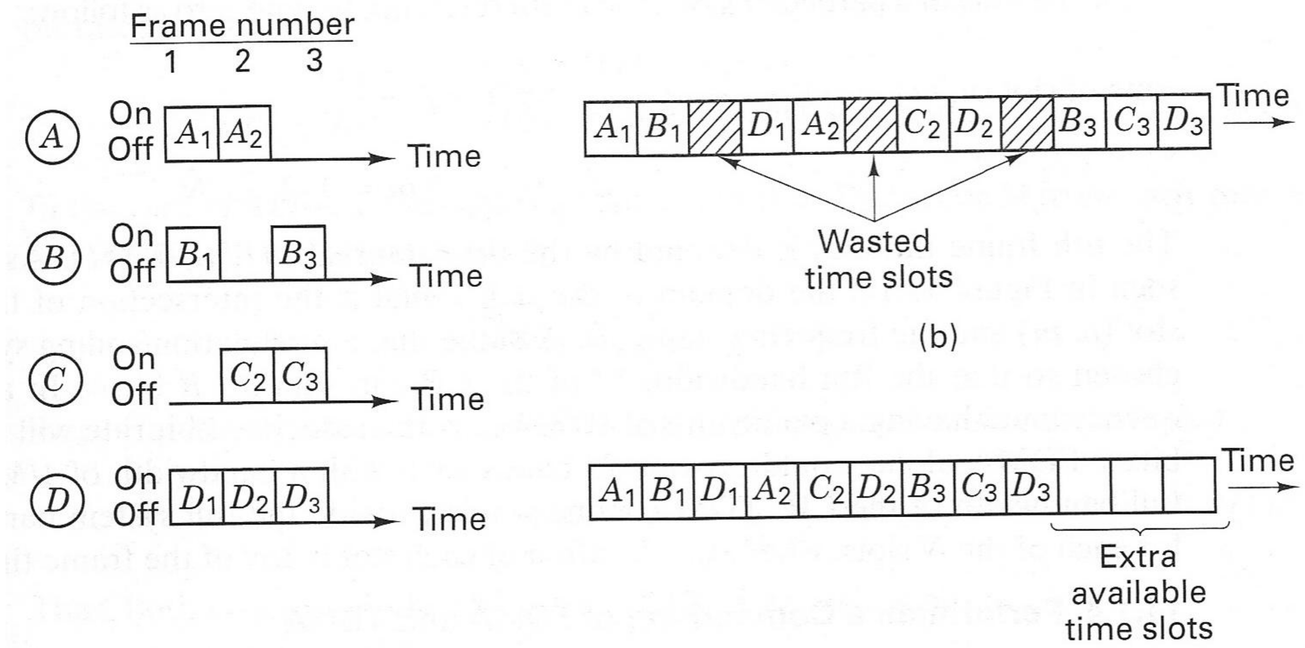
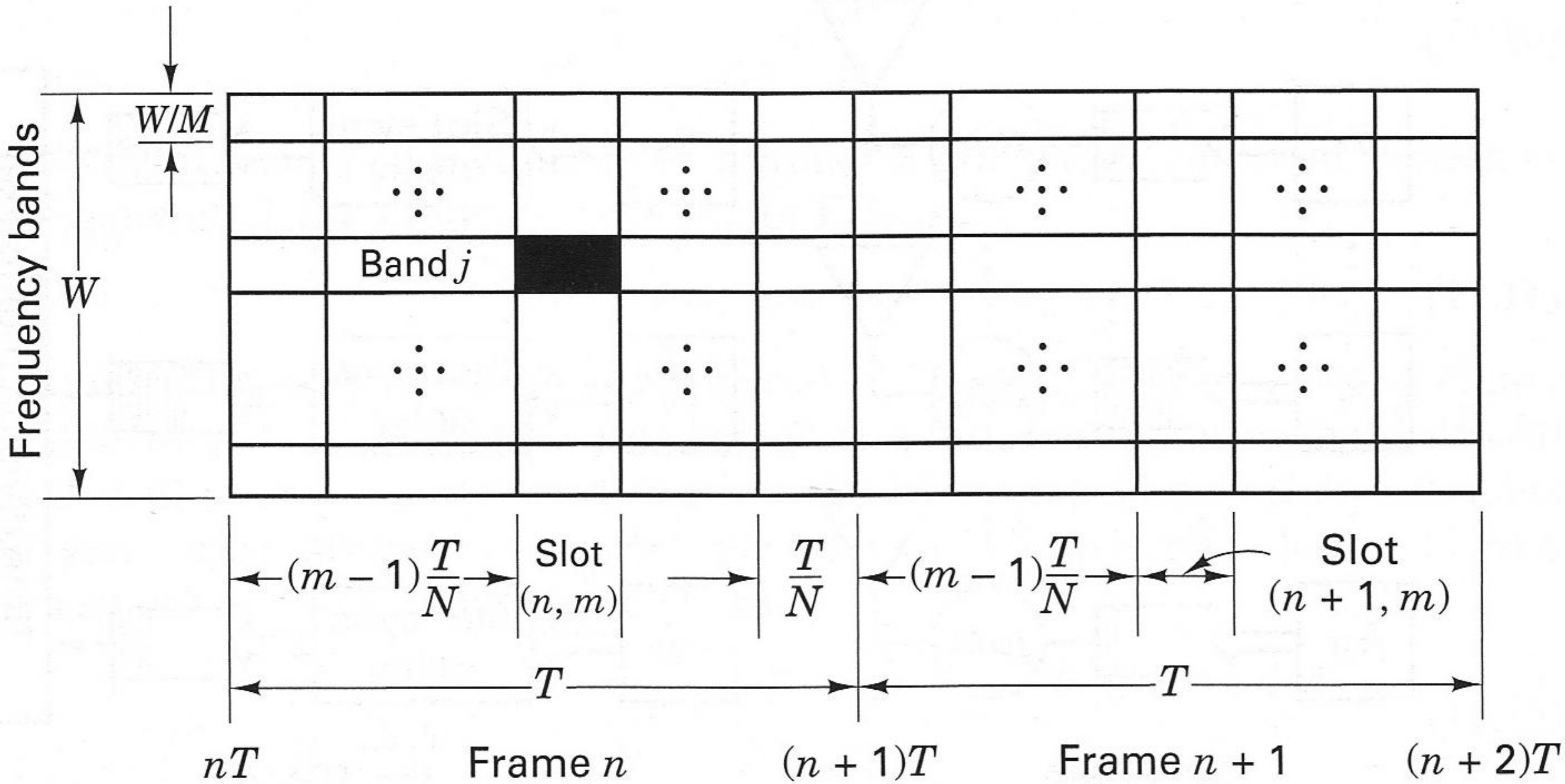
MULTIPLE ACCESS: TDMA

- **Dynamic-assignment TDMA (packet switching)**
  - A user is assigned a time-slot only when it has data to transmit
  - Advantage: better utilization of channel, efficient for bursty traffic.
  - Disadvantage: need extra control scheme (media access control, MAC) to determine which user should transmit



MULTIPLE ACCESS: CHANNELIZATION

- **Channelization**
  - Most practical systems use combined FDMA/TDMA



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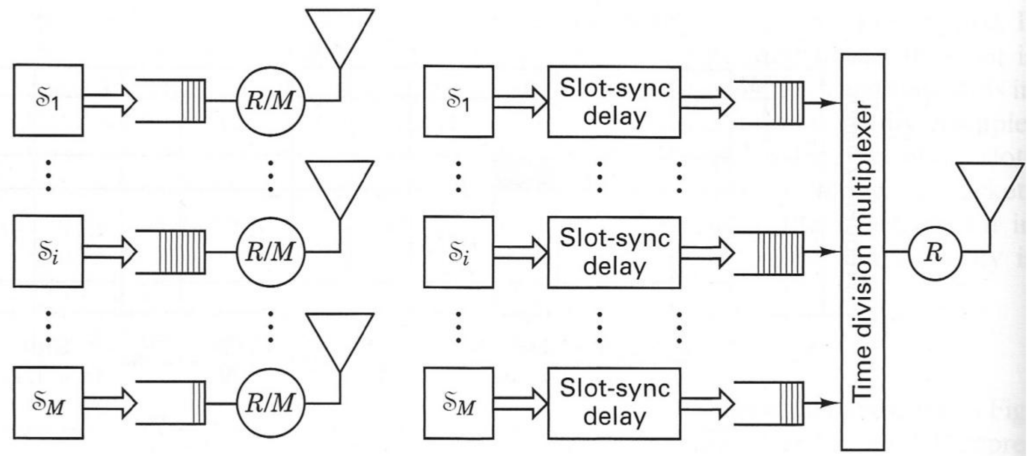
MULTIPLE ACCESS: FDMA V.S. TDMA

- **FDMA v.s. TDMA: Bit Rate**
  - Bit rate equivalence: with the same CR and same number of channels, FDMA and TDMA can support the same data rate on each channel
    - Assume the size of a packet is b bits, and there are M channels.
    - FDMA:
      - Bit rate of one channel: b/T bps
      - Total bit rate of M channels: R = M b /T bps
    - TDMA
      - Time are divided into M slots
      - b bits are transmitted in a duration of T/M: R = b/(T/M) = Mb/T bps



(a) FDMA (b) TDMA

MULTIPLE ACCESS: FDMA V.S. TDMA

- **FDMA V.S. TDMA: Delay**
  - Delay: TDMA is superior than FDMA in terms of message delay.
  - Definition: message delay

$$D = w + \tau$$

    - w: average waiting time prior to transmission
    - τ: transmission time (determines by the data rate)
  - Transmission time for a packet of b bits
    - FDMA: $\tau_{FD} = T$
    - TDMA: $\tau_{TD} = T / M$

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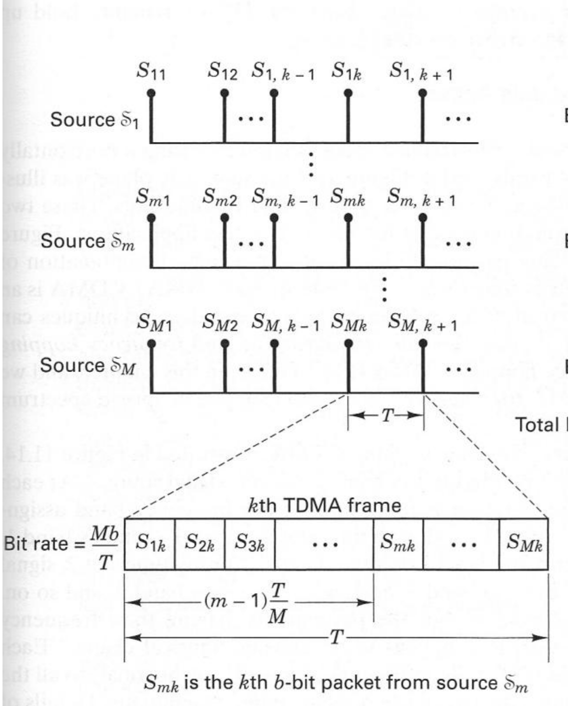
MULTIPLE ACCESS: FDMA V.S. TDMA

- **FDMA V.S. TDMA: Delay (Cont'd)**
  - Average waiting time for a packet of b bits: assume the packet arrives at the end of each frame
    - FDMA: $w_{FD} = 0$
    - TDMA:
      - The waiting time for the m-th user: $w_m = (m-1)T/M$
      - Average waiting time:

$$w_{TD} = \frac{1}{M}\sum_{m=1}^{M} w_m = \frac{1}{M}\sum_{m=1}^{M}(m-1)\frac{T}{M}$$

$$w_{TD} = \frac{T}{2}\left(1-\frac{1}{M}\right)$$



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MULTIPLE ACCESS: FDMA V.S. TDMA

- **FDMA V.S. TDMA: Delay (Cont'd)**
  - Message delay for FDMA:

$$D_{FD} = T$$

  - Message delay for TDMA:

$$D_{TD} = \frac{T}{M} + \frac{T}{2}\left(1 - \frac{1}{M}\right) = D_{FD} - \frac{T}{2}\left(1 - \frac{1}{M}\right)$$

  - TDMA has shorter message delay compared to FDMA

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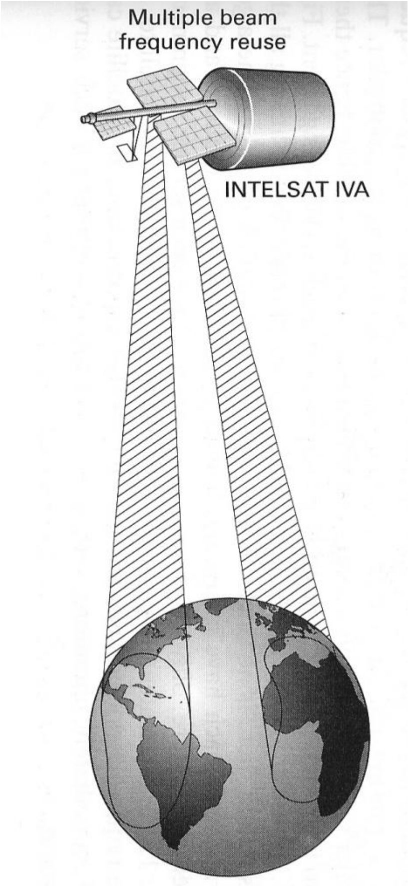
MULTIPLE ACCESS: CDMA

- **Code division multiple access**
  - The data of all users are transmitted on the same frequency band at the same time.
  - Each user is assigned a unique signature code
  - The receiver extract the information of one user by using the signature code of that user.
  - Two types of CDMA
    - Direct sequence CDMA (DS-CDMA)
    - Frequency hopping CDMA (FH-CDMA)

MULTIPLE ACCESS: SDMA

- **Space-division multiple access (SDMA)**
  - Use the space separation to share communication resource.
  - Example: People at two different locations can access the resource of the same satellite.



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