SATELLITE TRAFFIC

ECE 514E – RADAR & SATELLITE ENGINEERING

Monday, January 5, 2026

WHAT IS SATELLITE TRAFFIC ENGINEERING

1. **Satellite traffic engineering involves analyzing, modeling, and managing data flows through satellite communication systems** to optimize performance and resource utilization.
2. **Satellite networks have unique constraints including propagation delay, limited bandwidth, and high-cost resources** that make traffic engineering particularly challenging and important.
3. **Traffic Engineering Goals:** Maximize throughput, minimize delay, ensure QoS, and optimize resource allocation under satellite constraints.

TYPES OF SATELLITE TRAFFIC

Satellite networks carry diverse traffic types with different characteristics and requirements:

1. Broadcast Traffic

TV, radio, content distribution. High volume, one-to-many, relatively constant bit rate.

2. Bursty Data

Web browsing, email, file transfer. Variable bit rate, tolerant to delay.

3. Real-time Streaming

Live video, surveillance. Constant or variable bit rate, delay-sensitive.

4. Interactive Traffic

Voice, video conferencing, gaming. Sensitive to delay and jitter, bidirectional.

5. Bulk Data Transfer

Software updates, database synchronization. High volume, delay-tolerant.

TRAFFIC CHARACTERISTICS AND PARAMETERS

1. **Understanding traffic characteristics is essential for effective satellite network design and management.**
2. **Key Traffic Parameters:**
   a) **Bit Rate:** Average and peak data rates (bps)
   b) **Burstiness:** Ratio of peak to average rate
   c) **Packet Size:** Distribution of packet lengths
   d) **Inter-arrival Time:** Time between packets or sessions
   e) **Session Duration:** How long a connection lasts
   f) **Directionality:** Symmetric vs asymmetric traffic

TRAFFIC MODELING FOR SATELLITE NETWORKS

1. **Mathematical models help predict traffic behavior and help design efficient satellite systems.**
2. **Application:** Accurate traffic models enable dimensioning of satellite capacity, buffer sizing, and performance prediction.
3. **Common Traffic Models:**
   a) **Poisson Process:** Model random arrivals (e.g., phone calls). Memoryless with exponential inter-arrival times.

      $P(k \text{ arrivals in time } t) = (\lambda t)^k * e^{(-\lambda t) / k!}$

   b) **Markov Models:** State-based models for traffic with memory. Useful for modeling correlated arrivals.

   c) **Self-Similar Traffic:** Fractal-like traffic with similar statistical properties at different time scales. Common in data networks.

   d) **On-Off Models:** Alternates between active (sending) and idle periods. Good for bursty traffic.

TRAFFIC DEMAND PATTERNS

Satellite traffic exhibits distinct temporal and spatial patterns that affect network planning.

1. **Temporal Patterns:**
    - **Diurnal Variation:** Traffic peaks during evening hours (residential) or business hours (enterprise)
    - **Day-of-Week:** Weekday vs weekend patterns
    - **Seasonal Variation:** Holiday seasons, special events
    - **Flash Crowds:** Sudden traffic spikes from events or news
2. **Spatial Patterns:**
    - **Geographic Concentration:** Urban areas generate more traffic than rural,
    - **Beam Loading Variation:** Different spot beams carry different traffic loads.
    - **Route Asymmetry:** More downstream than upstream traffic typically.

TRAFFIC MEASUREMENT AND MONITORING

1. **Accurate measurement is crucial for understanding traffic patterns and managing satellite resources.**
2. **Traffic measurement Techniques include:**
   a) **Active Monitoring:** Sending probe packets to measure delay, loss, throughput. Adds overhead.
   b) **Passive Monitoring:** Observing actual traffic without interfering. SNMP, NetFlow, packet capture.
   c) **Sampling Methods:** Statistical sampling to reduce measurement overhead while maintaining accuracy.
   d) **Performance Metrics:** Throughput, delay, jitter, packet loss, availability, BER (Bit Error Rate).
3. **Importance:** Continuous traffic monitoring enables dynamic resource allocation, congestion detection, and quality of service assurance.

TRAFFIC FORECASTING FOR SATELLITE NETWORKS

1. **Traffic forecasting helps in capacity planning and resource allocation.**
2. **Long procurement and launch cycles for satellites (3-5 years) make accurate long-term forecasting critical**.
3. **Forecasting Methods include:**
   a) **Time Series Analysis:** AutoRegressive Integrated Moving Average (ARIMA), exponential smoothing based on historical data patterns.
   b) **Regression Models:** Relate traffic to external factors (events, user growth).
   c) **Trend Analysis:** Identify long-term growth trends for strategic planning.
   d) **Machine Learning:** Neural networks, LSTMs for complex pattern recognition.
4. **Forecasting Horizons:**
   a) **Short-term:** Minutes to hours for dynamic resource allocation
   b) **Medium-term:** Days to weeks for operational planning
   c) **Long-term:** Months to years for capacity expansion

TRAFFIC DIMENSIONING AND CAPACITY PLANNING

1. **Traffic dimensioning refers to how the required satellite capacity meets traffic demands with acceptable performance is determined.**
2. **Traffic Dimensioning Approaches include:**
   a) **Peak Hour Analysis**
      - Size capacity for busiest hour with acceptable performance degradation.
      - Capacity ≥ Peak Hour Traffic × (1 + Growth Margin)

   b) **Statistical Multiplexing**
      - Exploit non-simultaneous peak usage across multiple users.
      - Total Capacity < Sum of Individual Peak Rates
3. **Key Considerations:**
   a) **Grade of Service (GoS):** Acceptable blocking probability (e.g., 1% for voice).
   b) **Quality of Service (QoS):** Performance targets for delay, jitter, loss.
   c) **Growth Margin:** Extra capacity for unexpected growth (typically 20-30%).
   d) **Protection Capacity:** Redundancy for failures or interference.

ACCESS TECHNIQUES FOR DIFFERENT TRAFFIC TYPES

TRAFFIC TYPE	RECOMMENDED ACCESS	REASON
Constant Bit Rate (Voice)	FDMA or fixed TDMA	Predictable resource needs
Bursty Data	TDMA, DAMA, Random Access	Efficient for variable demands
Broadcast/Multicast	FDMA or TDM broadcast	One-to-many distribution
Interactive Real-time	Reserved TDMA, CDMA	Low delay, consistent QoS
Machine-type/IoT	Random Access, Aloha variants	Low overhead for small packets

QUALITY OF SERVICE (QOS) IN SATELLITE NETWORKS

1. **QoS mechanisms ensure different traffic types receive appropriate performance levels.**
2. **QoS Parameters for Satellite Traffic include:**
   - **Delay:** Propagation + processing + queueing delay (critical for interactive applications)
   - **Jitter:** Variation in delay (critical for voice/video)
   - **Packet Loss:** Due to errors or congestion
   - **Throughput:** Sustained and peak data rates
   - **Availability:** Percentage of time service meets QoS targets
3. **Satellite QoS Challenges:**
   - **Propagation delay (GEO:** ~250 ms one-way) limits delay-sensitive applications
   - **Atmospheric effects cause variable error rates**
   - **Asymmetric links complicate QoS mechanisms**
   - **Onboard processing adds variable delay**

TRAFFIC ROUTING IN SATELLITE NETWORKS /01

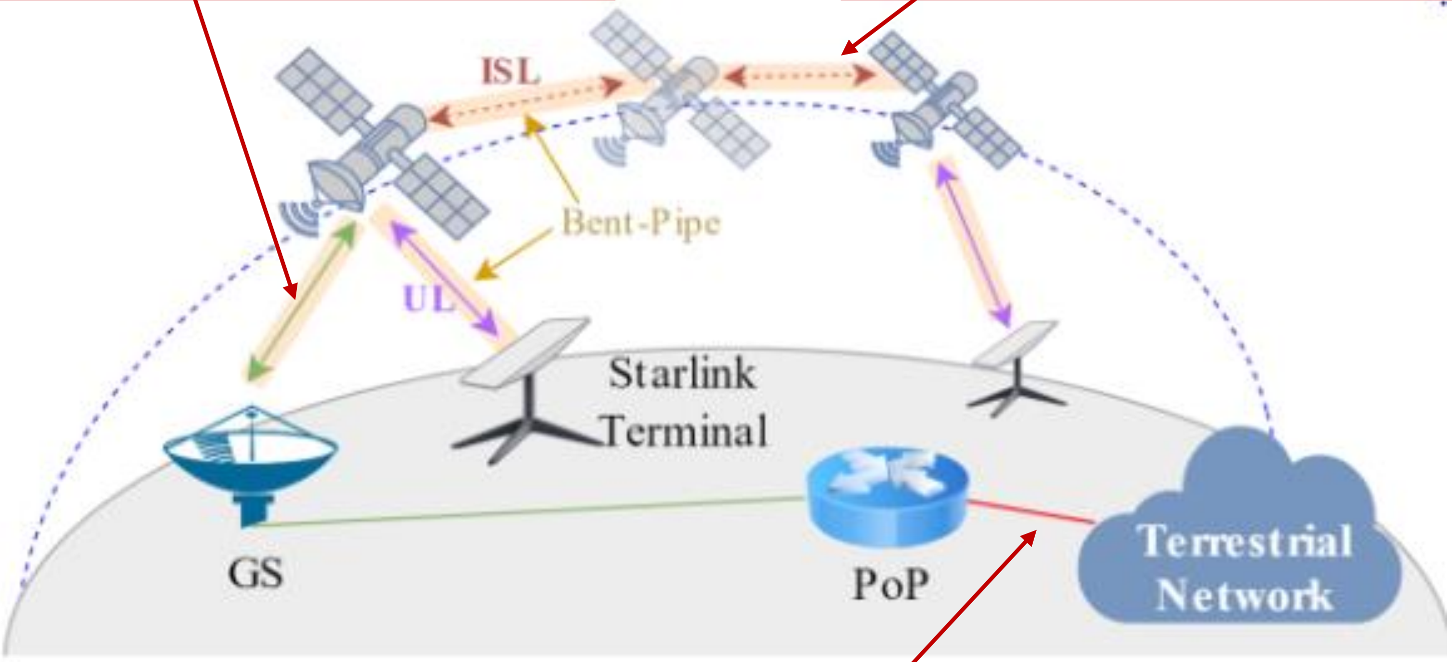
1. **Traffic routing determines the path traffic takes through satellite networks.**
2. **Satellite traffic Routing Approaches:**
   a) **Bent-pipe Routing:** Satellite as simple repeater. Traffic goes up and down through same satellite. Simple but inefficient for mesh connectivity.
   b) **Onboard Processing Routing:** Satellite processes and routes traffic between beams. Enables single-hop mesh connections.
   c) **Inter-Satellite Links (ISL):** Traffic routed through multiple satellites via laser or radio links. Forms space-based backbone network.
   d) **Multi-layer Routing:** Combines satellite and terrestrial paths for optimal end-to-end routing.

TRAFFIC ROUTING IN SATELLITE NETWORKS /02

3. **Routing Metrics for Satellite Traffic:**
   a) **Propagation Delay:** Critical for real-time applications
   b) **Link Capacity:** Avoid congested links
   c) **Error Rate:** Prefer links with better signal quality
   d) **Cost:** Satellite capacity is expensive resource
   e) **Path Stability:** Especially important for LEO systems
4. **Dynamic Routing:** In LEO constellations, routing tables must be updated frequently (every few seconds) as topology changes.

Bent-pipe Routing:
Satellite as simple repeater. Traffic goes up and down through same satellite. Simple but inefficient for mesh connectivity.

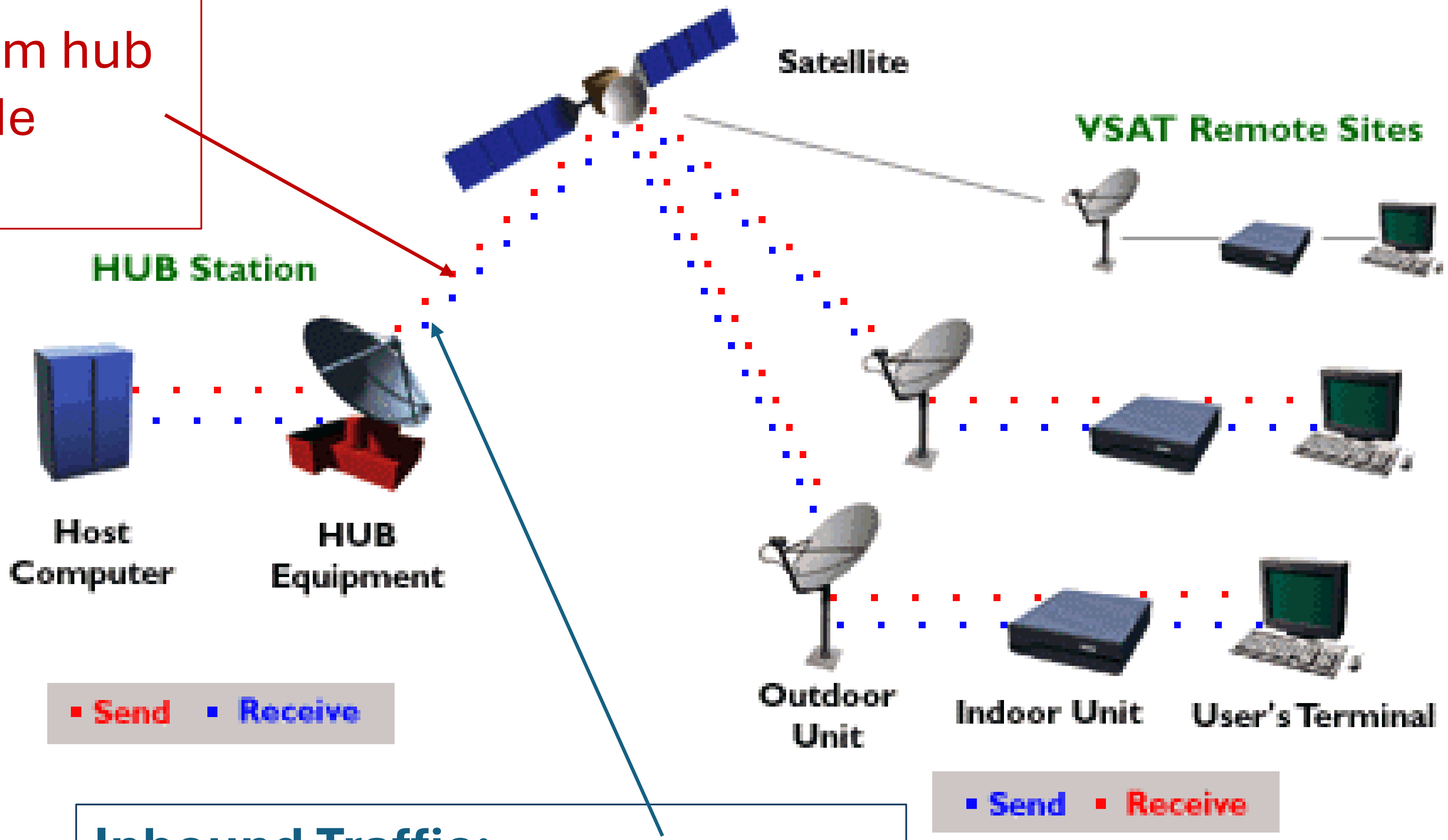
Inter-Satellite Links (ISL):
Traffic routed through multiple satellites via laser or radio links. Forms space-based backbone network.



Multi-layer Routing: Combines satellite and terrestrial paths for optimal end-to-end routing.

TRAFFIC ANALYSIS CASE STUDY: VSAT NETWORKS

1. **Very Small Aperture Terminal (VSAT) networks** provide enterprise connectivity with star or mesh topologies.
2. **VSAT Network Architecture:**
   a) **Hub Station:** Central control and gateway to terrestrial network
   b) **Remote Terminals:** Many small user terminals
   c) **Outbound (forward) link:** Hub to remotes (TDM broadcast)
   d) **Inbound (return) link:** Remotes to hub (MF-TDMA typically)
3. **VSAT Traffic Pattern**
   a) **Outbound Traffic:** High-speed broadcast from hub to all remotes. Can include Internet, video, voice.
   b) **Inbound Traffic:** Many low-rate streams from remotes to hub. Typically bursty data.
   c) **Asymmetry Ratio:** Outbound:Inbound typically 4:1 to 10:1



Outbound Traffic:
High-speed broadcast from hub to all remotes. Can include Internet, video, voice.

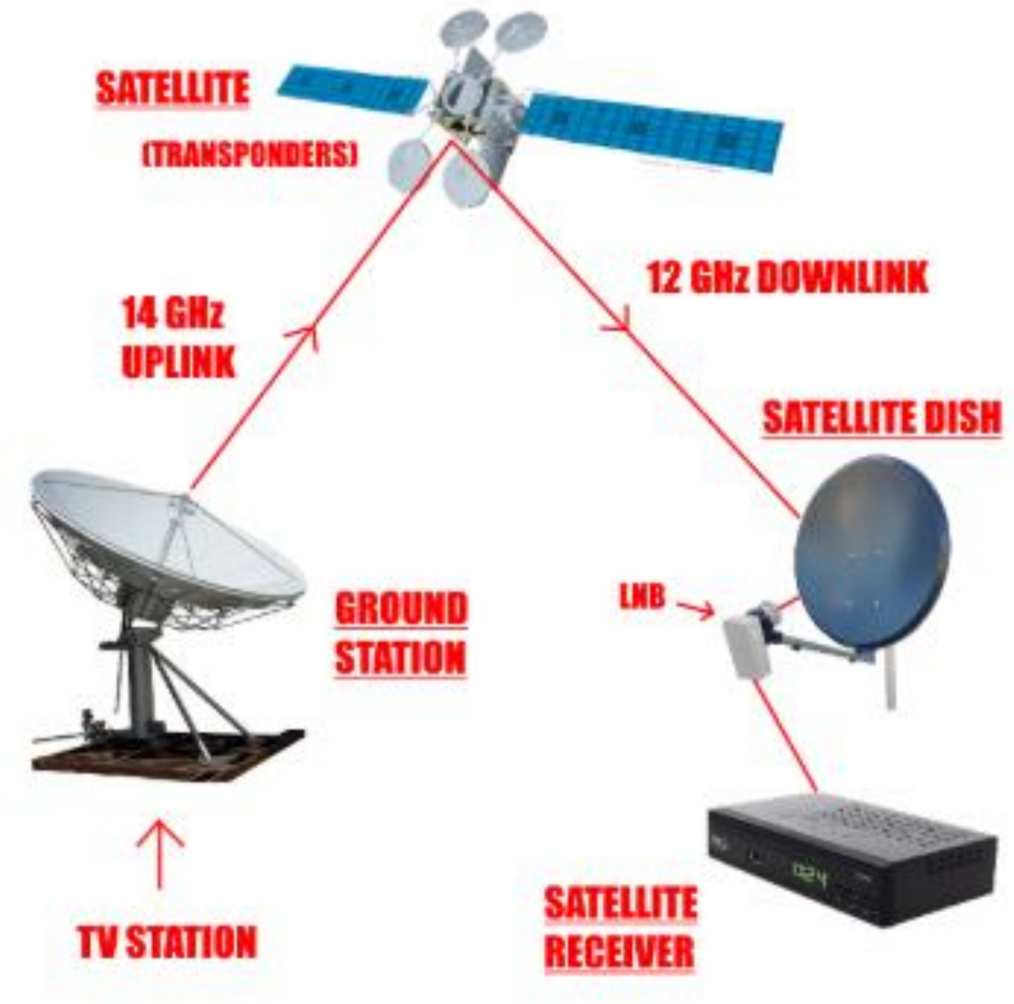
Inbound Traffic:
Many low-rate streams from remotes to hub. Typically bursty data.

Traffic Engineering Challenges:

1. **Many-to-One Inbound:** Multiple remotes share return channel capacity
2. **Fairness:** Ensure all remotes get fair share of return capacity
3. **Efficiency:** Minimize overhead in MF-TDMA framing
4. **QoS:** Support different application requirements

TRAFFIC ANALYSIS CASE STUDY: SATELLITE BROADCASTING

1. **Direct-to-home (DTH) satellite Television** is a major application with distinctive traffic patterns.
2. **Broadcast Traffic Characteristics:**
   a) **One-to-Many:** Same content to millions of subscribers
   b) **High Bandwidth:** HD channel: 8-15 Mbps, 4K channel: 20-30 Mbps
   c) **Constant Bit Rate:** MPEG-encoded video has relatively constant rate
   d) **Multicast Efficiency:** Sending once to many users is bandwidth-efficient
   e) **Prime Time Peaks:** Evening viewing creates predictable traffic patterns



MODERN TRENDS IN SATELLITE BROADCASTING

1. **Video on Demand (VoD):** Unicast traffic patterns emerging
2. **Ultra HD/4K:** Increasing bandwidth requirements
3. **Hybrid Broadcast / Broadband:** Combining satellite with internet delivery
4. **Personalized Advertising:** Targeted ad insertion requires more sophisticated traffic management

SUMMARY AND KEY PRINCIPLES

1. **Satellite traffic engineering combines communication theory, queuing theory, and network optimization.**
2. **Key Principles:**

- **Understand Traffic Characteristics:** Different applications have different patterns and requirements
- **Model Accurately:** Use appropriate traffic models for analysis and simulation
- **Plan for Peaks:** Dimension capacity for peak loads with appropriate margins
- **Exploit Statistical Multiplexing:** Aggregate traffic to improve efficiency
- **Prioritize Traffic:** Use QoS mechanisms to ensure critical applications perform well
- **Monitor Continuously:** Measure traffic to detect patterns and problems
- **Adapt Dynamically:** Adjust resource allocation based on current conditions
- **Consider Satellite Constraints:** Propagation delay, weather effects, limited bandwidth

CAREERS IN SATELLITE ENGINEERING

Satellite traffic engineering skills are valuable for roles in satellite network design, operations, capacity planning, and research. Careers in this sector include:

1. **Space Traffic Management (STM) Engineer:** A developing specialization that involves creating sophisticated tracking algorithms and predictive models for orbital mechanics to avoid collisions and manage space debris.
2. **Satellite Network Engineer:** Focuses on ensuring strong and secure satellite signals. Responsibilities include planning and assembling communication systems, conducting link budget analysis to maximize network performance, troubleshooting interference, and ensuring compliance with telecommunication standards and protocols.
3. **Satellite Operations Engineer:** monitor and control satellites from the ground to ensure functionality and correct trajectory. They manage data transmission and resolve technical anomalies.
4. **RF (Radio Frequency) Engineer:** Specializes in the hardware and signal aspects of satellite communication, optimizing RF parameters for reliable communication links between satellites and ground stations.