SATELLITE MULTIPLE ACCESS TECHNIQUES

ECE 514E – RADAR & SATELLITE ENGINEERING

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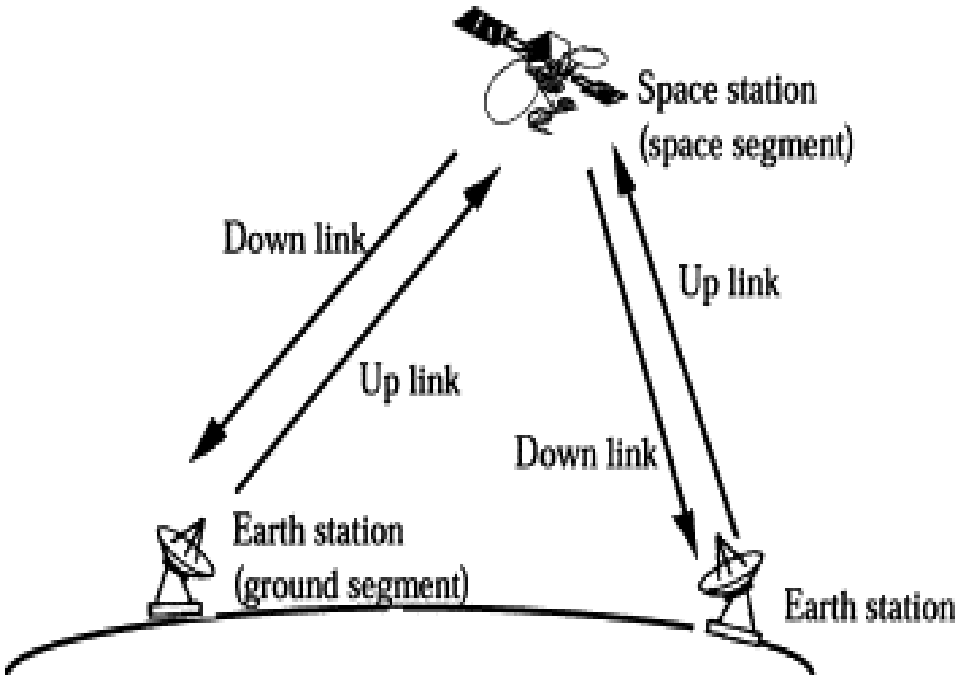
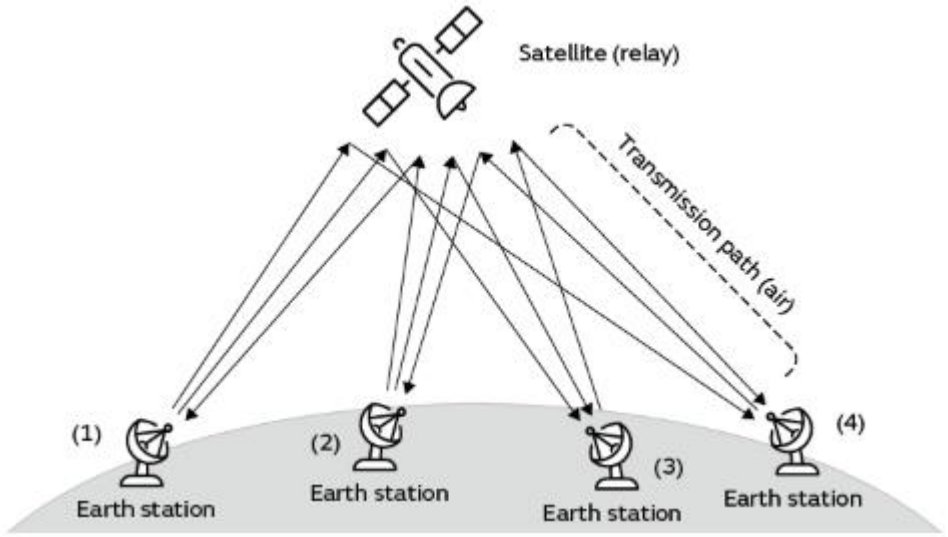
SATELLITE COMMUNICATION - RECAP

1. **Satellite communication systems are vital for global connectivity**, enabling telephony, television broadcasting, internet access, weather forecasting, and military applications.
2. **Communication satellites are essentially microwave repeaters in space that receives signals from Earth, amplifies them, and retransmits them back to Earth.**
3. **Multiple access techniques** allow multiple users to share the limited satellite communication resources efficiently.



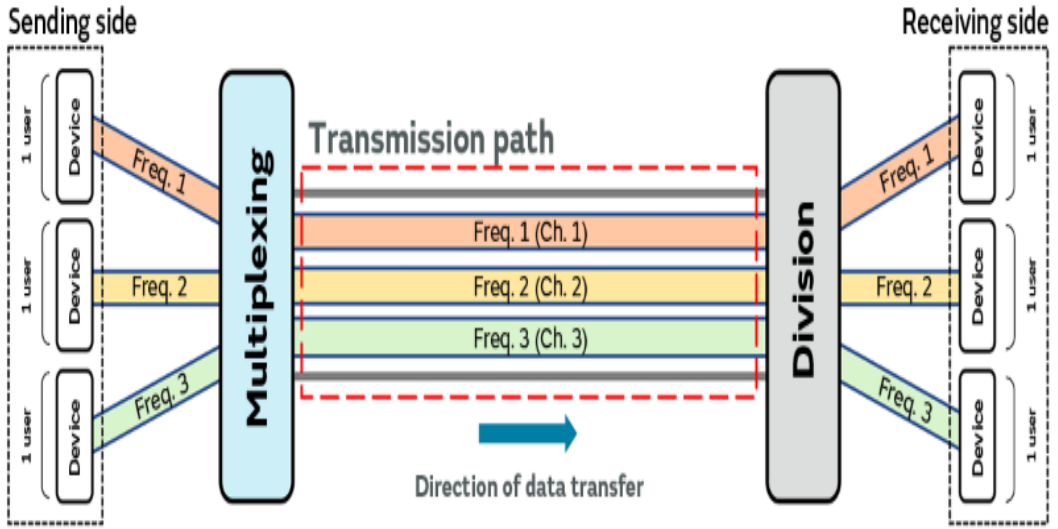
WHAT IS MULTIPLE ACCESS?

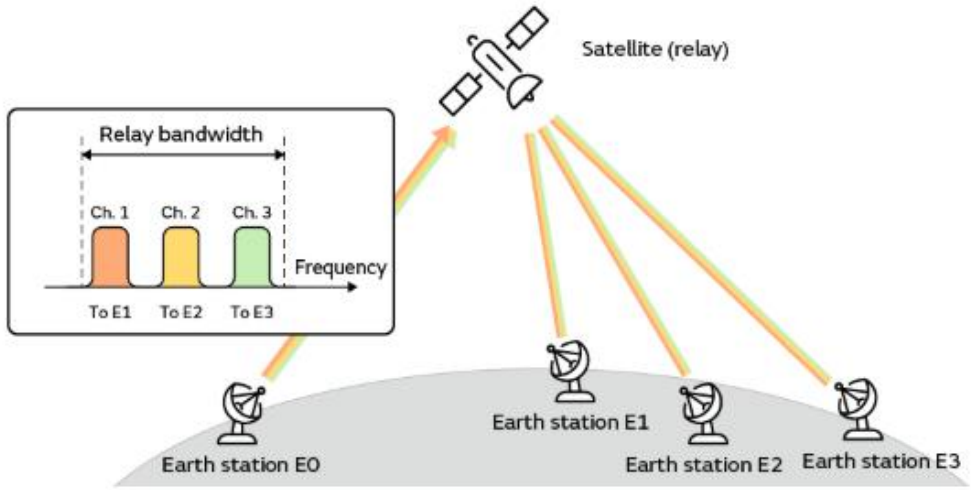
1. **Multiple Access is a method/technique that enables multiple earth stations** to interconnect their communication channels through a common satellite transponder.
2. **In satellite communications**, the resources that need to be shared include:
    1. **Bandwidth** (frequency spectrum)
    2. **Time** (transmission time slots)
    3. **Code** (unique coding sequences)
    4. **Space** (antenna beams)



FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

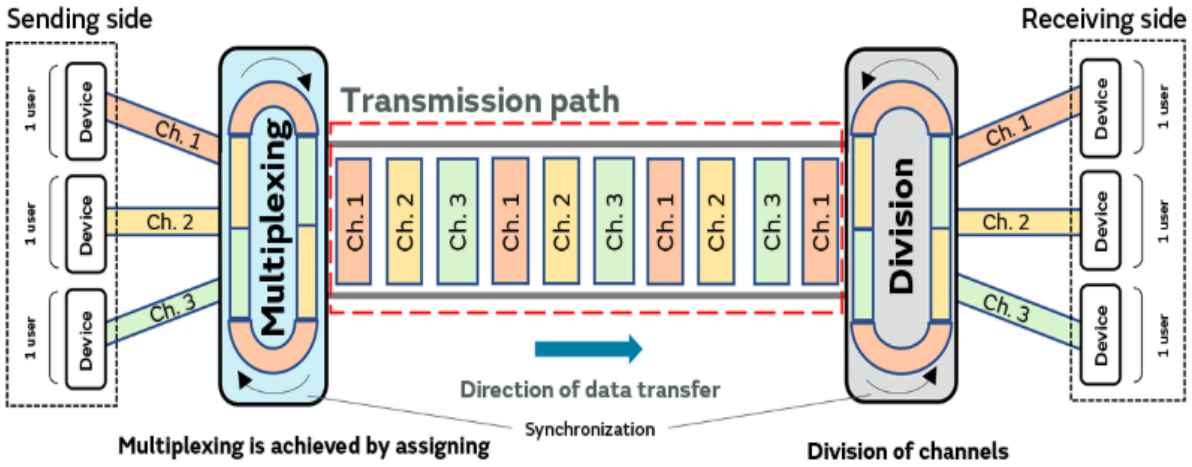
1. **FDMA divides the total available bandwidth into multiple non-overlapping frequency bands**, each assigned to a different user.
2. **Characteristics of FDMA:**
   a) Each user is allocated **a unique frequency band**
   b) Supports **continuous transmission**
   c) Guard bands are needed between channels to prevent interference
   d) Simple to implement but not very flexible
   e) Used in traditional analogue satellite systems

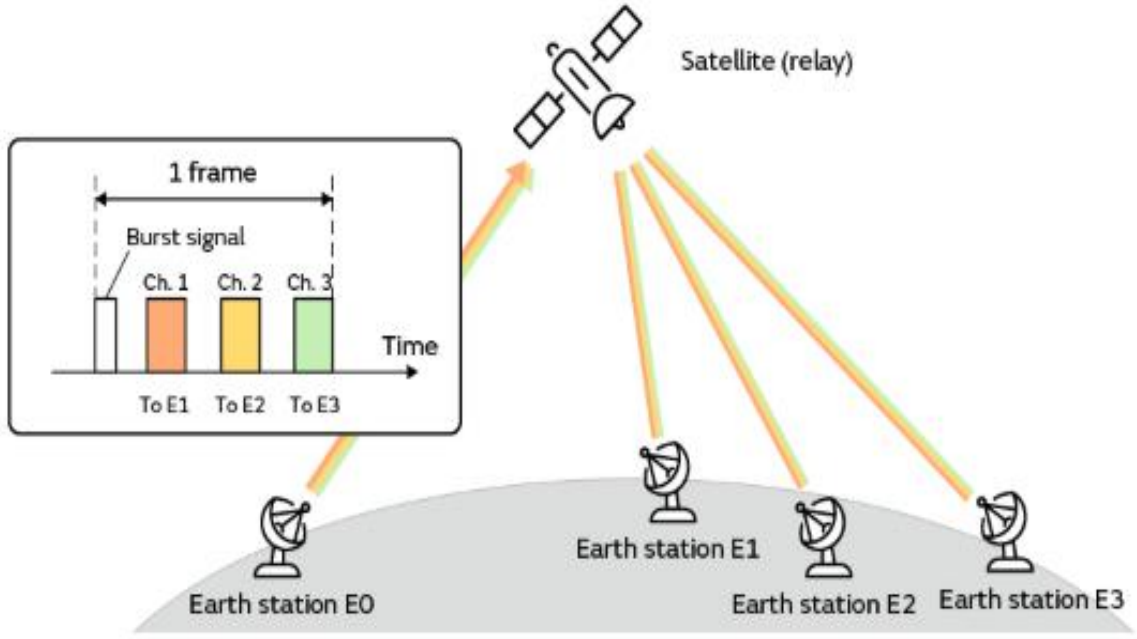




TIME DIVISION MULTIPLE ACCESS (TDMA)

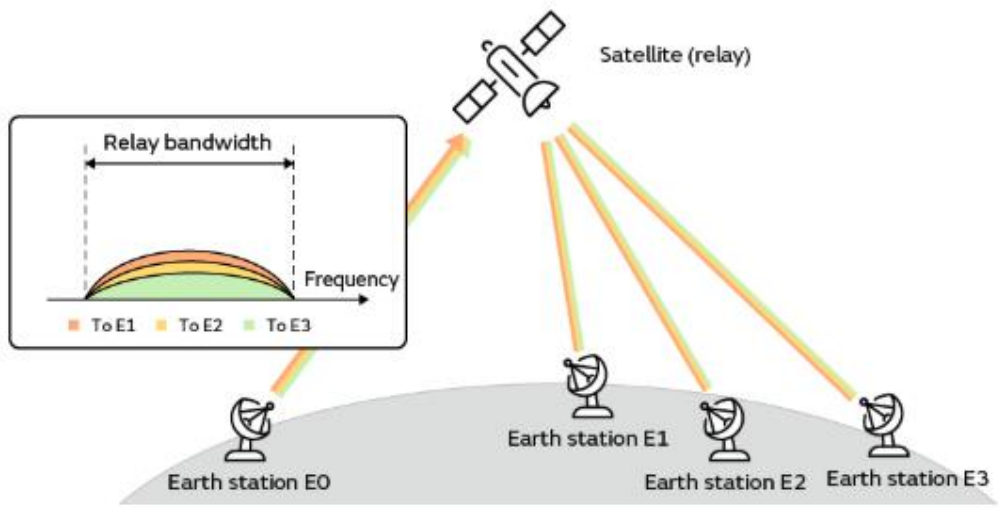
1. **TDMA divides the available time into sequential time slots**, with each user assigned specific time slots for transmission.
2. **Characteristics of TDMA:**
   a) **All users share the same frequency** but at different times
   b) **Requires precise synchronization** between all stations
   c) **More flexible than FDMA** for varying traffic demands
   d) **Guard times are needed between slots** to prevent overlap
   e) **Digital transmission is natural** for TDMA systems

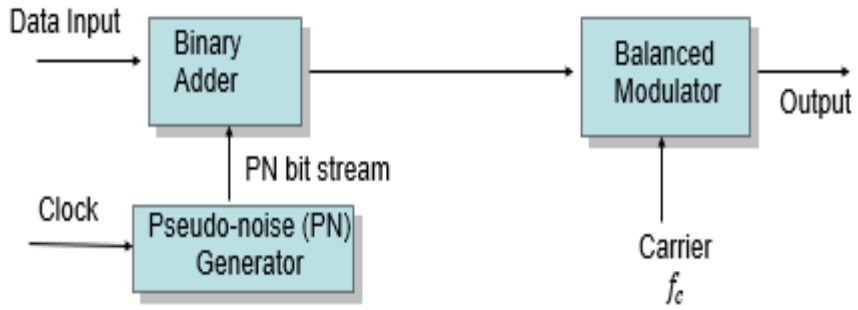




CODE DIVISION MULTIPLE ACCESS (CDMA)

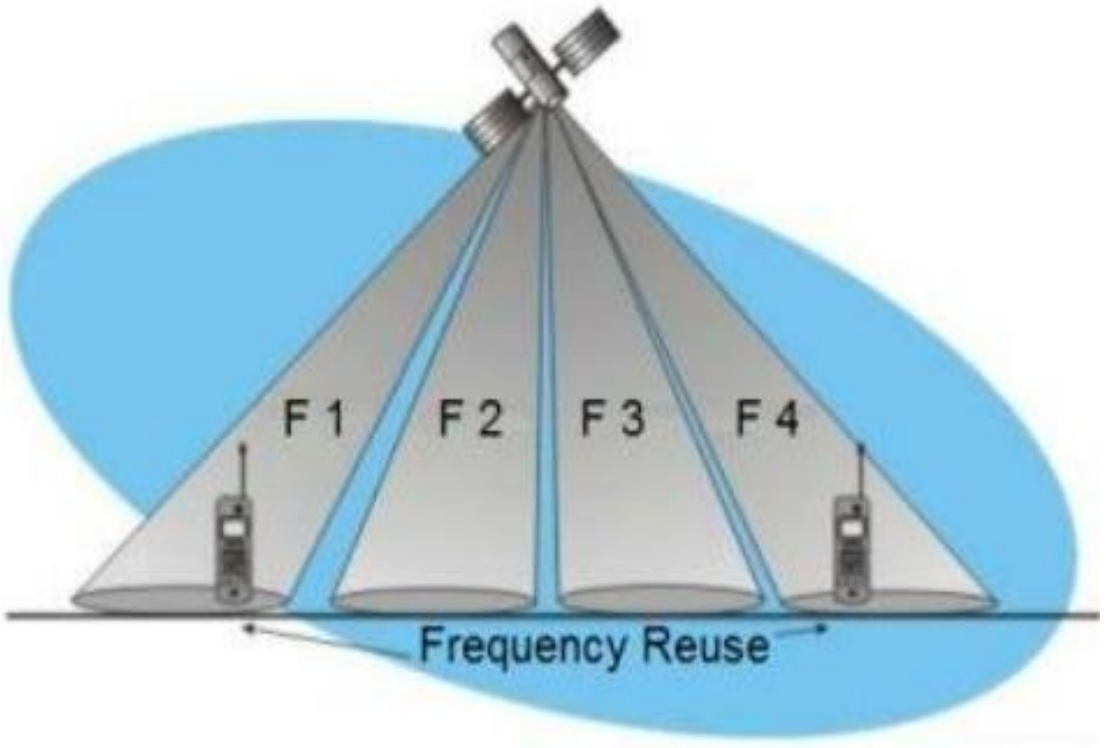
1. **CDMA allows multiple users to transmit simultaneously on the same frequency by using unique spreading codes** to distinguish between users.
2. **Characteristics of CDMA:**
   a) **Uses spread spectrum technology**
   b) Each user has a **unique pseudo-random code**
   c) **Resistant to interference and eavesdropping**
   d) **Soft capacity limit - performance** degrades gradually as users increase
   e) **Requires power control** to avoid near-far problem





SPACE DIVISION MULTIPLE ACCESS (SDMA)

1. **SDMA separates users based on their physical location using spot beam antennas** or phased array systems.
2. **Characteristics of SDMA:**
   a) **Uses directional antennas** to create spatial separation
   b) **Allows frequency reuse** across different beams
   c) **Increases system capacity** significantly
   d) **Requires complex antenna systems** and beam management
   e) **Often combined with other multiple access techniques**



COMPARISON OF MULTIPLE ACCESS TECHNIQUES

TECHNIQUE	RESOURCE DIVIDED	ADVANTAGES	DISADVANTAGES
FDMA	Frequency	Simple, continuous transmission	Inefficient for bursty traffic, guard bands needed
TDMA	Time	Flexible, efficient for digital systems	Requires synchronization, guard times needed
CDMA	Code	Secure, soft capacity, no frequency planning	Complex, near-far problem, requires power control
SDMA	Space	Frequency reuse, high capacity	Complex antennas, requires beam tracking

HYBRID MULTIPLE ACCESS SCHEMES

Modern satellite systems often combine multiple access techniques to leverage their respective advantages.

1. MF-TDMA

- **Multi-Frequency TDMA** combines FDMA and TDMA
- Different carriers with TDMA on each carrier
- Used in VSAT networks (DVB-RCS2)

2. FDMA/CDMA

- Frequency hopped or hybrid direct sequence
- Used in military satellites for anti-jamming

3. SDMA/TDMA

- Beam hopping with TDMA scheduling
- Used in high-throughput satellites

4. OFDMA/TDMA

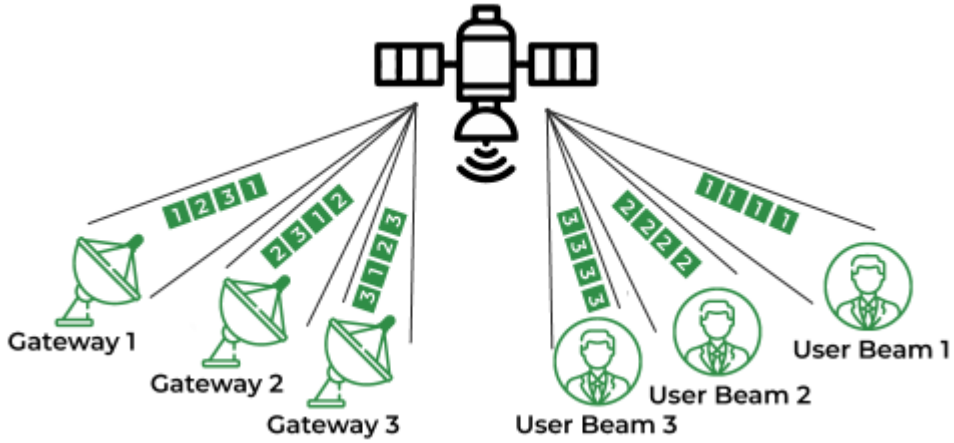
- Dynamic resource allocation in both frequency and time
- Used in 5G satellite integration

DEMAND ASSIGNMENT MULTIPLE ACCESS (DAMA)

1. **DAMA dynamically allocates satellite resources** based on actual user demand rather than using fixed assignments.
2. **DAMA Operation**
   a) **User requests channel** when needed
   b) **Control station** assigns resources
   c) **User transmits data**
   d) **Resources released** after transmission
3. **Advantages of DAMA:**
   a) **Efficient resource utilization**
   b) **Supports bursty traffic** effectively
   c) Can accommodate **varying QoS requirements**
   d) **Scalable for large networks**

SATELLITE SWITCHED TDMA (SS-TDMA)

1. **SS-TDMA combines TDMA with onboard switching** to dynamically connect different uplink and downlink beams.
2. **Key Features of SS-TDMA:**
   a) **Onboard processing and switching**
   b) **Dynamic reconfiguration** of beam connections
   c) **Efficient for mesh networks** with varying traffic patterns
   d) **Reduces need for double-hop connections**
   e) **Used in advanced military and commercial satellites**



ADVANTAGES/DISADVANTAGES OF SS-TDMA

1. **Advantages of Satellite Switched TDMA**
   a) As TDMA is digital
   b) It has Resistance to noise and interference.
   c) According to changing traffic demands, this system can be easily reconfigured.
   d) Can easily handle mixed voice, traffic data, and video.
   e) Intermodulation distortion/noise is been reduced.
2. **Disadvantages of Satellite Switched TDMA**
   a) Precisely synchronization is been required.
   b) If we are using all the transponder bandwidth, then we require a high bit rate of transmission on each and every earth station. Which means it requires high transmission power than the FDMA.
   c) Because of the high transmitting bit rate, it is not suited for narrow-band signals which come from the small earth stations.

ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDMA)

1. **OFDMA is a multi-user version of OFDM that divides the bandwidth into multiple orthogonal subcarriers, allocating subsets to different users.**
2. **Advantages of OFDMA for Satellite:**
   a) Robust against frequency-selective fading
   b) Efficient spectrum utilization
   c) Flexible resource allocation
   d) Compatible with MIMO techniques
3. **Modern Application:** OFDMA is used in next-generation satellite systems for broadband services, supporting adaptive coding and modulation based on link conditions.

SYNCHRONIZATION IN MULTIPLE ACCESS SYSTEMS

1. **Proper synchronization is critical for many multiple access techniques**, especially TDMA and CDMA.
2. **Basic Synchronization Types:**
   a) **Frame Synchronization**
      - Identifying start of TDMA frames
      - Uses unique words or preamble sequences
   b) **Slot Synchronization**
      - Aligning transmissions to correct time slots
      - Critical for TDMA efficiency

MULTIPLE ACCESS IN LOW EARTH ORBIT (LEO) CONSTELLATIONS

1. **LEO satellite constellations like Starlink, OneWeb, and Kuiper present unique multiple access challenges** due to satellite motion and handovers.
2. **LEO Constellation Challenges**
   a) Satellites move rapidly (period ~90-120 min)
   b) Continuous handovers between satellites
   c) Doppler shift effects
   d) Dynamic beam coverage patterns
3. **Multiple Access Solutions for LEO:**
   a) **Beam Hopping:** Rapid switching of beams to serve different areas
   b) **Advanced TDMA:** With dynamic slot allocation for handovers
   c) **SDMA with Steerable Beams:** Tracking user terminals
   d) **Inter-Satellite Links:** Forming space-based networks

CAPACITY ANALYSIS OF MULTIPLE ACCESS TECHNIQUES

Understanding how to calculate the capacity of different multiple access schemes is essential for system design.

1. FDMA Capacity:

Total bandwidth B divided among N users:

Each gets B/N Hz (minus guard bands)

2. TDMA Capacity:

Frame duration T_f with N slots:

Each user gets T_f/N seconds per frame (minus guard Time)

3. CDMA Capacity (Simplified):

$$\text{Number of users } N \approx \frac{1 + (W/R)}{E_b/N_0}$$

where W is bandwidth, R is data rate

PERFORMANCE METRICS FOR MULTIPLE ACCESS

METRIC	DESCRIPTION	IDEAL CHARACTERISTICS
THROUGHPUT	Total successful data transmission rate	High, approaching channel capacity
DELAY	Time from packet generation to successful reception	Low and predictable
FAIRNESS	Equitable resource allocation among users	All users get fair share
SCALABILITY	Performance with increasing number of users	Graceful degradation
COMPLEXITY	Implementation difficulty and cost	Low complexity, low cost
ROBUSTNESS	Performance under adverse conditions	Resistant to interference, fading

FUTURE TRENDS IN SATELLITE MULTIPLE ACCESS

1. Non-Terrestrial Networks (NTN)

- Integration with 5G/6G terrestrial networks
- Seamless handover between terrestrial and satellite

2. Machine Learning-Based Access

- AI-driven resource allocation
- Predictive scheduling based on traffic patterns

3. Reconfigurable Payloads

- Software-defined satellite transponders
- In-orbit reconfiguration of access schemes

4. Quantum Communications

- Quantum key distribution for secure access
- Quantum-resistant algorithms

SUMMARY AND KEY TAKEAWAYS

1. **Core Principle:**

   Satellite multiple access techniques enable efficient sharing of limited satellite resources among multiple users.

1. **Fundamental Techniques:**
   a) **FDMA:** Divides frequency spectrum; simple but inflexible
   b) **TDMA:** Divides time; efficient for digital, needs sync
   c) **CDMA:** Uses codes; secure, soft capacity
   d) **SDMA:** Uses spatial separation; enables frequency reuse

2. **Advanced Concepts:**
   a) **DAMA:** Dynamic resource allocation based on demand
   b) **Random Access:** For bursty traffic (ALOHA, CSMA)
   c) **Hybrid Schemes:** Combine advantages of multiple techniques
   d) **Synchronization:** Critical for system performance