Introduction to WANs
Networld + Interop

Developed & Presented by

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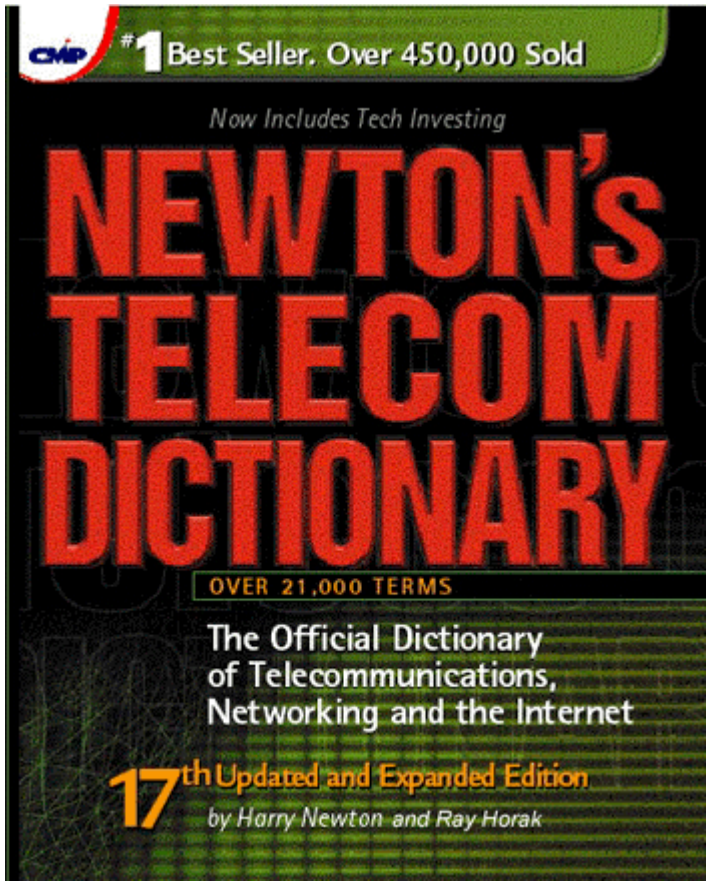
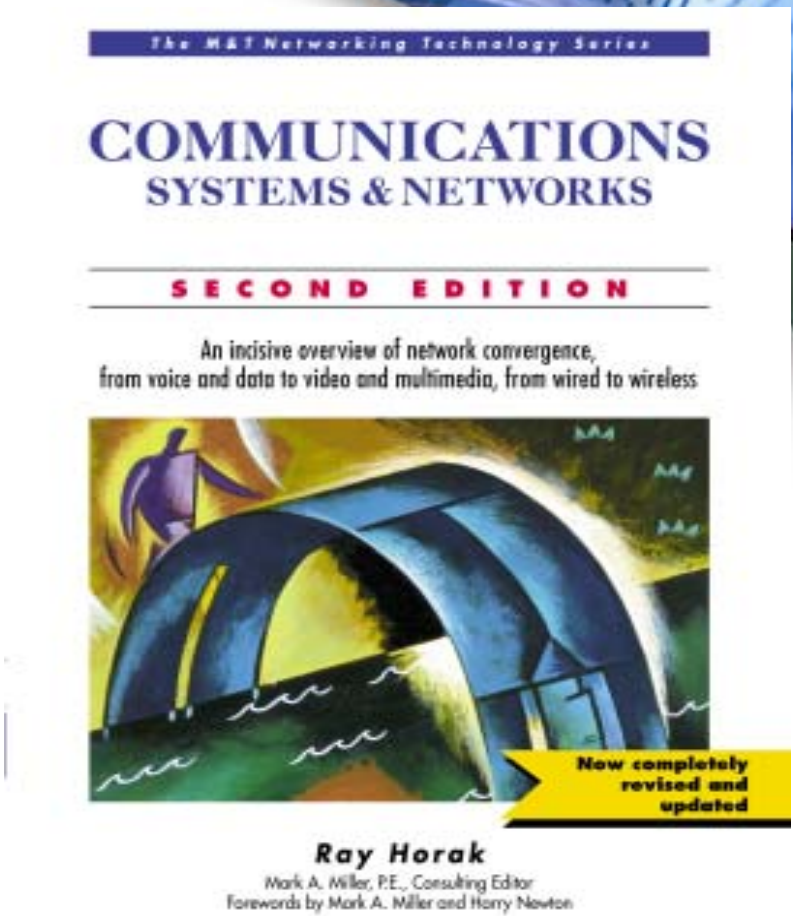


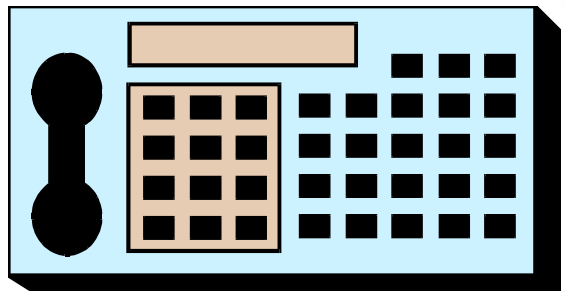


Suggested Reading

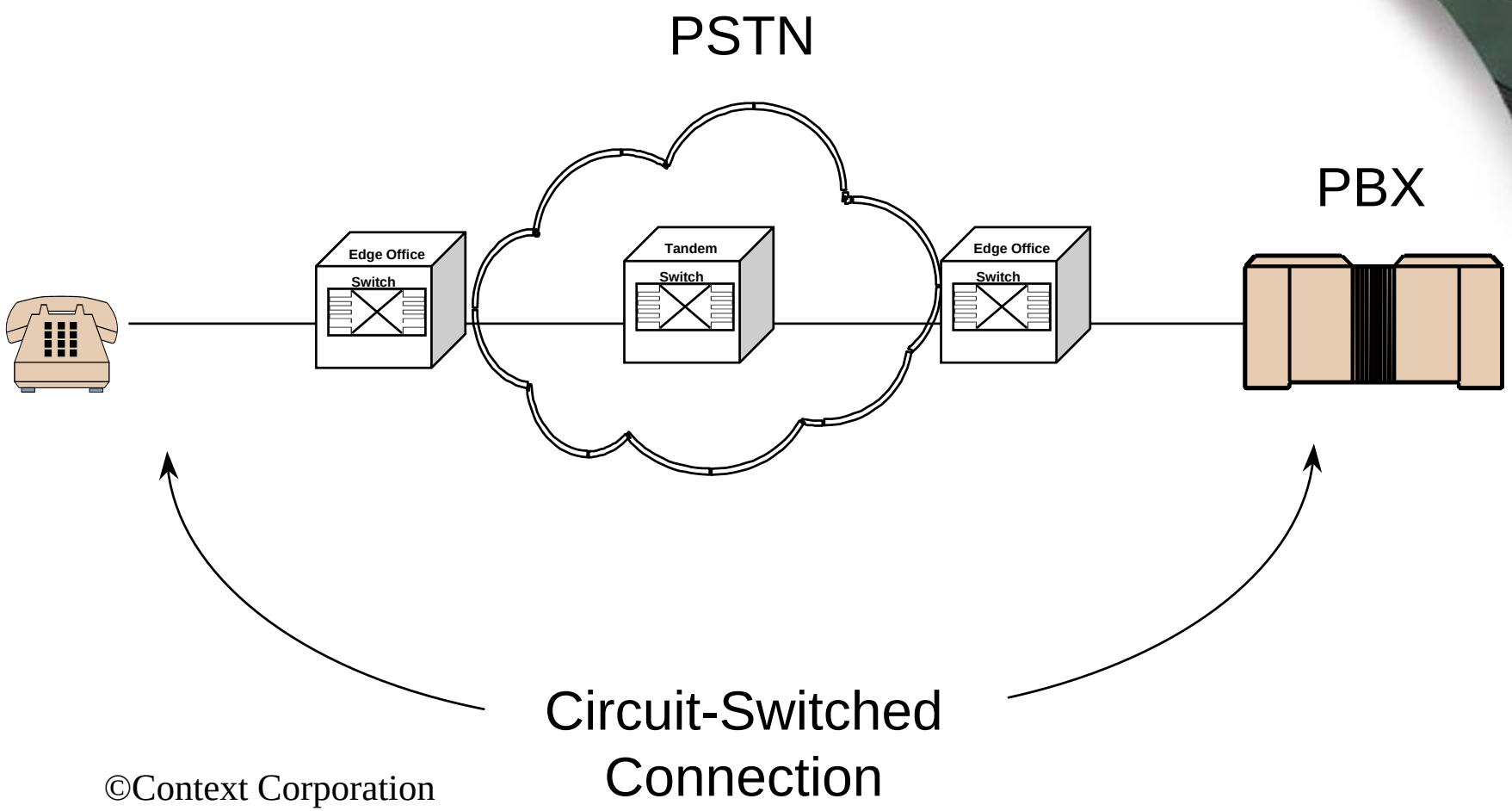
www.commweb.com

Evolution of Data Networking: The Voice Model

- Analog
- Two-Wire
- Bidirectional
- Circuit-Switched
- Ubiquitous & Affordable
- Interconnected
- Hierarchical
- Data over Voice Networks

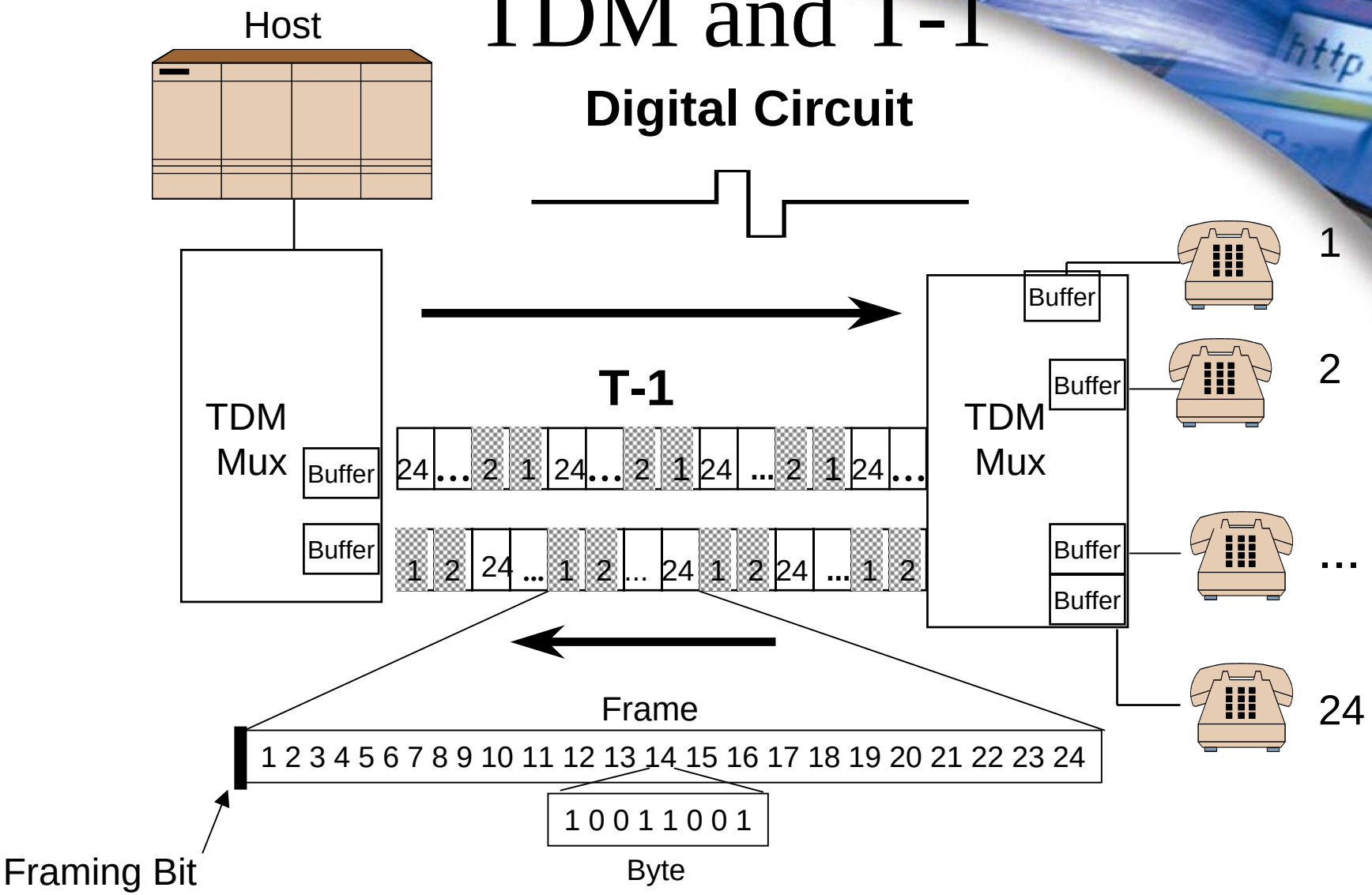


Circuit-Switching

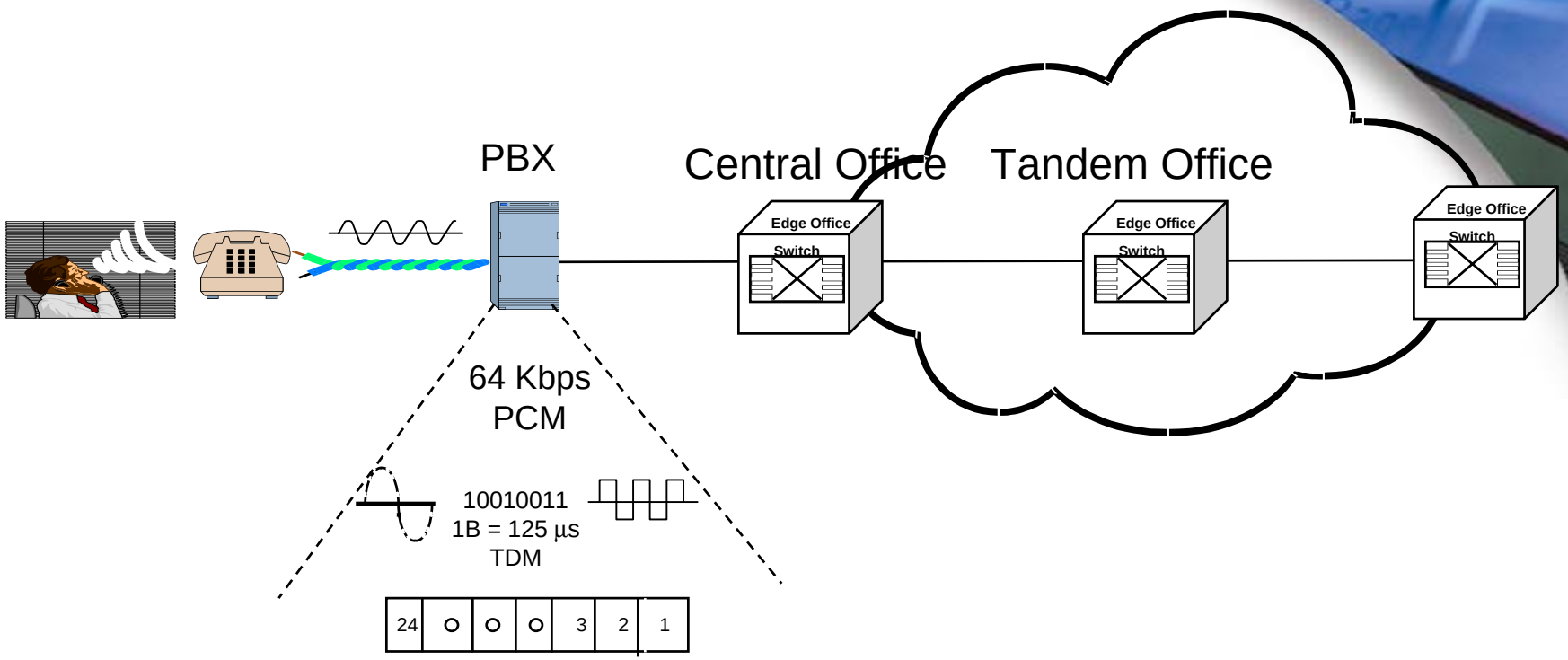


TDM and T-1

Digital Circuit



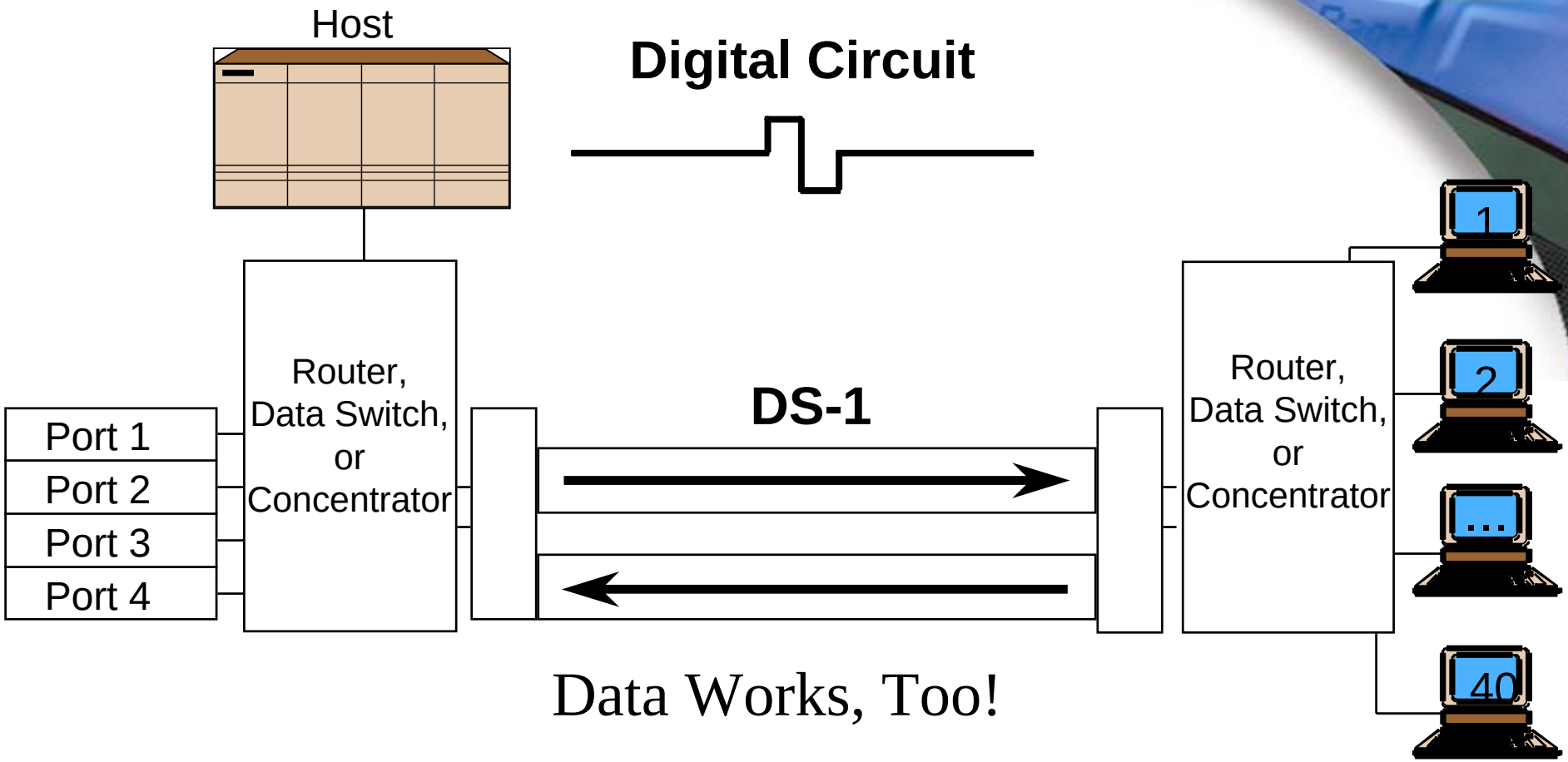
Conventional PSTN



Circuit-Switching & TDM: Optimized for Voice

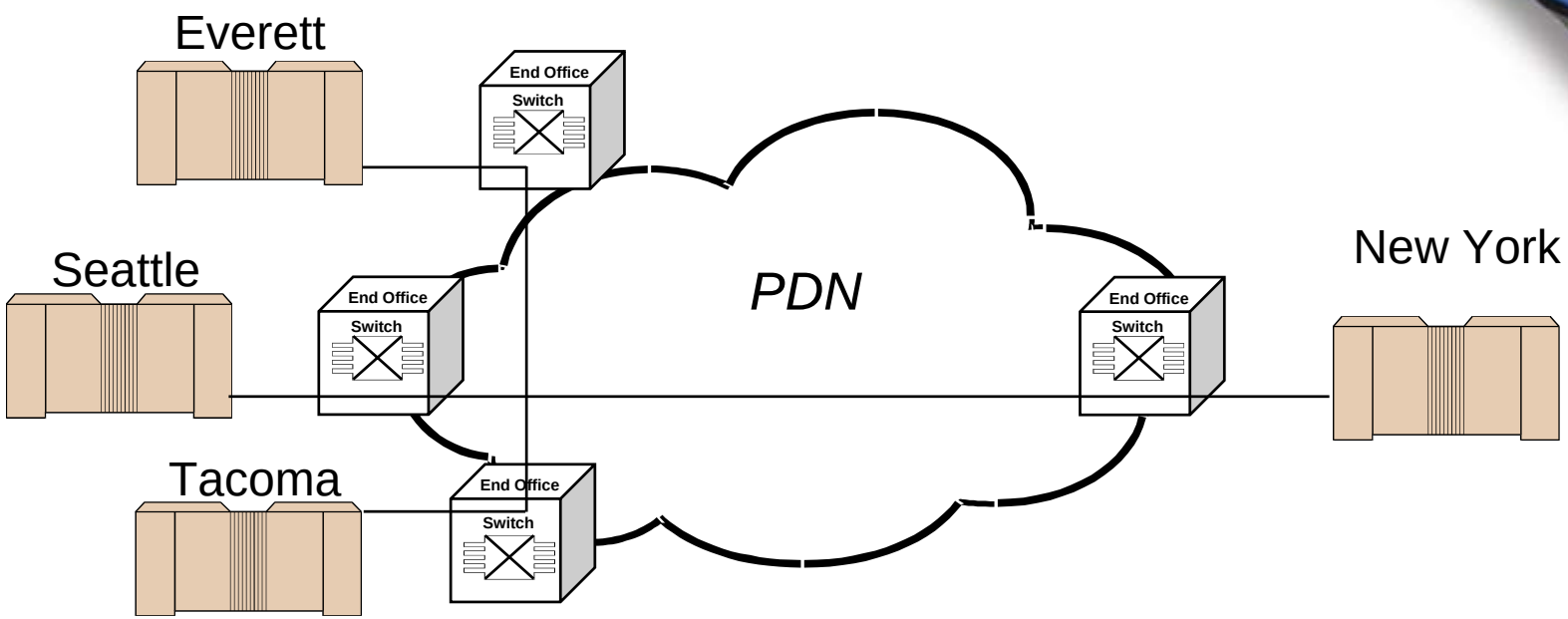
- Connection-Oriented
  - Temporary
  - Continuous
  - Exclusive
- Resources Committed
  - From Call Setup
  - To Call Teardown
- Latency& Jitter NOT Allowed
- Highly Effective, But Highly Inefficient

Unchannelized T-1



Data Works, Too!

Dataphone Digital Service (DDS)



DDS Characteristics

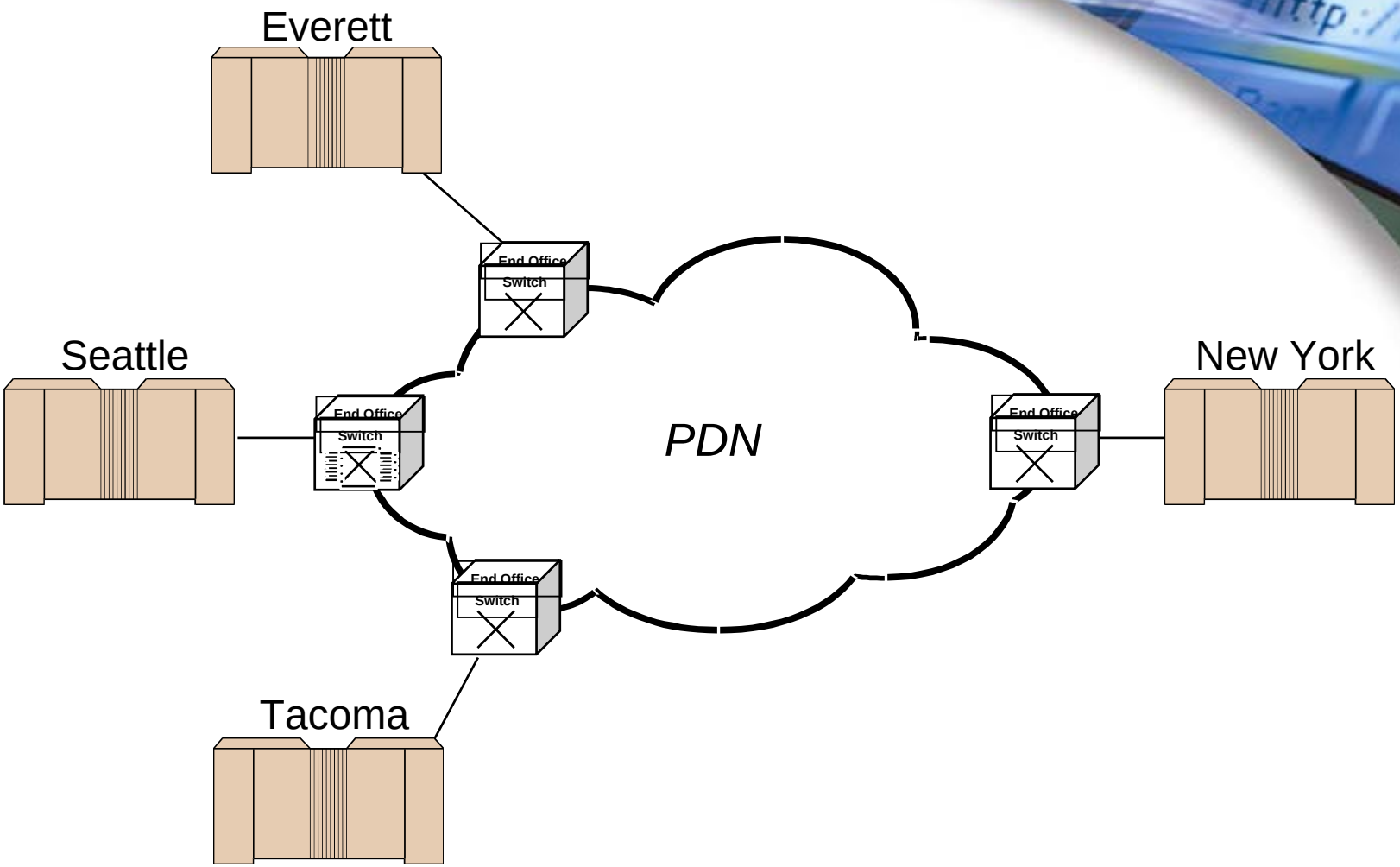
- Dedicated Network
  - Point-to-Point
  - Multipoint
- Cost
  - Distance
  - Bandwidth
- Full-Duplex (FDX)
- 4-Wire

- Digital (End-to-End)
- Synchronized
- Bandwidth up to 56/64 Kbps
- Widely Available
- Data-Only
- Reliable
- Subject to Catastrophic Failure

DDS Applications

- Connecting Data Centers
  - File Transfer
  - Data Backup
- Image Transfer
- CAD/CAM
- E-Mail
- Group IV Facsimile
- Access to Frame Relay, SMDS, ATM
- Transaction Processing

Switched 56/64



Switched 56/64 Kbps Characteristics

- Circuit-Switched
- Cost
  - Duration
  - Distance
  - Bandwidth
  - Scalability
- Full-Duplex (FDX)
- 4-Wire
- Digital (End-to-End)
- Synchronized
- Bandwidth up to T1
- Widely Available
- Data-Only
- Reliable
- Configuration Simplified

Switched 56/64 Kbps Applications

- Connecting Data Centers
  - File Transfer
  - Data Backup
- Image Transfer
- CAD/CAM
- E-Mail
- Group IV Facsimile
- Access to Frame Relay, SMDS, ATM
- Backup to DDS

T-Carrier

- Digital
- Dedicated
  - Access
  - Transport
- Medium-Independent
- Unbiased
  - Voice
  - Data
  - Video

T-carrier Hierarchy

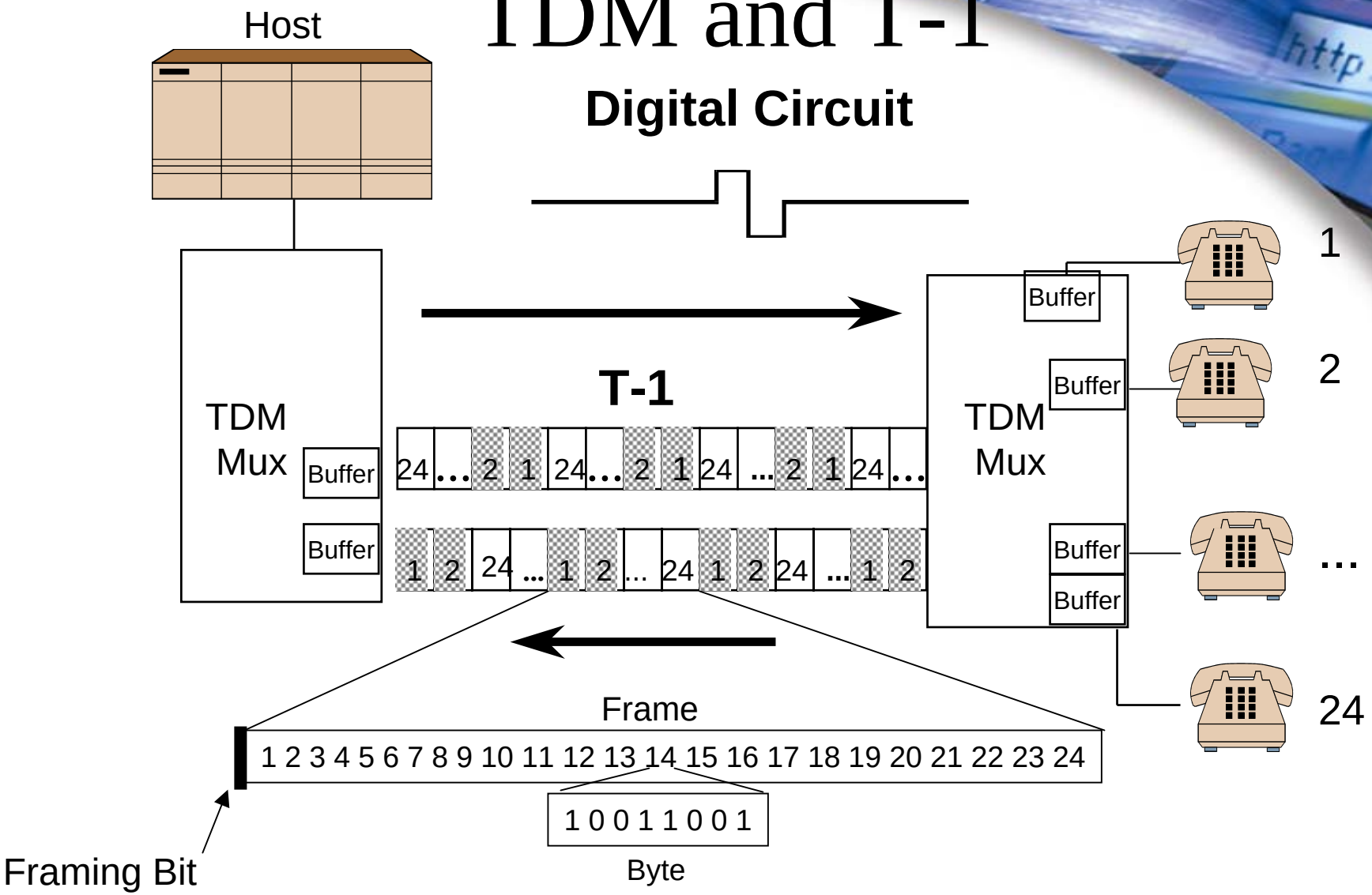
Digital Signal (DS) Number	Signaling Rate	# 64 Kbps Channels (DS-0's)
DS-0	64 Kbps	1
DS-1 (T-1)	1.544 Mbps	24
DS-1C (T-1C)	3.152 Mbps	48
DS-2 (T-2)	6.312 Mbps	96
DS-3 (T-3)	44.736 Mbps	672
DS-4 (T-4)	274.176 Mbps	4,032

M13 Multiplexer

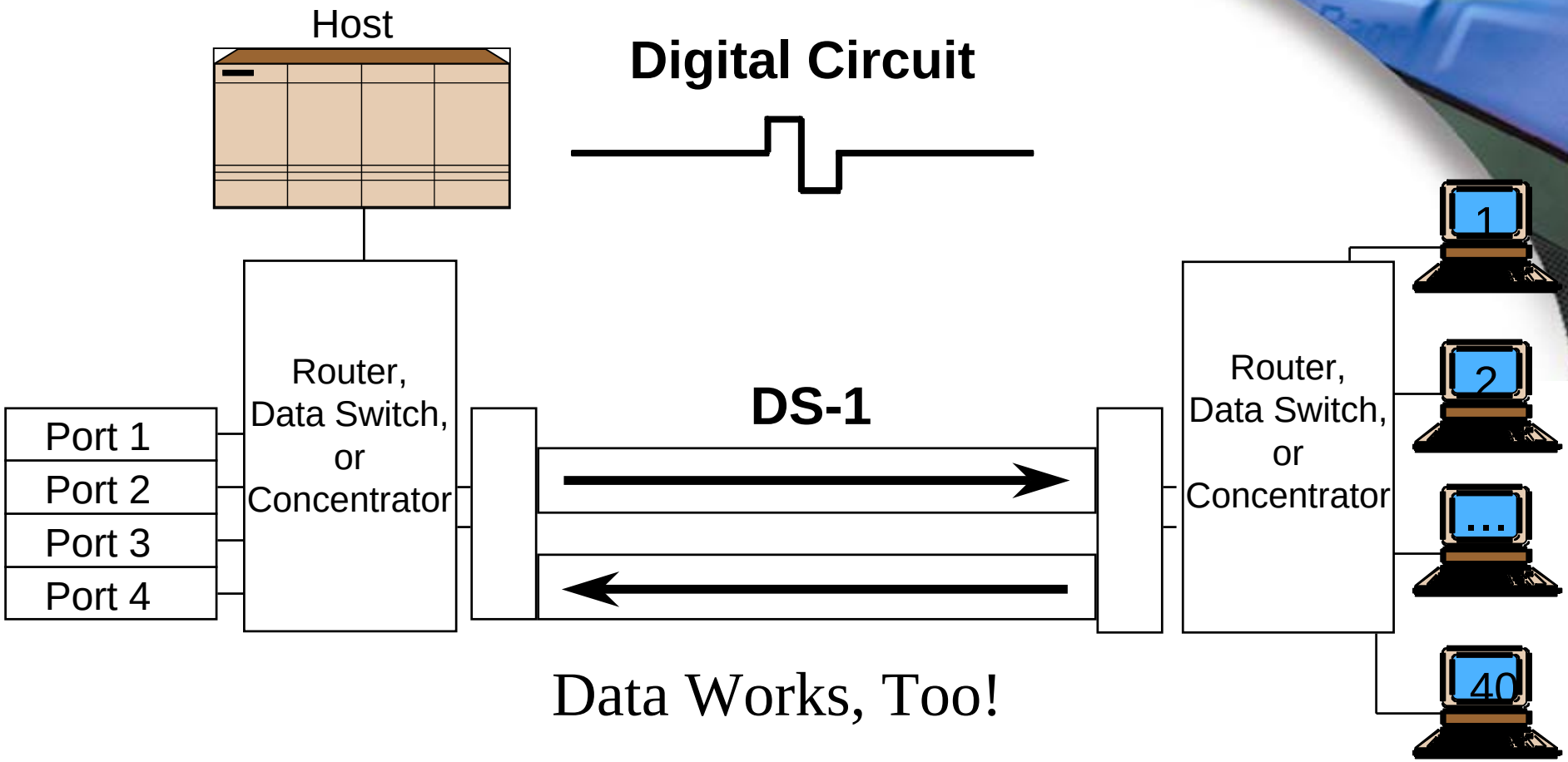
- Interfaces T-1 and T-3
- Time Division Multiplexer (TDM)
- Muxes 28 T-1 Frames on Transmit Side
  - Builds up a T-3
- DeMuxes 28 T-1 Frames on Receive Side
  - Tears down a T-3

TDM and T-1

Digital Circuit

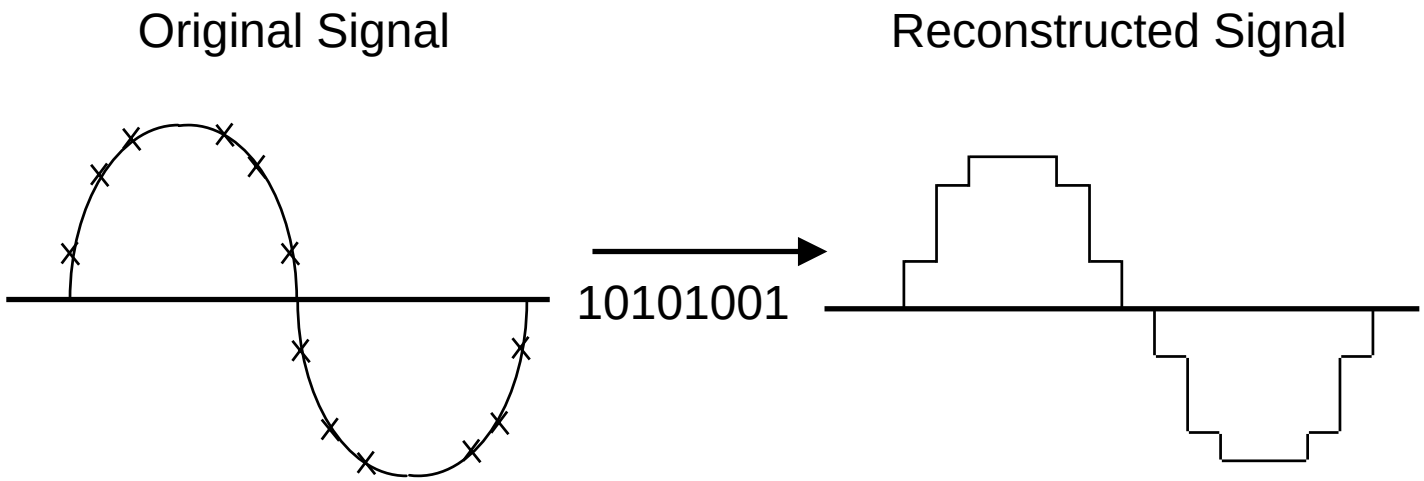


Unchannelized T-1



Data Works, Too!

Pulse Code Modulation (PCM) Voice Encoding



TDM is a Repetitious Process

8,000 times a second

x 8 bits

64,000 bits per second

T-1 Signaling Rate

24 channels per frame

x 8 bits per byte

192 bits per frame

+ 1 framing bit

193 bits per frame

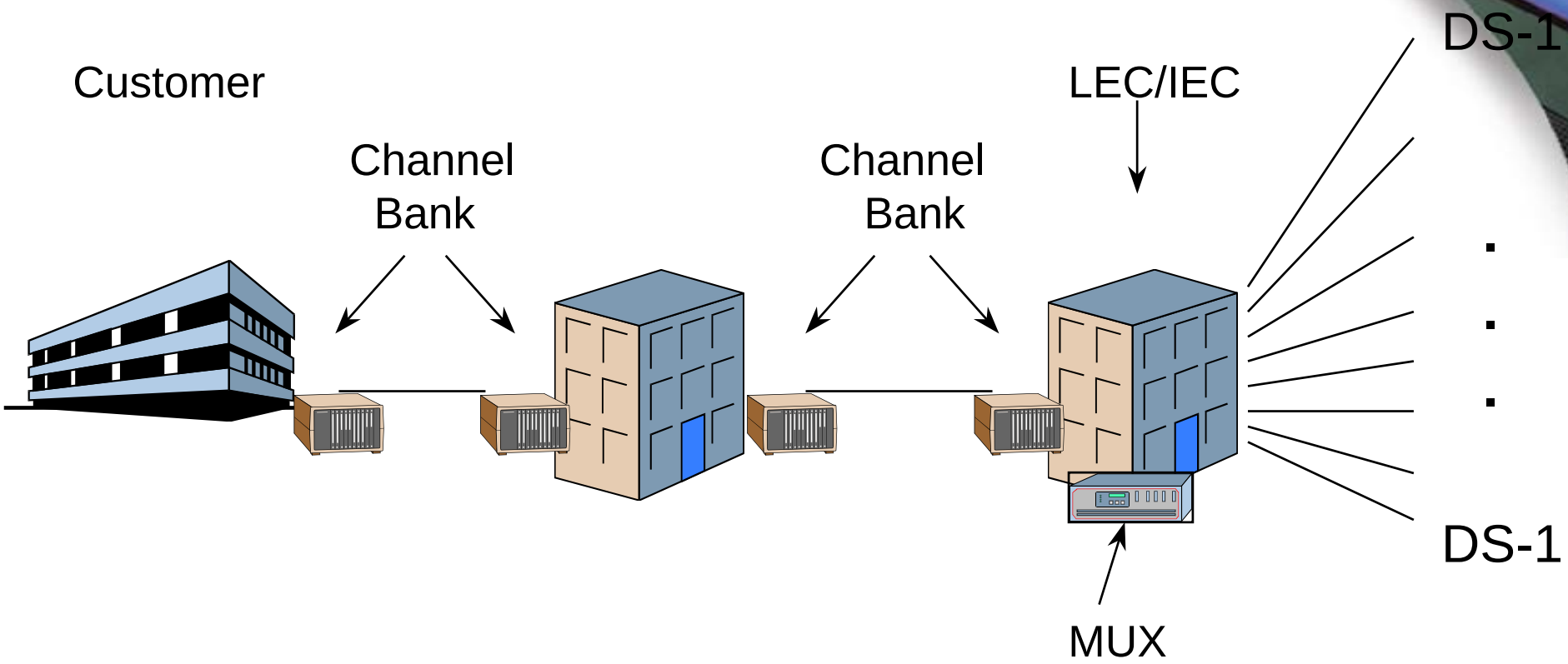
x 8,000 times per second

1,544,000 bits per second

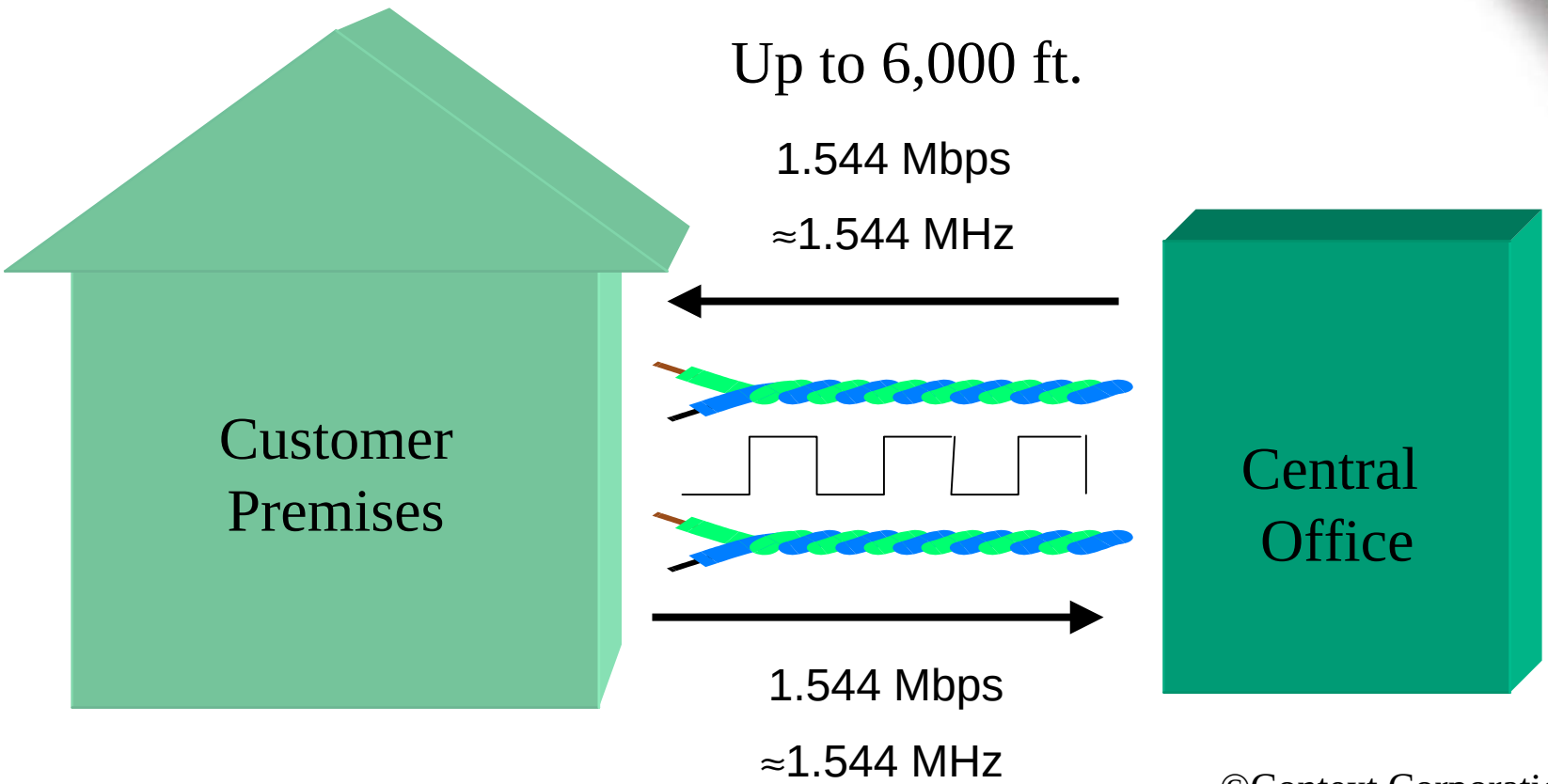
T-Carrier: Voice Encoding Schemes

- Pulse Code Modulation (PCM)
  - 64 Kbps
- Differential PCM (DPCM)
  - 32 Kbps
- Adaptive Differential PCM (ADPCM)
  - 32 Kbps (also 40, 24 & 16 Kbps)
- Digital Speech Interpolation (DSI)
  - Silence Suppression
  - 8 Kbps or 4 Kbps

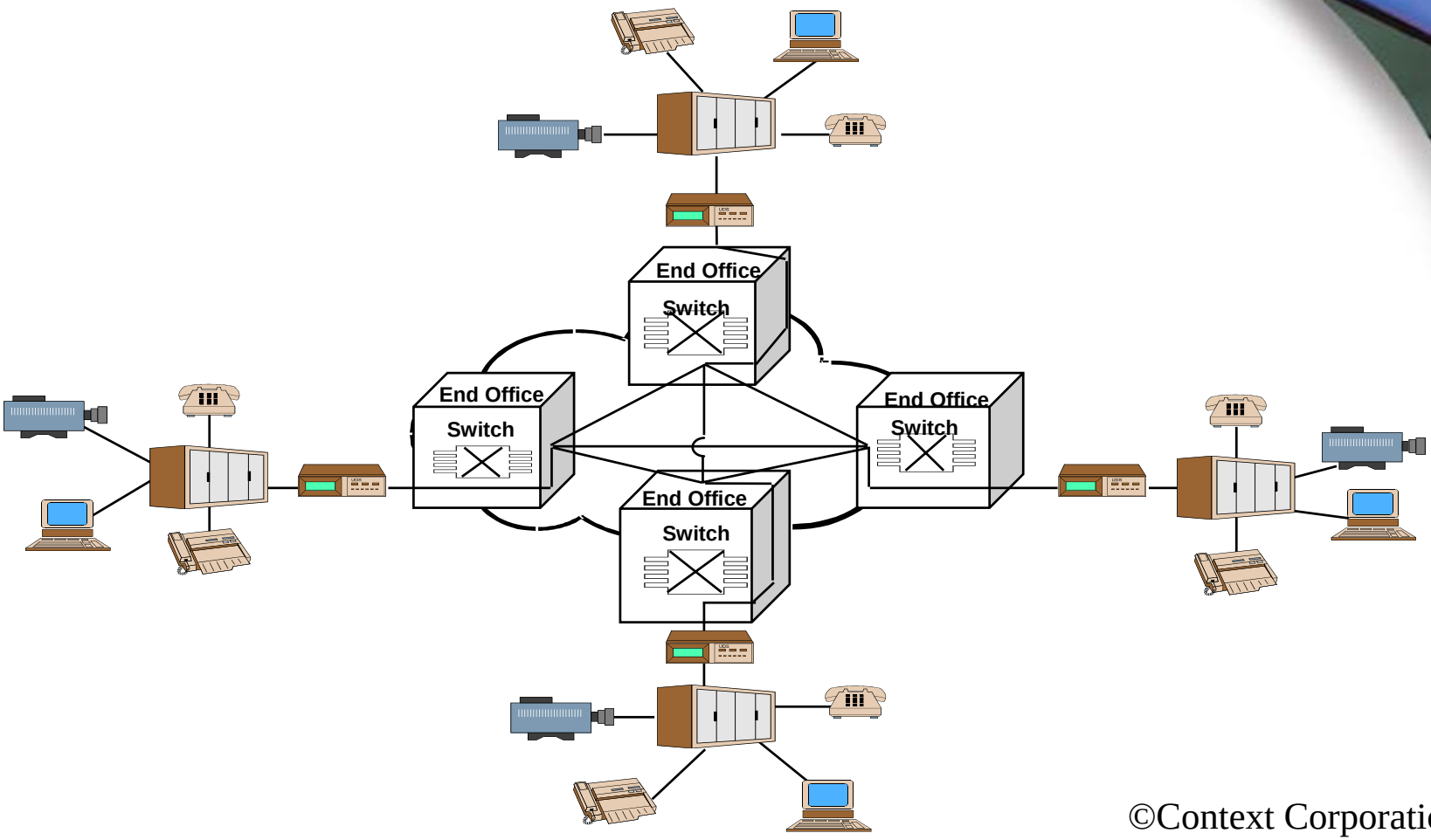
T-Carrier Access



T-1 Access over UTP

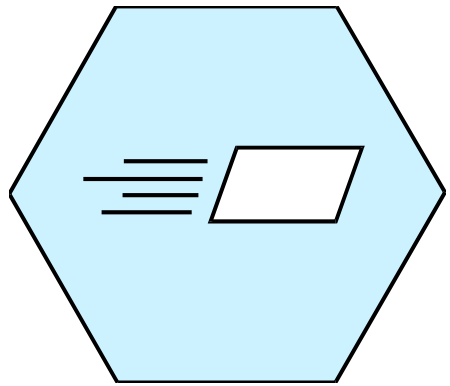


T-carrier Private Network

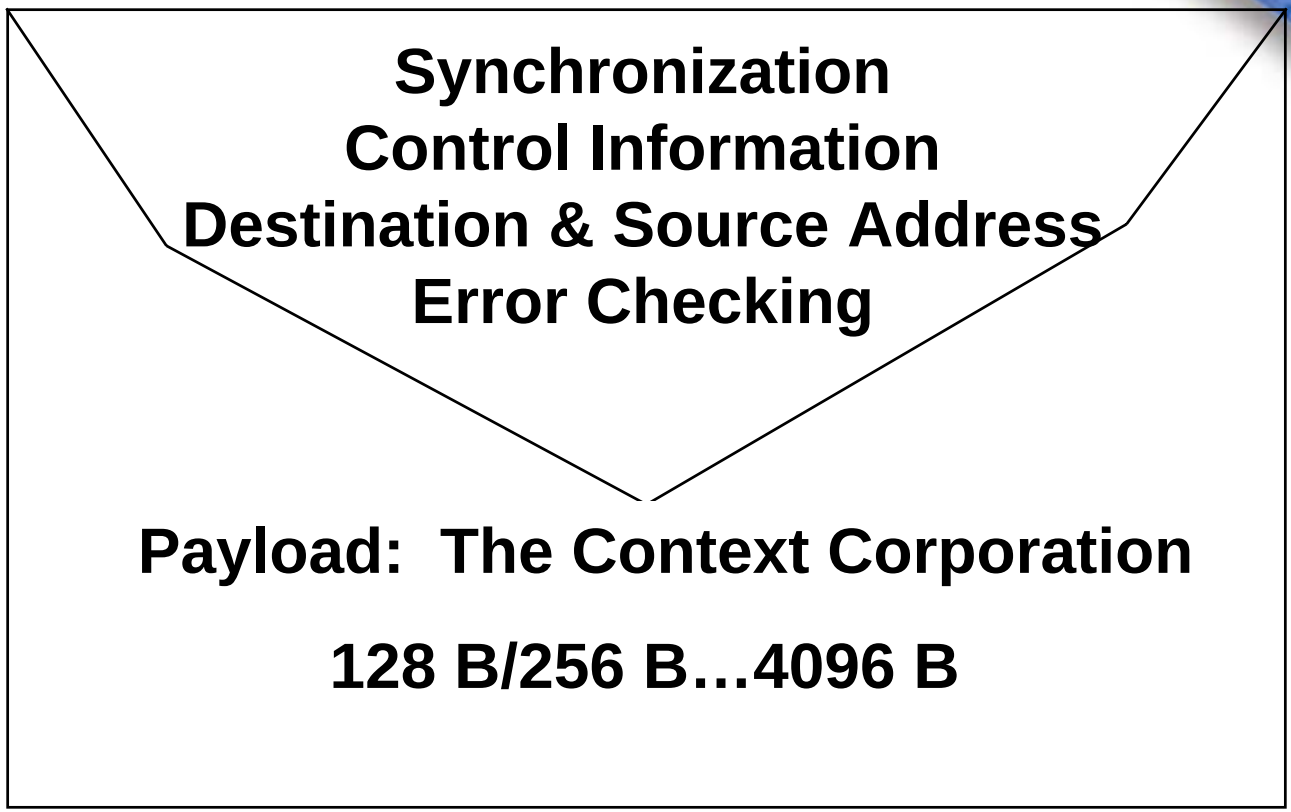


X.25 Packet Switching General Characteristics

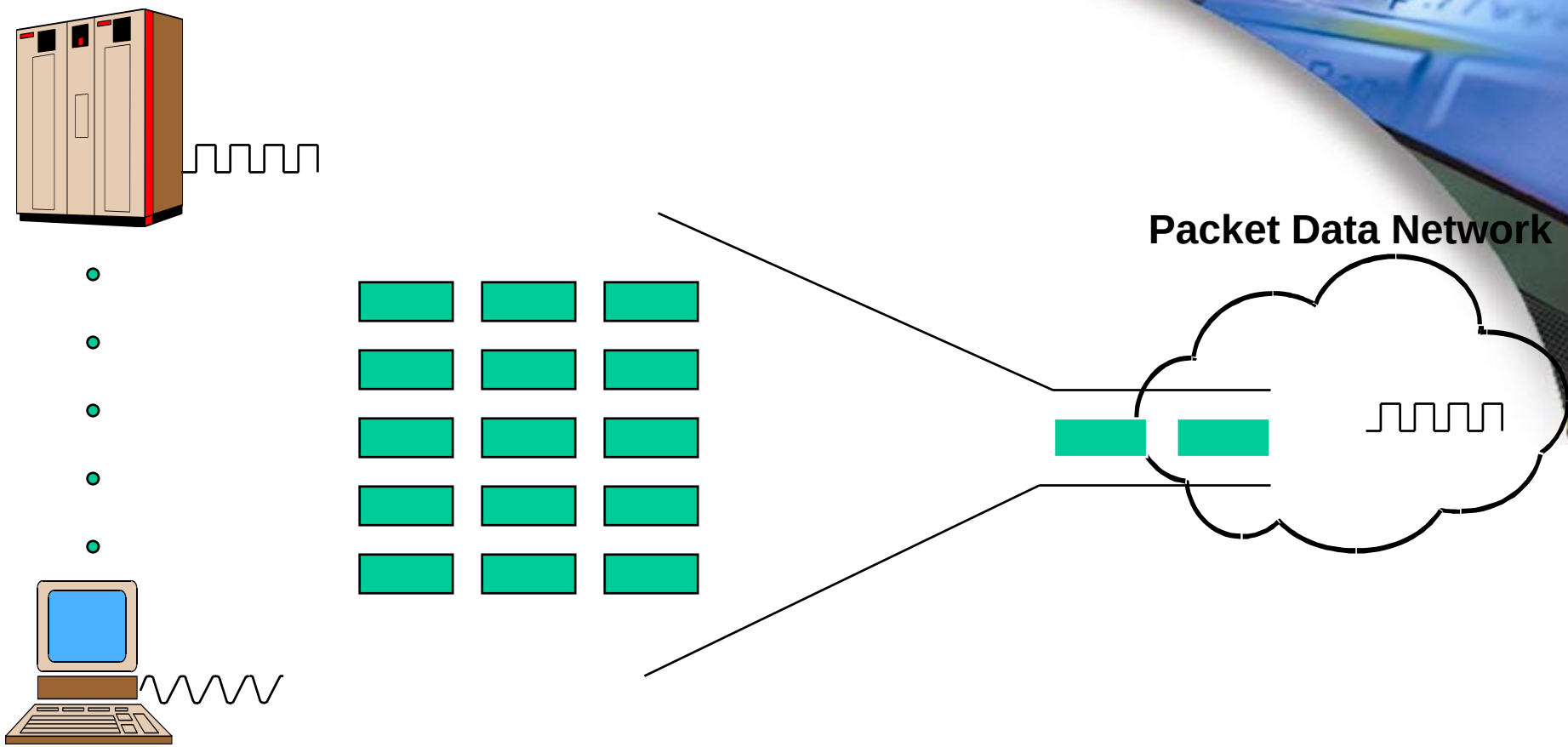
- Shared Network (PVCs & SVCs) = Efficiency
- Highly Redundant
- Highly Scalable
- Access
  - Analog or Digital
  - Dial-up or Dedicated
- Conversational (2-Way)
- Data-Only
- Error Correction
- Latency
- Protocol Conversion Supported
- Priority Transmission Supported
- Distance Insensitive $$$



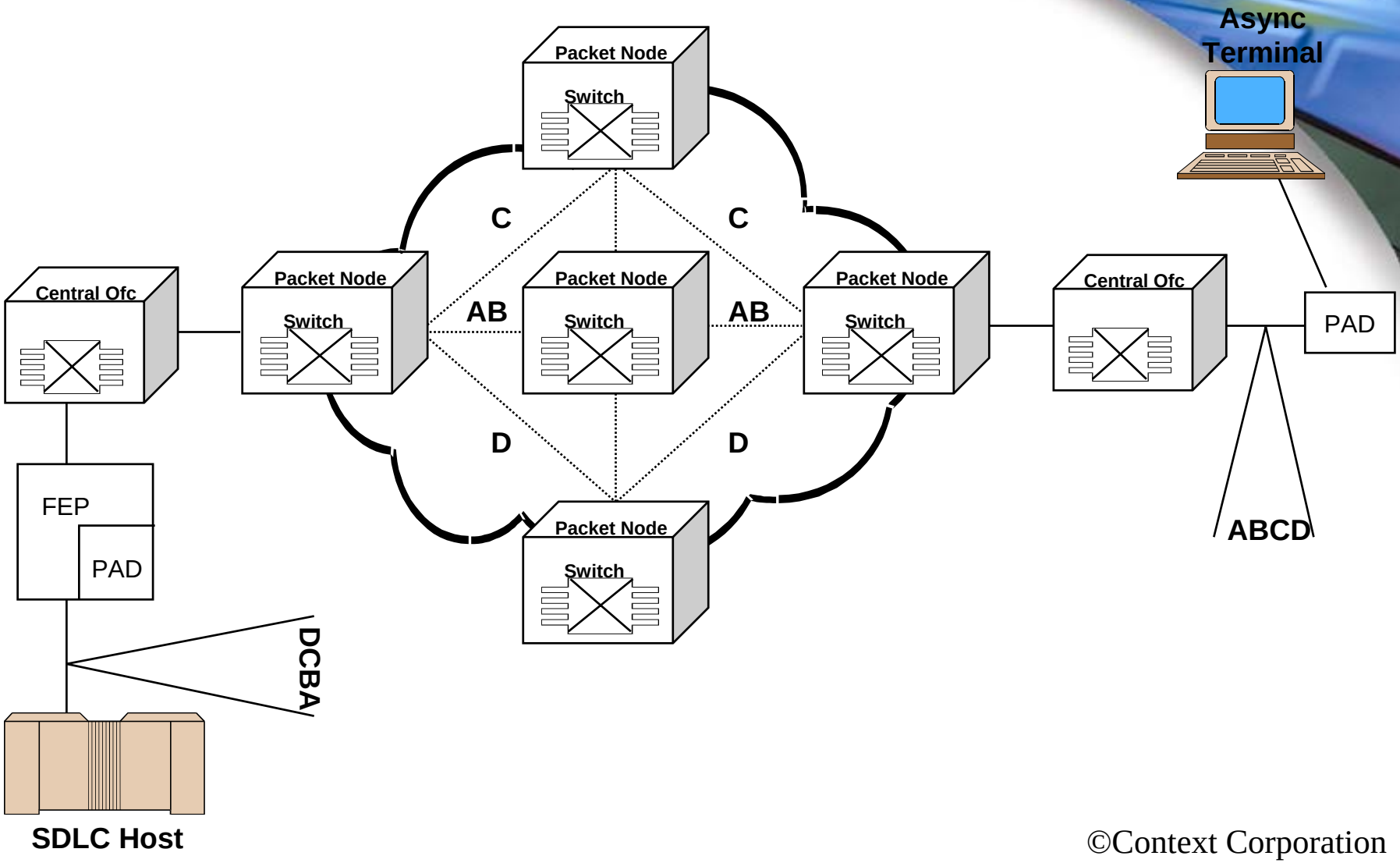
X.25 Packet Format



Data over IP

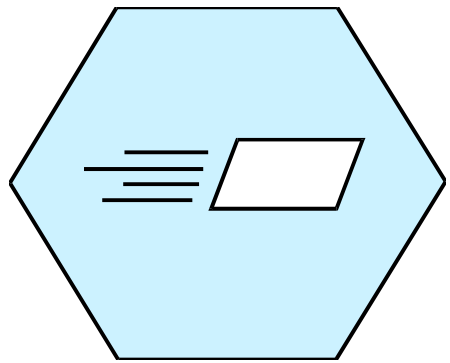


Packet-Switching



X.25 Packet Switching: Applications

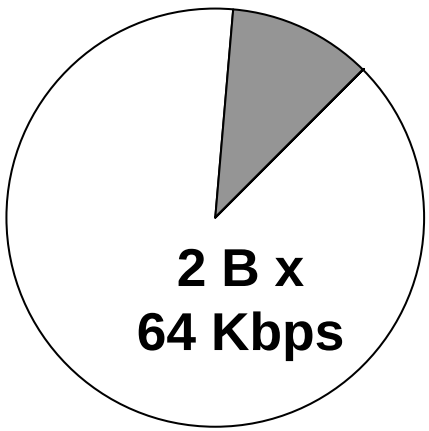
- Interactive Time-Sharing
- On-Line Interactive Processing (Reservations Systems)
- Messaging (E-Mail)
- Batch Transfer
- Internet Access
- Transaction Processing (e.g., ISDN)



ISDN Interfaces

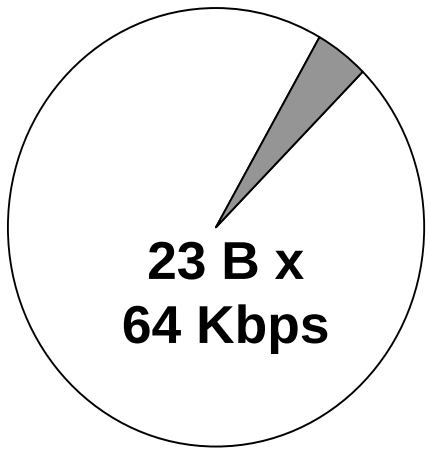
BRI/BRA

D x 16 Kbps



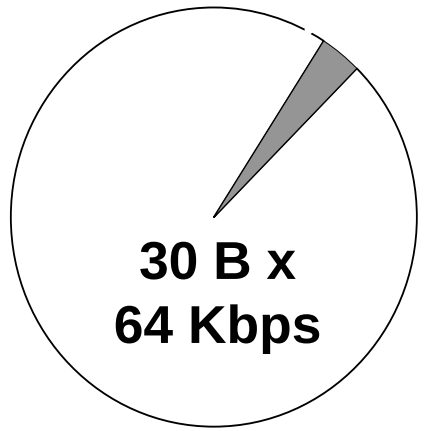
PRI (US)

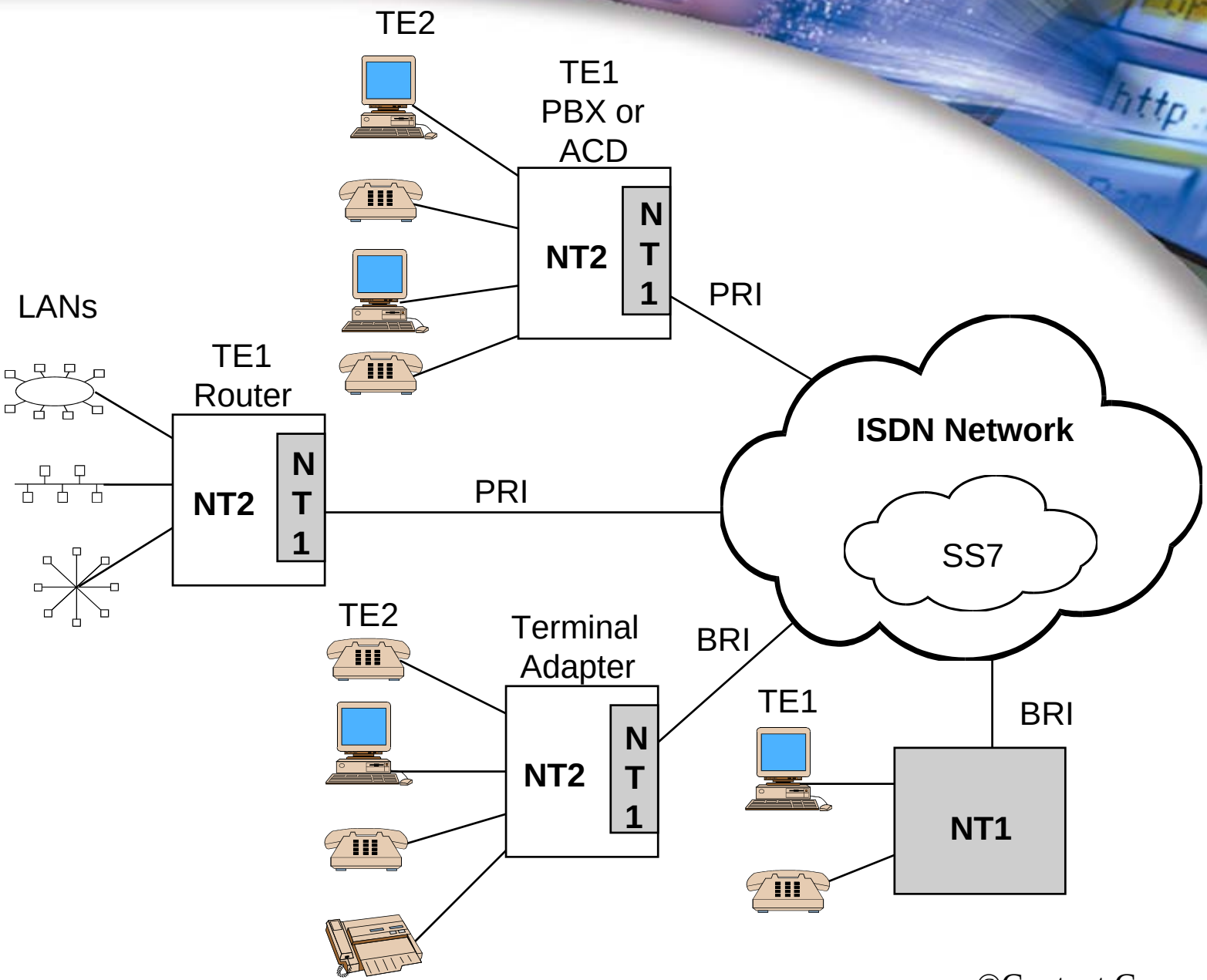
D x 64 Kbps



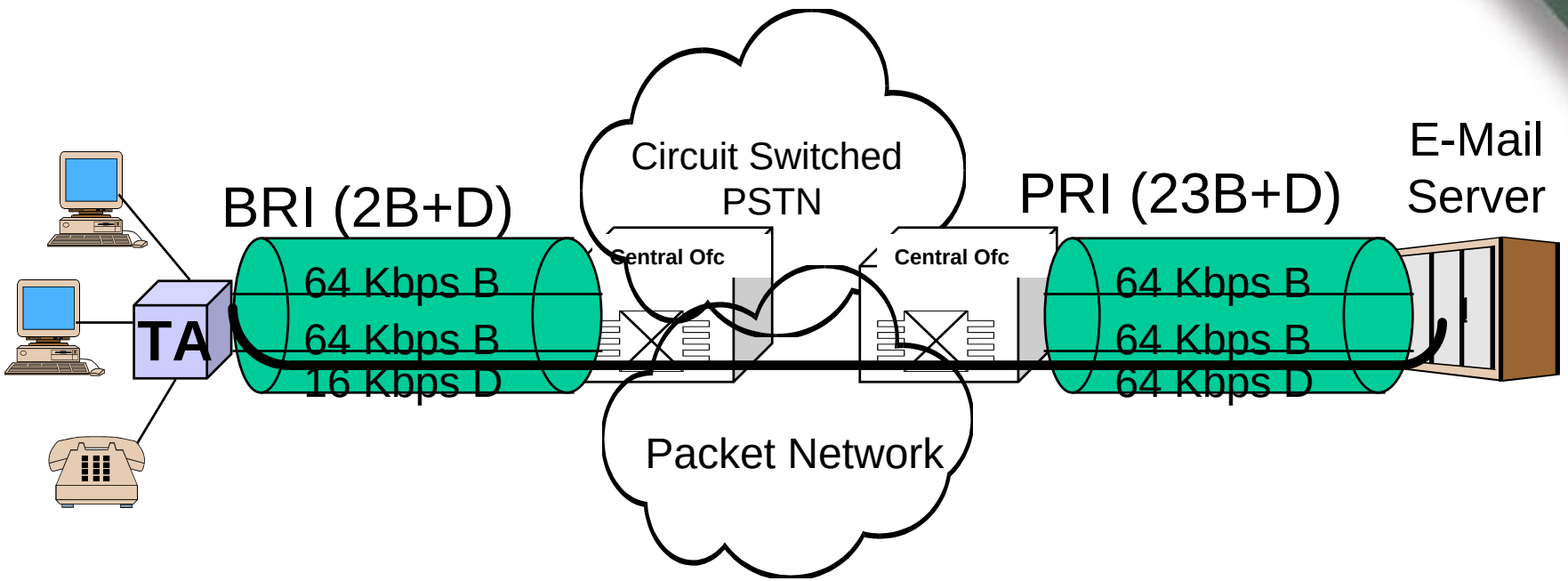
PRA (Europe)

D x 64 Kbps





Always On/Dynamic ISDN (AO/DI)



ISDN Characteristics & Benefits

- Digital
- Circuit-Switched
- Small Set of Interfaces
- Wide Range Services
- Rate Adaption
- Bandwidth-on-Demand
- Out-of-Band Signaling
- Signaling System 7
- Faster Call Set-up
- CLID
- Interoperability
  - X.25
  - Frame Relay
  - SMDS
  - ATM

ISDN Characteristics & Drawbacks

- Availability Limited
- Line Cost
- Equal Access Charges
- Usage Surcharges
- Hardware & Software Costs
- Standards Implementations Vary

ISDN Applications

- Centrex
- Small Office-Home Office (SOHO)
- Telecommuting
- Video Communications
- Imaging
- Remote LAN Access
- Incoming Call Centers
- Emergency Services
- Access to Frame Relay, SMDS, ATM

BroadBand Networks: Characteristics

I speak and I write...but more, it's with light(ning) that I connect.

poet Giovanni Pascole, 1891

translated by Daniel Minoli

- Bandwidth: T-3+
- Bandwidth-on-Demand
- Error Performance Excellent
- Network Management Prospects
- Availability Limited
- Capital Cost: High
- Cost per Bit Transported: Low

generic Digital Subscriber Line (xDSL)

- Asymmetric DSL (ADSL)
- Rate Adaptive DSL (RADSL)
- G.lite (ADSL lite)
- ISDN DSL (IDSL)
- High-bit-rate DSL (HDSL)
- Symmetric DSL (SDSL)

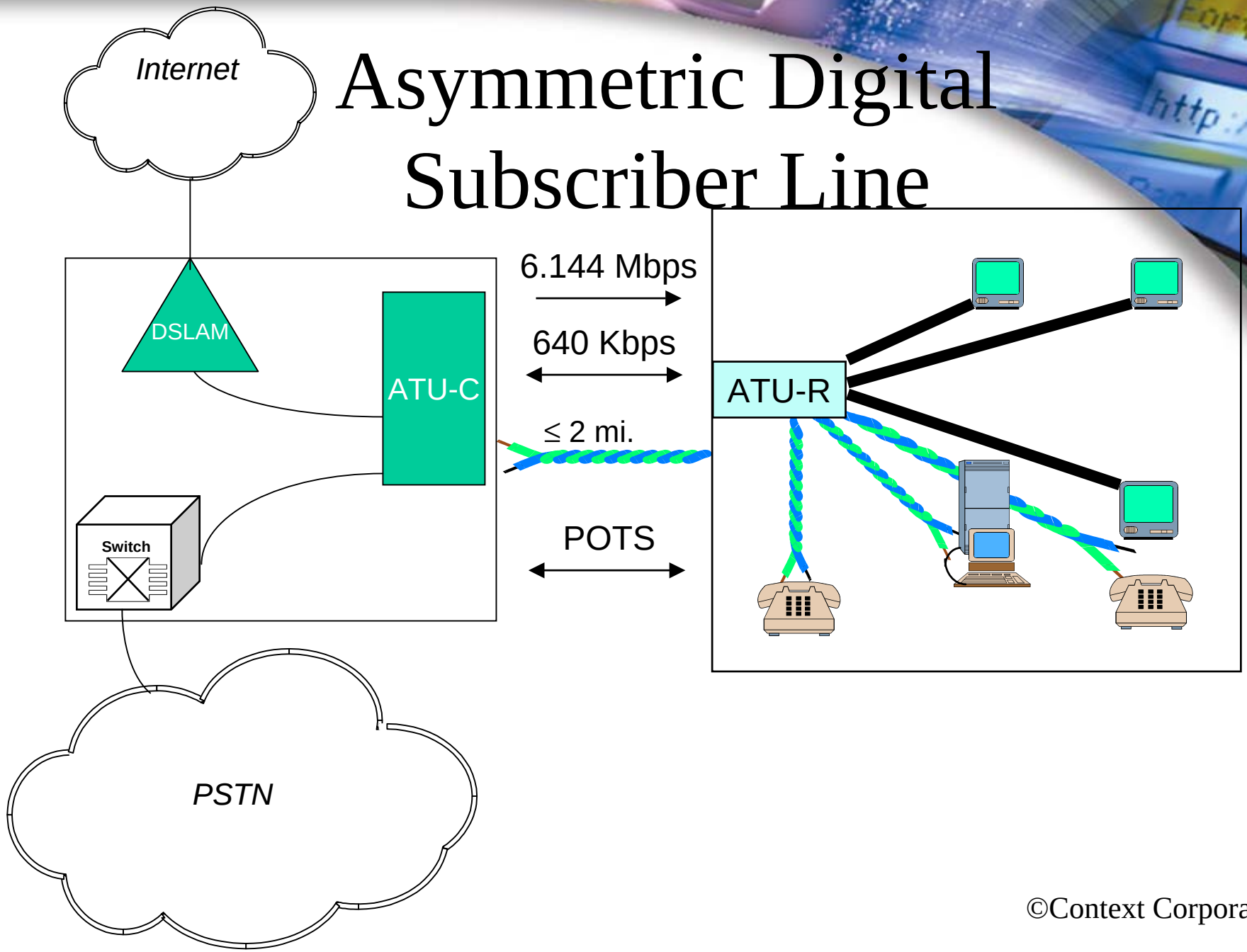
DSL Characteristics

- Always On
- Dedicated Loop
- ILEC Local Loop
- Telecom Act of 1996
- UTP Medium
- Applications
  - Internet Access
  - Voice
  - Entertainment TV
- Frequency Division Multiplexing (FDM)
  - Voice: 4 KHz and below
  - Data and Video: 25 KHz and above
- Digital Channels:
  - Data and Video
  - Highly Compressed

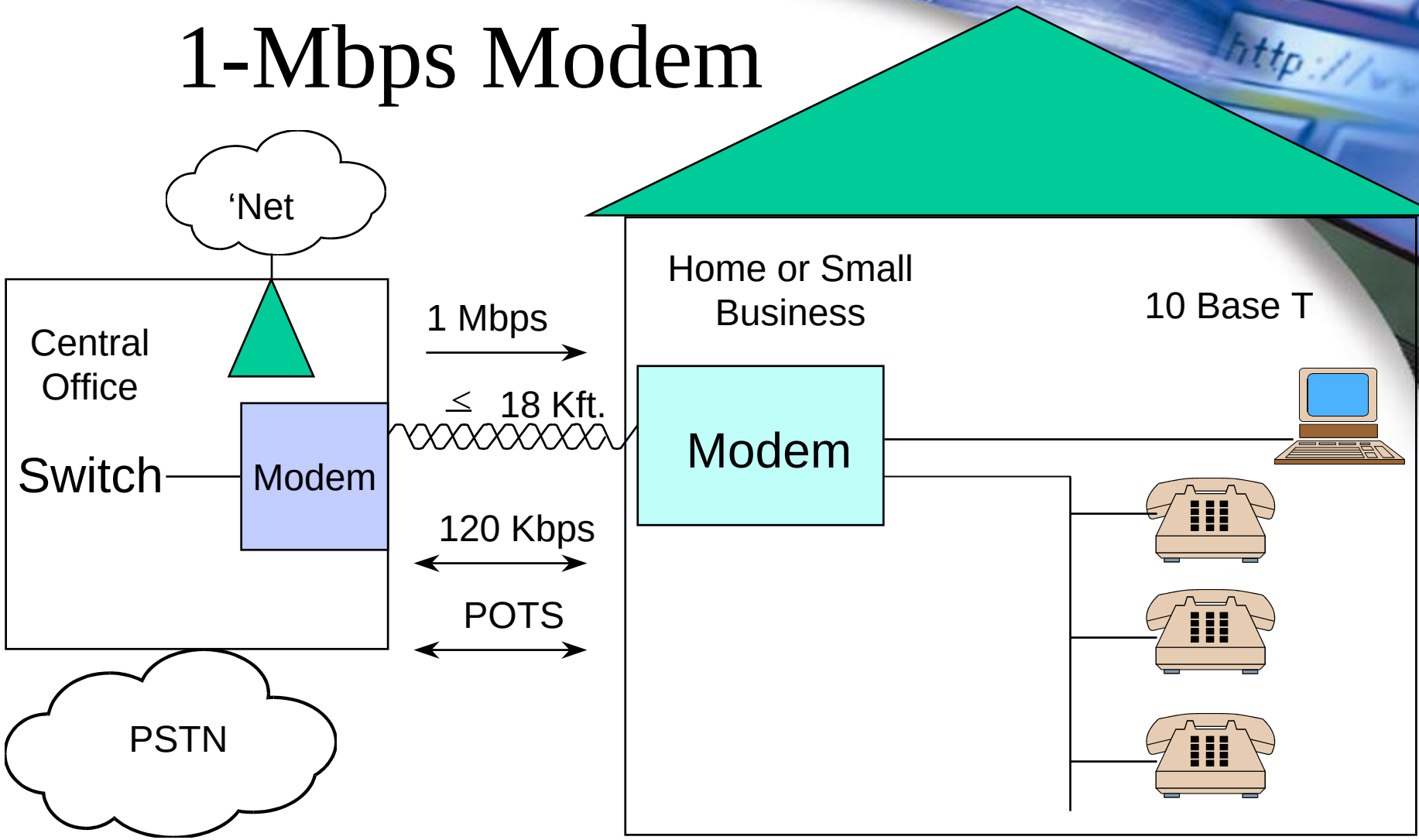
Local Loop Issues

- Loop Length
- Splices and Mixed Gauges
- Bridged Taps
- Load Coils
- Interference
- Inside Wire
- Voice Terminal Signaling States
- Digital Loop Carrier
- Splitters or Modems
  - Centralized
  - Decentralized
- DSL Access Multiplexers
- SPOT Frames

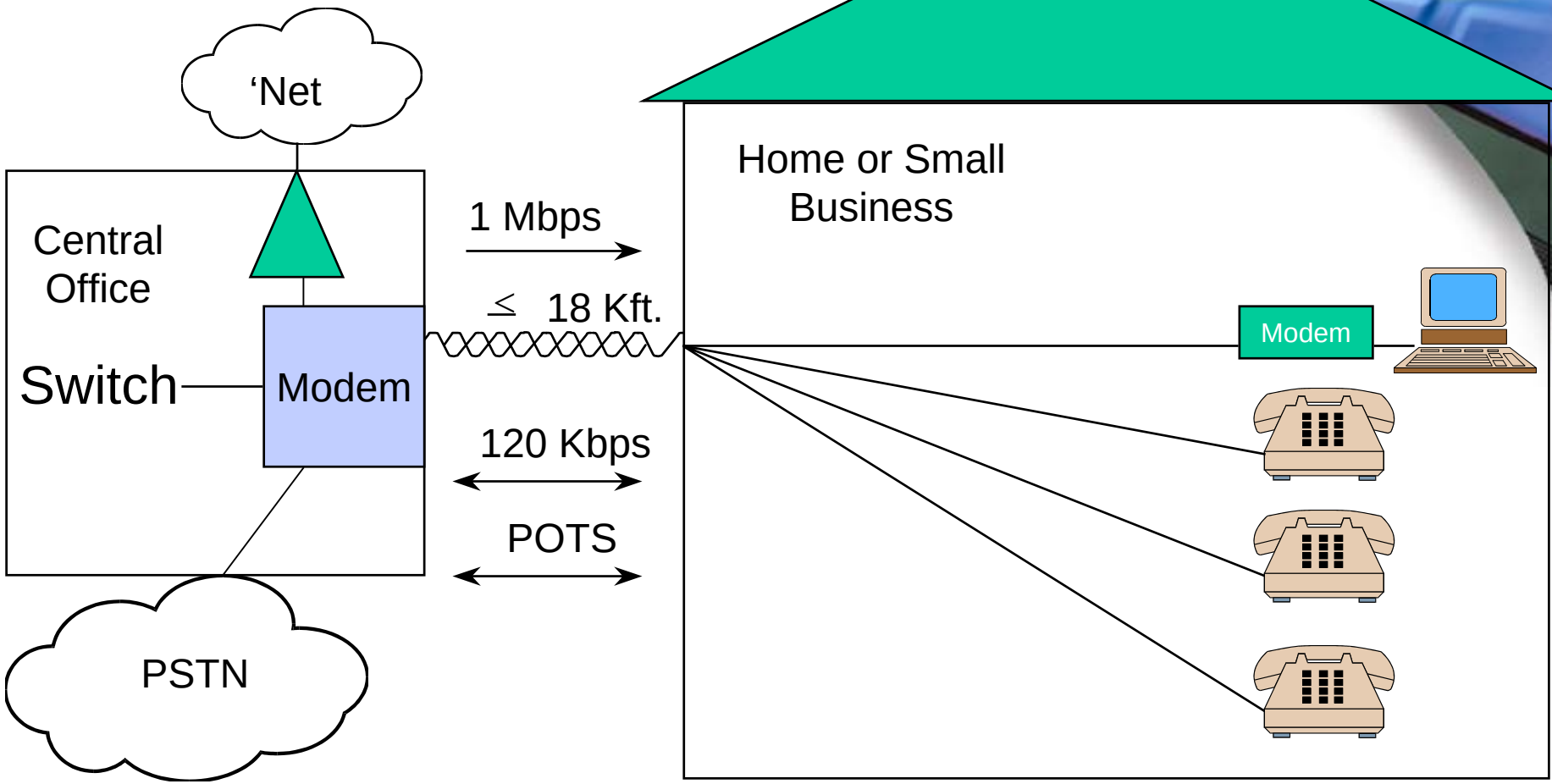
Asymmetric Digital Subscriber Line



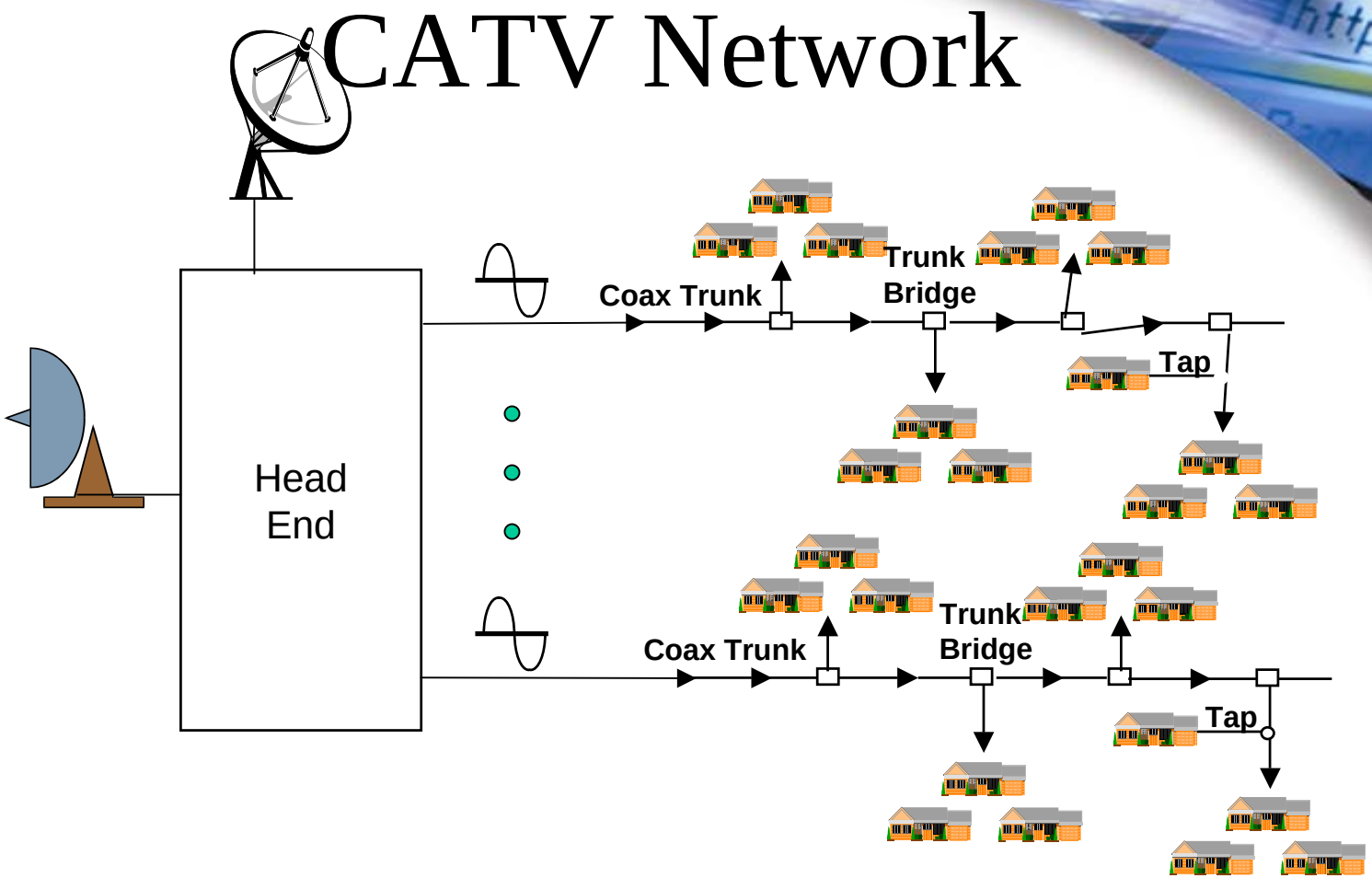
RADSL
1-Mbps Modem



G.Lite 1/1.5-Mbps Modem



CATV Network



CATV Network Characteristics

- **Shared Local Loop ala 10Base5 Ethernet**
- **Tree and Branch Architecture**
- **Closed System**
- **Medium**
  - Analog Coax
  - Hybrid Fiber Coax (HFC)
- **Applications**
  - Entertainment TV
  - Packet Internet Access
  - Packet Voice
- **DOCSIS Standard**
- **Frequency Division Multiplexing (FDM)**
  - TV
    - 6 MHz Channels
  - Data:
    - 6 MHz Downstream
    - 5-42 MHz Upstream
  - Voice: Packet
- **Digital Channels:**
  - Data and Video
  - Highly Compressed

SDH/SONET: Defined

SDH/SONET is a set of international standards for broadband communications over fiber optic transmission systems, supporting full interconnectivity and interoperability. Switching and multiplexing techniques are defined. Asynchronous, synchronous and isochronous traffic are supported.

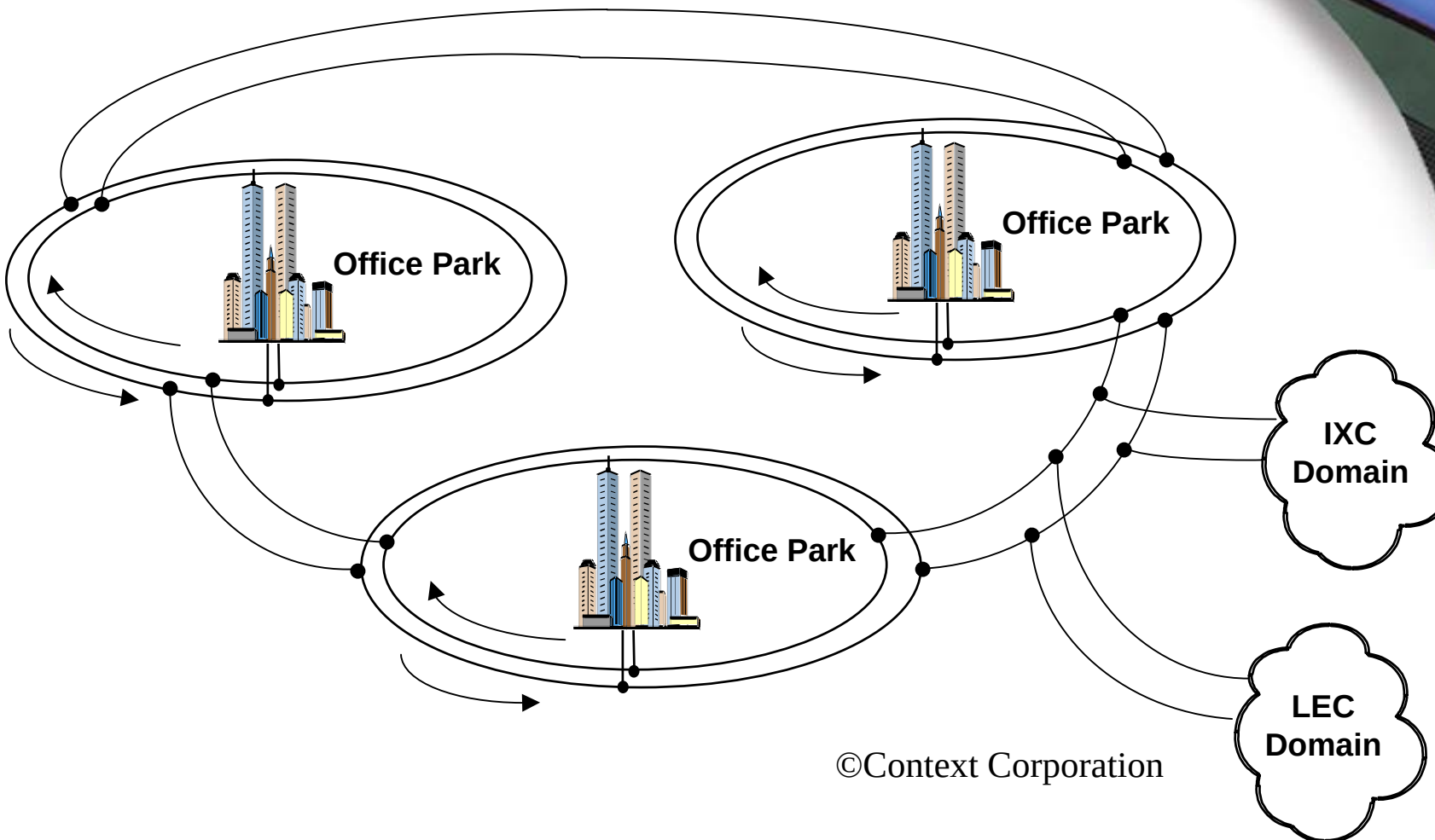
SONET/SDH

- Highly Standardized
- Built On T-Carrier
- TDM At The Optical Level = SPEED
- Optimized For Voice (Data Works, Too)
- Optimized For Network Management
- Optimized For Redundancy
- Expensive & Overhead-Intensive

Synchronous Digital Hierarchy

LEVEL	STS	STM	SDH/SONET	DS-3 Channels	Voice Channels
OC-1	STS-1		51.84 Mbps	1	672
OC-2			103.68 Mbps	2	1,344
OC-3	STS-3	STM-1	155.52 Mbps	3	2,016
OC-4		STM-3	207.36 Mbps	4	2,688
OC-9	STS-9	STM-3	466.56 Mbps	9	6,048
OC-12	STS-12	STM-4	622.08 Mbps	12	8,064
OC-18	STS-18	STM-6	933.12 Mbps	18	12,096
OC-24	STS-24	STM-8	1.244 Gbps	24	16,128
OC-36	STS-36	STM-12	1.866 Gbps	36	24,192
OC-48	STS-48	STM-16	2.488 Gbps	48	32,256
OC-96	STS-96	STM-32	4.976 Gbps	96	64,512
OC-192	STS-192	STM-64	9.953 Gbps	192	129,024
OC-768	STS-768	STM-256	39.812 Gbps	768	516,096

SONET Topology



SDH/SONET: Advantages

- Interconnectivity & Interoperability
- Support for Broadband Services
- Low Transmission Costs
- Aggregation of Traffic
  - Voice
  - Data
  - Video
  - Image
- Simplicity of Multiplexing (ADMs)
- Reduced Delay
- Network Management
- Extendible to Premise

SDN/SONET: Applications

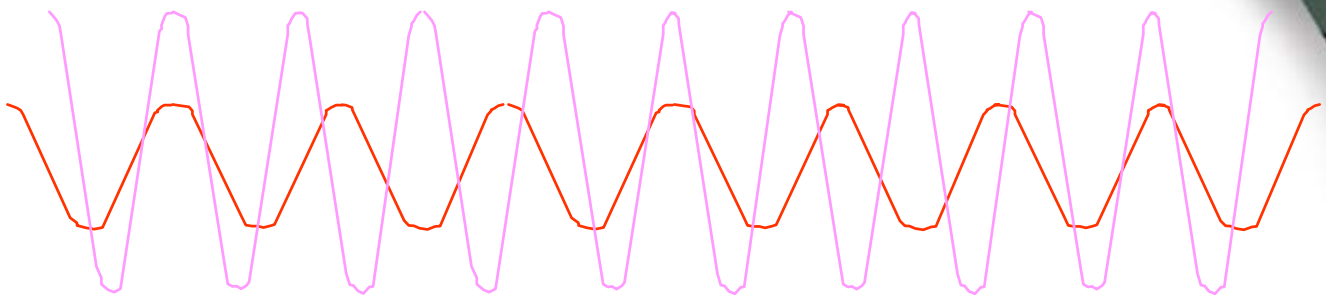
- Carrier Backbone Networks
- Converged Public Networks
- Campus Environments
- Mission-Critical Environments
- Bandwidth-Intensive Local Loops

DWDM

- Pure Optics
- FDM At The Optical Level
- 40 Lambdas Currently Supported
- 100’s Of Lambdas In The Future
- Each Lambda Effectively Separate *Pipe*
- Each Lambda Optimized For Traffic:
  - 1 Point Of Origin
  - 1 Destination
  - 1 QoS

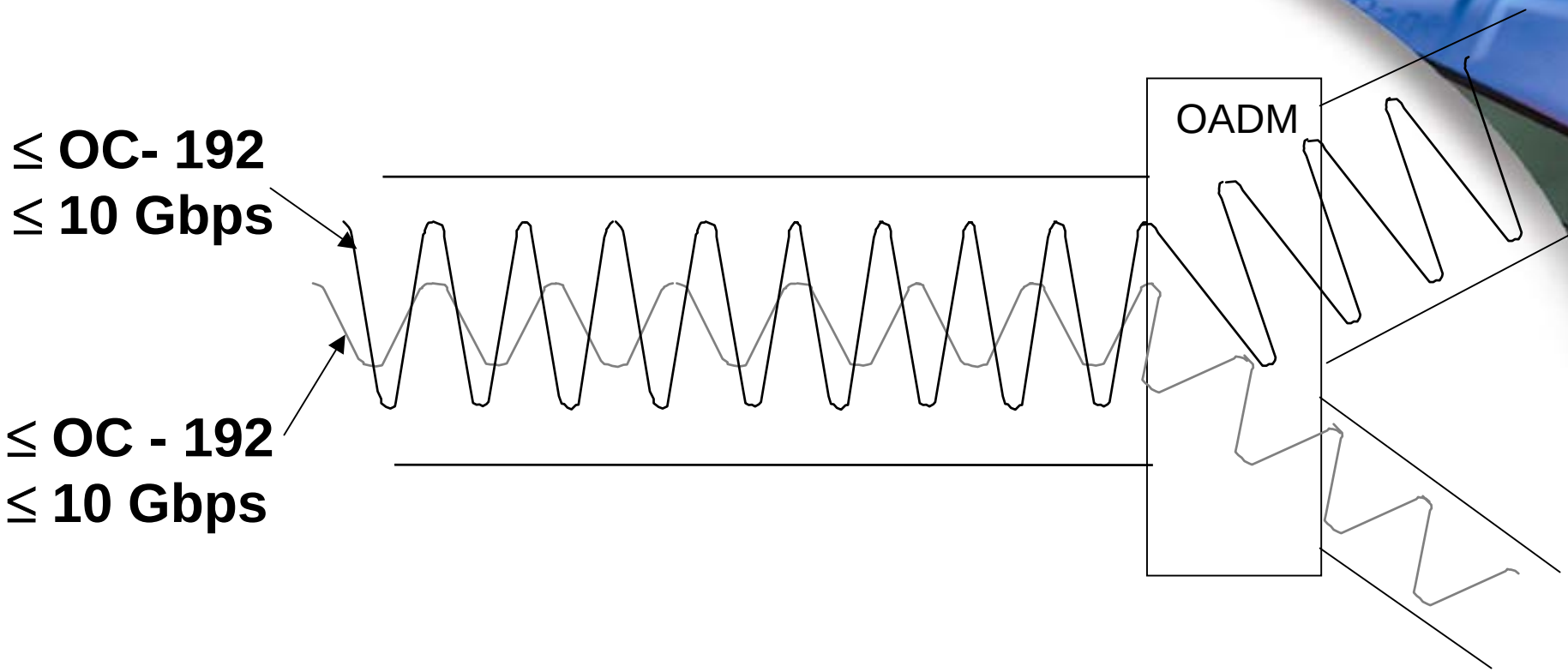
Wavelength Division Multiplexing

≤ OC- 192
≤ 10 Gbps



≤ OC - 192
≤ 10 Gbps

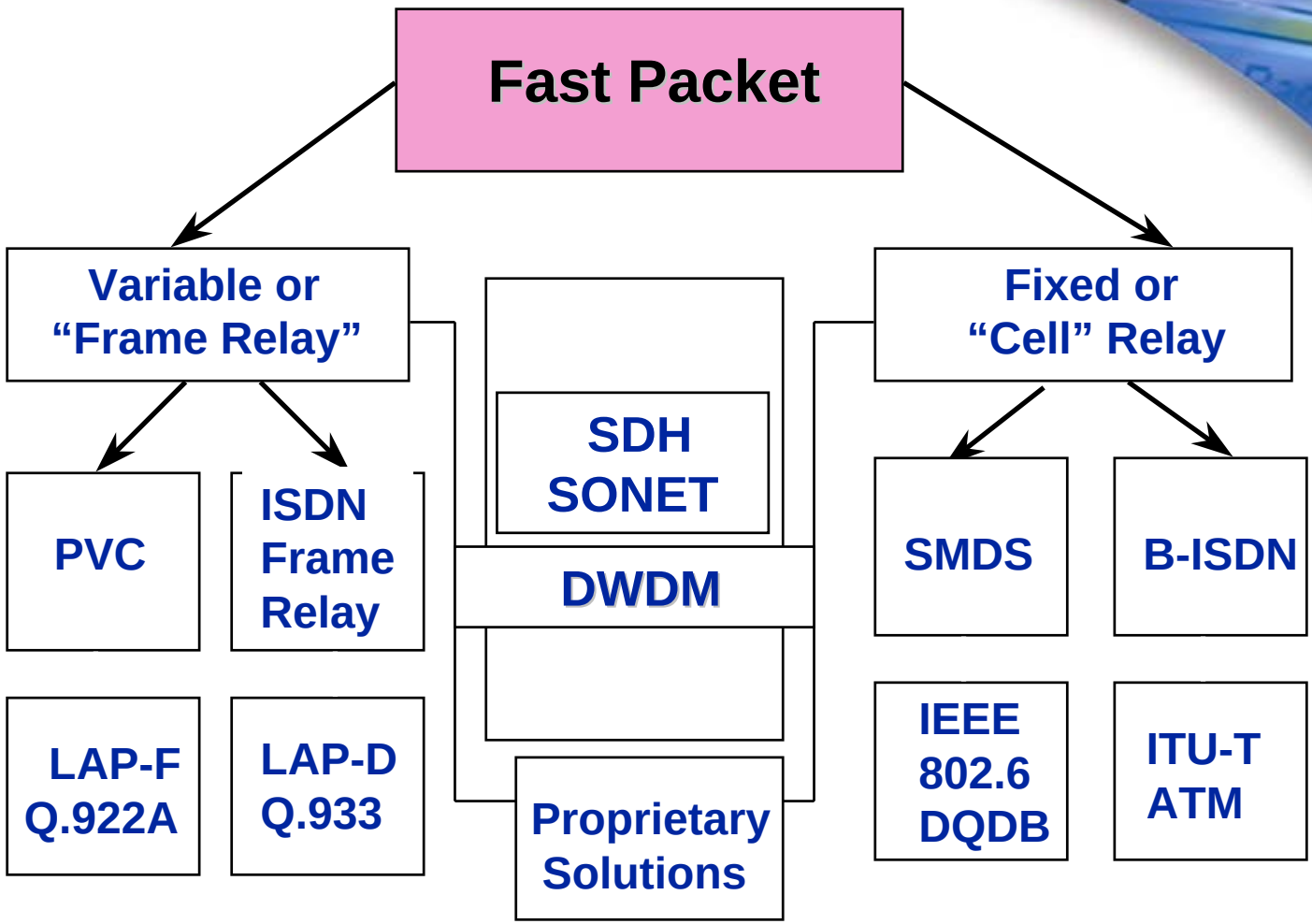
Optical Add/Drop Multiplexer



SONET vs. DWDM

- Usually One or The Other, But
- NOT Mutually Exclusive
- SONET over Lambda Can Be Done

Broadband Services

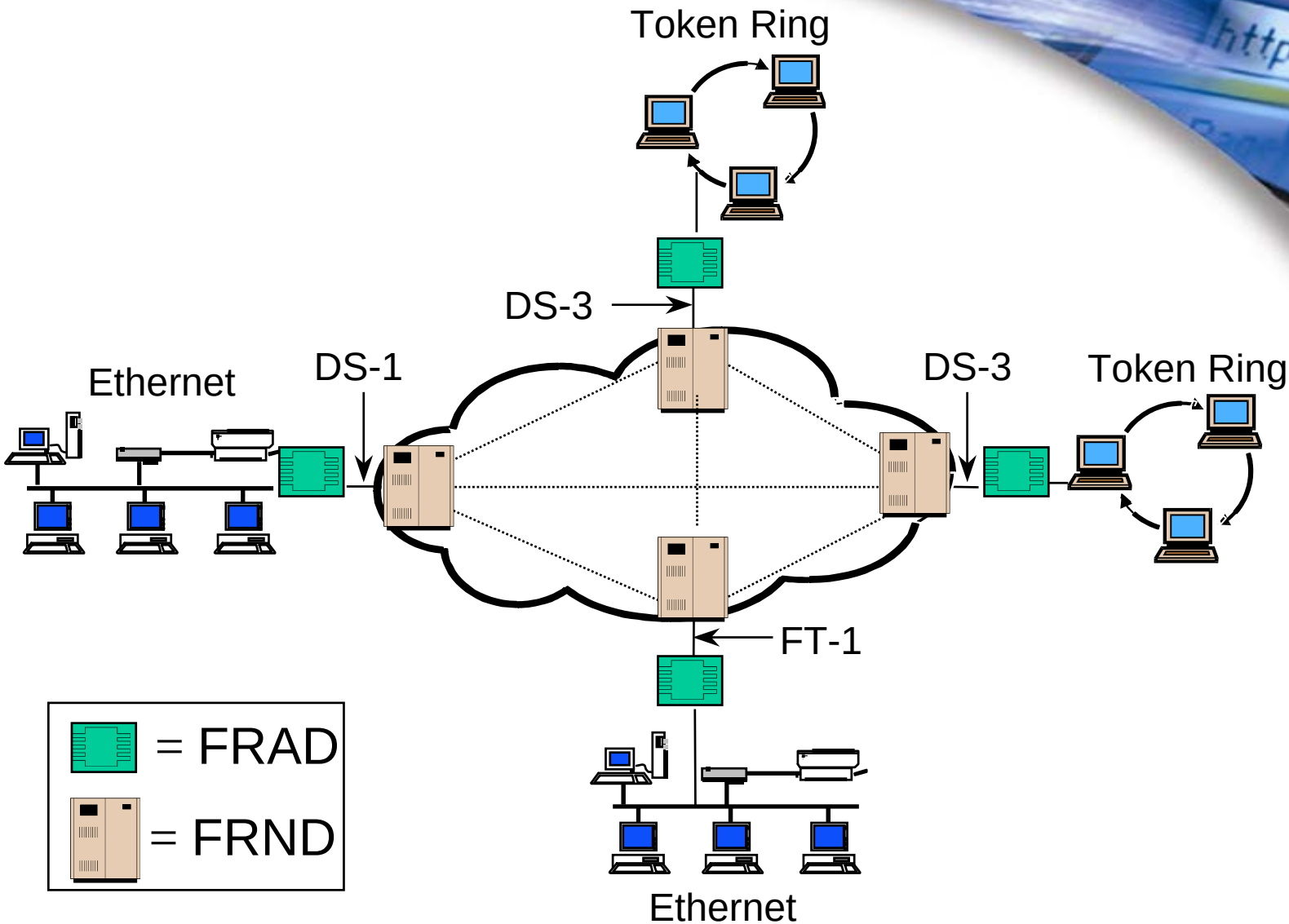


Frame Relay Defined

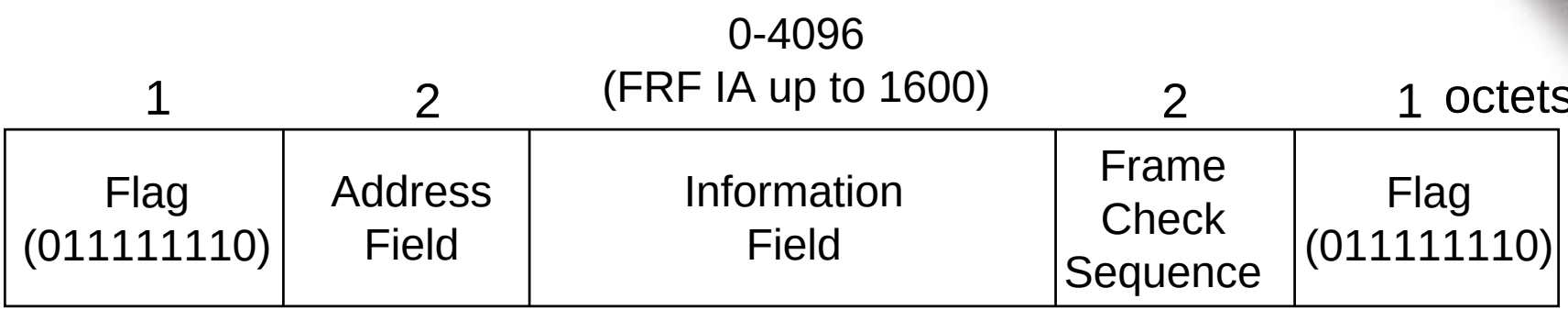
Frame Relay is an interface standard defined by ANSI and the ITU-T. Implementation Agreements (IAs) are published by the Frame Relay Forum. Access to the Frame Relay network is accomplished using the LAP-D protocol developed for ISDN and at rates of 56/64 Kbps, DS-1 or DS-3. Frame Relay is a connection-oriented service.

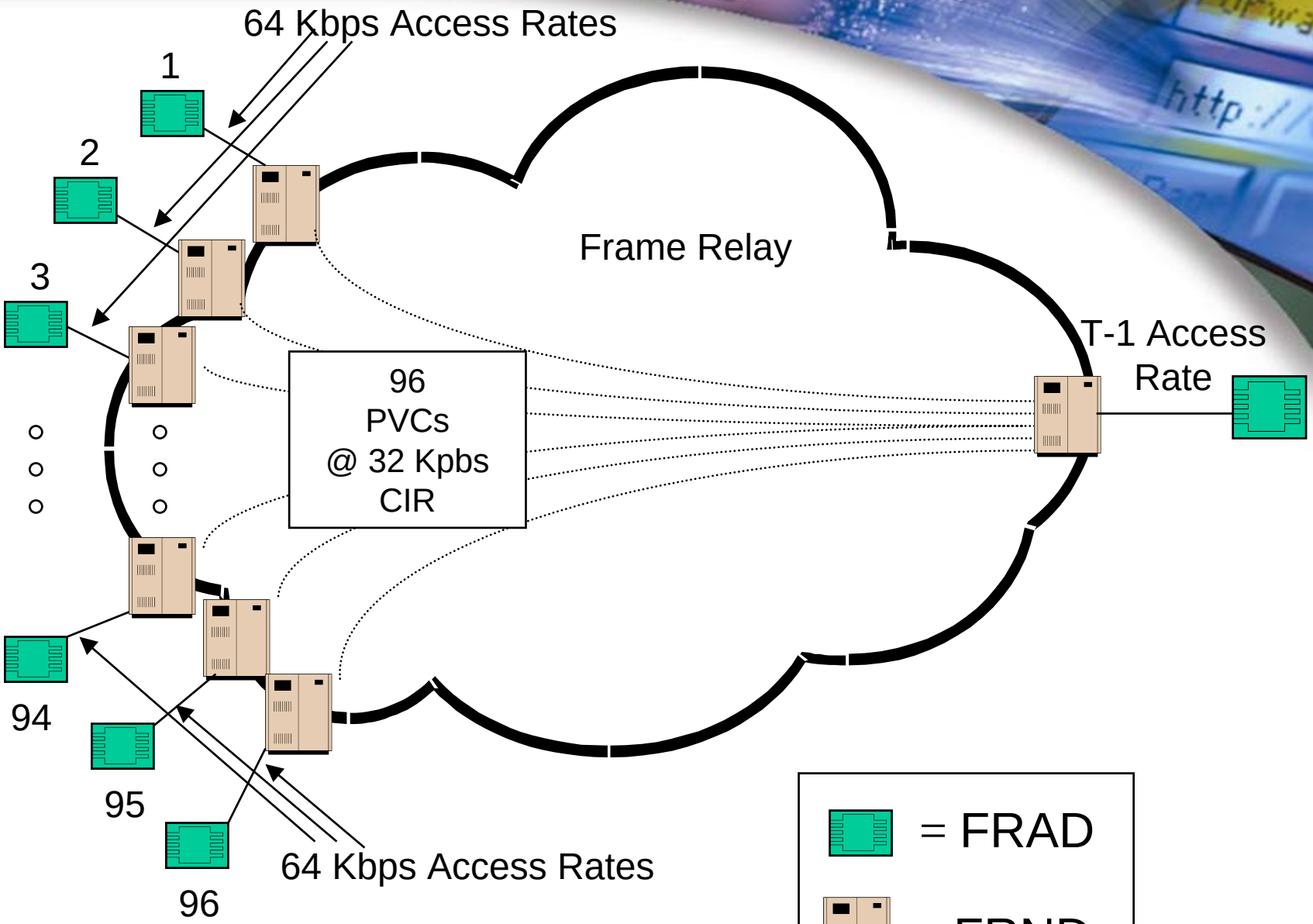
Frame Relay: Optimized For LAN Internetworking

- Widely Available
- Highly Cost-Effective
- Reliable
- Secure
- Not Going Away
- IP-Enabled Frame Avoids Cost of PVCs

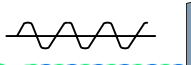


Frame Relay Frame Format

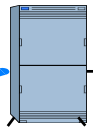




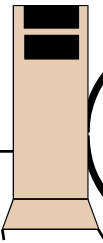
VoFR

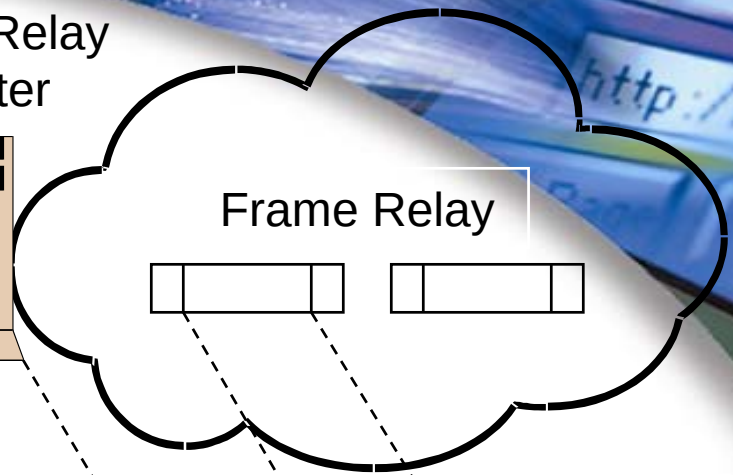


PBX



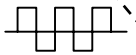
Frame Relay Router

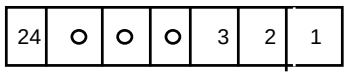


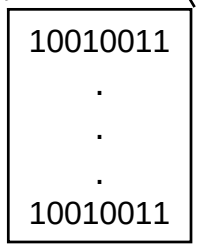


64 Kbps PCM

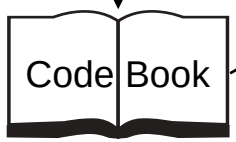
10010011
1B = 125 µs
TDM

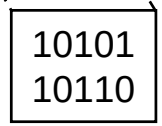






80 B = 10 µs
80 B x 8 bits = 640





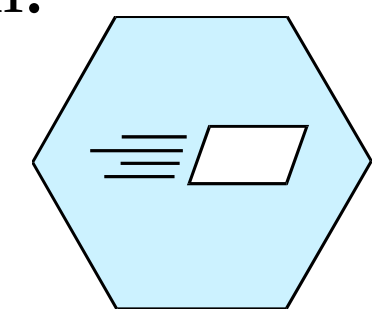
160 bits

Voice over Frame Relay (VoFR): Compression Is The Key

- **G.711**
  - PCM
  - 64 Kbps
  - MOS 4.4
- **G.723**
  - H.324 Umbrella
  - 6.3 & 5.3 Kbps
  - MOS 3.5-3.98
- **G.726 (FRF.11)**
  - ADPCM
  - 40,32,24 & 16 Kbps
  - MOS 4.2
- **G.728**
  - LD-CELP
  - 16 Kbps
  - MOS 4.2
- **G.729 (FRF.11)**
  - CS-ACELP
  - 8 Kbps
  - MOS 4.2

Asynchronous Transfer Mode (ATM)

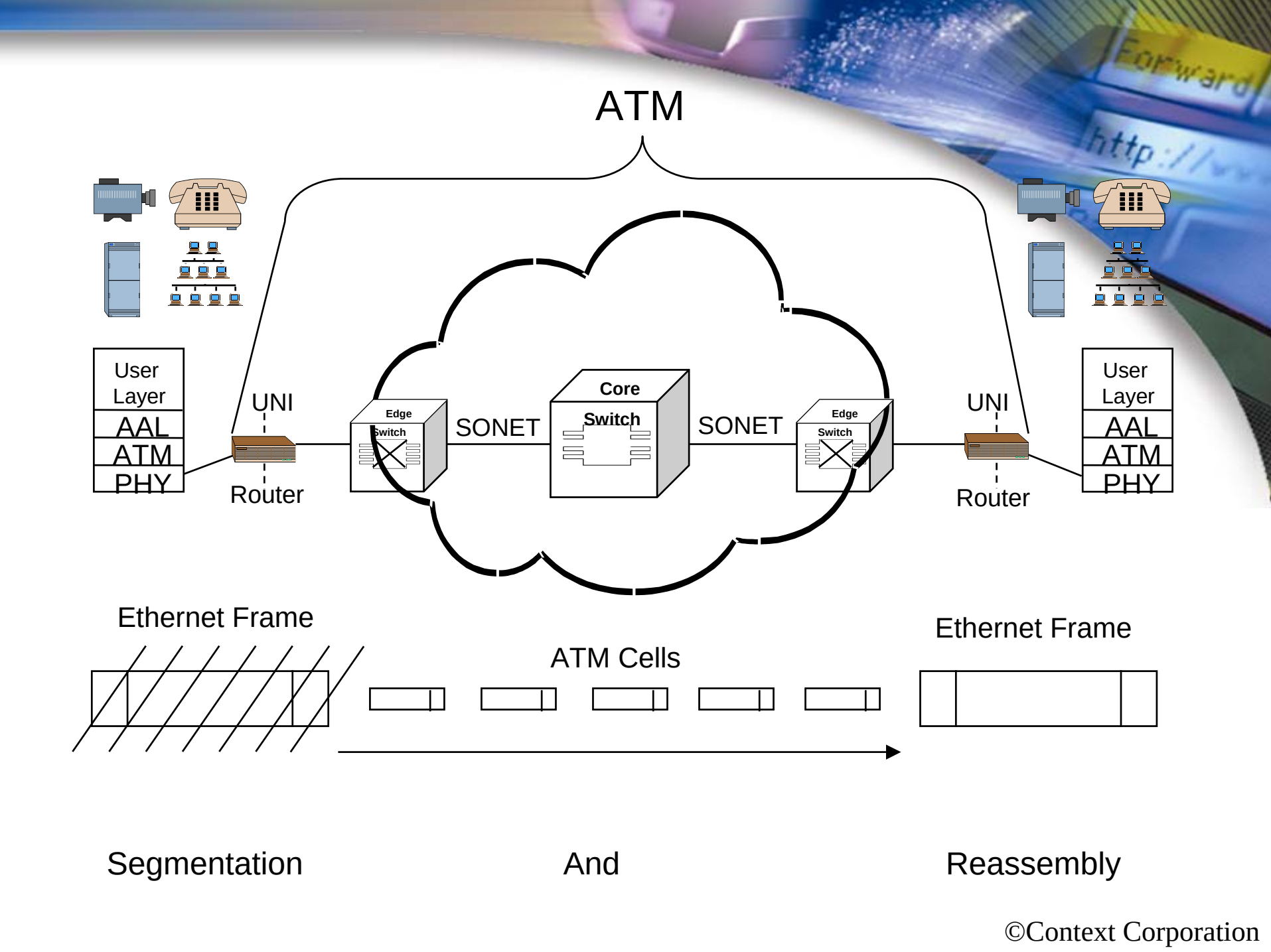
ATM is a fast-packet, connection-oriented cell-switching technology for broadband communications; fixed length cell of 53 octets is standard. Access is generally at speeds of DS1+, although a 25 Mbps ATM technology is also available. ATM is generally thought of as a backbone network technology, although it has application on the premise, as well.



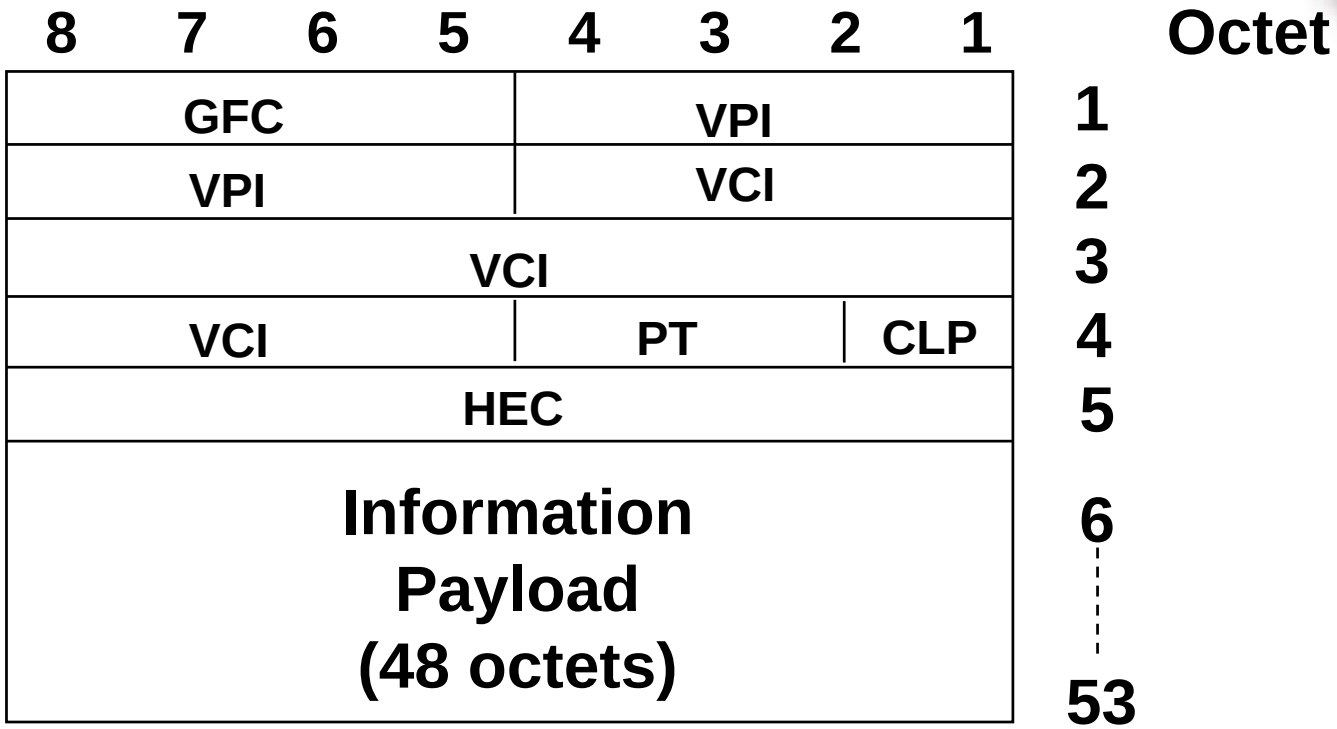
ATM: Optimized For Everything

Service Classes

- Constant Bit Rate (CBR)
- Real-Time Variable Bit Rate (rt-VBR)
- Non Real-Time Variable Bit Rate(nrtVBR)
- Unspecified Bit Rate (UBR)
- Available Bit Rate (ABR)

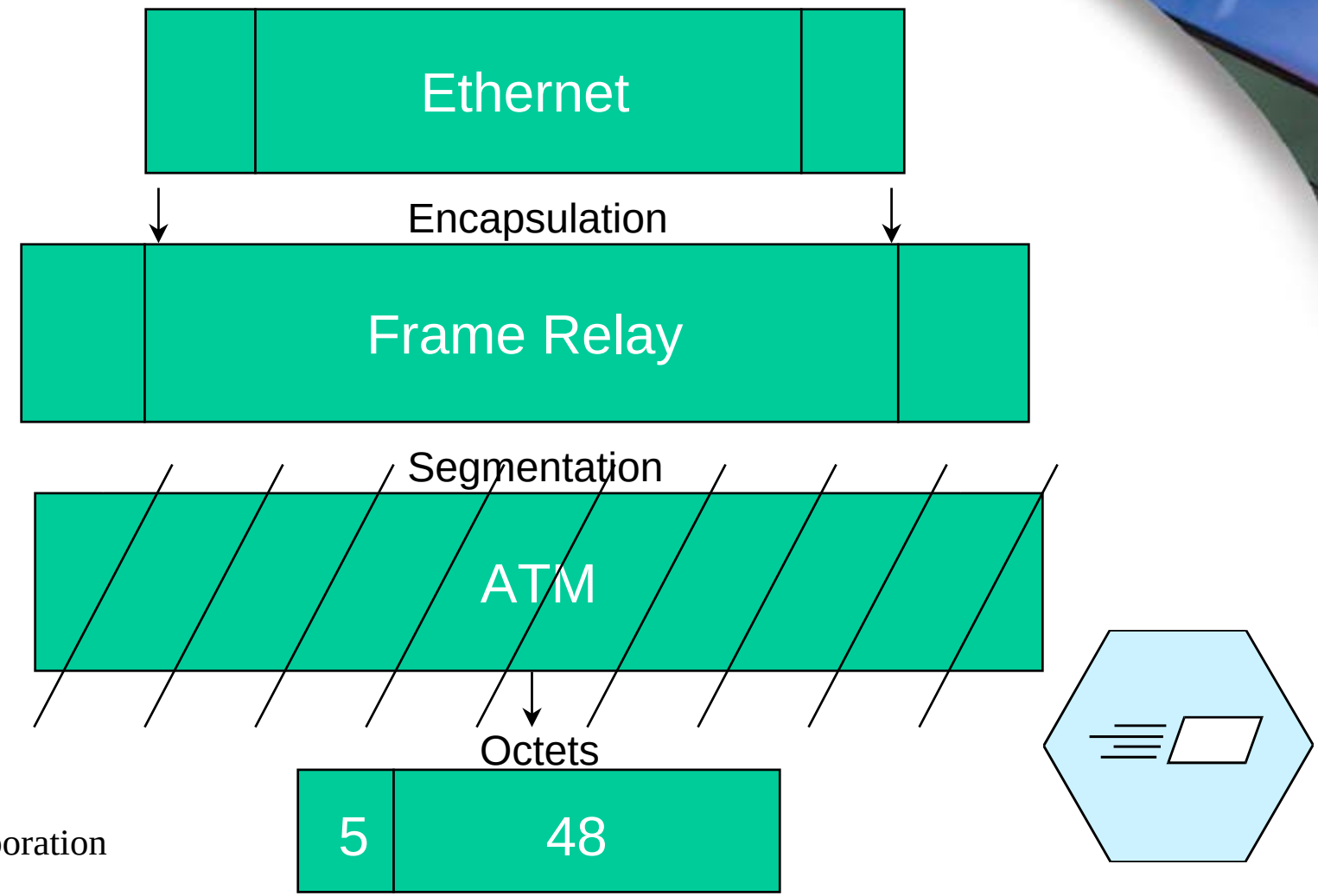


ATM Cell Structure



Notes:
- GFC: Generic Flow Control
- VPI: Virtual Path Identifier
- VCI: Virtual Channel Identifier
- PT: Payload Type
- CLP: Cell Loss Priority
- HEC: Header Error Control

Fragmentation and Segmentation



ATM QoS: Service Categories

- Constant Bit Rate (CBR)
- Real-Time Variable Bit Rate (rt-VBR)
- Non Real-Time Variable Bit Rate (nrtVBR)
- Unspecified Bit Rate (UBR)
- Available Bit Rate (ABR)

Constant Bit Rate (CBR)

- Continuous Data Flow
- Intolerant of Loss and Delay
- Traffic Parameters: PCR, CDVT
- QoS Parameters: CDV, CTD, CLR
- Applications: Uncompressed
  - Voice
  - Audio
  - Video

Real-Time Variable Bit Rate (rt-VBR)

- Bursty
- Data Integrity: Timing and Control
- Traffic Parameters: PCR, CDVT, SCR, MBS, BT
- QoS Parameters: CLR
- Applications: Compressed
  - Voice
  - Audio
  - Video

Non Real-Time Variable Bit Rate (nrtVBR)

- Bursty
- Tolerant of Delay and Loss
- Traffic Parameters: PCR, CDVT, SCR, MBS, BT
- QoS Parameters: CLR
- Applications: Compressed
  - X.25, Frame Relay, SMDS, LAN-to-LAN
  - Transaction Processing
  - nrt, Buffered Voice and Video

Unspecified Bit Rate (UBR)

- Best Effort
- Traffic Parameters: PCR, CDVT
- QoS Parameters: None
- Applications:
  - File Transfer
  - E-Mail

Available Bit Rate (ABR)

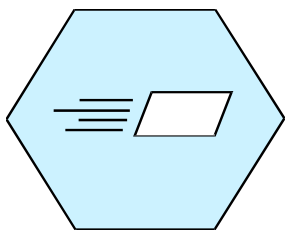
- Best Effort
- VBR with Flow Control, Minimum Transmission Rate, Specified Performance Parameters
- Traffic Parameters: PCR, CDVT, MCR
- QoS Parameters: None
- Applications: Not Real Time

ATM Applications

- Point-to-Point
- Point-to-Multipoint Conferencing
  - Video
  - Multimedia
- Data Networking (LAN, MAN, WAN)
- Image Networking
- Video Networking
- Voice Networking

ATM Advantages

- Digital
- High Bandwidth
- Bandwidth-on-Demand
- Any-to-Any Connectivity
- Mesh Networking
- High Throughput
- Error Performance
- Access Control
- Congestion Control
- Protocol-Independent

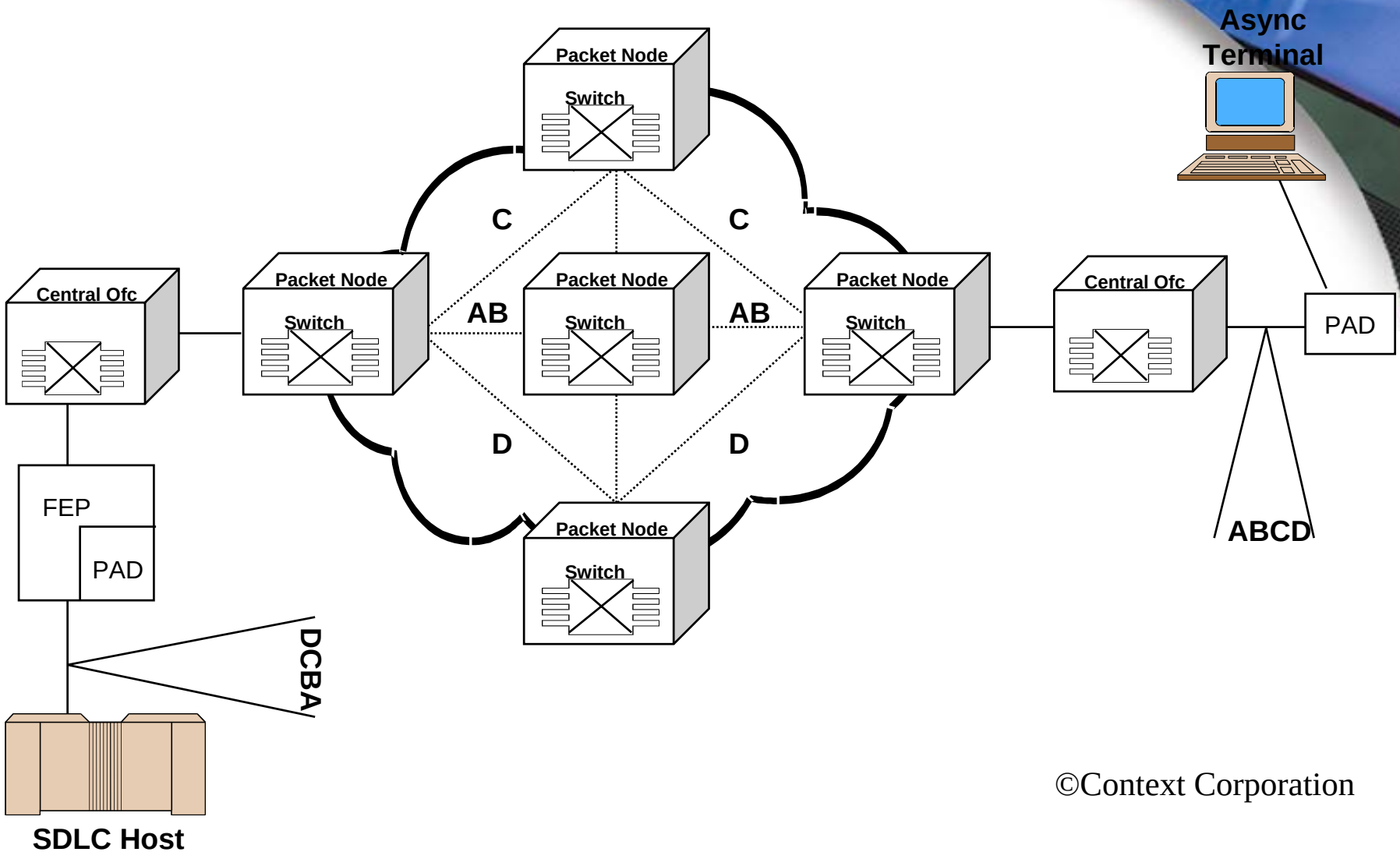


- Supports Async, Sync and Isoc Traffic
- Supports Data, Image, Voice and Video
- Supports Compressed and Uncompressed
- Supports Realtime and Non-Realtime
- Interconnection to X.25, Frame Relay, SMDS,...
- Network Reconfiguration Simplified
- Scalable

ATM Disadvantages

- Limited Availability
- Requires Equipment Upgrade
- Voice & Video Questionable
- Network Management Not Fully Standardized
- Expensive
- Technically Demanding

Packet-Switching



TCP/IP Protocol Suite

- Layer 3: IP
- Layer 4: TCP
- Layer 7:
  - UDP
  - TELNET
  - FTP
  - SMTP
  - SNMP

Birth of TCP/IP

- Early 1970s: Stanford University begins work on ARPANET internetworking protocols
- 1974: Vinton Cerf and Robert Kahn publish paper on packet protocol
- 1980: TCP/IP development completed
- 1983: TCP/IP mandated for ARPANET

TCP/IP: Optimized For Interactive Datacom

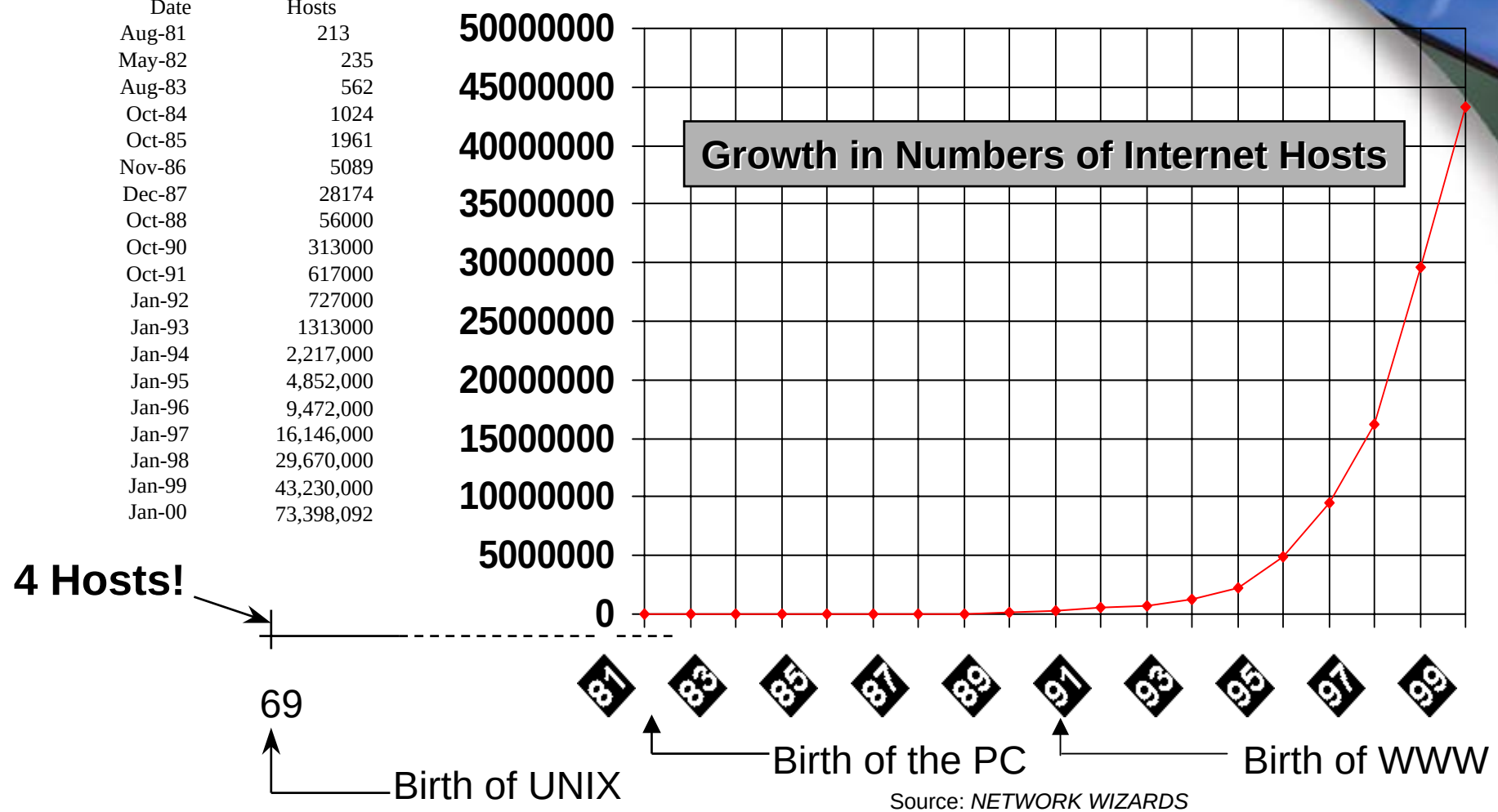
- Public Domain Protocol
- Ubiquitous
- Connectionless = Unreliable

  TCP Adds Virtual Connection
- Insecure

  Developed For Trusted User Community
- Layer 7 Protocols Add Applications Focus

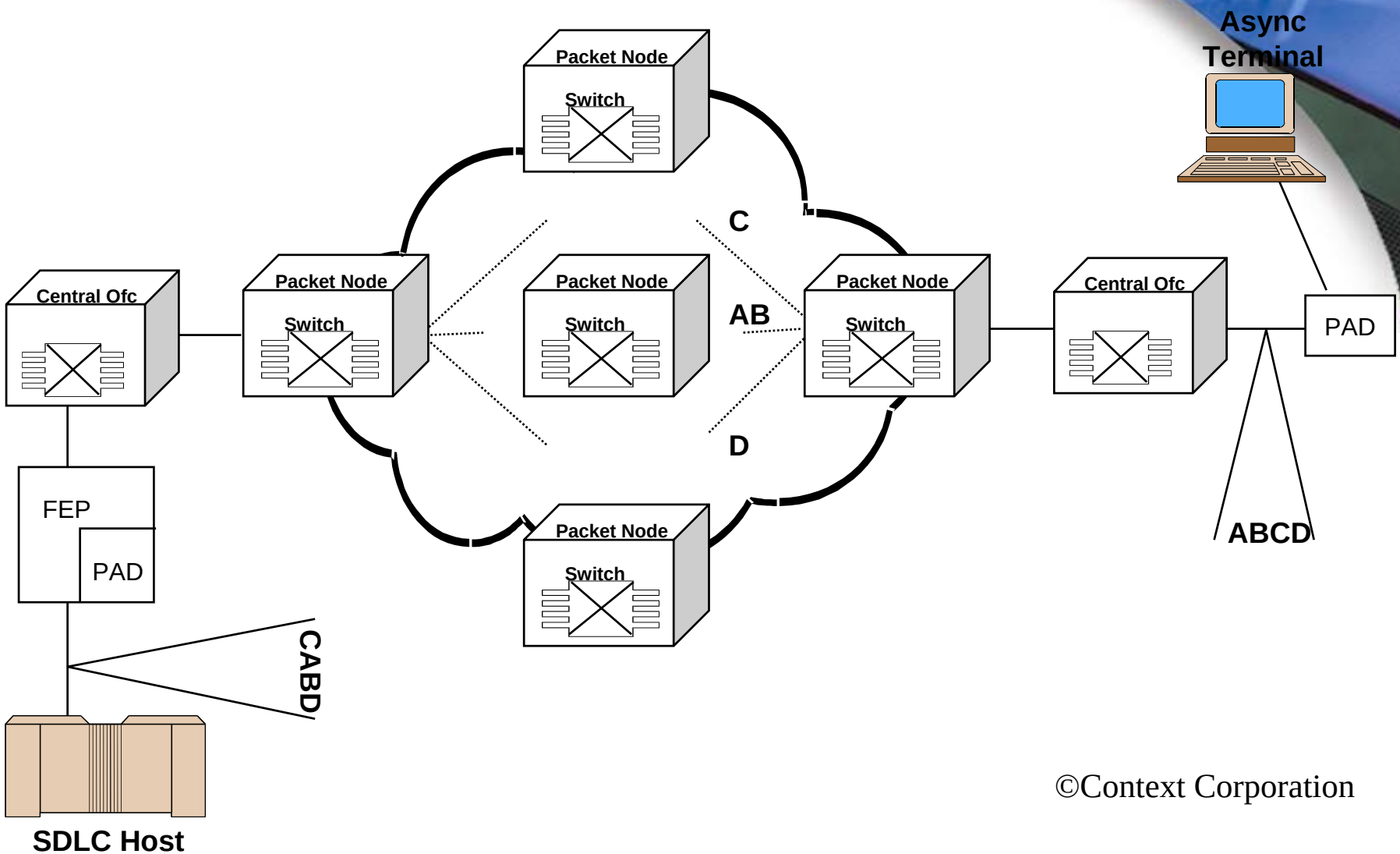
Internet Growth

Date	Hosts
Aug-81	213
May-82	235
Aug-83	562
Oct-84	1024
Oct-85	1961
Nov-86	5089
Dec-87	28174
Oct-88	56000
Oct-90	313000
Oct-91	617000
Jan-92	727000
Jan-93	1313000
Jan-94	2,217,000
Jan-95	4,852,000
Jan-96	9,472,000
Jan-97	16,146,000
Jan-98	29,670,000
Jan-99	43,230,000
Jan-00	73,398,092



Source: *NETWORK WIZARDS (http://www.nw.com) and MARK GIBBS, GIBBS & CO.*

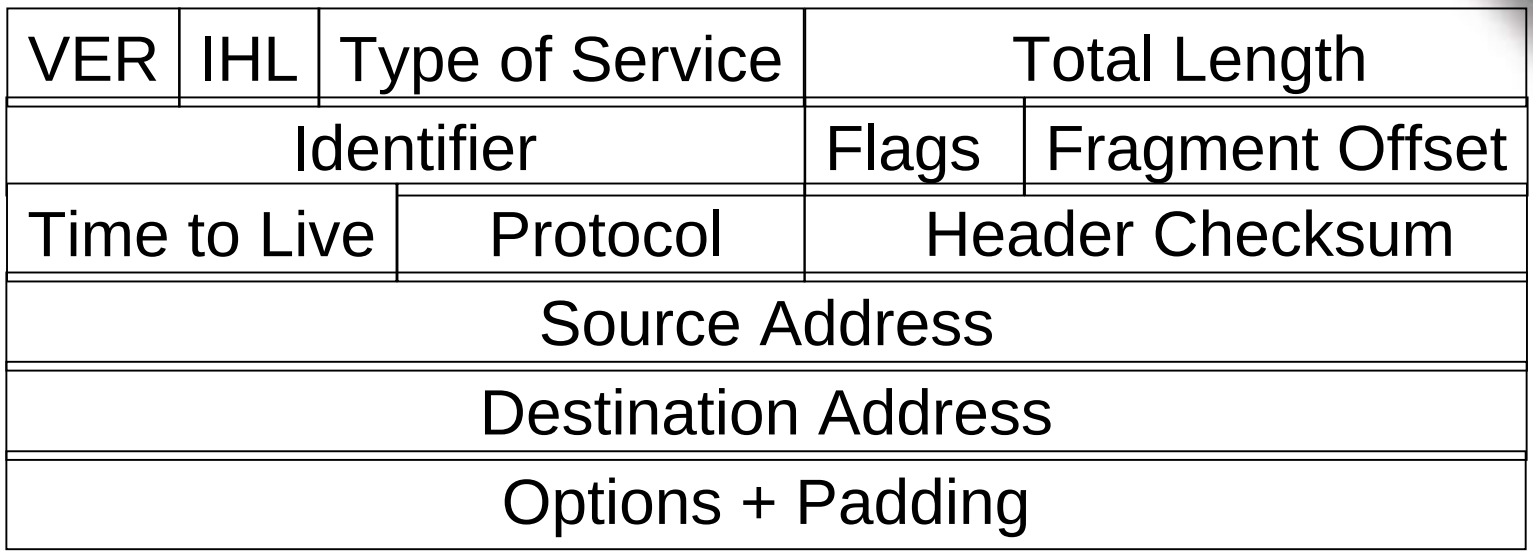
IP: Connectionless Data Delivery



Internet Protocol (IP)

- Connectionless Datagram Delivery
- Routing of Datagrams through Gateways
- Datagram-Oriented
- Best Effort Protocol
- Addressing: Dotted Decimal Notation
- Supports Routing Control
- Supports Multiple Service Types

IPv4 Header



Total Datagram = 576-65,536 Octets

Header = 20 Octets Overhead

IPv4 Limitations

- Addressing Scheme Too Limited (32 bits)

  Only 4,294,967,296 Addresses!
- Address Assignment Inflexible

  Class A, B, C
- Application-Level Protocols Not Tightly Integrated
- QoS Not Supported, Only *Best Effort*
- Security Lacking

IPv6 To The Rescue

- Header Doubled To 40 Octets
- Address Field Increased To 128 Bits
  - Virtually Inexhaustible
- Address Assignment More Flexible
- Application-Level Protocols Integrated
- QoS Supported
- Security Improved

IPv6 Prioritization

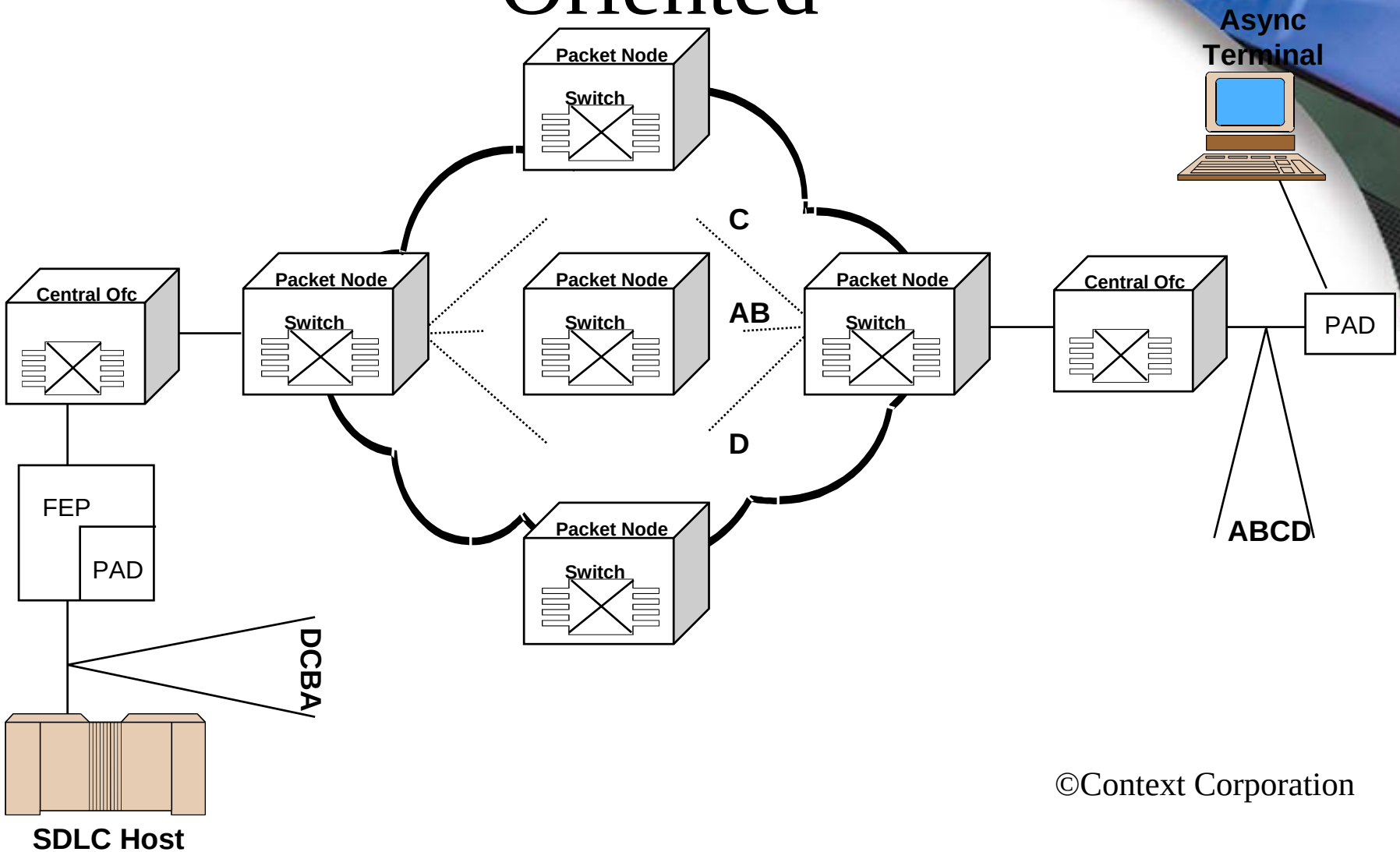
- Priority Field
- Source Host Assigns Delivery Priority, e.g.:
  - High: Voice and Video
  - Low: Network Management
- Flow Label for Stream-Oriented Data
- QoS: Work in Progress

IPv6 Efficiency and Flexibility

Additional, Optional Headers Include:

- Hop-by-Hop Extension
- Routing Header
- Fragment Header
- Jumbo Payload Option

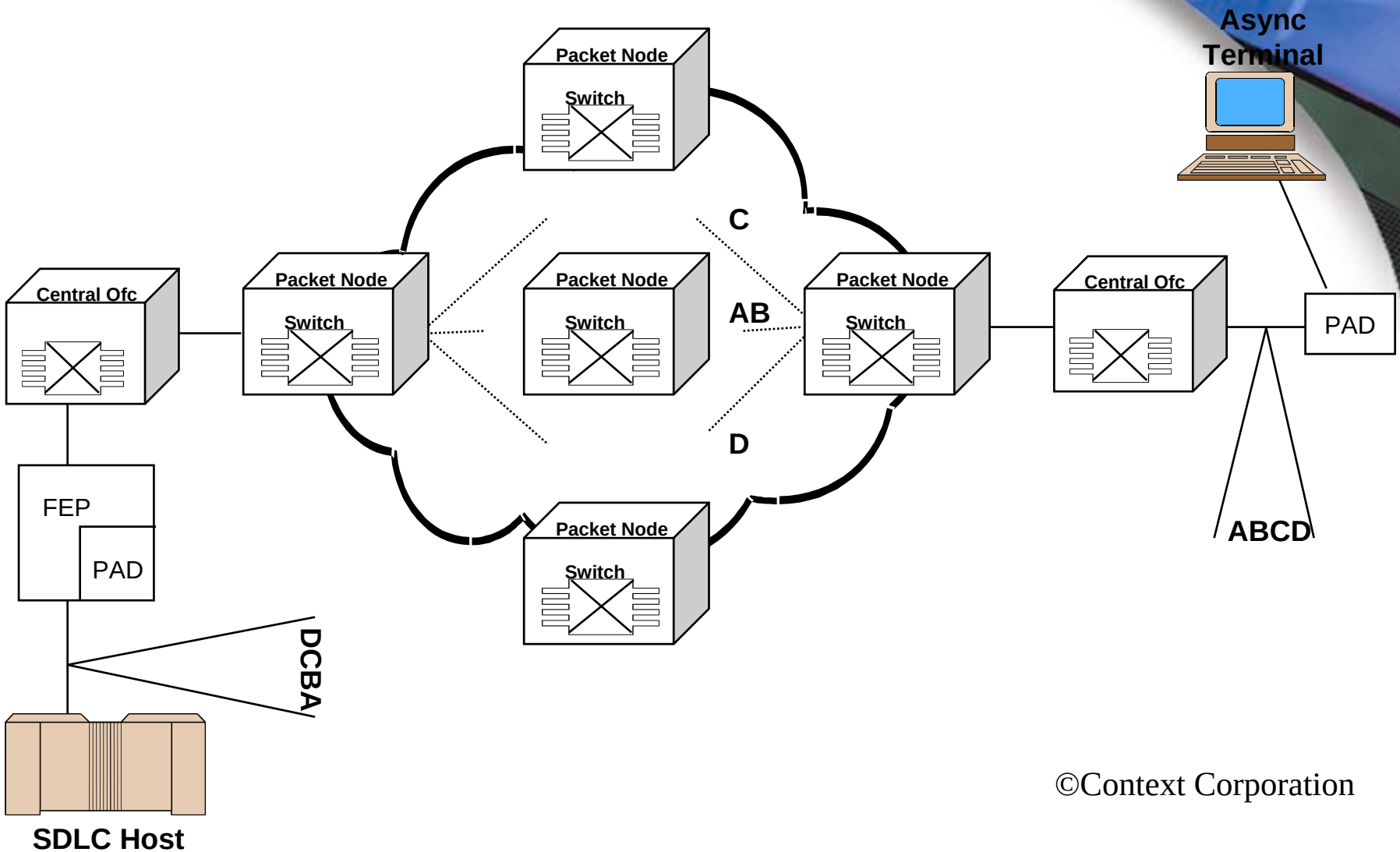
TCP: Virtually Connection-Oriented



Transmission Control Protocol (TCP)

- Add 20 Octets Overhead, But
- Reliable Datastream Transport
- Connection-Oriented (Virtual)
- Virtual Circuits (VCs)
- Guaranteed Packet Delivery
  - Sequencing
  - End-to-End Flow Control
  - Error Control

UDP: Emphasize Applications



User Datagram Protocol (UDP)

- Simplified, Host-to-Host Protocol
- 8 Octets Overhead
- Connectionless
- Unreliable
- Runs on Top of IP

UDP SOURCE PORT	UDP DESTINATION PORT
UDP MESSAGE LENGTH	UDP CHECKSUM
DATA	
…	

Application-Layer Protocols

- TELNET (Telecommunications Network)
- FTP (File Transfer Protocol)
- SMTP (Simple Mail Transfer Protocol)
- SNMP (Simple Network Management Protocol)

Intranets and Extranets

Internet Turned Inward

- Intranets: Internal To The Organization
- Extranets: Intranets Opened To Others
  - Customers
  - Affiliates and Partners
  - Vendors

Virtual Private Networks (VPNs)

Not A Private Network, but *Virtually* Private

- IP-Based Network
  - Public Internet
  - Other IP-Based Network
- Some Characteristics of Private Network

Virtual Private Networks (VPNs)

Private Network	Virtual Private Network
• Dedicated Resources	• Shared Resources
• Highly Secure	• Somewhat Secure
• No Usage Charges	• Usage Charges?
• Lengthy Configuration	• Rapid Configuration
• Not Scalable	• Highly Scalable
• Catastrophic Failure	• Redundant/Resilient
• Optimized for Performance	• Optimized for Efficiency

VPN Security

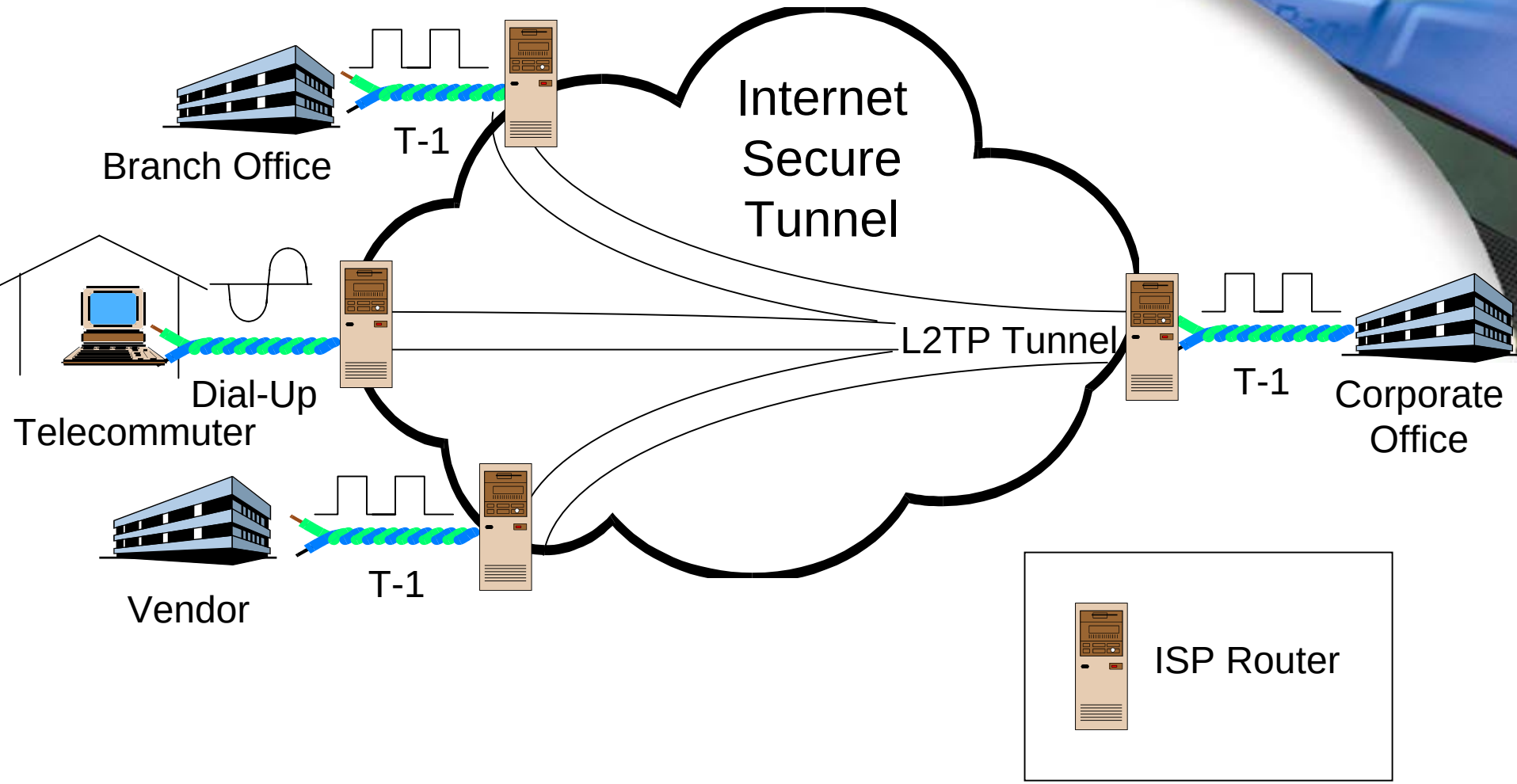
- Authentication
- Encryption
- Tunneling

VPN Application Scenarios

All About Cost-Effectiveness

- Remote Access
  - Telecommuters and Remote Workers
- Intranets
  - Linking Offices
- Extranets
  - Vendors, Customers, Affiliates and Distributors

Tunneling Protocols



Voice over IP (VoIP): The Next Generation PSTN?

Voice over a packet data network?

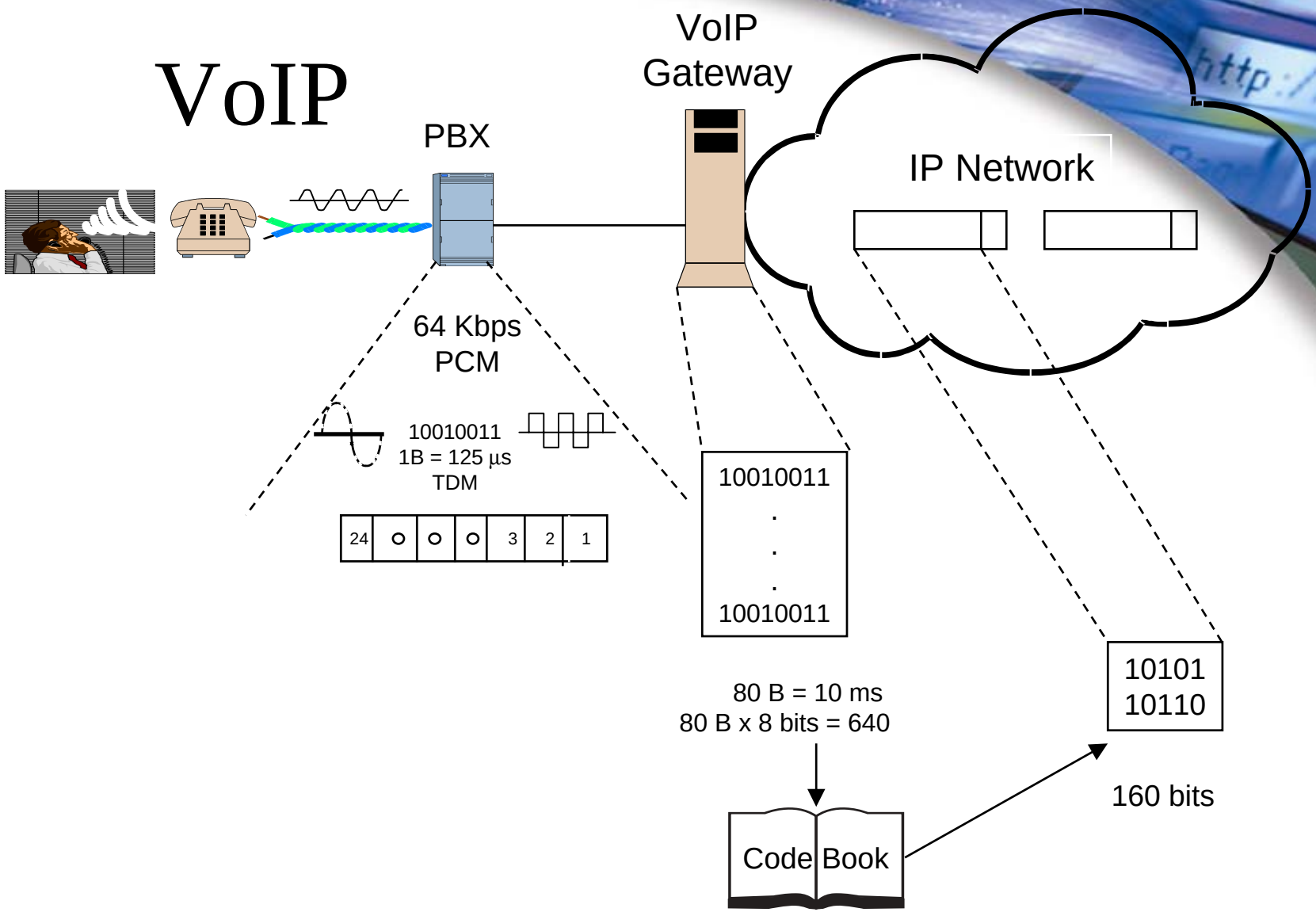
Will it work?

It doesn't make sense!

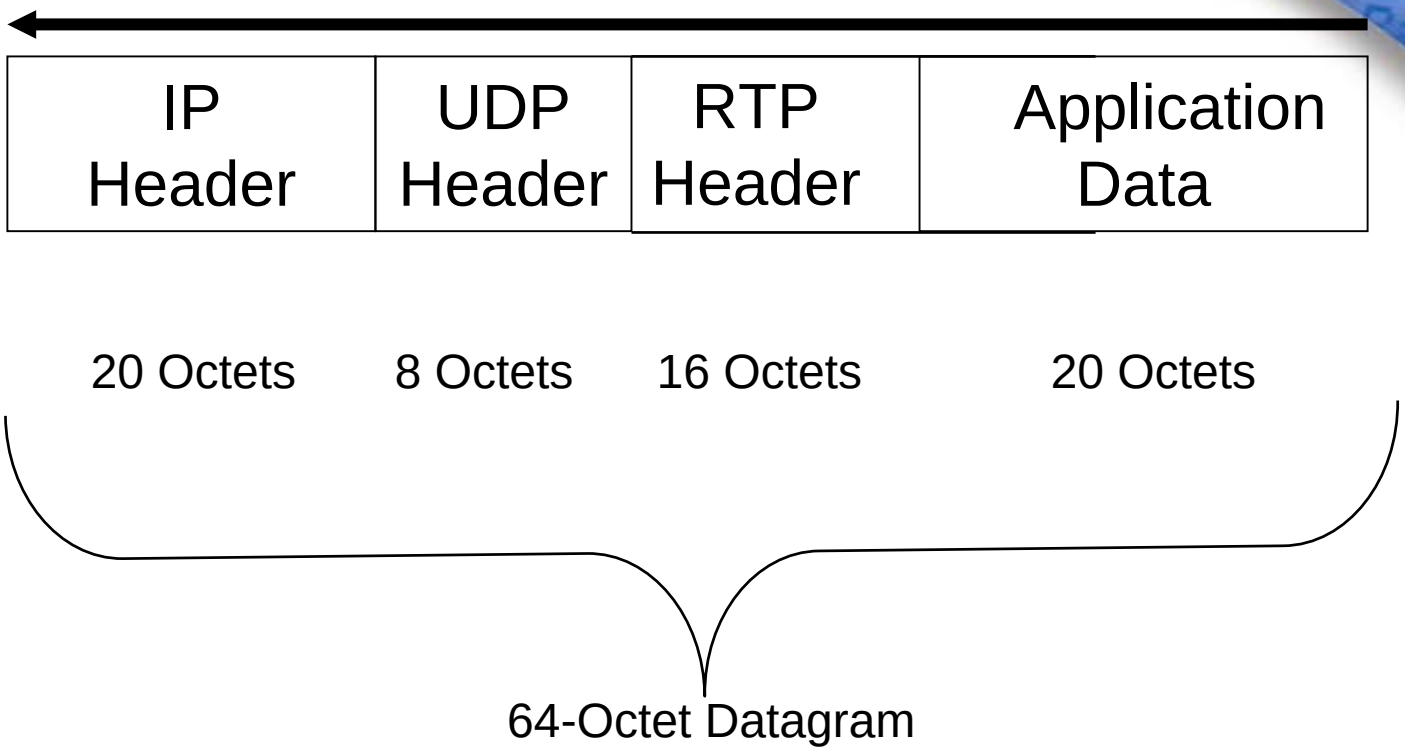
Or does it?

Let us seek the truth….

VoIP



VoIP Transmission Framing



VoIP: Too Good To Be True?

Highly Shared Network = Efficiency

Compression = Even Greater Efficiency

Efficiency = Low Cost

BUT

What About Quality?

VoIP: Too Good To Be True?

Classic Design Trade-Off

Efficiency versus Effectiveness

Cost versus Performance

Problematic, But Doable

Solution:

Packet Data Network Optimized For Voice

Voice over Packet: Compression Is The Key

- **G.711**
  - PCM
  - 64 Kbps
  - MOS 4.4
- **G.723**
  - H.324 Umbrella
  - 6.3 & 5.3 Kbps
  - MOS 3.5-3.98
- **G.726 (FRF.11)**
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  - MOS 4.2
- **G.728**
  - LD-CELP
  - 16 Kbps
  - MOS 4.2
- **G.729 (FRF.11)**
  - CS-ACELP
  - 8 Kbps
  - MOS 4.2

Voice over Internet Protocol (VoIP)

Advantages

- Low Cost
  - Network: Highly-Shared (Voice and Data)
  - Access: Integrated Voice and Data

Disadvantages

- Quality: Questionable and Variable
- Multiple Standards
- Additional Cost
  - PBX Interface
  - Voice-Capable Gateway (Router)

So, What's The Bottom Line?

- Circuit-Switching Will Fade, Not Disappear
- Frame Relay Will Fade, Not Disappear
- TCP/IP Will Continue To Explode
- IPv6 Will Replace IPv4…
  - Thanks To Wireless
- ATM Will Continue To Grow
  - In The Core, For Sure
  - At The Edge In Some Cases

So, What's The Bottom Line?

- SONET Will Continue To Grow…
  More Slowly
- DWDM Will Grow At Incredible Rate
- DSL Will Regain Steam
- CATV Modems Will Continue To Grow
- Wireless Will Explode
  3G Technologies, $$$ Spectrum
  But, That's Another Story

Thanks! I’m Outta Here!