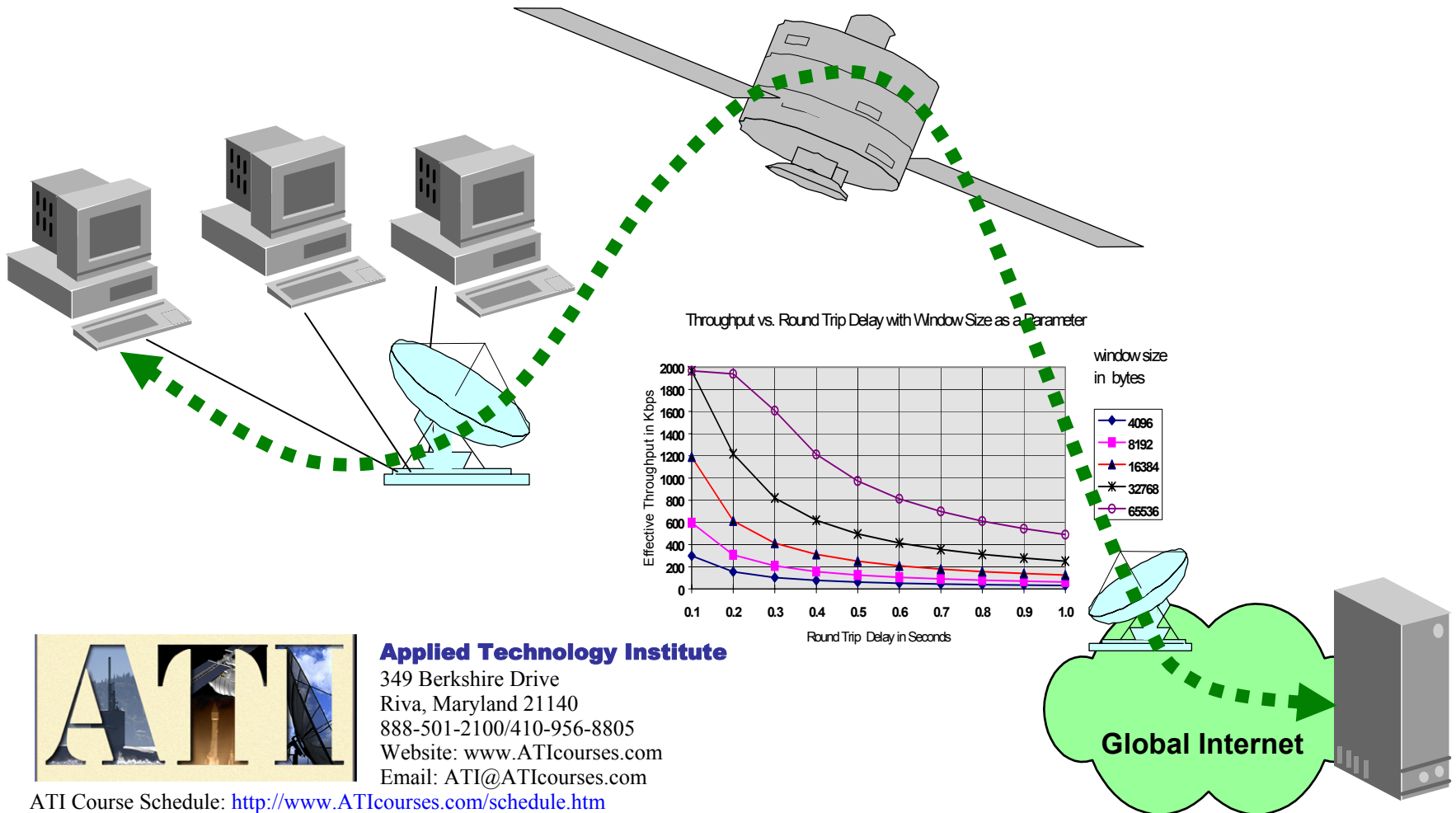


IP NETWORKING OVER SATELLITE

For Government, Military and Commercial Enterprises



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Burt H. Liebowitz is a Principal Engineer at the MITRE Corporation responsible for the economic and technical analysis of wireless systems. He has more than 30 years experience in computer networking, most recently with Internet-over-satellite services. He has served as a consultant to leading companies providing such services. He was President of NetSat Express, and before that Chief Technical Officer for Loral Orion, responsible for satellite-based networking products. Mr. Liebowitz has authored two books on distributed processing, written numerous articles on computing and communications systems, and lectured extensively on computer networking. He holds three patents for satellite-based data networking systems. Mr. Liebowitz has B.E.E. and M.S. in Math degrees from Rensselaer Polytechnic Institute, and an M.S.E.E. from Polytechnic Institute of Brooklyn.

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Seminar Outline

- 1- Introduction and Purpose
 - 2- Fundamentals of Data Networking
 - 3- The Internet and Its Protocols
 - 4- Quality of Service Issues in IP Networks
 - 5- Satellite Data Networking Architecture
 - 6- System Design and Economic Issues for
Satellite-Based IP Networks
 - 7- TDMA/DAMA Design Example
 - 8- Predicting Performance in Mission-Critical
Networks
 - 9- Conclusions and a View of the Future
- Bibliography and Table of Acronyms***

Part 1 –Introduction and Purpose of Seminar

- Provide satellite engineers with an insight into the benefits, issues and challenges associated with using Internet Protocols (IP) over satellite
- In doing so we will:
 - review the basics of data networking telecommunications
 - discuss the the Internet and Internet Protocols
 - discuss how satellites are used to support high performance Intranets* and Content Delivery applications
 - provide examples of satellite-based Internet architectures
 - discuss quality of service** (QoS) in IP networks

*An Intranet is a private network that utilizes the Internet Protocol

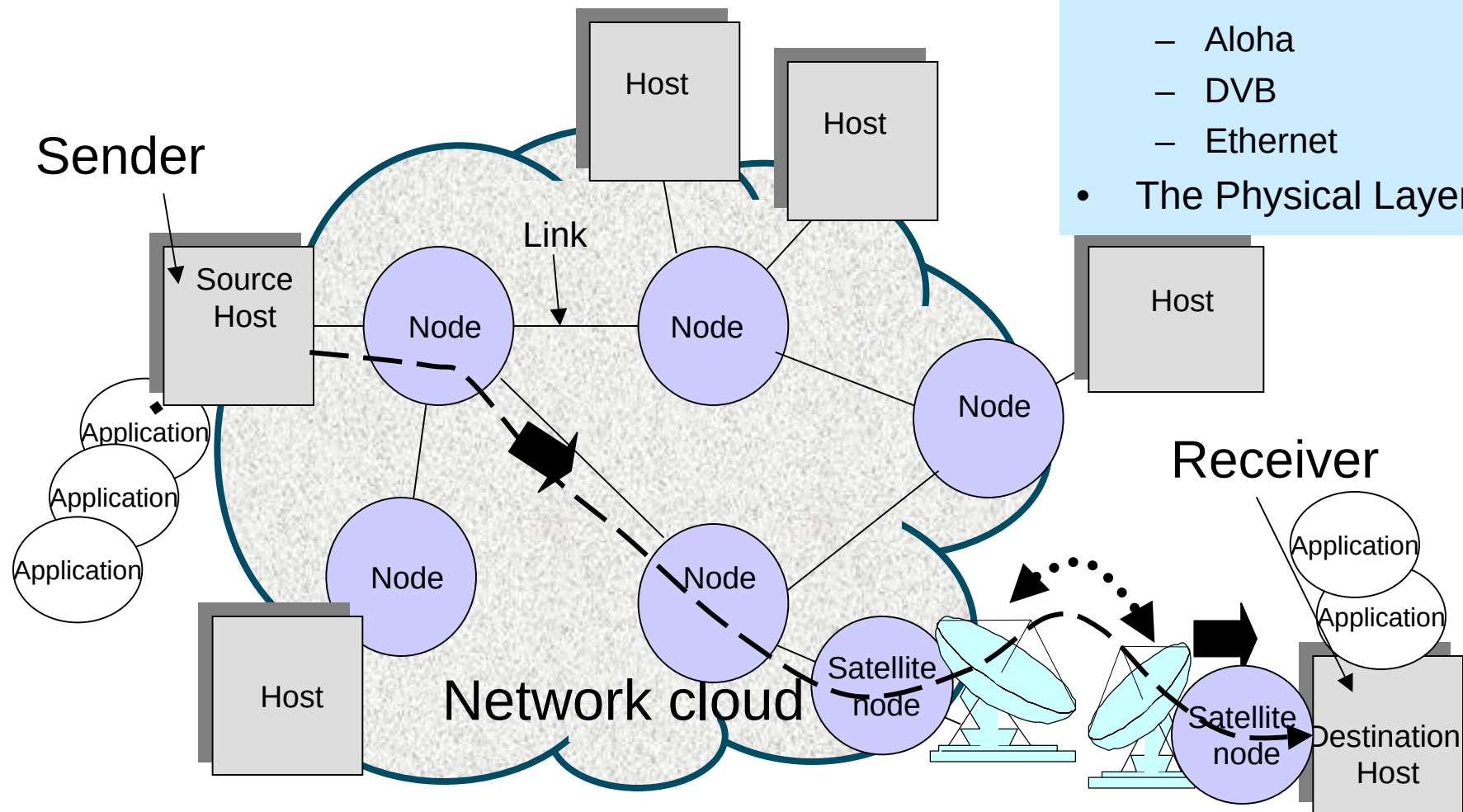
** Quality of Service: attributes that describe the speed and reliability of data transmissions

Some Comments on Satellites

- Satellites have a long history in telecommunications
 - get us to places that fiber does not reach
 - excellent characteristics for multicasting
- Use of satellites creates some issues for IP which we will address in this seminar
 - long propagation delay
 - higher bit error rates than terrestrial links
 - asymmetric routes
 - limited capacity compared to fiber
 - high cost for point to point bandwidth
 - security issues
 - reliability and availability issues

Part 2 - Fundamentals of Data Networking

- Overview
- Issues
- Protocol Layers
- Link Layer Protocols
 - Frame Relay
 - ATM
 - Aloha
 - DVB
 - Ethernet
- The Physical Layer



Data Networking

- Data networks are used to transmit digital data from one point to another
 - A **session** is a two-way flow of digital data between two applications in different host computers
 - Each **flow** represents a one-way transfer of a message from one application to another along a **path** in the network
 - Each **message** is broken into units of transfer called packets
 - A **packet** consists of a header, payload and trailer
- Digital networks were developed to transmit computer files
 - can also be used for voice and video, since analog signals can be digitized

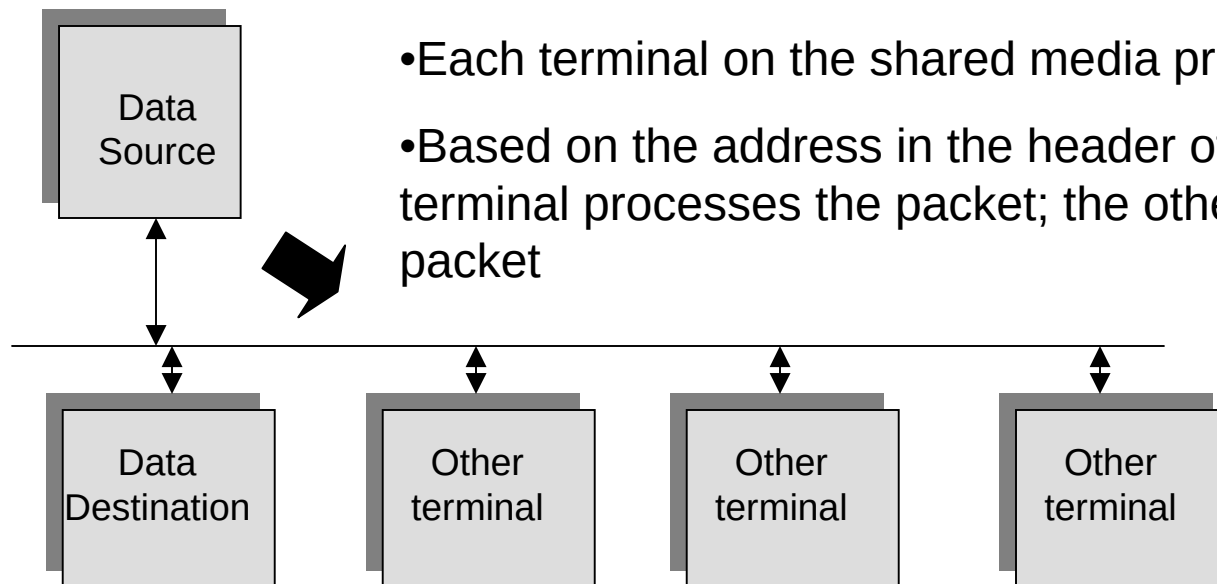
Data Networking Issues

- Moving packets from a source to a destination
 - delivering packets correctly and in order
 - delivering packets in a timely fashion
- Flow control
 - insuring that network nodes do not get overloaded
- Quality of Service for voice and video packets
 - quantitative measures of performance, including packet delay, variation in delay, throughput, packet loss
- Network Management
 - fault detection and correction
 - provisioning of circuits and routing paths
 - performance management
 - accounting and billing
 - security
- Establishment of standards so that devices can interoperate

Broadcast Packet Network

- Used when a network consists of a shared medium
 - The medium could be cable, satellite link or terrestrial wireless link
- If a cable is used, we generally call the network a local area network (LAN)
- In a broadcast packet network:

- The data source broadcasts its packets on the shared medium
- Each terminal on the shared media processes the packet
- Based on the address in the header of the packet, the destination terminal processes the packet; the other terminals discard the packet



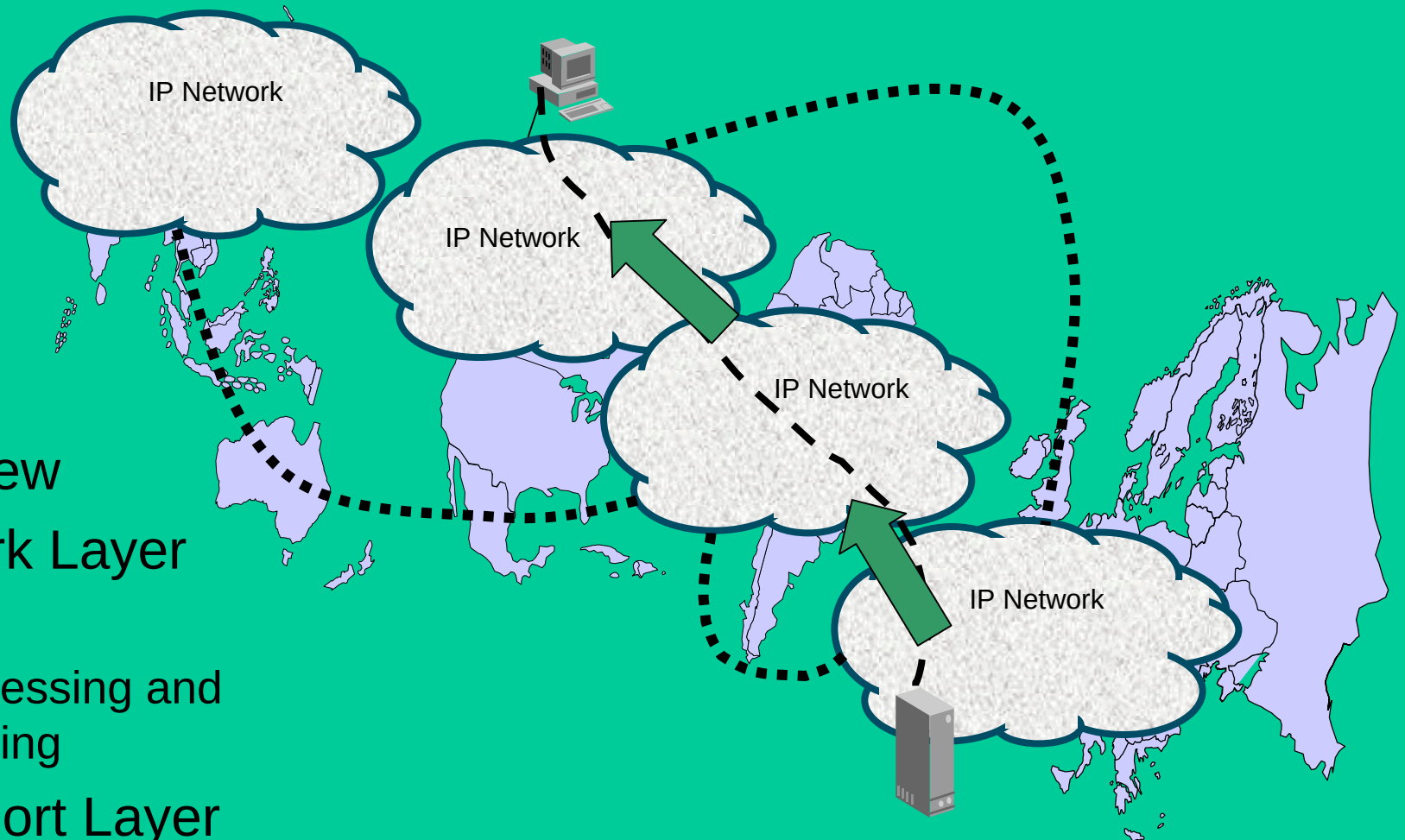
There is a chance for collisions if two or more terminals decide to transmit a packet at approximately the same time

A Layered Approach

- Open Systems Interconnection (OSI) model developed in 1970s to provide a reference for describing network protocols
- Partitions network operations into specific modules called layers
- Each layer communicates with peer layer in another computer, machine, node, switch etc.
- OSI approach has seven layers

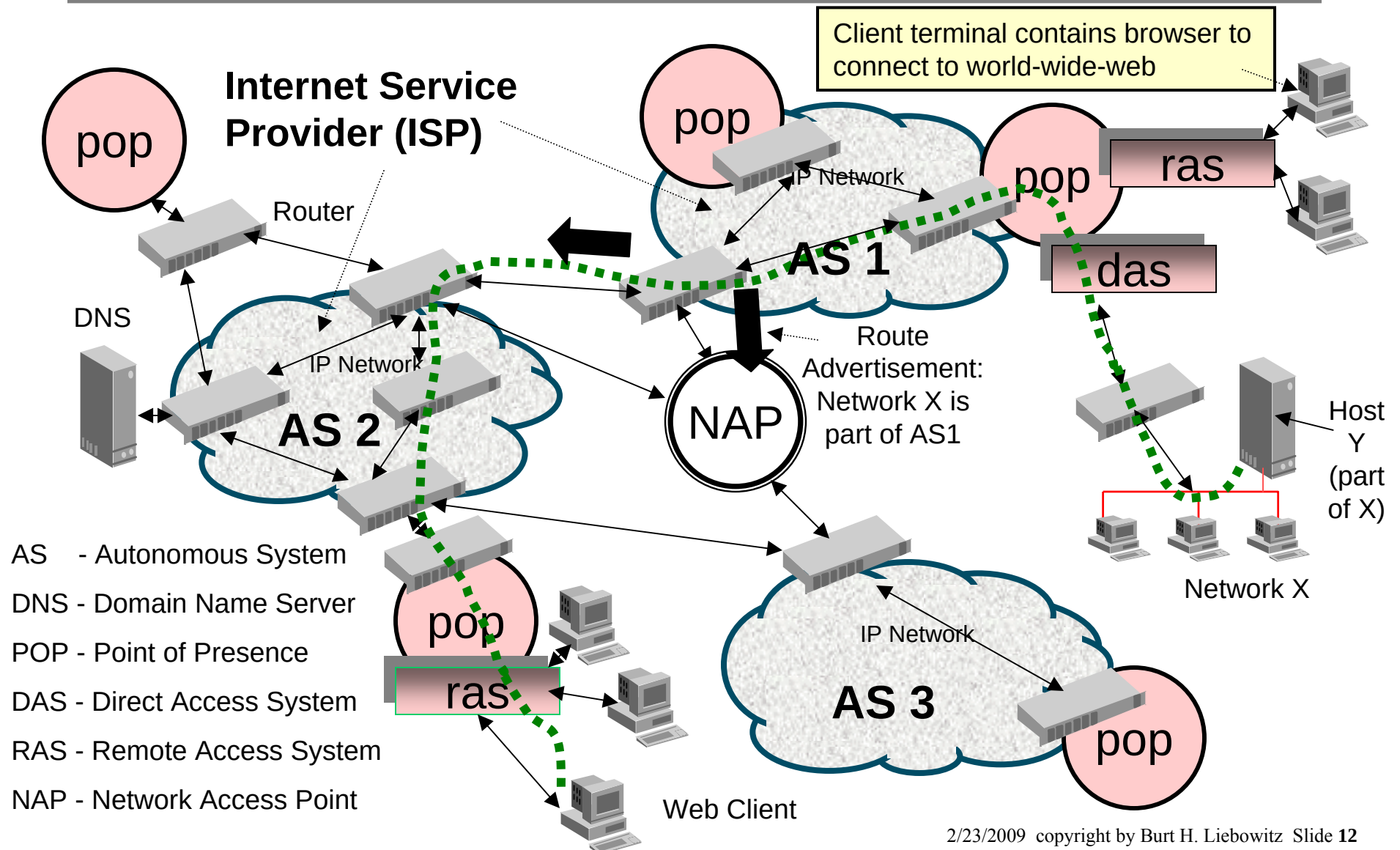
<i>Application</i>	Supports the end user application - e. g. email
<i>Presentation</i>	Defines the meaning (syntax) of data - e.g. the meaning of a byte
<i>Session</i>	Manages end user exchange of data
<i>Transport</i>	Provides message integrity across multiple data links, networks
<i>Network</i>	Defines interface to a network; routing within, between networks
<i>Data Link</i>	Transfer of data across one communications link
<i>Physical</i>	Creation and reception of physical signals - the “bit”

Part 3 - The Internet and Its Protocols

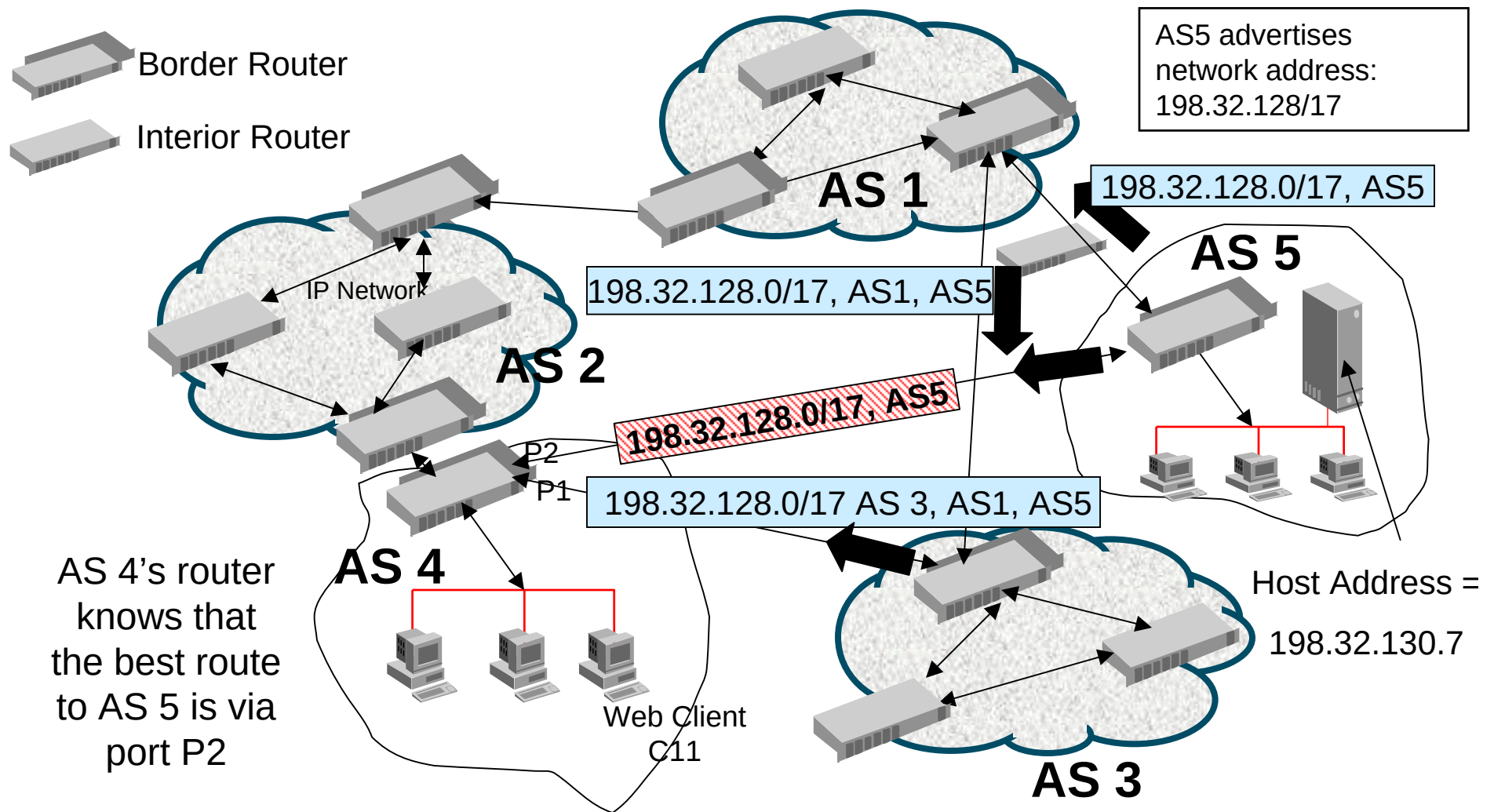


- Overview
- Network Layer
 - IP
 - Addressing and Routing
- Transport Layer
 - UDP
 - TCP

Internet Structure

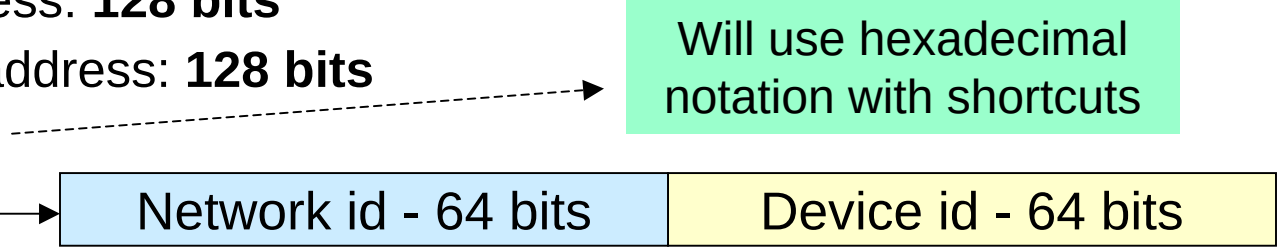


BGP-4 Routing Example



IP Version 6

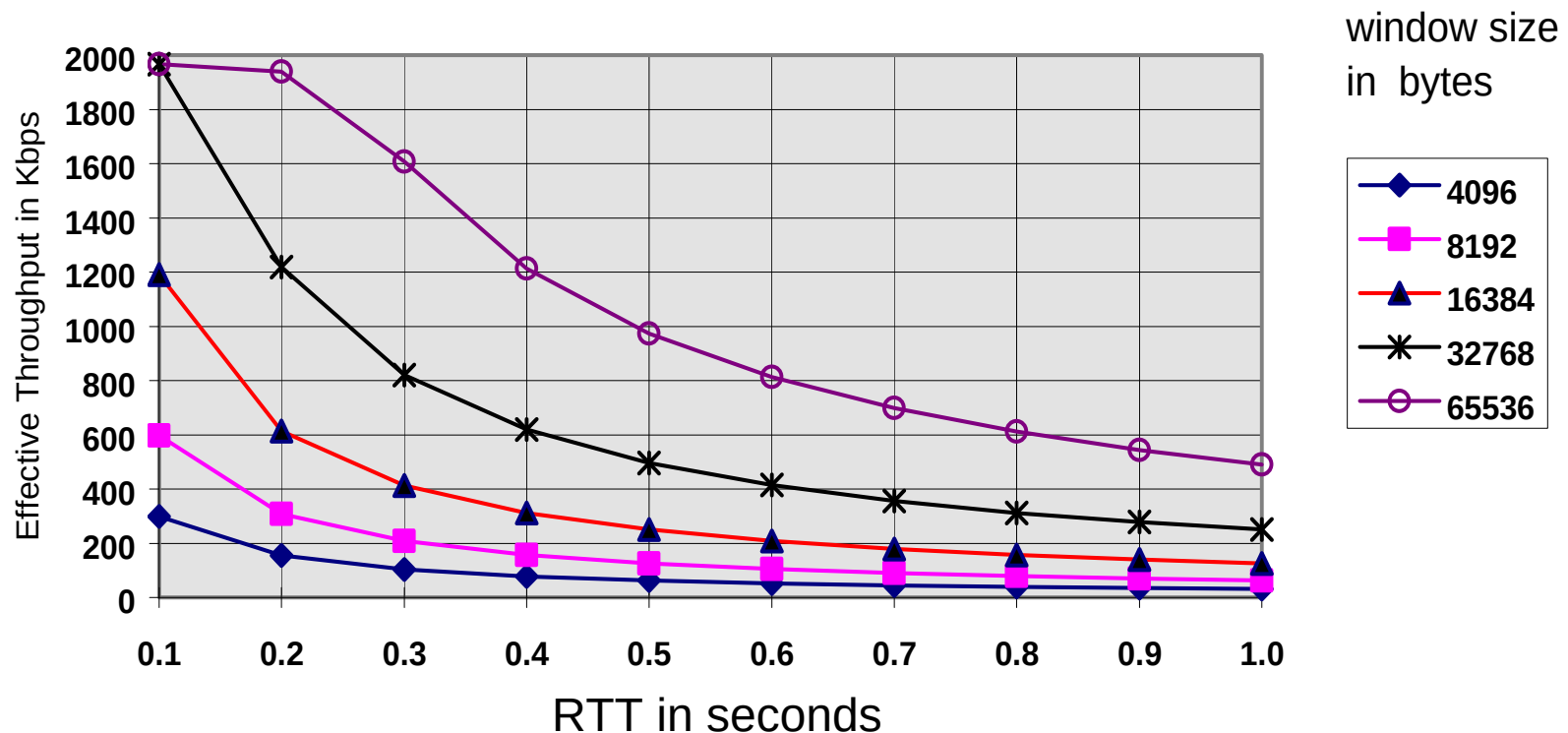
Reference: Cisco White Paper
<http://www.cisco.com/warp/public/732/abc/docs/abcipv6.pdf>

- Newer standard to replace IP Version 4
 - Primarily driven by need to increase number of IP addresses
- Format (**40-byte header!**)
 - version id: 4 bits
 - traffic class: 8 bits (for difserv, intserv, priorities)
 - Flow label: 20 bits (tie into RSVP or ATM)
 - Payload length: 16 bits
 - Next header identifier: 8 bits (indicates next header in the IP packet)
 - Hop limit (time to live): 8 bits
 - Source address: **128 bits**
 - Destination address: **128 bits**
- IP v6 address
 - Unicast: 

Network id - 64 bits	Device id - 64 bits
----------------------	---------------------
 - Multicast (one to many)
 - Anycast (one to anyone in a group of identical hosts)

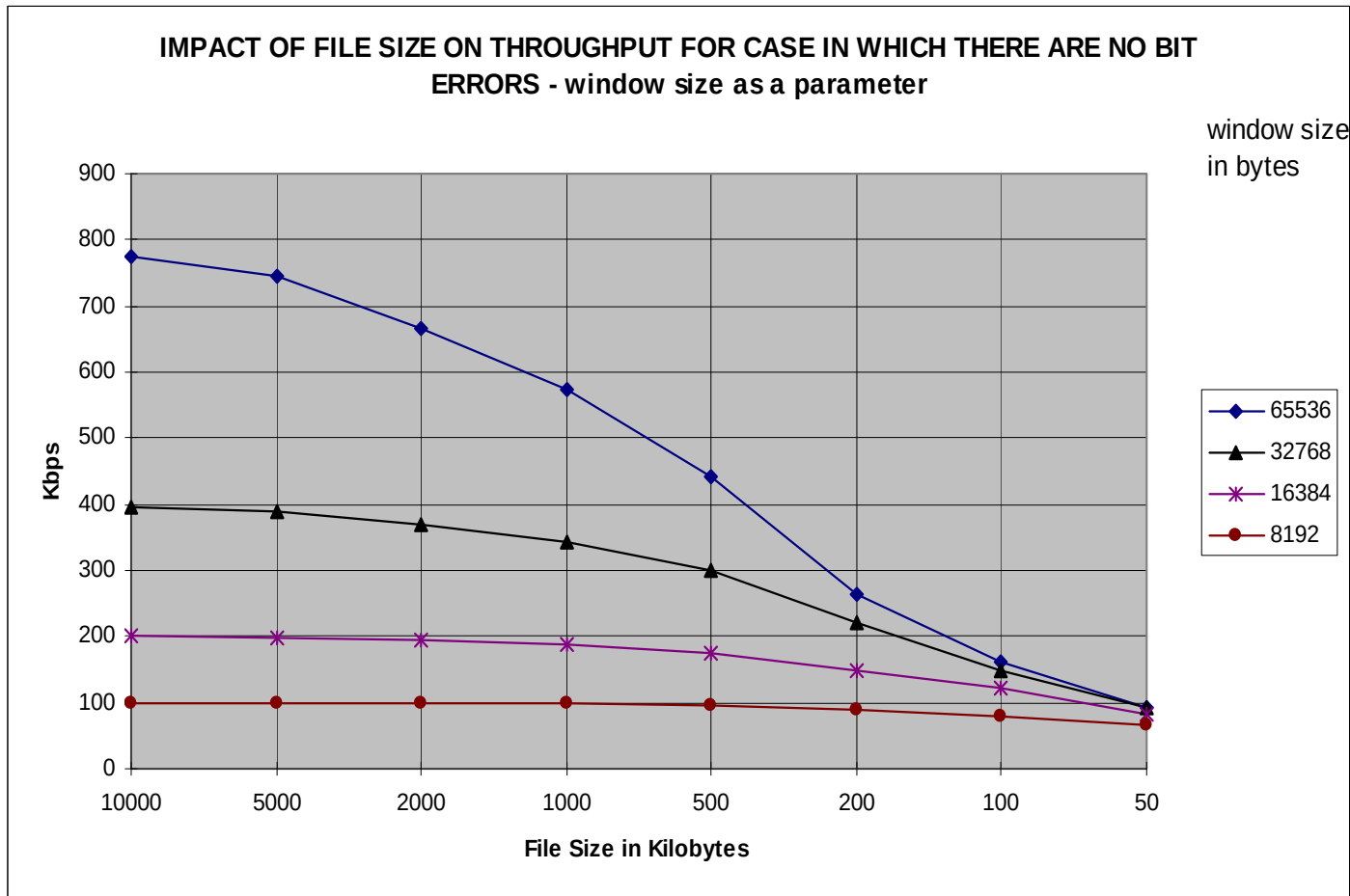
Impact of TCP Window Size and RTT on Throughput

Throughput vs. RTT With Window Size as a Parameter



Effective Throughput in a Non-Congested, Error-Free Link with Channel Speed of 2048 Kbps – assuming very long file transfer

Slow Start Impact is a Function of File Size, RTT and Window



FOR THIS CASE:

RTT = 600 ms

Segment Payload = 512 bytes

TCP overhead = 20 bytes

IP overhead = 20 bytes

Frame overhead = 5 bytes

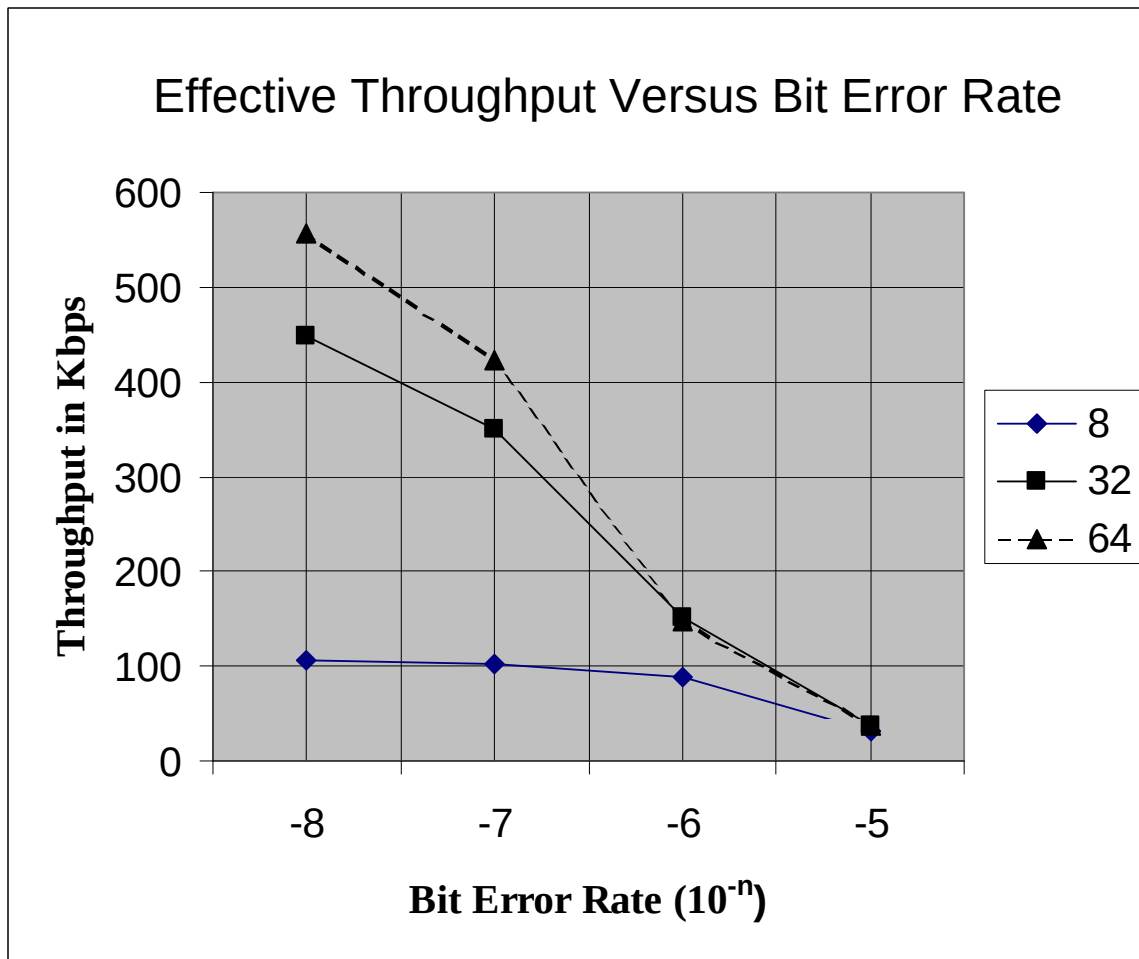
No congestion

No bit errors

Channel Speed - 2048 Kbps

Impact of Bit Errors on TCP/IP Throughput

- Unfortunately TCP cannot tell the difference between a packet loss due to bit errors or congestion - therefore TCP overreacts to bit errors by reducing throughput
- The moral of this story is that it is essential to have a link with a low bit error rate!



File Size is 1 MB

RTT is 540 ms

Figure shows impact of Window Size (in Kbytes)

It should be noted that impact of bit errors will diminish as file size decreases

Measurements provided courtesy of Mentat Corporation (now part of Packeteer)

Part 4 - Quality of Service (QoS) Issues in IP Networks

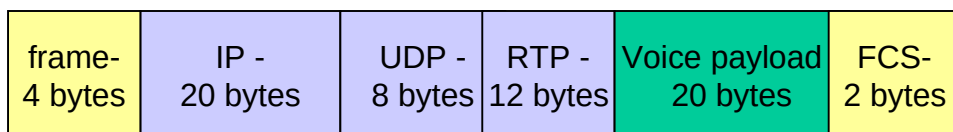
This Section Discusses

- QoS requirements for inelastic flows such as voice and video
- Response time for elastic, web-based file transfers
- General methods available to support QoS in IP Networks
- Network Management
 - Monitoring
 - Security

QoS: the ability of a network to deliver packets within specified metrics including packet loss, delay, jitter.

VOIP Overhead Example

- G.729 (CS-ACELP)
 - Each voice sample encompasses 10 bytes
 - Each sample created every 10 ms (8 Kbps rate)
 - Cisco default packs two voice samples into one IP packet
- Uncompressed header of 40 bytes, plus 4 bytes for framing overhead and 2 bytes for frame check sequence (FCS).



RTP: Real
Time Protocol

- Therefore we use 66 bytes to transmit 20 bytes of payload.
- Hence we need $66/20 \times 8 = 26.4$ Kbps for one-way voice flow
- Encapsulation and encryption can add more overhead
- However, header compression and “silence suppression” can decrease average bw utilization!

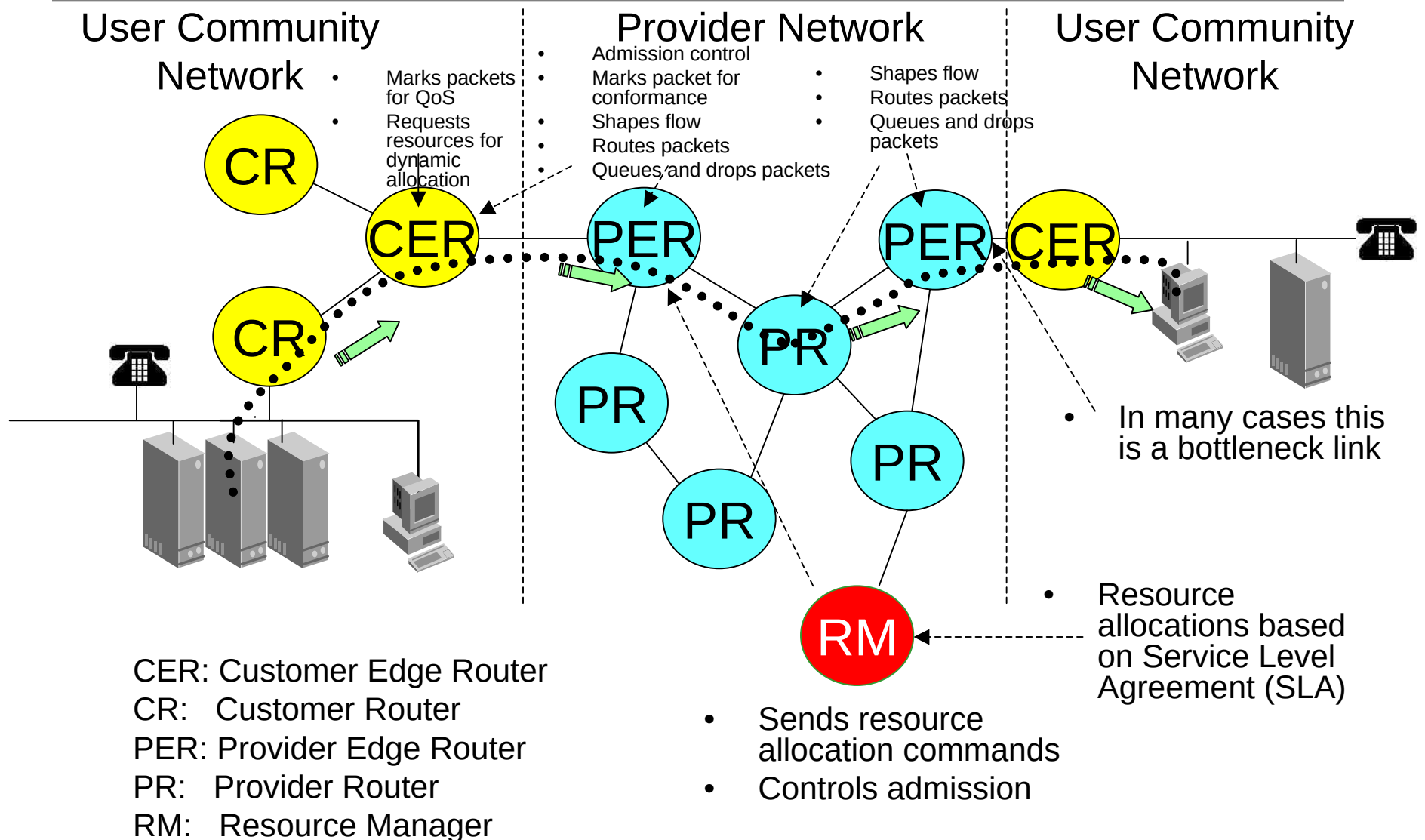
Video Streams over IP

- Video has same issues as voice and in fact could be more complicated.
- Video needs higher bandwidth
- Voice and data streams must be synchronized
- Some video compression schemes are bursty
 - instantaneous bandwidth depends on picture activity.
- There are standards for sending video over IP
- One-way video is not affected by delay
- Two-way video conferencing has same delay issues as voice.
- A full discussion of video is beyond the scope of this seminar

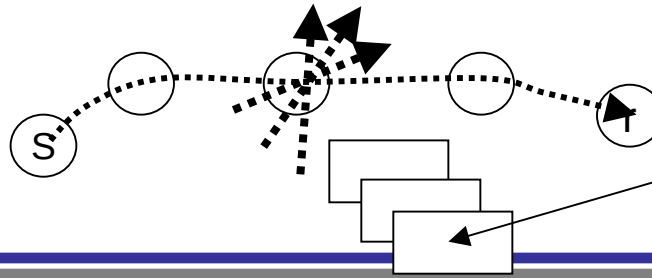
Elastic Flows – HTTP Example

- HTTP is used to transmit web pages
- Runs on top of TCP/IP (reliable protocol)
- Zero bit error tolerance
- There is a three-way handshake at the beginning of the session
- Transfer is complicated by fact that a single request might require several objects
- Each object requires its own session
- Typical web transfer is 5 to 10 kilobytes, but could be much more

QoS Framework



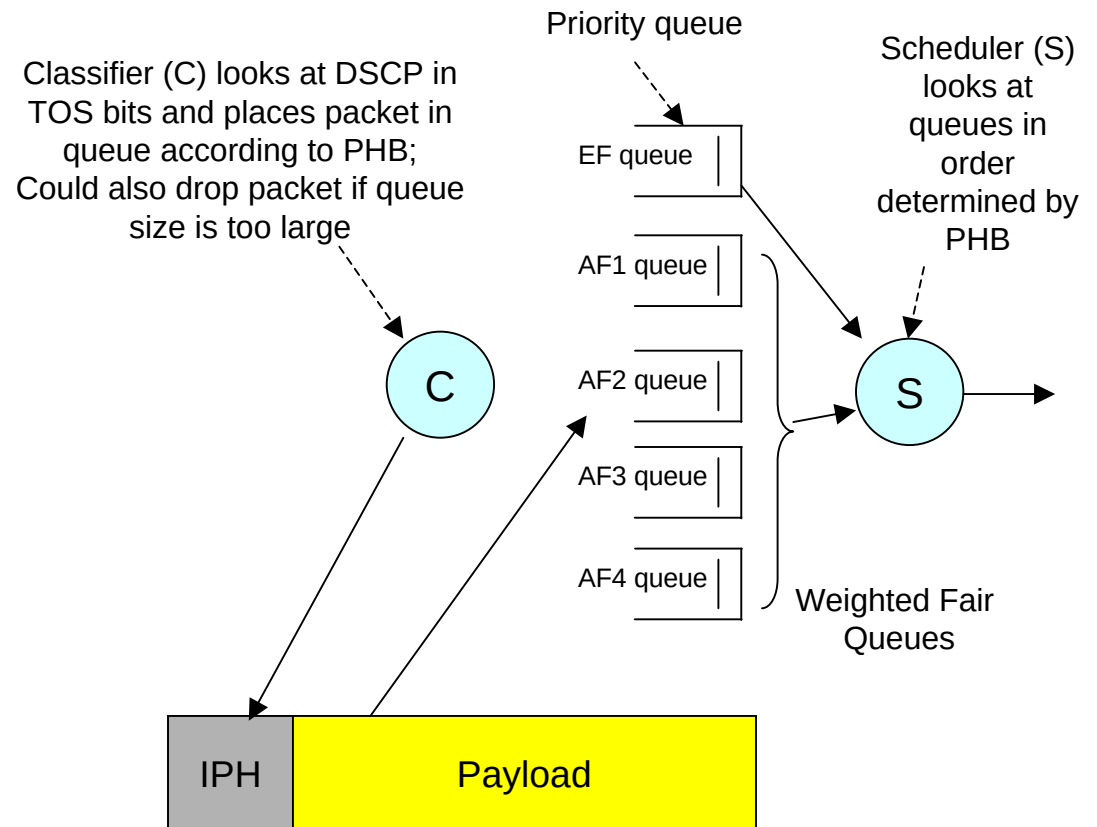
DiffServ - QoS that Scales Well



Service description for *each service class* at each node

- Differentiated Service Architecture (DiffServ) RFC2475
 - Each flow is mapped into a service class at its network entry point
 - Each flow is traffic-shaped at the entry point based on service class
 - Each packet is marked with a service indicator - the Differentiated Service Code Point (DSCP)
- Each intermediate node maps the DSCP into a “per-hop behavior” (PHB) and could change the DSCP. A PHB can define
 - A bandwidth requirement - usually shared with other flows
 - A priority for the class
- Unlike Intserv, a Diffserv node does not have to keep track of individual flows

EF: expedited forwarding
AF: Assured forwarding



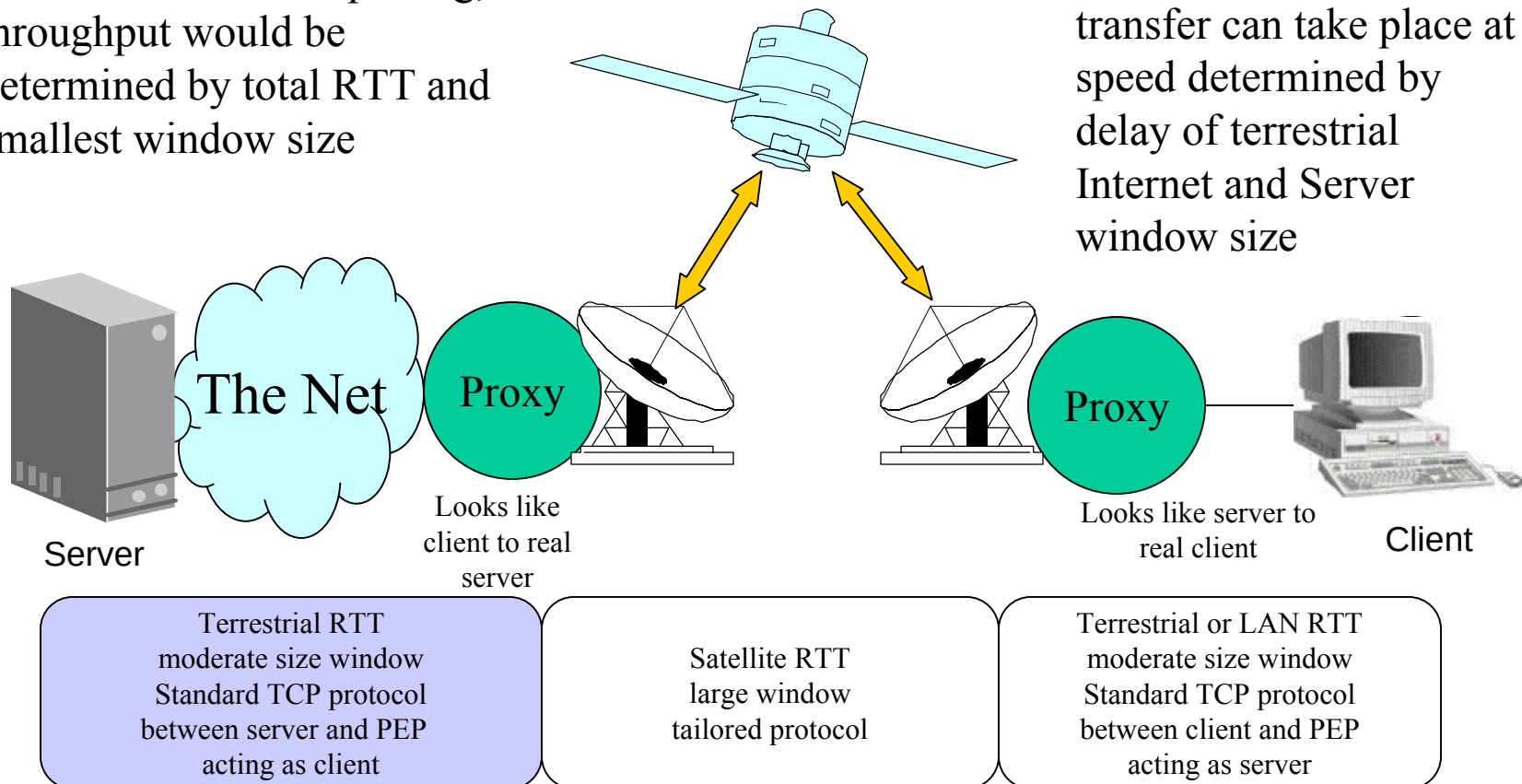
Performance Enhancement – Proxies (PEP)

This approach violates the end to end integrity of TCP- but could be used where the satellite link is the termination of the session

PEP splits the TCP session-

1 - Without session splitting, throughput would be determined by total RTT and smallest window size

2- With session splitting, transfer can take place at speed determined by delay of terrestrial Internet and Server window size

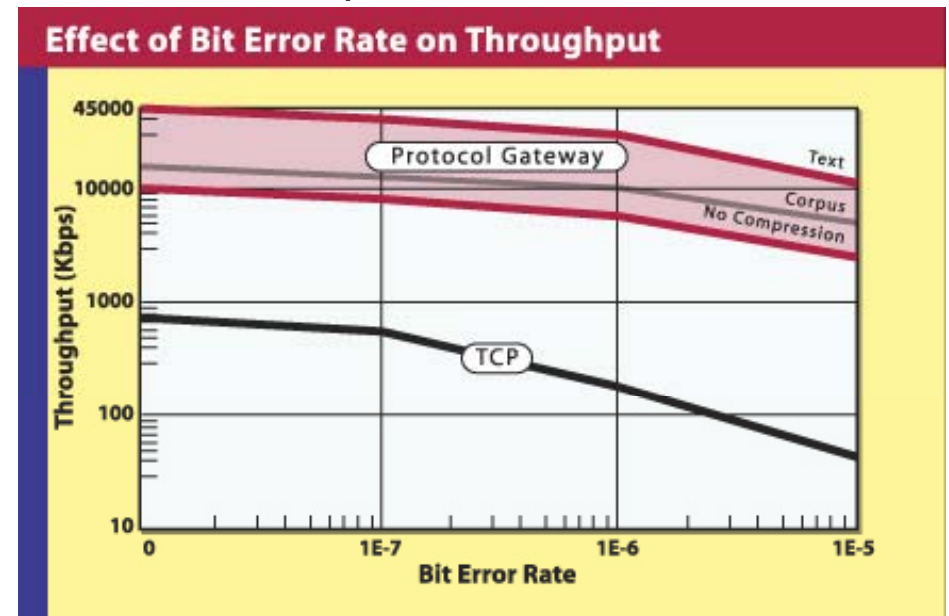
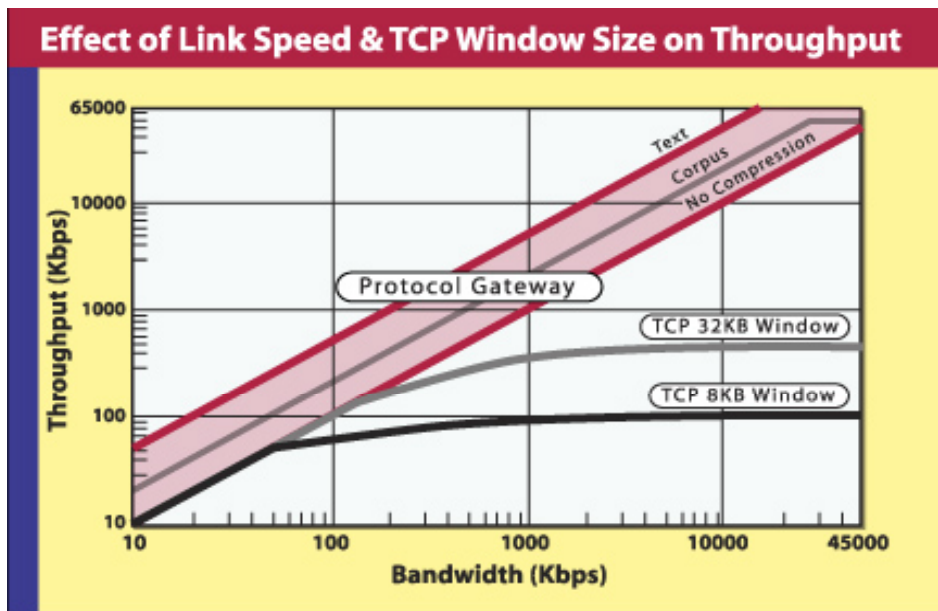


Mentat, Flash, Fourelle provide Performance Enhancing Software; SkipWare provides PEP based on SCPS

PEP versus TCP Performance for Single File Transfer

Courtesy of Mentat Corporation
Extracted from "Satellites and the Internet", DC Palter, SatNews Publishers Inc.

- Impact of Window Size on Effective Throughput
 - TCP window size of 8 and 32 Kbytes
 - Compressed and non-compressed text
 - 540 ms RTT
- Can Improve Performance over a Satellite Link With Errors
 - TCP window size of 64 Kbytes
 - Compressed and non-compressed text
 - Graph is for 1 Mbyte file over 10 Mbps link

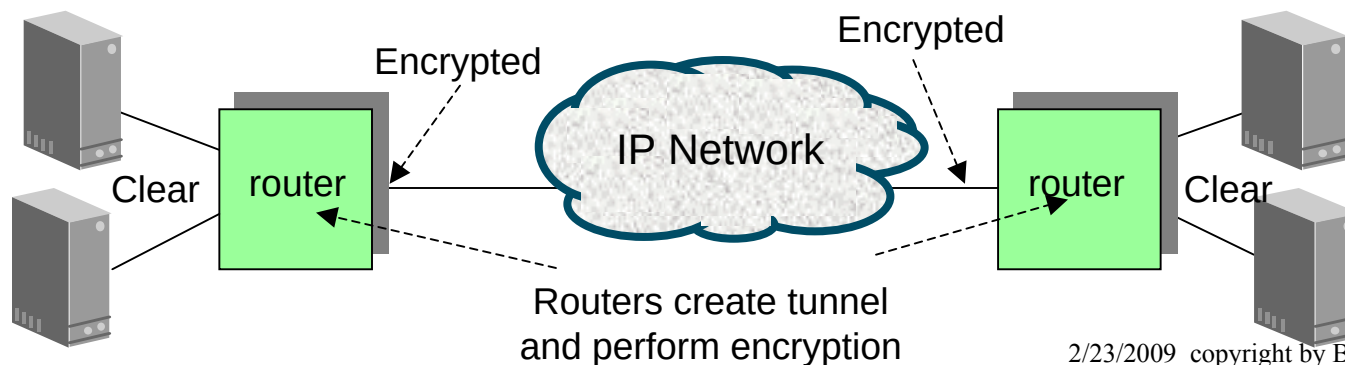


Note; "Corpus" refers to standard set of files used to measure compression effectiveness

IPsec Modes of Service

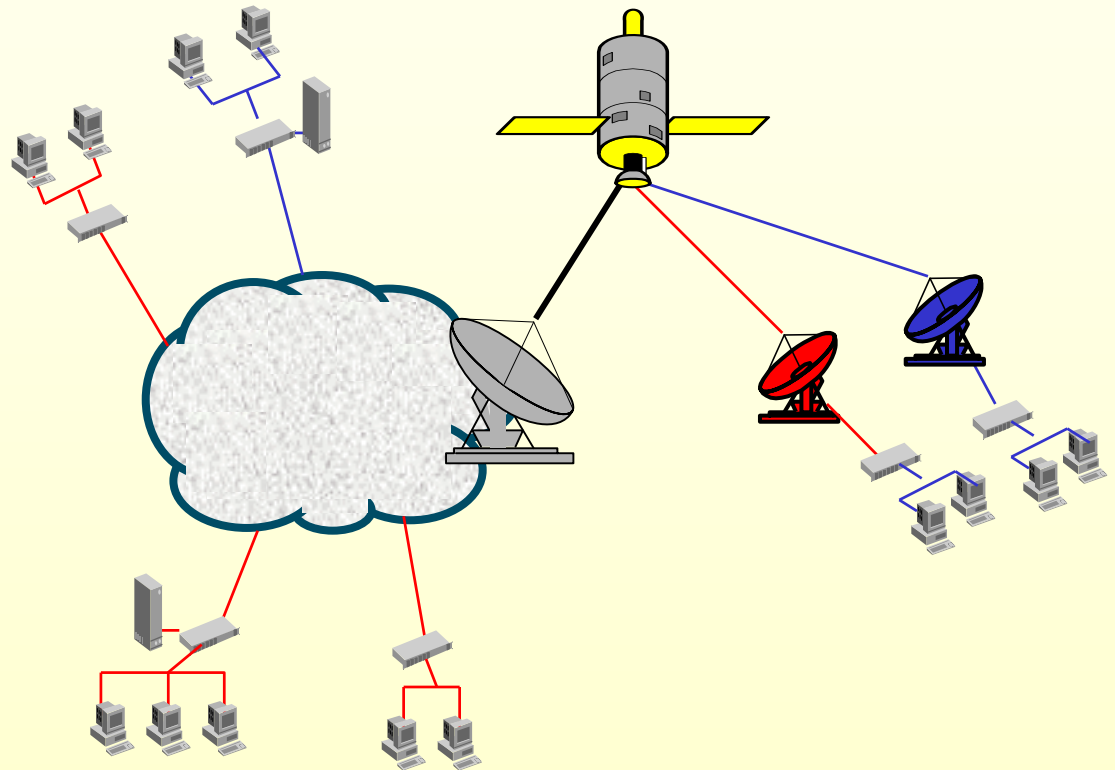
- Transport (Tactical*)
 - Original IP header in the clear, rest of packet is encrypted and authenticated
 - Encryption provided at host location
 - Encryption negotiated between hosts
- Tunnel (Strategic*)
 - Original IP packet is encrypted including header
 - Encryption and new header is provided at tunnel end point (router)
 - tunnel negotiated between end points associated with networks

*“Tactical” and
“Strategic” are terms
used in HAIPE



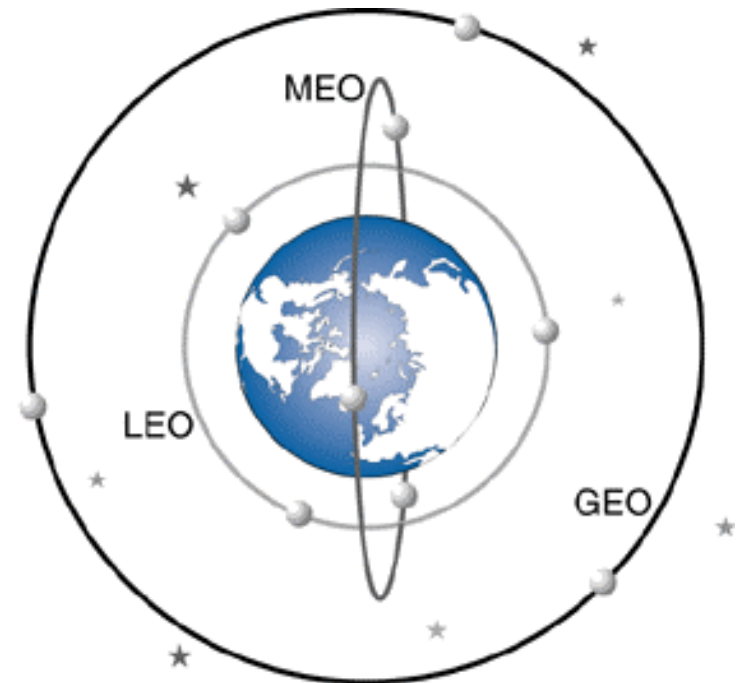
Part 5 - Satellite Data Networking Architectures

- Space Segment
- Earth Segment and Technology
 - point to point
 - point to multipoint
 - shared downstream
 - return links
 - terrestrial
 - » dedicated
 - » shared DAMA links
 - satellite
 - full mesh



Space Segment Overview

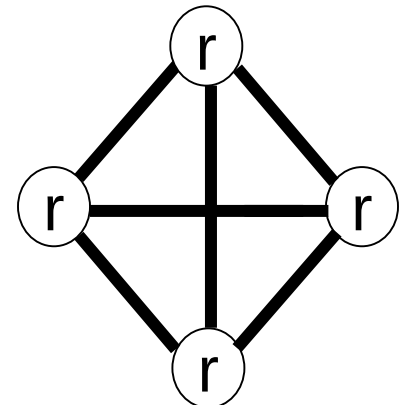
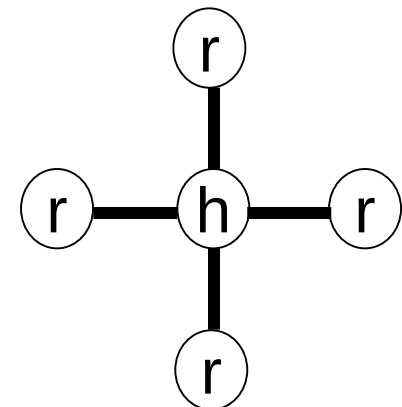
- Low Earth Orbit (LEO) - 400 to 1000 mile orbit
- Medium Earth Orbit (MEO) - 6,250 to 12,500 mile orbit
- Geosynchronous Earth Orbit (GEO) 22,500 mile orbit
- We will focus on GEOs*
 - most satellite data links are run over GEOs
 - GEOs can use stationary antennas
 - GEOs have wide coverage area
 - On the other hand
 - ~250 ms one way delay
 - distance attenuates signals



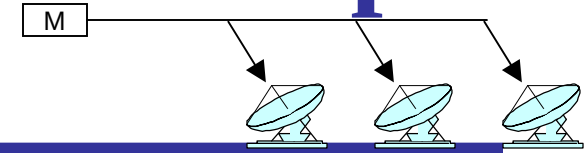
*Will discuss LEOs and advanced satellites later in this seminar

Earth Segment Architectures for Data Networking

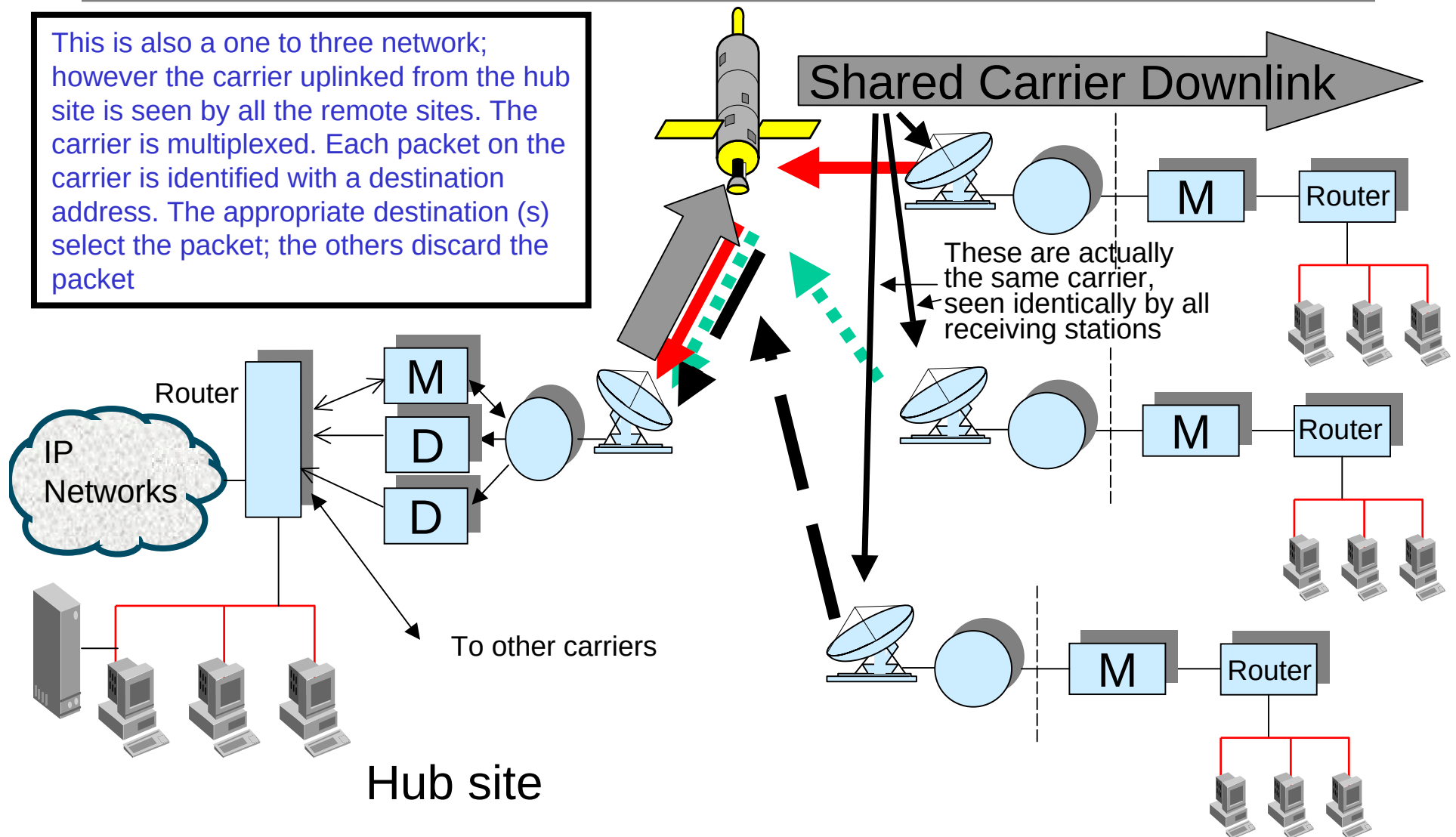
- Point to Point
- Point to Multipoint
 - Multiple SCPC (FDMA)
 - Shared Outbound Carriers -
 - Time Division
 - Code Division Multiple Access (CDMA)
 - Return Channel Options
- One-Hop Meshed Networks
 - FDMA
 - TDMA



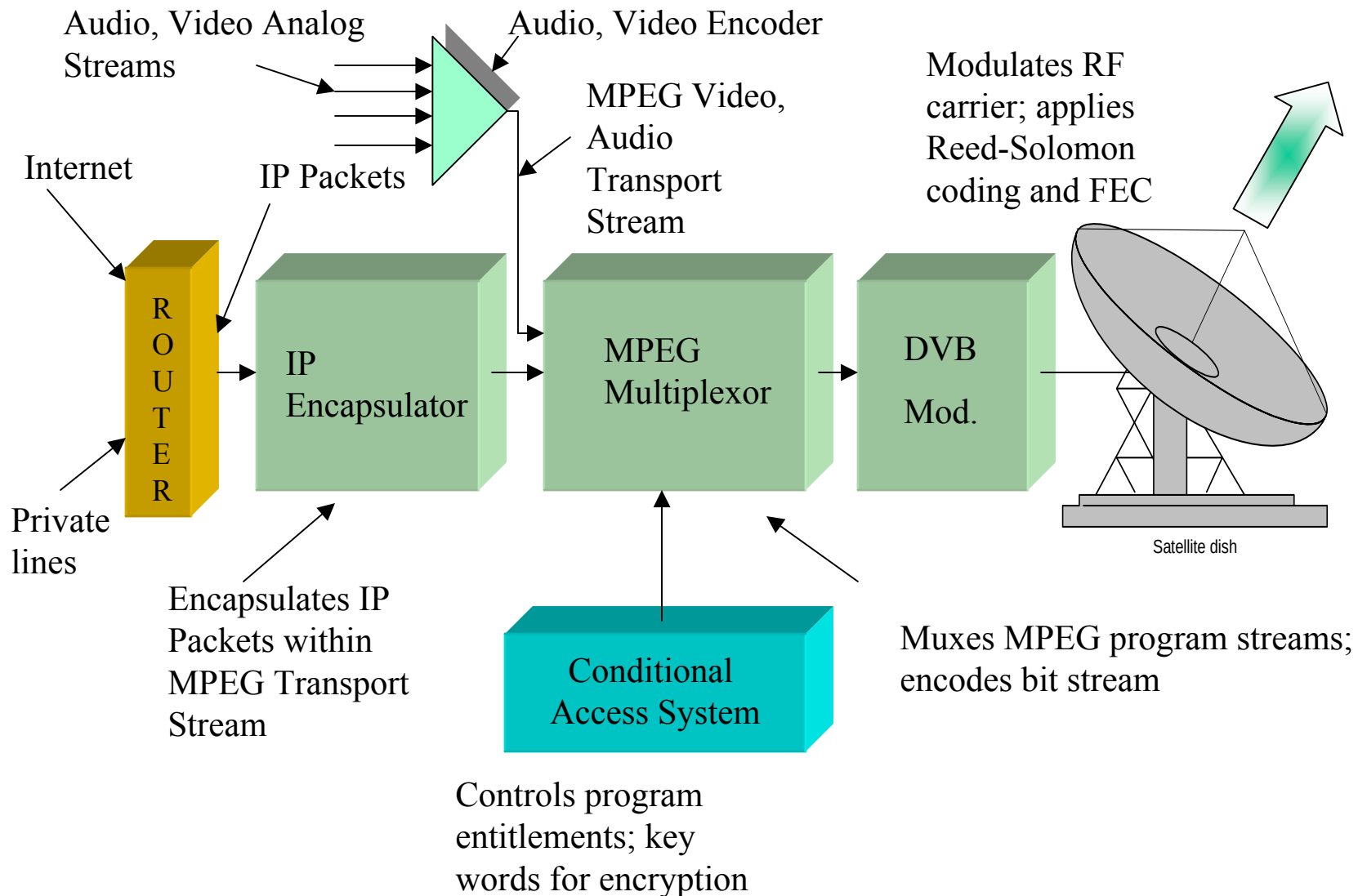
A Shared Carrier Point to Multipoint Network



This is also a one to three network; however the carrier uplinked from the hub site is seen by all the remote sites. The carrier is multiplexed. Each packet on the carrier is identified with a destination address. The appropriate destination (s) select the packet; the others discard the packet



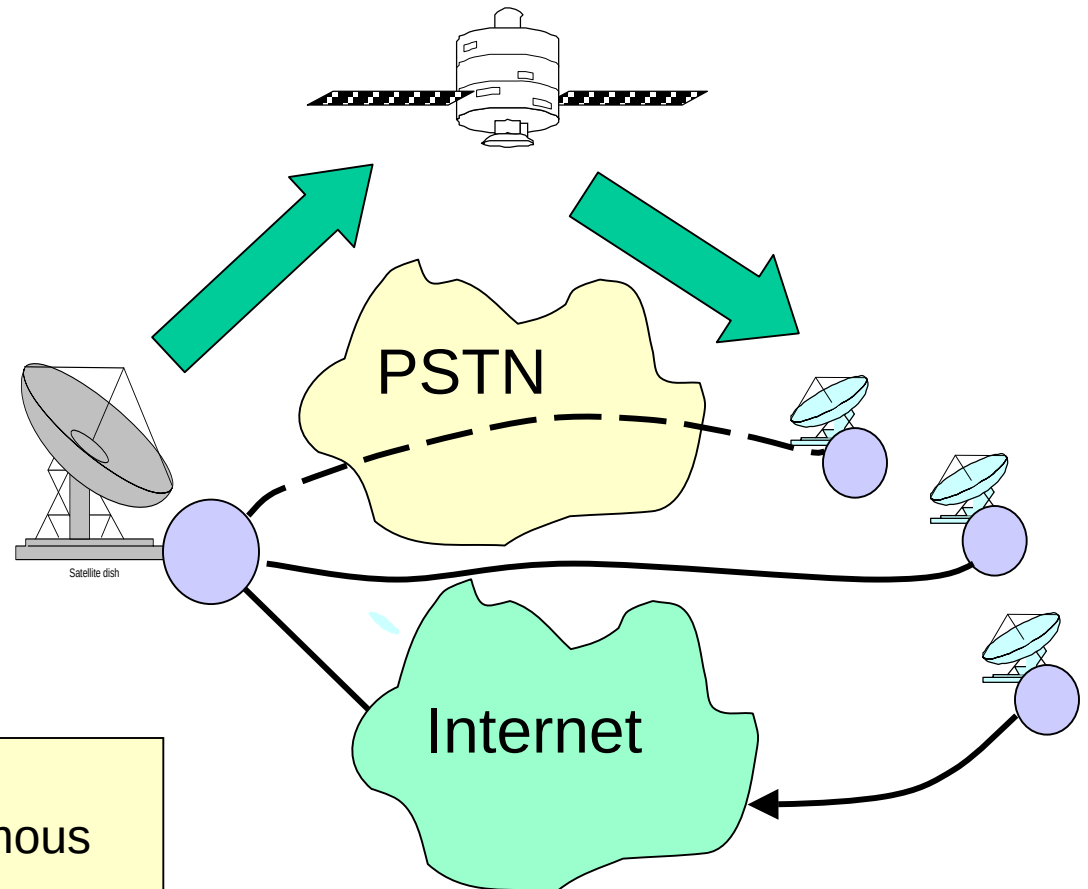
DVB Uplink Data Flow



Terrestrial Return Options

Terrestrial Path Options (hybrid system)

- Dedicated Link Back to Satellite Hub - rarely used
- Dial up Link - used in home and small office situations
- Internet Link - used in areas where terrestrial infrastructure exists but is expensive



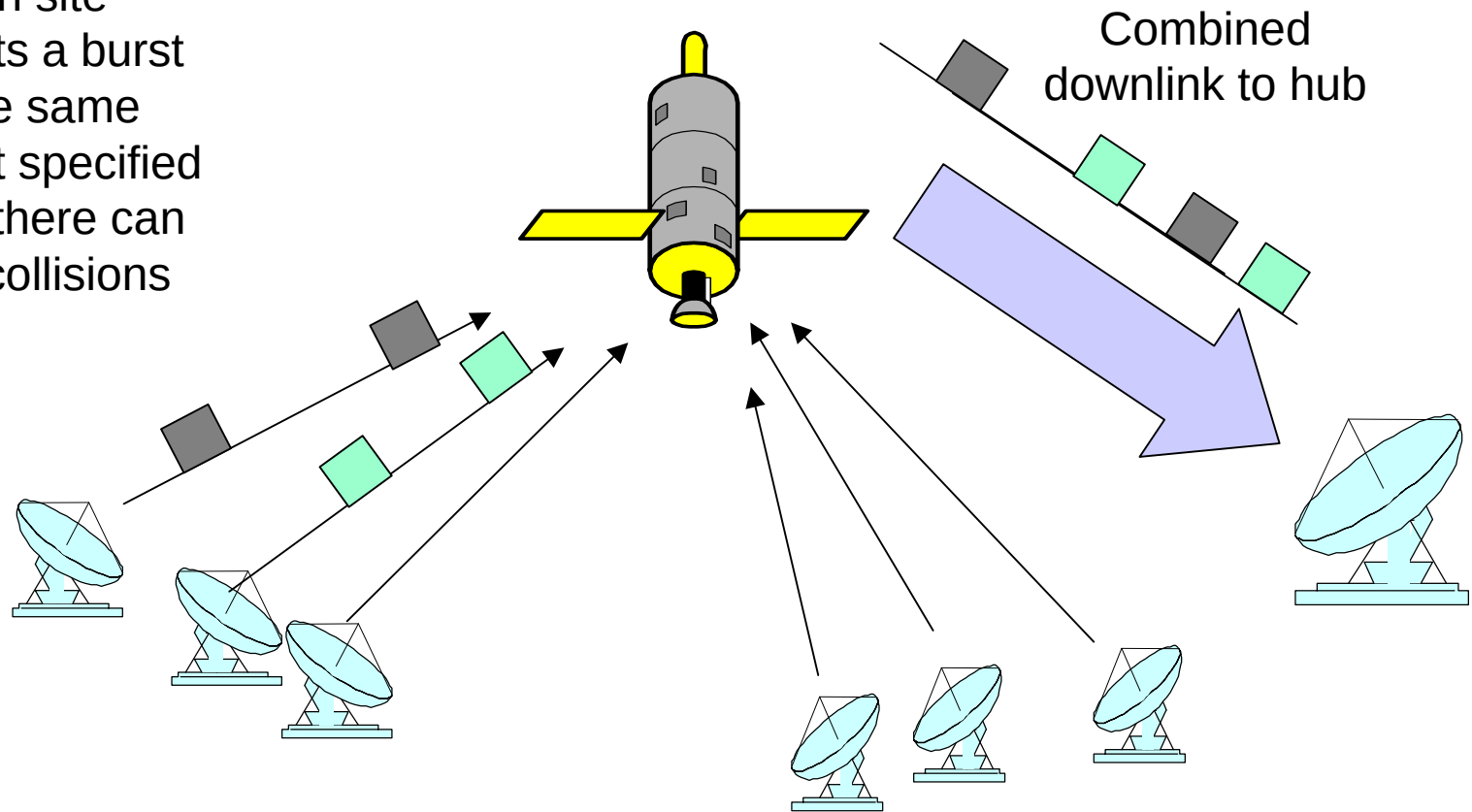
Potential Routing Issue

Case 1 - customer is an autonomous system with its own addresses

Case 2 - customer is not an AS

TDMA/DAMA Return Links

Each site
transmits a burst
on the same
carrier at specified
times - there can
be no collisions



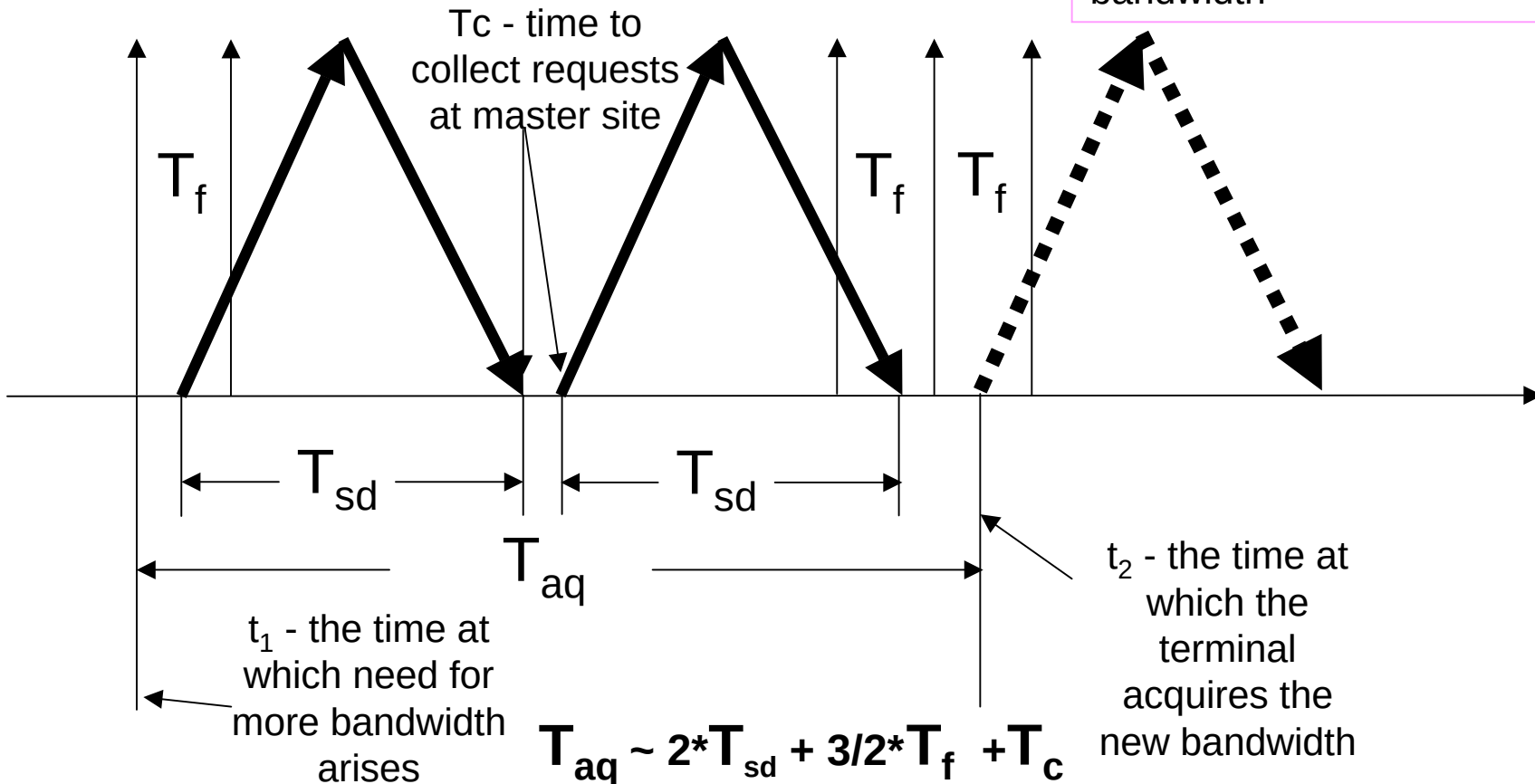
Time Division Multiple Access (TDMA)
Demand Assigned Multiple Access (DAMA)

Requesting Bandwidth - continued

Assumption: requests are made using low utilization aloha signaling channel - probability of collision is very low.

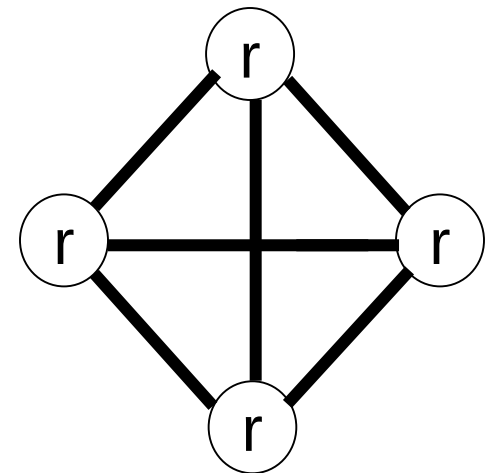
- Timing Considerations

T_f Time duration of frame
 T_{sd} One-way satellite delay
 T_{aq} Time to acquire new bandwidth

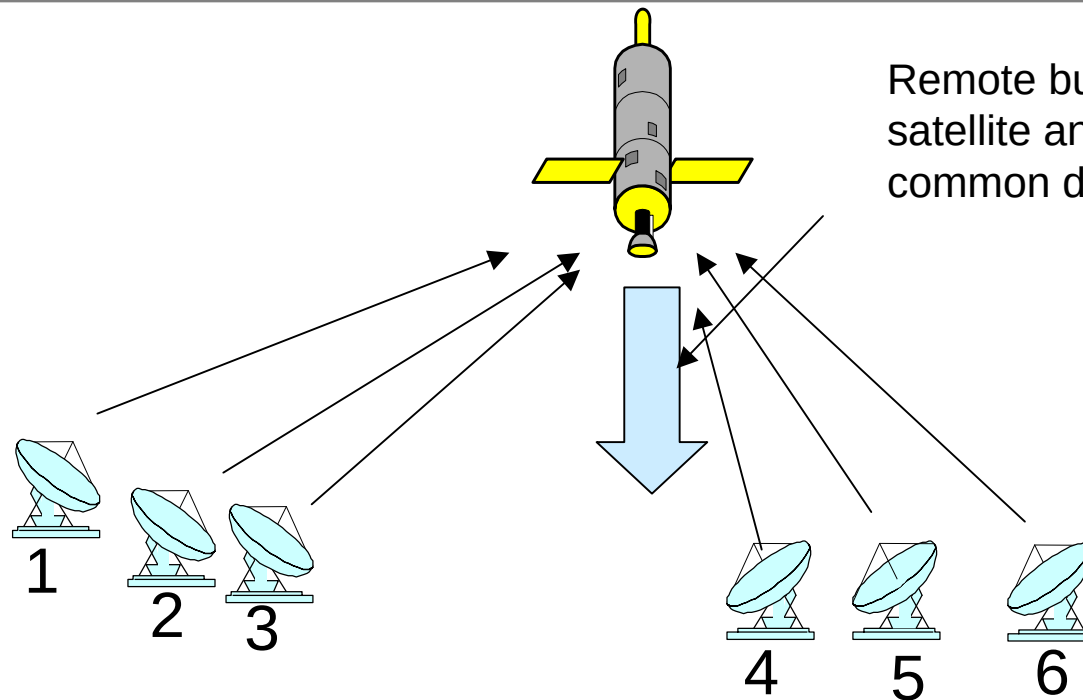


Full-Mesh Network

- A full-mesh network is one in which each node can talk to each other node with only one satellite hop
- Most commercially available full-mesh networks are based on SCPC DAMA or TDMA/DAMA technology



TDMA DAMA Full-Meshed Networks



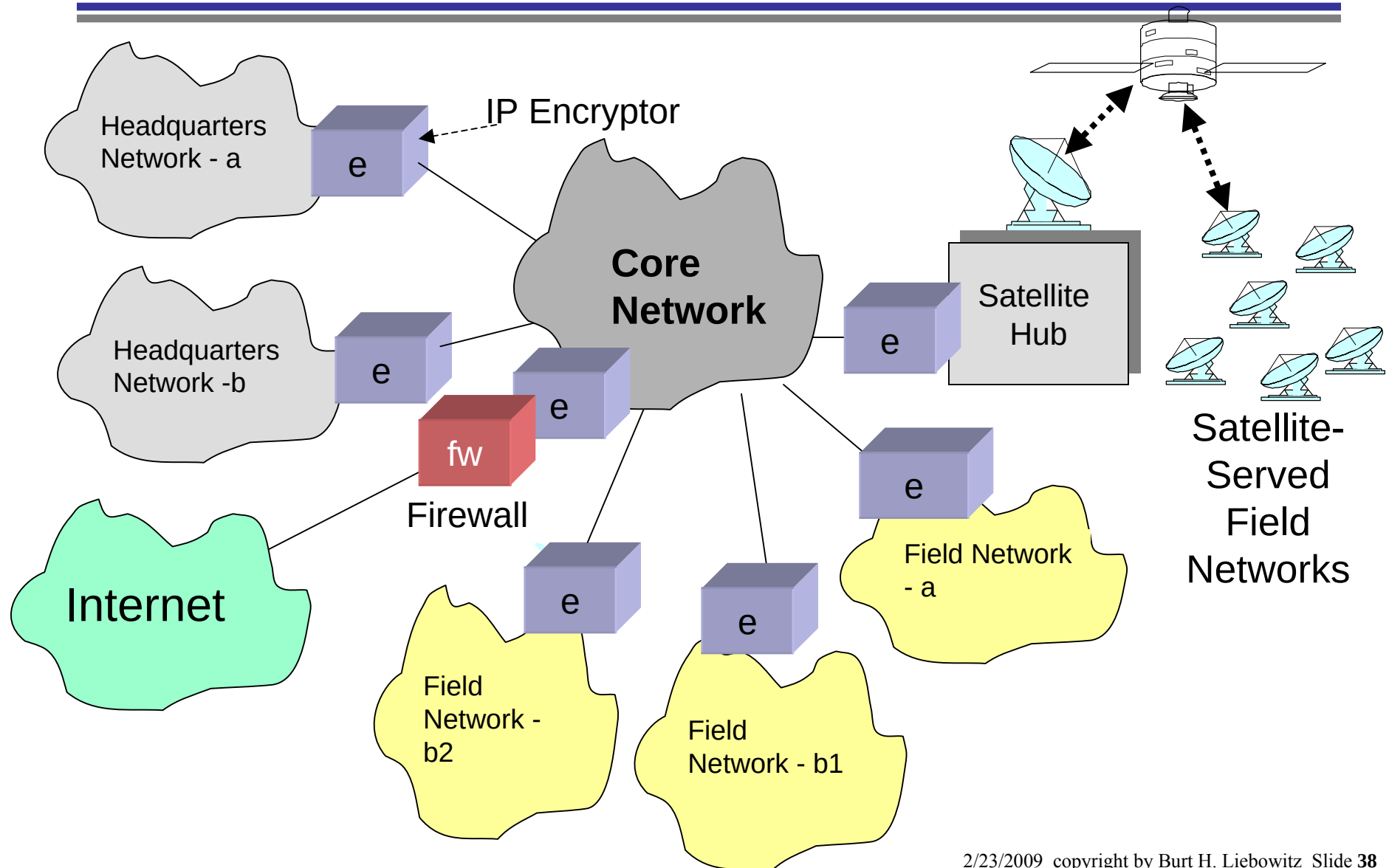
Similar to TDMA return link except that all remote sites look at the same down link; in that way each remote site can transmit directly to each other remote site without having to go thru a hub site

One site is designated as a control site; it processes bandwidth requests and creates the burst plan

PART 6: System Design and Economic Issues for Satellite-Based IP Networks

- Large Scale Mission-Critical Intranets
 - Architectures
 - Impact of Mobility
 - Need for QoS
 - Multicast Applications and Shared Service Hubs
- Economics of Commercial Applications
 - Backbone ISP Services
 - Direct to User Applications

Multiple Enterprise Secure Network -1

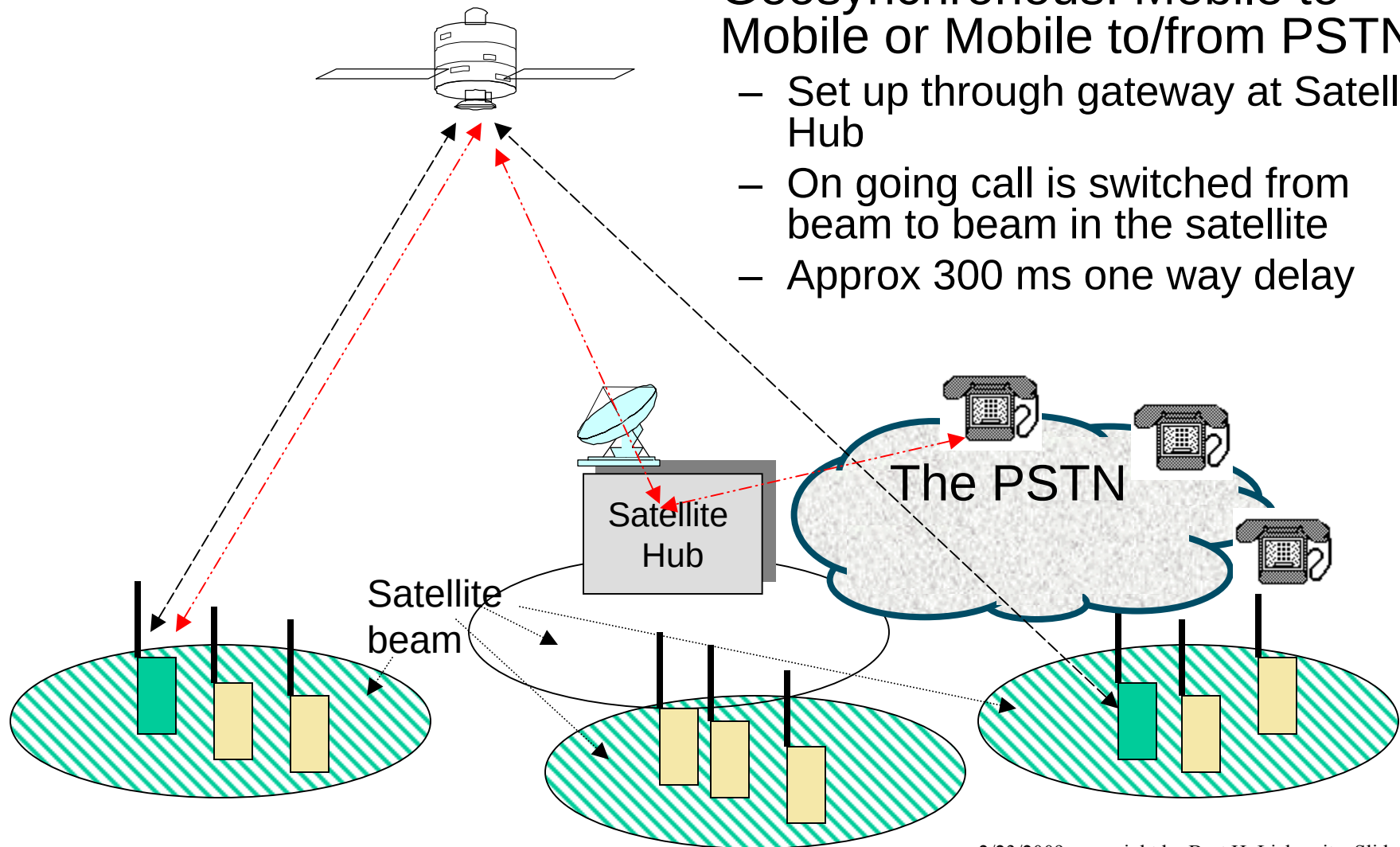


Options For Satellite-Based Field Network Sites

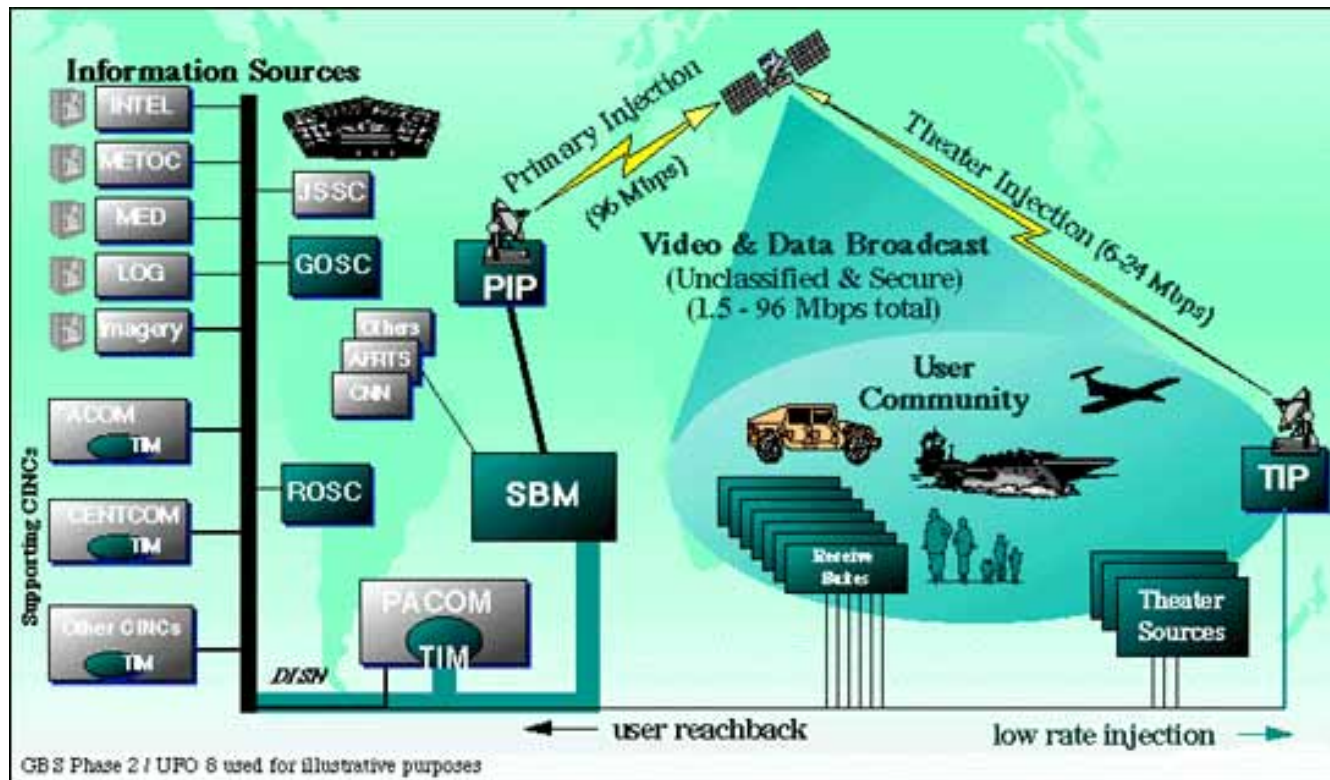
- Fixed
 - single local area network (LAN)
 - single terminal
 - mobile gateway to a terrestrial mobile network
 - large network
 - landline connectivity
 - wireless connectivity
 - both
- Mobile Satellite Services (MSS -direct to user)
 - foot
 - land vehicle
 - ship
 - airplane

Satellite Mobile Network – Geo Based System

- Geosynchronous: Mobile to Mobile or Mobile to/from PSTN
 - Set up through gateway at Satellite Hub
 - On going call is switched from beam to beam in the satellite
 - Approx 300 ms one way delay



Global Broadcast Service



- Push information to the warfighter using DVB technology
- Return via DVB/RCS or DoD secure network
- Teleport ties into high speed terrestrial network
- Provides high speed downlink to small (18-inch) dishes

Calculation of Number of Subscribers Per Transponder

- Two types of Subscribers
 - Browsing Subscriber – 10 Kbytes every 60 seconds
 - Streaming Subscriber – 128 Kbps
- Streamers represent 40% of total subs
- Provision for Overhead – 5% of total channel
- Maximum throughput on downstream transponder – 40 Mbps
- Question: How many total subscribers can we fit on transponder and still provide QoS for streams and high effective throughput for browsing subscribers?
- To answer this we need to expand on the concept of effective throughput

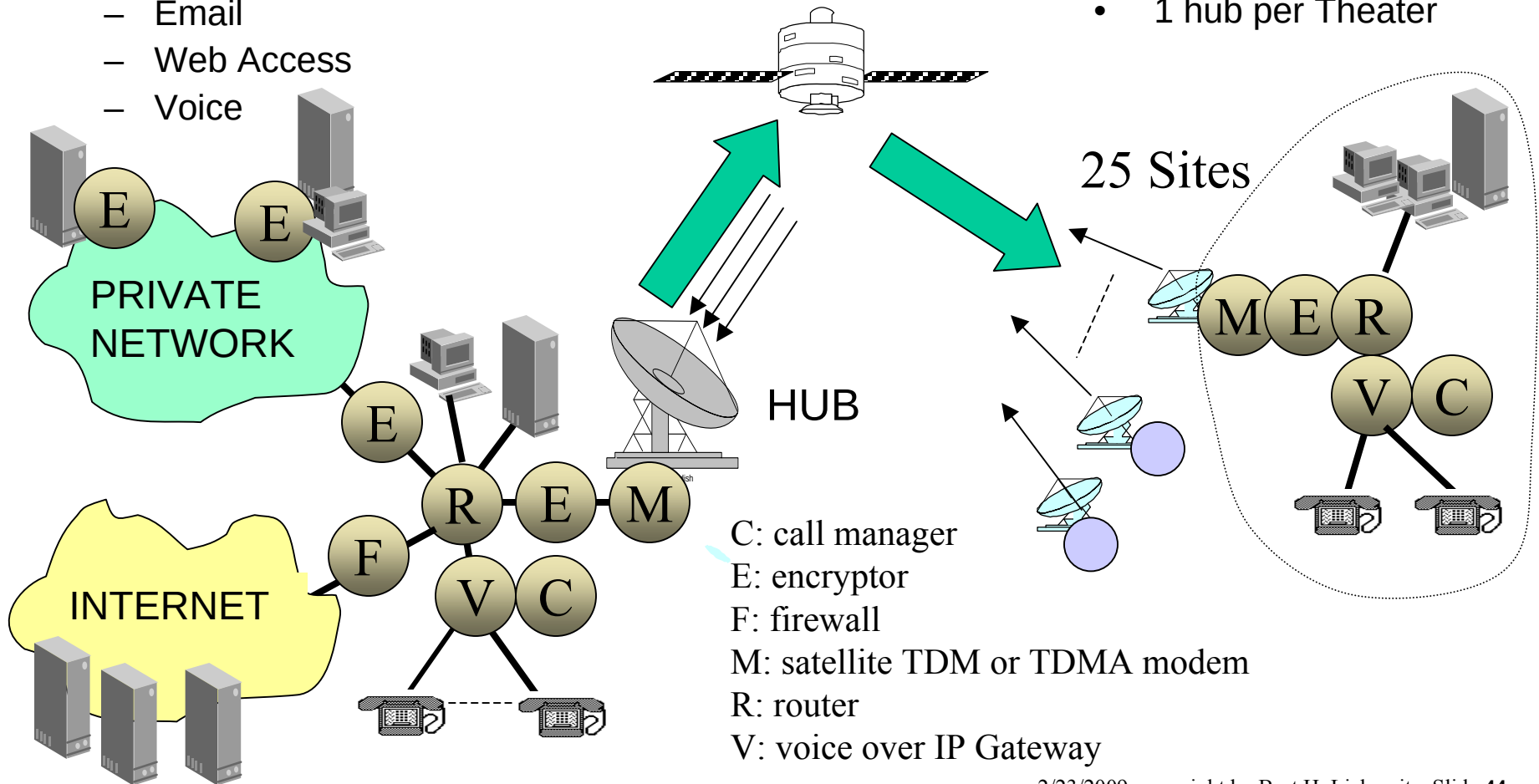
Part 7 - A TDMA/DAMA Design Example

- Enterprise Application
 - Star network
- Compare Different Architectural Approaches To Determine
 - Minimum bandwidth approach
 - Lowest cost approach

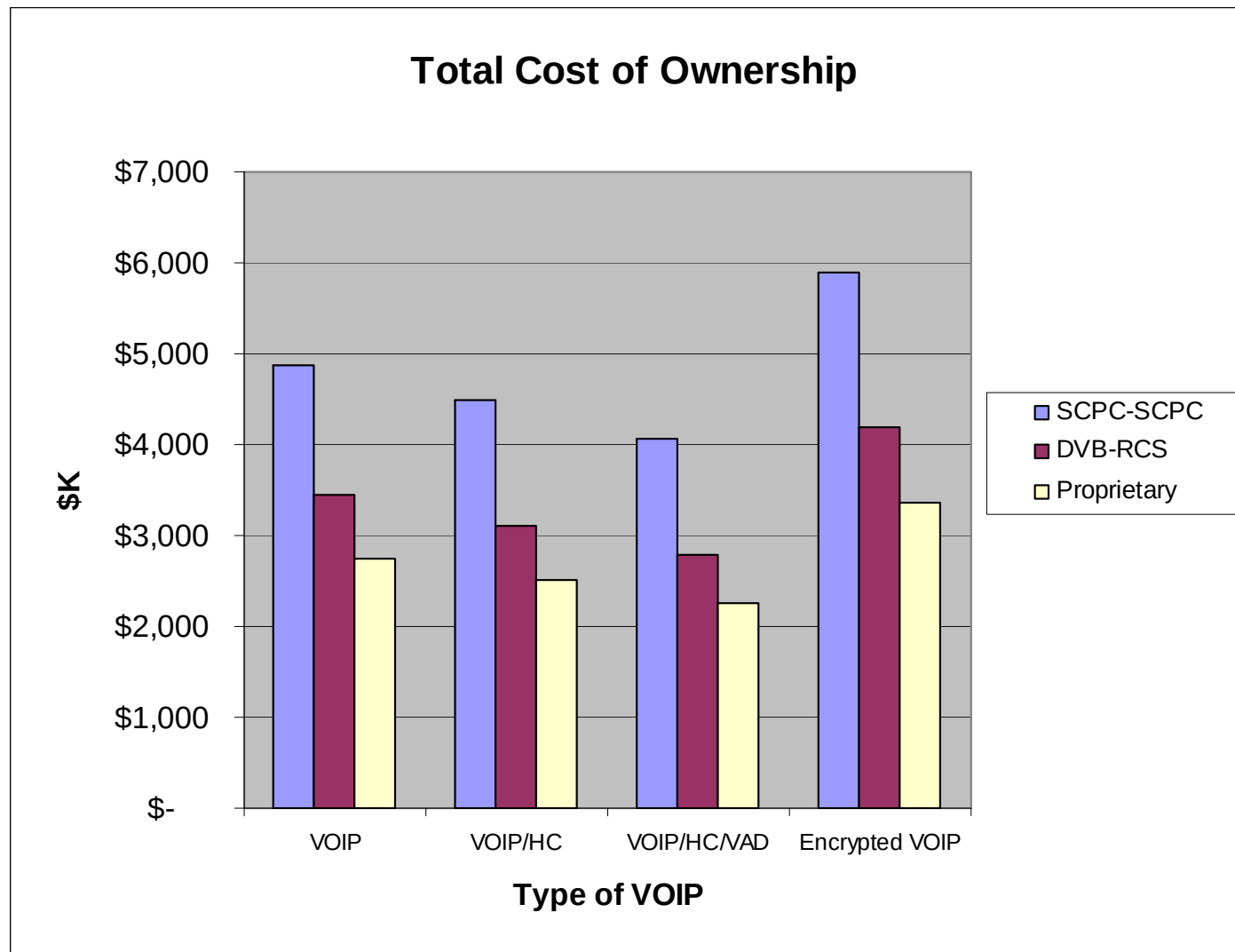
NETWORK MODEL

- Major Applications
 - Access to Enterprise Data Base
 - Specialized Transactions
 - Email
 - Web Access
 - Voice 

- 1 Theater
- 25 Sites per Theater of Operation
- 1 hub per Theater



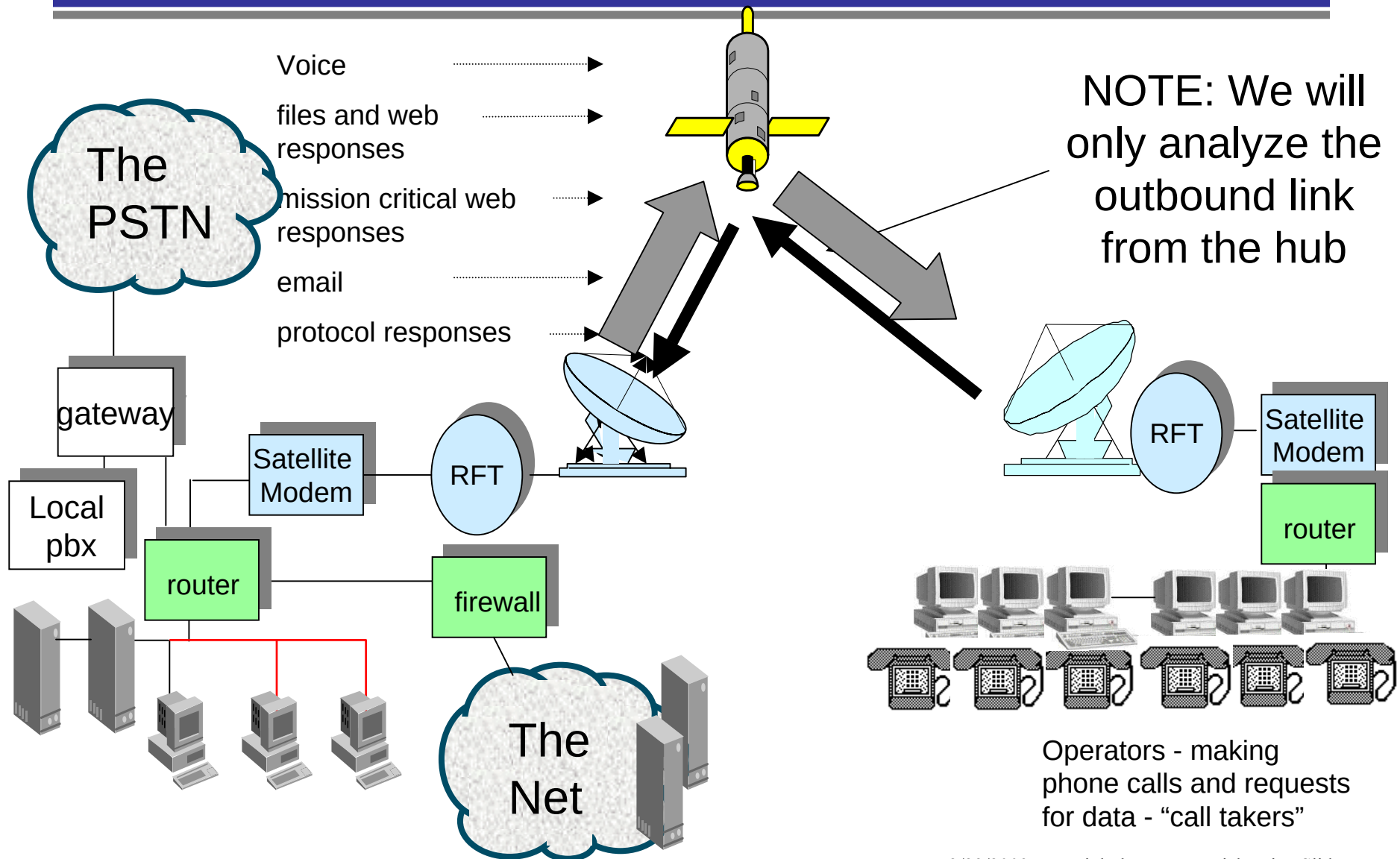
Cost Based on VOIP Methodology



Part 8 – Predicting Performance in Mission-Critical Networks

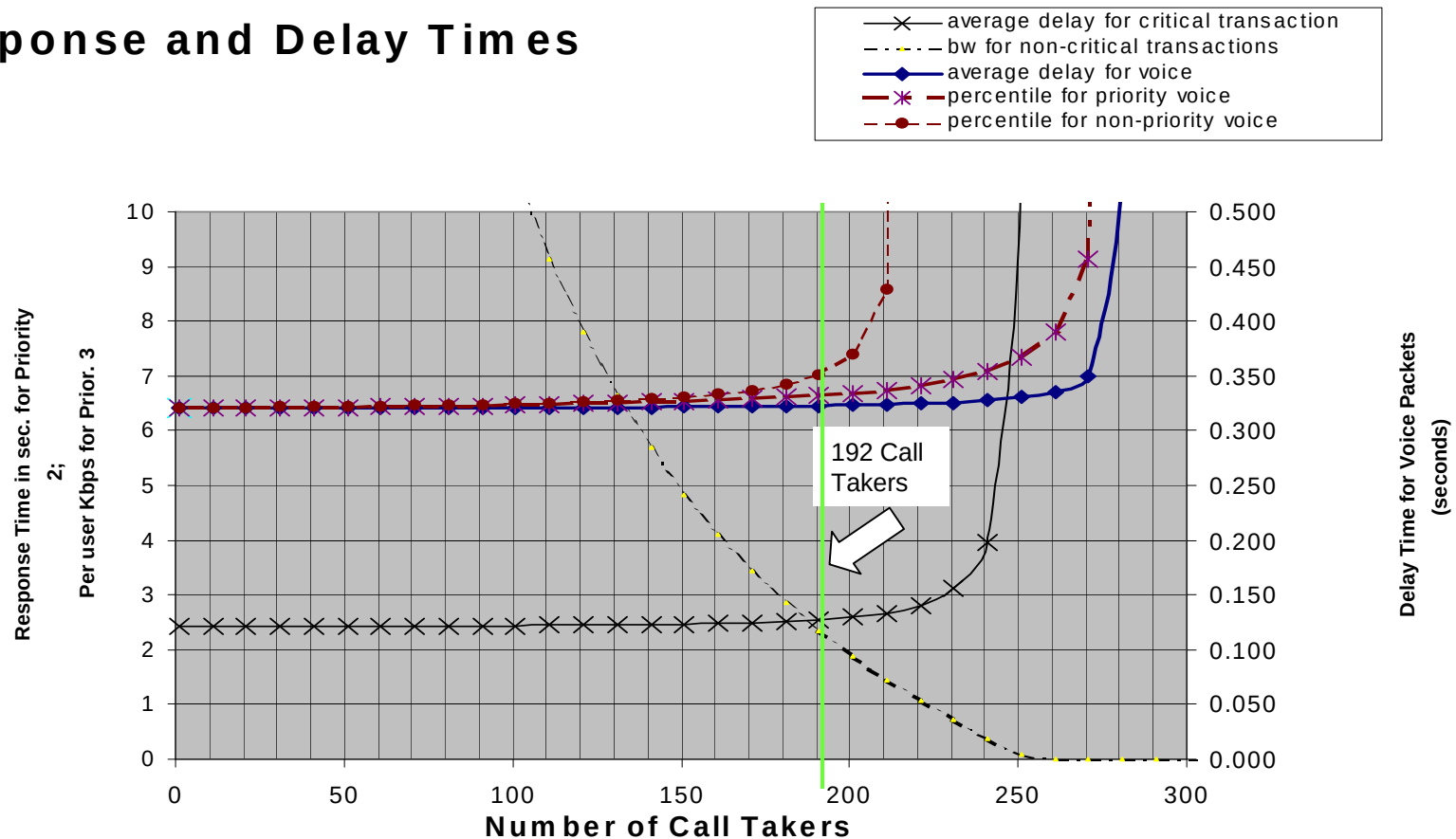
- Overview and Definitions
- A Reference Problem
- Introduction to Queuing Theory
 - single server
 - priority queues
- Application of Queuing Theory to Reference Problem
- Use of Simulation

Reference Network



RESPONSE TIME CURVES: We would like to know the average response time for each of the transactions, based on the number of call takers serviced on the 1.8 Mbps line. In this way we can see the impact of traffic on response time, and determine if we can indeed handle the 192 call takers envisioned for this service.

Response and Delay Times



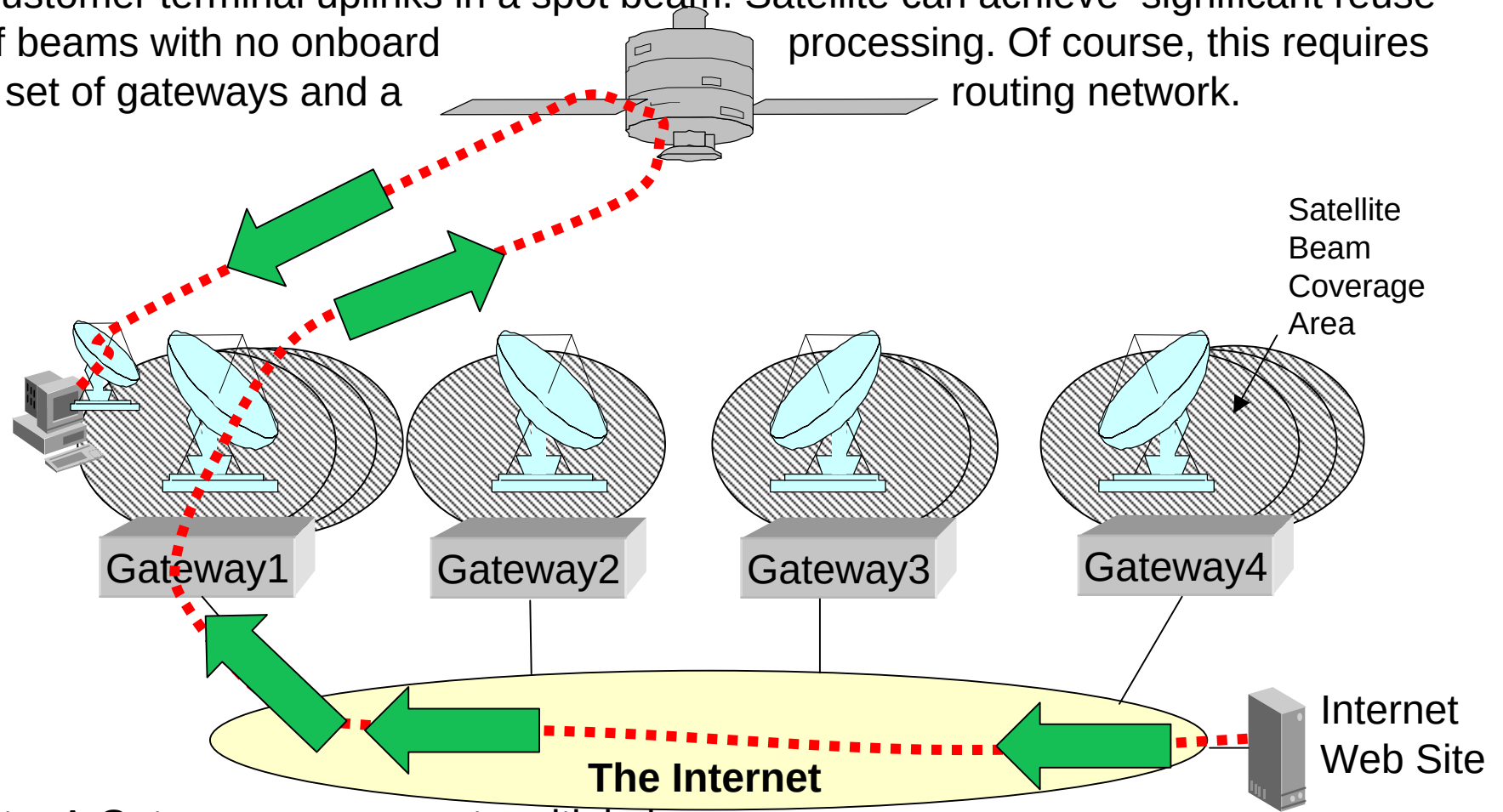
Note: This graph is for traffic flowing from the hub - there will be less traffic in the other direction

Part 9 - A View of the Future

- Satellite Enhancements
 - More power and large antennas
 - Spot beams and frequency reuse
 - On board processing
 - Inter-satellite links
 - Ka and higher band satellites
- Advanced Satellites
 - Commercial
 - Military
- The “Ideal” Earth Station

Connectivity in Spot Beam Satellite – Used for Star-Based Applications Such as Internet

For Internet case, each Gateway is connected to an Internet Access Point. Customer terminal uplinks in a spot beam. Satellite can achieve significant reuse of beams with no onboard processing. Of course, this requires a set of gateways and a routing network.



Note: A Gateway can support multiple beams;
therefore we do not need a Gateway per Beam