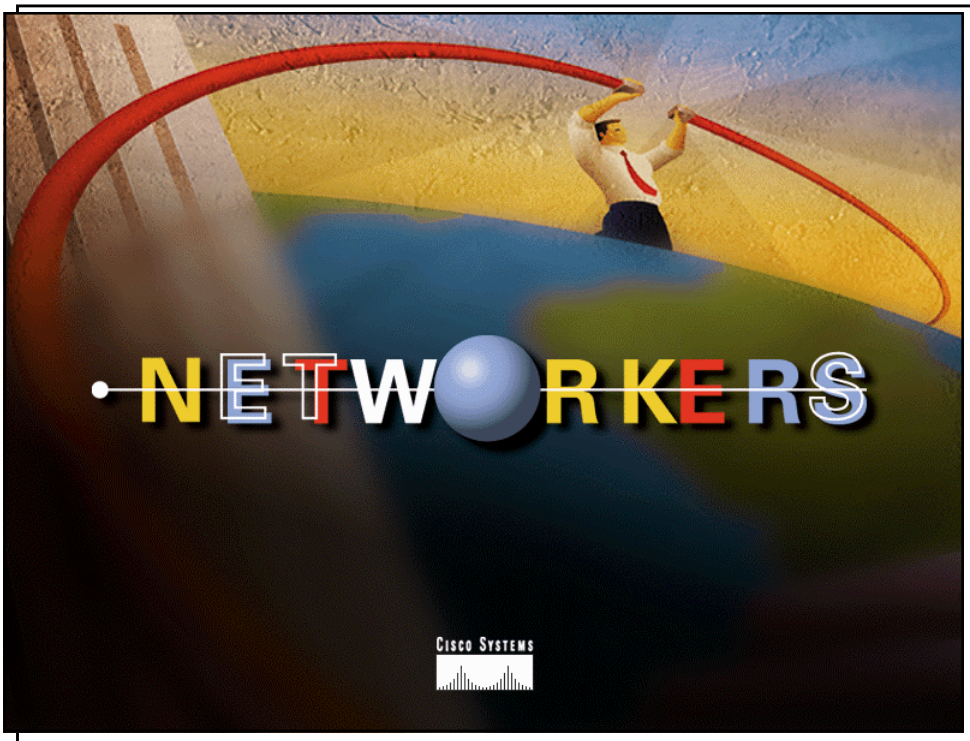

Objectives

- Understand the voice quality factors in an integrated data/voice network
- Describe integrated data/voice network transport mechanisms
- Understand the engineering requirements in data/voice networks to meet voice quality requirements
- Know where to look for the “Gremlins” in integrated data/voice networks

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Agenda

- Establishing Target Parameters for Quality
- Network Technology Trade-Offs
- Voice over Frame Relay Network Design
- Voice over ATM Network Design

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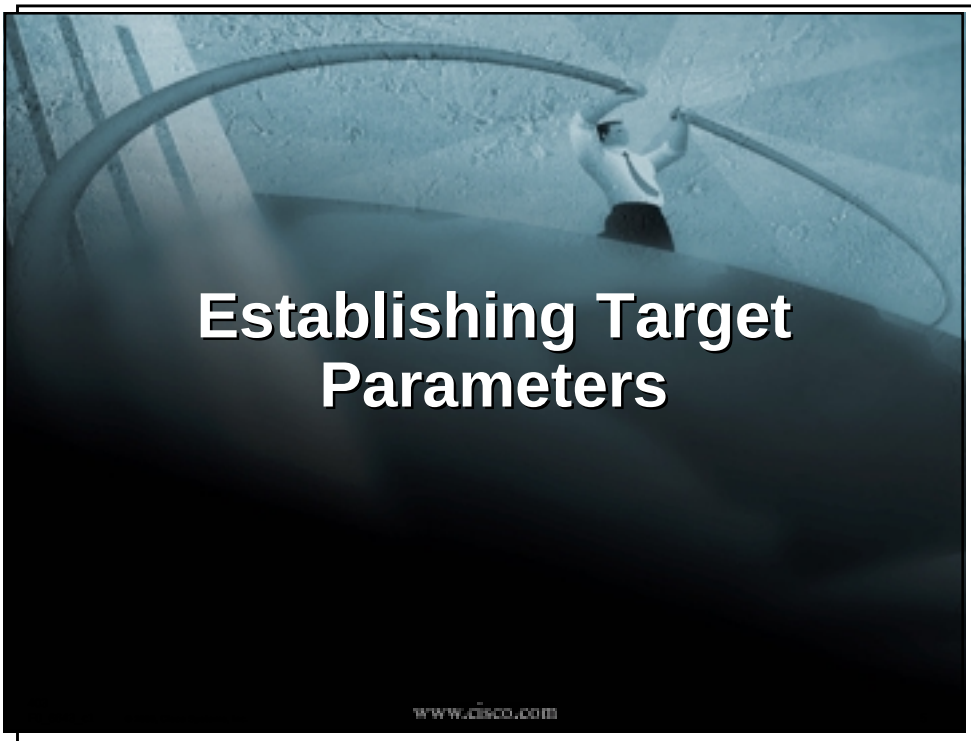
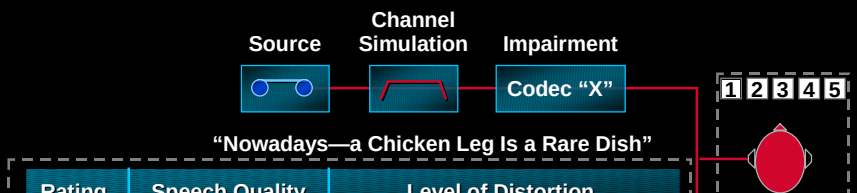


Voice Quality Factors

- Mean opinion score
- Coding
- Compression
- Delay

Mean Opinion Score



"Nowadays—a Chicken Leg Is a Rare Dish"

Rating	Speech Quality	Level of Distortion
5	Excellent	Imperceptible
4	Good	Just Perceptible—Not Annoying
3	Fair	Perceptible—Slightly Annoying
2	Poor	Annoying but Not Objectionable
1	Unsatisfactory	Very Annoying—Objectionable

MOS of 4.2 = Toll Quality

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Voice Quality Guidelines

Compression Method	MOS Score	Delay (Msec)	Bit Rate (Kbps)
PCM (G.711)	4.4	0.75	64
ADPCM (G.726)	4.1	1	32–24–16
LD-CELP (G.728)	3.65	3–5	16
CS-ACELP (G.729)	3.9	15	8
CS-ACELP (G.729a)	3.65	15	8
MPMLQ or ACELP (G.723.1)	3.8	30	6.3–5.3

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Voice Delay Guidelines

One Way Delay (Msec)	Description
0–150	Acceptable for Most User Applications
150–400	Acceptable Provided that Administrations Are Aware of the Transmission Time Impact On the Transmission Quality of User Applications
400 +	Unacceptable for General Network Planning Purposes—However—It Is Recognized that in Some Exceptional Cases this Limit Will Be Exceeded

ITU's G.114 Recommendation

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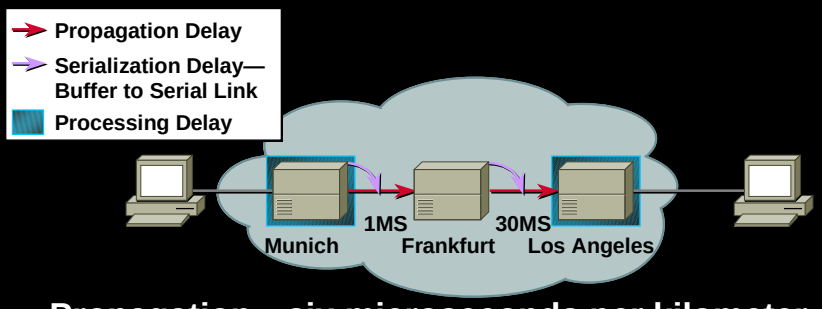
Fixed Delay Components



- Propagation—six microseconds per kilometer
- Serialization
- Processing
  - Coding/compression/decompression
  - Packetization

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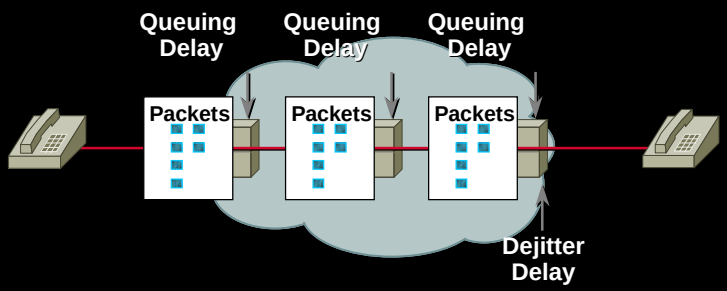
Variable Delay Components



- Dejitter buffers
- Queuing delay
- Variable packet sizes

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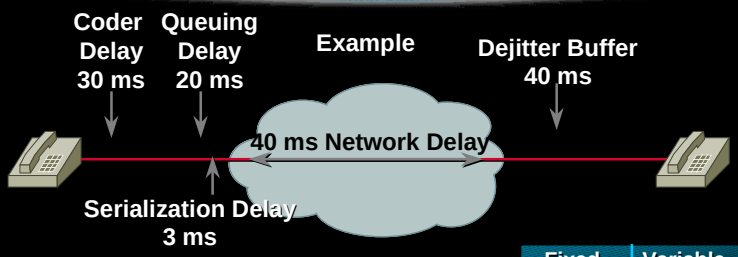
Calculate Delay Budget



	Fixed Delay	Variable Delay
Propagation Delay		
Coder Delay G.729 (15 Msec Per 10 Bytes)	30 Msec	
Packetization Delay—Included in Coder Delay		
Queuing Delay 64 Kbps Trunk		20 Msec
Serialization Delay 64 Kbps Trunk	3 Msec	
Network Delay (Public Frame Relay Network)	40 Msec	
Dejitter Buffer	40 Msec	
Total	113 Msec	20 Msec

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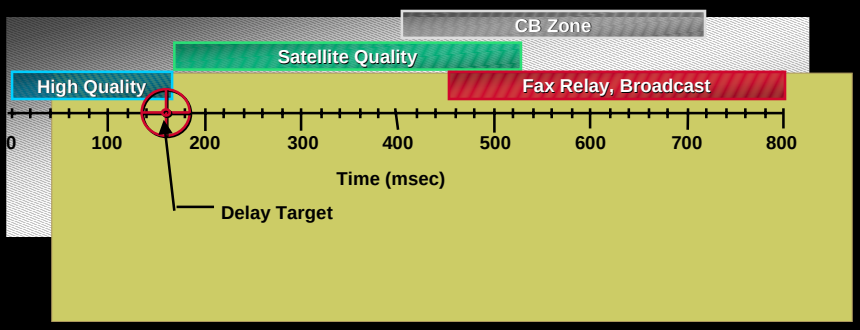
Delay—How Much Is Too Much?

Cumulative Transmission Path Delay



ITU's G.114 Recommendation = 0–150 msec 1-Way Delay

Target Parameters

- MOS—business/toll quality
- Coding—G.729, G.711
- Compression—8k, 64k
- Delay—Calculate network

Technology Trade-Offs

- Frame vs cell
- Mesh vs star
- Transport vs translate

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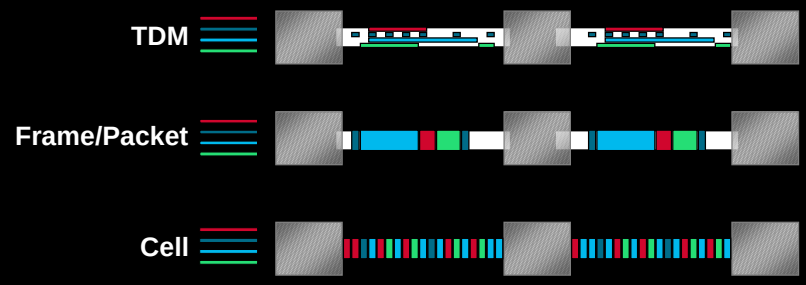
TDM vs Frame vs Cell



- TDM—Constant delay, wasted bandwidth
- Frame/packet—variable delay, highly efficient
- Cell—improved delay, less efficient

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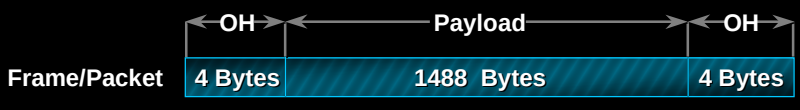
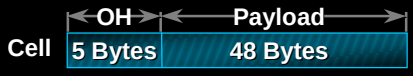
Packet Efficiency



Payload = 1488 Overhead = 8 Efficiency = 99.5%



Payload = 48 Overhead = 5 Efficiency = 89.6%

- Small vs large packet sizes
- Fixed vs variable sized packets

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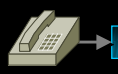
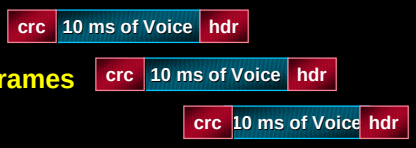
Voice Payload Options



Original Voice Information

- **Small payload**
  - Low delay
  - High overhead
  - High PPS
  - High CPU load

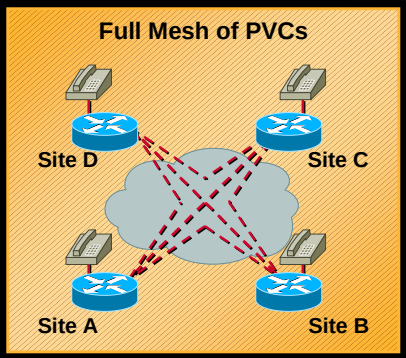
3 Small Frames

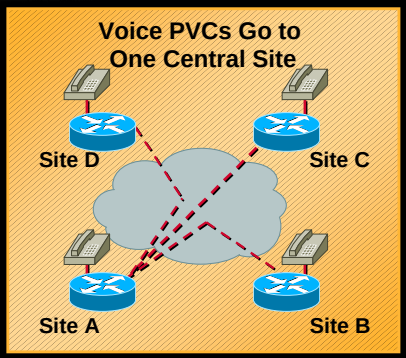


- **Large payload**
  - High delay
  - Low overhead
  - Low PPS
  - Low CPU load

1 Large Frame

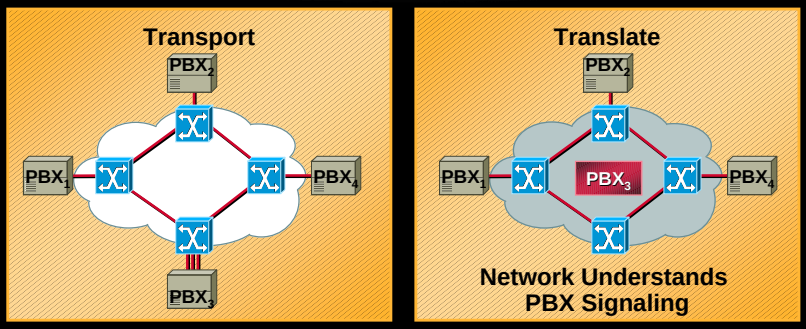
Network Design Options





- Separate voice and data PVCs—maximizes quality of service
- Combine voice and data on one PVC—minimizes recurring costs
- Or use some combination

Transport vs Translate Model



- ATM
- Frame Relay
- Router-based backbone—such as TCP/IP
- Or a mixture of the above

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Design Trade-Offs

- TDM, frame, cell-efficiency, delay, cost
- Mesh vs star—performance vs cost
- Transport vs translate—signaling

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Voice Over Frame Relay Network Design

- A brief tour of FRF.11
- Why FRF.12?
- Network design considerations
- Bandwidth calculations

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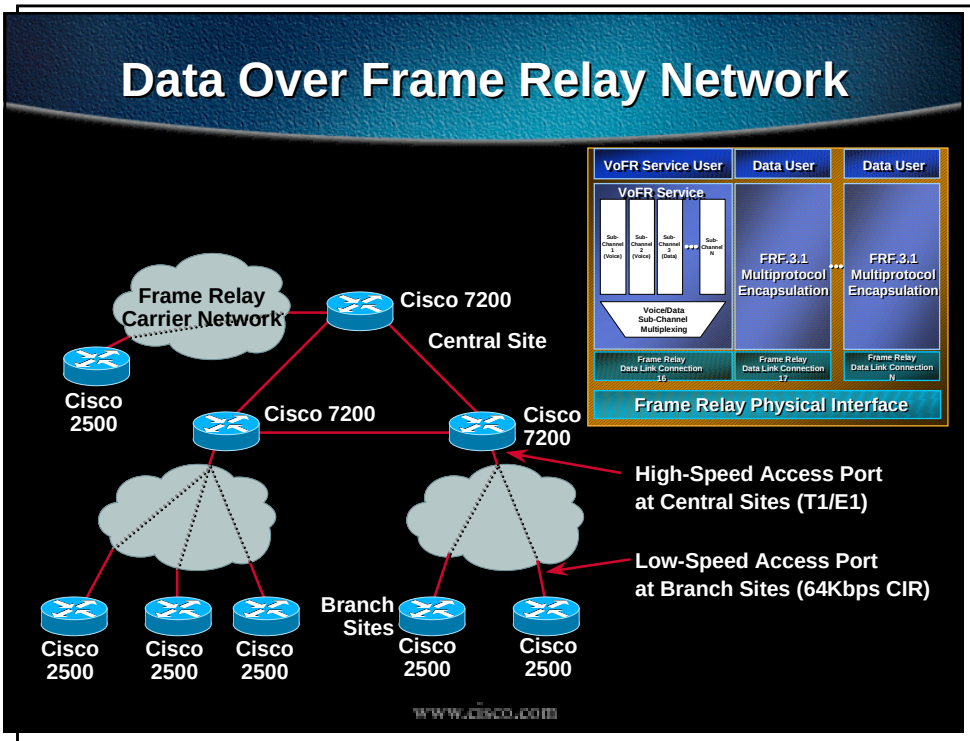
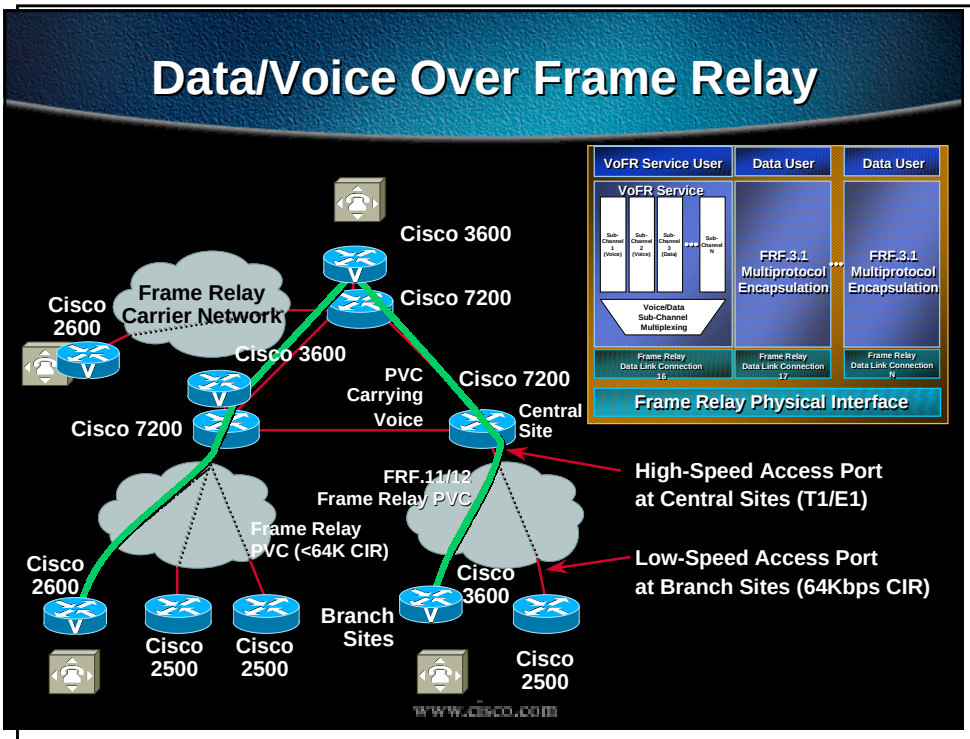
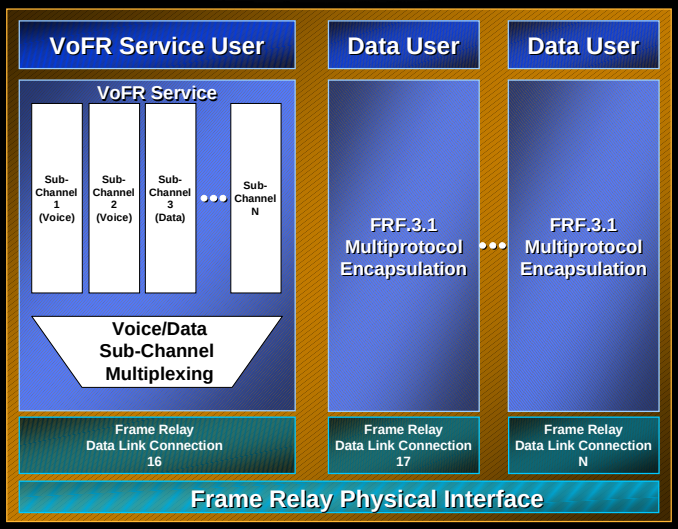




VoFR Multiplexing Model

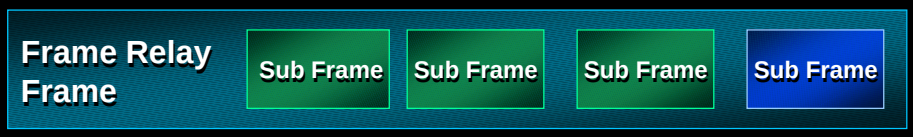


Source: Frame Relay Forum

FRF.11 Frame Format

FLAG
Frame Relay Header
FRF.11 Sub-Frame Header
Payload
FCS
FLAG

Voice and Data Encapsulation



- Multiframes transport

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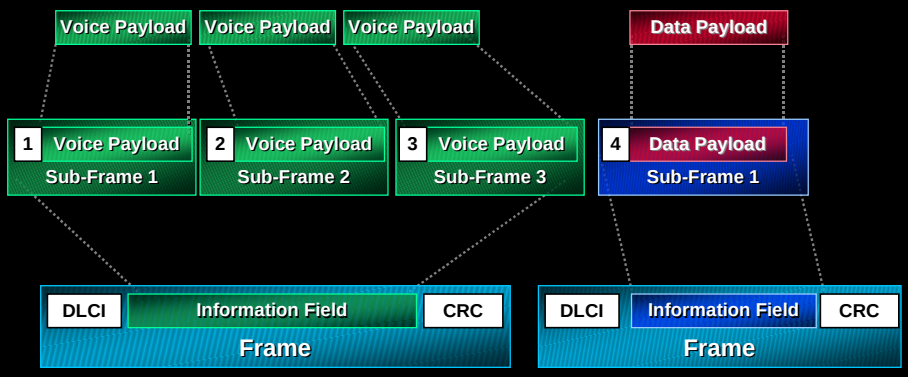
Multiple Subchannel Payloads in an FRF.11 Frame



Source: Frame Relay Forum

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FRF.11 Concept

- Extension of Frame Relay application support for compressed voice
- Multiplexing of up to 255 subchannels
- Support of multiple payloads
- Support of data sub-channel

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FRF.11 Equipment Classes

- Class 1 equipment
  - Transmission equipment in high-bandwidth environments
  - Requires G.727 EADPCM compliance
- Class 2 equipment
  - Optimizes performance over low bandwidth trunks

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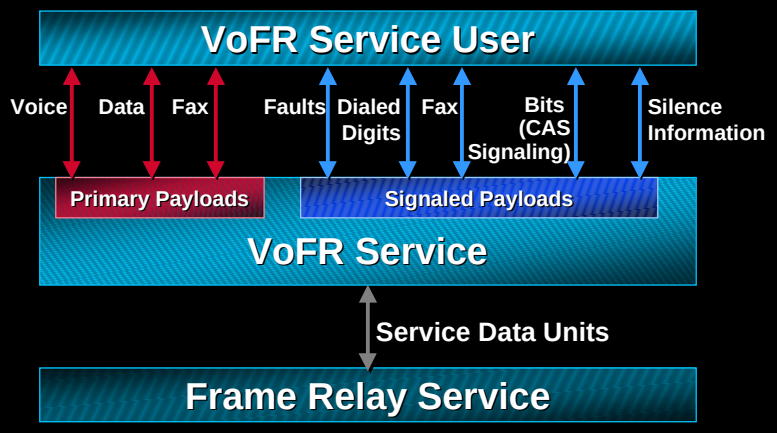
VoFR Services



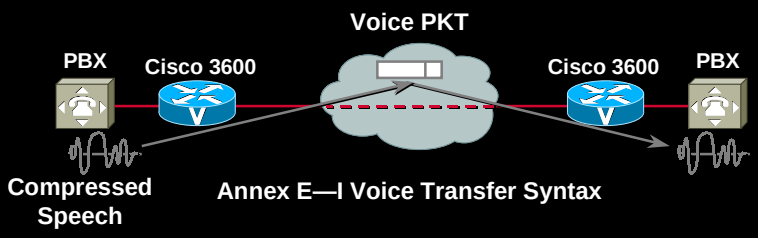
Source: Frame Relay Forum

FRF.11 Class 2 Services

- Dialed digits transfer syntax (Annex A)
- Signaling bit transfer syntax (Annex B)
- Data transfer syntax (Annex C)
- FAX relay transfer syntax (Annex D)
- CS-ACELP transfer syntax (Annex E)
- PCM/ADPCM transfer syntax (Annex F)
- G.727 D/E EADPCM voice transfer syntax (Annex G)
- G.728 LD-CELP transfer syntax (Annex H)
- G.723.1 MP-MLQ dual rate speech coder (Annex I)

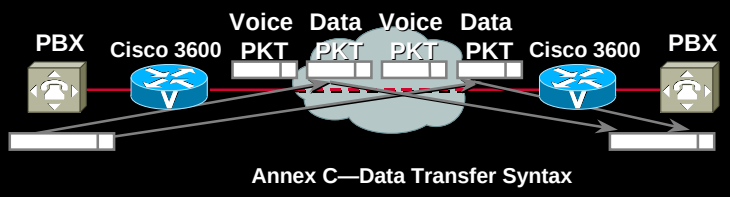
Note: Cisco Does Not Currently Support Annex G

FRF.11 Annex E, F, G, H, I: Voice Transfer Syntax



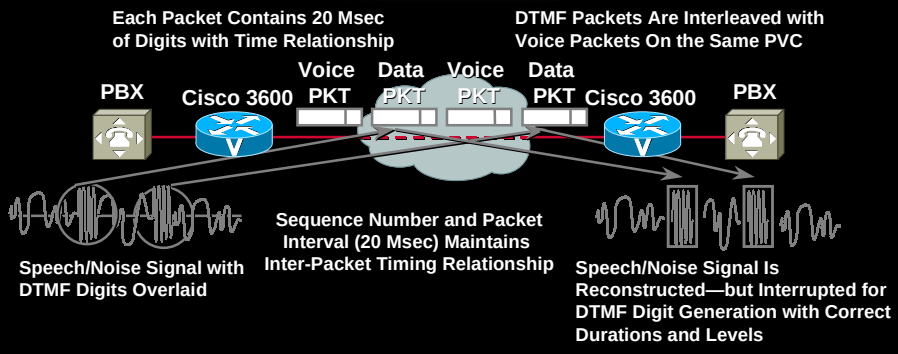
- CODEC syntax specified per annex—i.e.; Annex E—CS-ACELP G.729
- Annex F—Generic PCM/ADPCM G.711, G.726, G.727
- Annex H—LD-CELP G.728, Annex I—G.723.1
- Sequence number and coding type are optional

FRF.11 Annex C Data Transfer Syntax



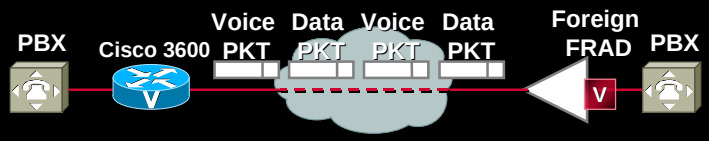
- FRF.11 subframe headers allow data and voice subchannels within a PVC
- Each packet contains a whole or a fragment of an original data frame
- Original frames smaller than the fragmentation threshold are encapsulated with both the B and E bits set

FRF.11 Annex A Dialed Digit Transfer Syntax



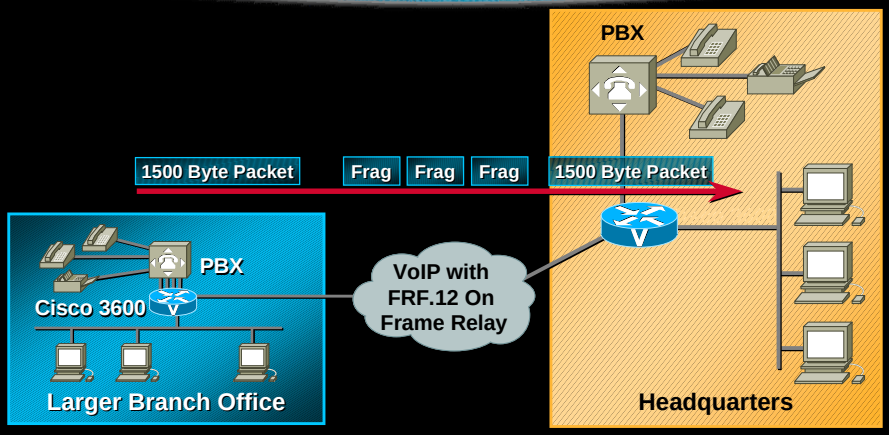
- Supports DTMF transmission for high compression CODECs
- Originating VFRAD detects DTMF and codes; destination VFRAD reproduces DTMF
- When there has been no DTMF activity for 60 msec, no more Annex A frames are generated until the next DTMF digit is detected

FRF.11 Interoperability



- In theory FRADs from different vendors can interoperate with FRF.11
- Your mileage may vary

Why FRF.12?



- Multiple PVCs—some with FRF3.1 data on same physical interface
- Can be used with VoIP
- Fragments and interleaves large data frames with voice packets

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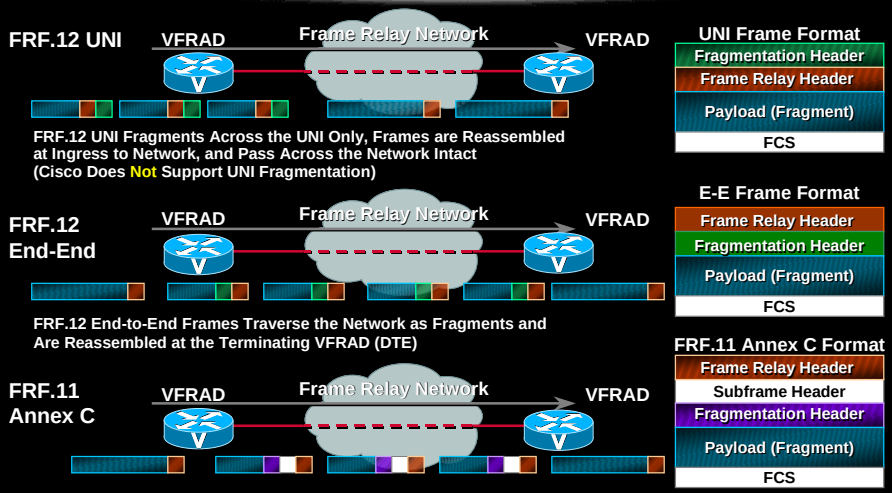
Comparison of FRF.11/12 Fragmentation Schemes



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Fragmentation Frame Size Matrix

Real Time Packet Interval

Link Speed	10 ms	20 ms	30 ms	40 ms	50 ms	100 ms	200 ms
56 kbps	70 Bytes	140 Bytes	210 Bytes	280 Bytes	350 Bytes	700 Bytes	1400 Bytes
64 kbps	80 Bytes	160 Bytes	240 Bytes	320 Bytes	400 Bytes	800 Bytes	1600 Bytes X
128 kbps	160 Bytes	320 Bytes	480 Bytes	640 Bytes	800 Bytes	1600 Bytes X	3200 Bytes X
256 kbps	320 Bytes	640 Bytes	960 Bytes	1280 Bytes	1600 Bytes X	3200 Bytes X	6400 Bytes X
512 kbps	640 Bytes	1280 Bytes	1920 Bytes X	2560 Bytes X	3200 Bytes X	6400 Bytes X	12800 Bytes X
768 kbps	1000 Bytes	2000 Bytes X	3000 Bytes X	4000 Bytes X	5000 Bytes X	10000 Bytes X	20000 Bytes X
1536 kbs	2000 Bytes X	4000 Bytes X	6000 Bytes X	8000 Bytes X	10000 Bytes X	20000 Bytes X	40000 Bytes X

X—Fragmentation not an issue due to BW + Interval Combination

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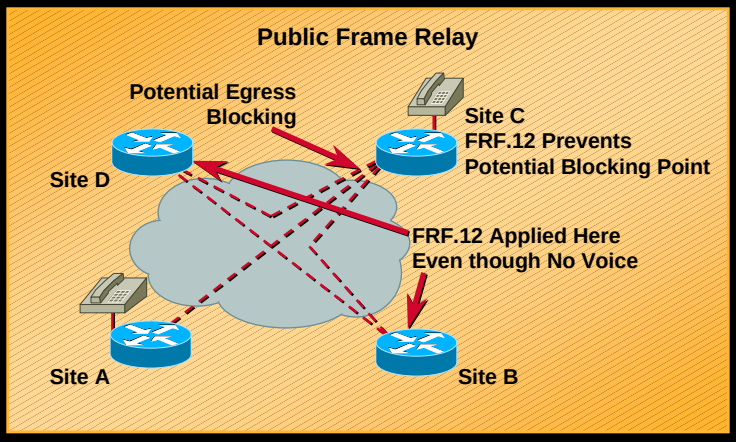
Egress Blocking/Fragmentation



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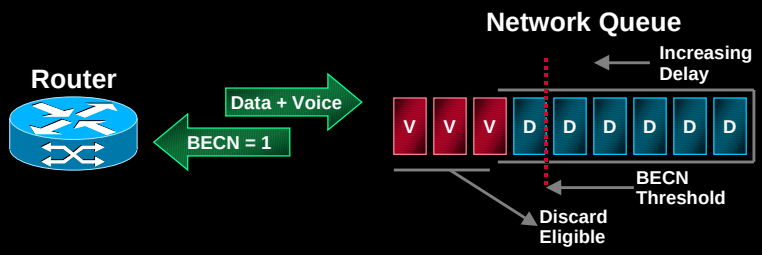
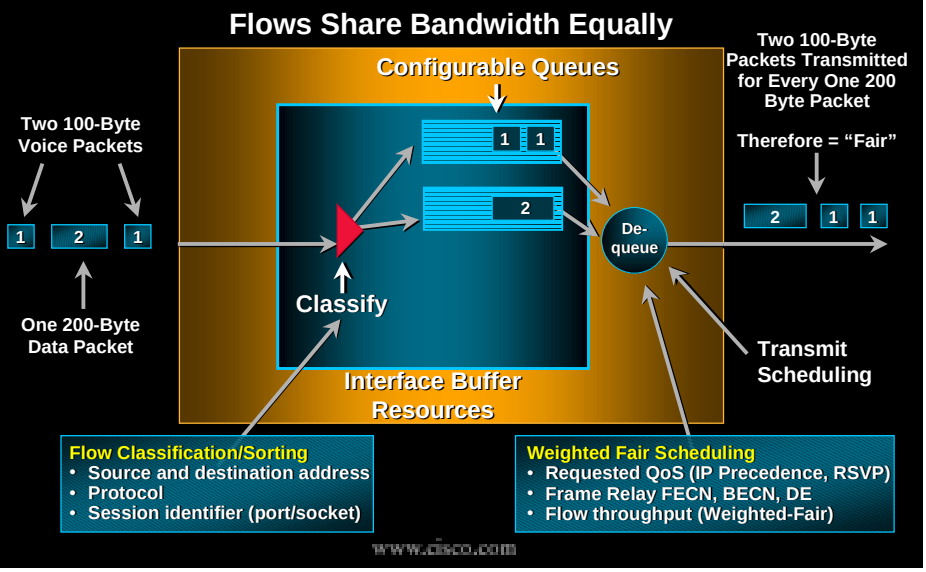
VoFR Network Design Considerations

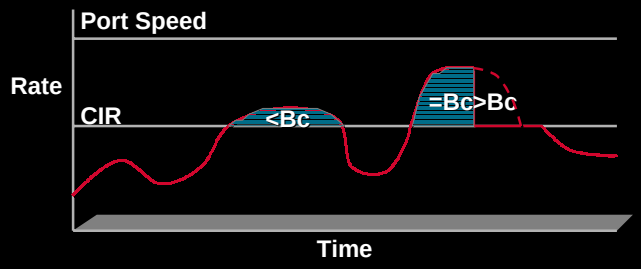


- If network queues are filling…
  - Voice may experience excessive delay
  - Voice may be discarded
  - Router throttles back on BECN—but it's too late—queues are full and voice packets are dropped
- Voice quality may be negatively affected

VoFR Design Considerations—Queuing (WFQ)



Frame Relay Traffic Shaping



- Traffic shaping provides voice and data quality of service
- Allows better utilization of CIR by shaping data

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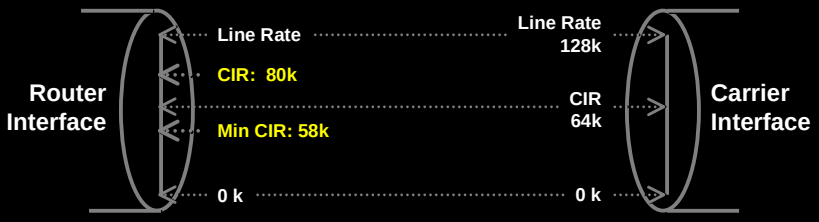
Single PVC Design Considerations



- Goal is best voice quality, NOT data volume
- Contract CIR to meet calculated requirements
- Shape conservatively
- Have carrier set BECN threshold to a smaller setting
- Set traffic shaping parameters for finest granularity

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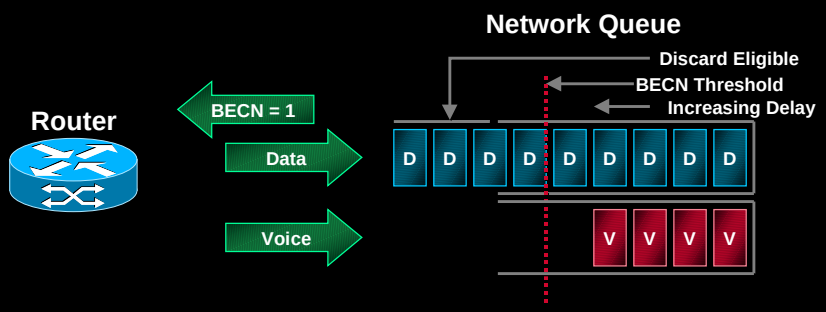
Multiple PVC Design Considerations



- Separate queues maintain voice quality
  - More deterministic—voice won't burst
- Priority PVCs from carrier for voice

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Calculating VoFR Bandwidth

- Assumptions:
  - G.729 Codec at 8 Kbps
  - 50 PPS (using 2–10 ms samples)
  - 2 bytes of DLCI header
  - 2 bytes of FRF.11 header
  - 1 byte of sequence number
  - 2 byte CRC

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Calculating VoFR Bandwidth

- Voice payload calculation
  - 20 Msec voice sample * 8 Kbps (for G.729)/ 8 bits/byte = 20 bytes
  - Note: to derive the payload for G.711, substitute 64 kbps = 160 bytes
- Packet size calculations
  - 20 byte payload + 7 byte Header = 27 bytes (Header = DLCI/FRF.11/seqn/CRC)
- Bandwidth calculations
  - 27 b/voice packet * 8 bits/byte * 50 pps = 10.8 Kbps per call

CIR Critical Factors

- PVC design
  - Full mesh vs star
  - Shared vs separate PVCs for voice and data
- Potential concurrent calls
  - Bandwidth per call
  - Switched through calls
- Pre-existing data environment
  - Utilization prior to adding voice

VoFR Summary

- FRF.11 standards-based voice and function syntax
- FRF.12 standards-based fragmentation for data, mitigates delay and delay variation
- Proper PVC design for network requirements
- Balance voice quality, delay, bandwidth, CIR

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VoFR Summary

- Avoid tandem (multiple) conversions
- Calculate delay for chosen design
- Check for Egress blocking
- Calculate CIR for total potential voice and/or data per PVC
- Configure queuing and traffic shaping

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References

- [1] FRF.3.1, R. Cherukuri (ed), Multiprotocol Encapsulation Implementation Agreement, June 22–1995
- [2] FRF.9, D. Cantwell (ed), Data Compression Over Frame Relay Implementation Agreement, January 22–1996
- [3] FRF.11.1 K. Rehbehn, R. Kocen, T. Hatala (eds), Voice Over Frame Relay Implementation Agreement, December 1998
- [4] FRF.12, A. Malis (ed), Frame Relay Fragmentation Implementation Agreement, 1997
- [5] ITU Recommendation Q.922, ISDN Data Link Layer Specification for Frame Mode Bearer Services, 1992

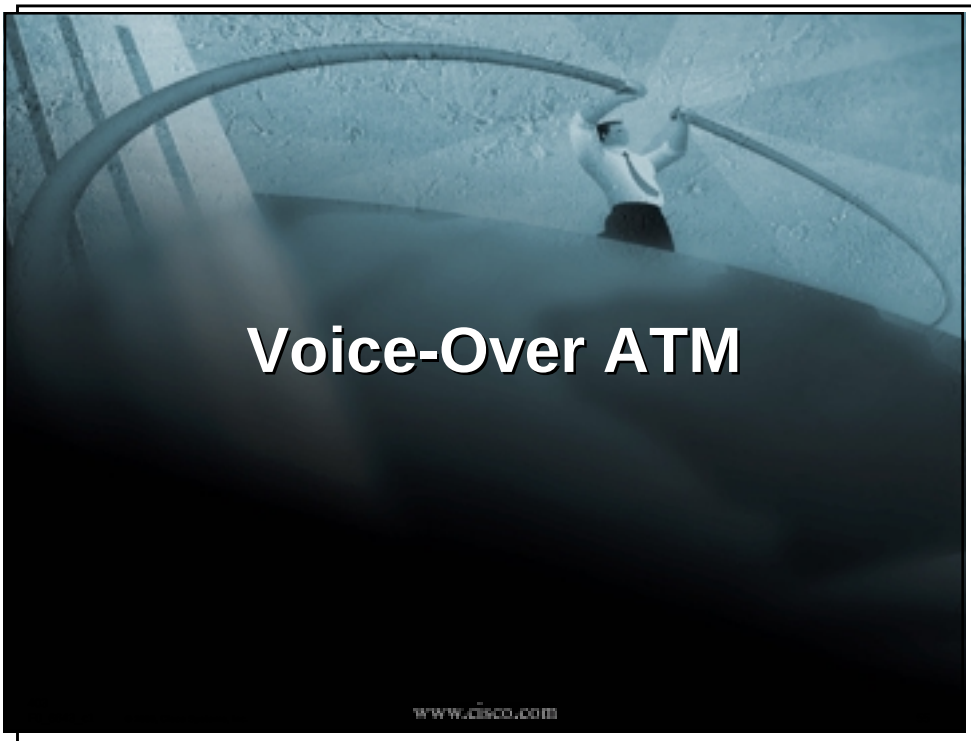
Web Sites

- **Cisco**

  http://www.cisco.com—search on VoFR

- **Frame Relay Forum**

  http://www.frforum.com/



Voice-Over ATM Network Design

- ATM reference model
- ATM service categories
- Circuit emulation
- Packetized voice
- Network designs
- Bandwidth calculations

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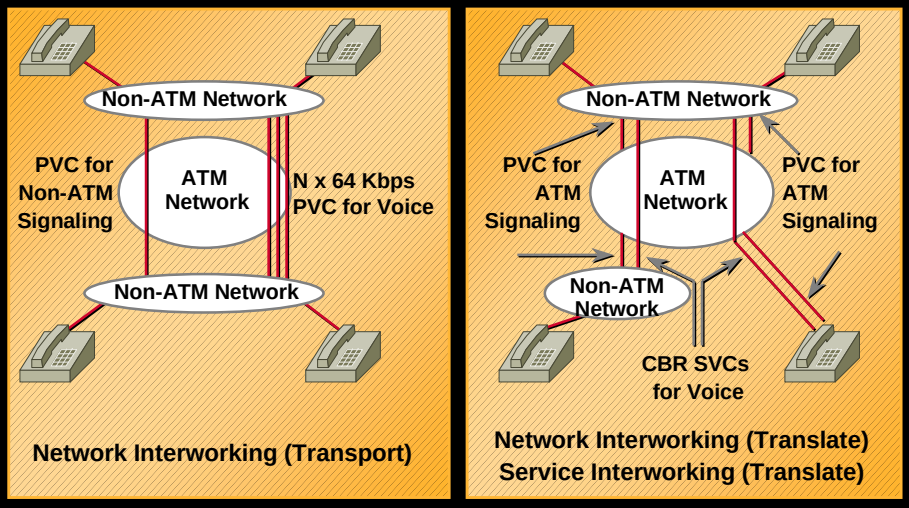
VoATM Signaling



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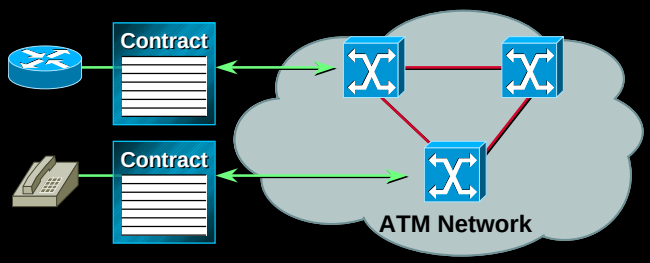
ATM Service Criteria



- **Contract**
  - Traffic descriptors
    - Peak cell rate
    - Sustainable cell rate
    - Maximum burst size
    - Minimum cell rate
  - Quality of service
    - Delay
    - Cell loss

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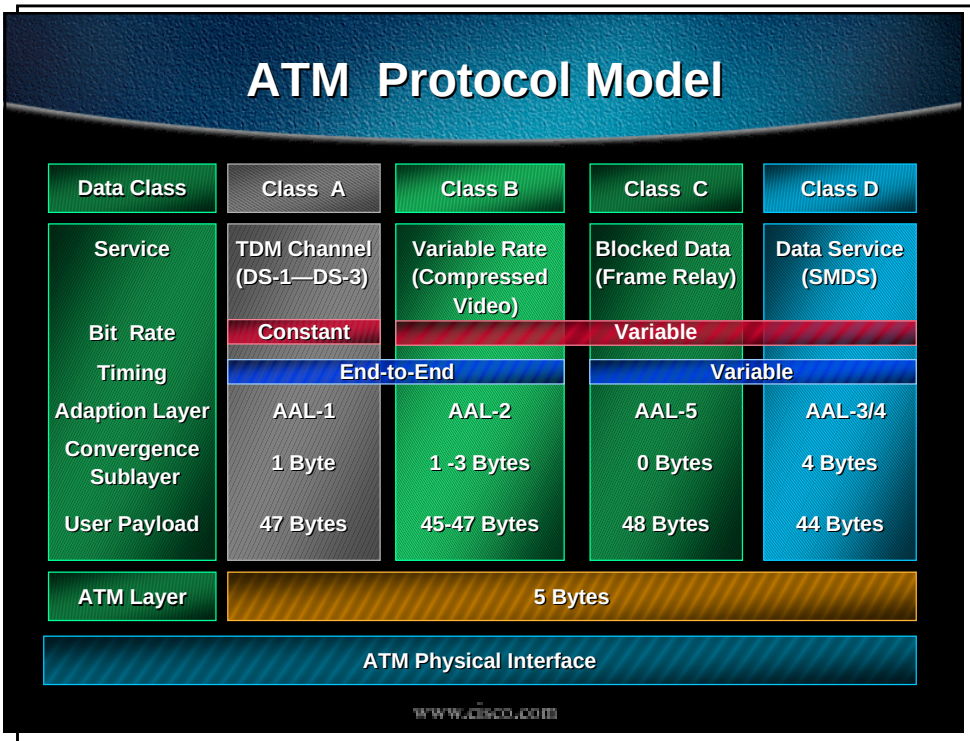
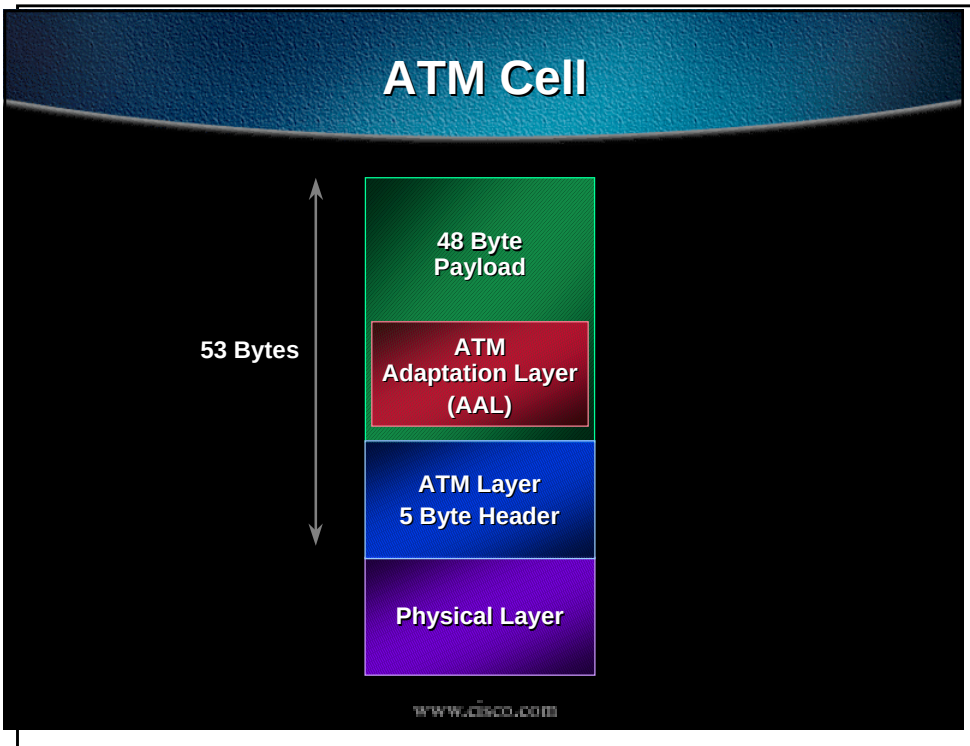
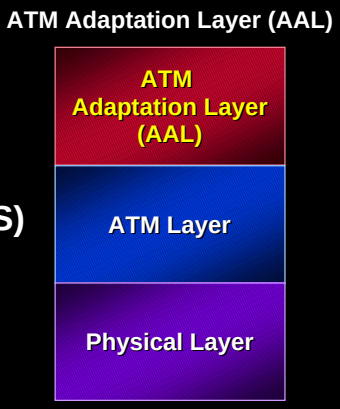




ATM Reference Model

- Two sublayers
  - Convergence Sublayer (CS)
  - Segmentation and Reassembly (SAR)



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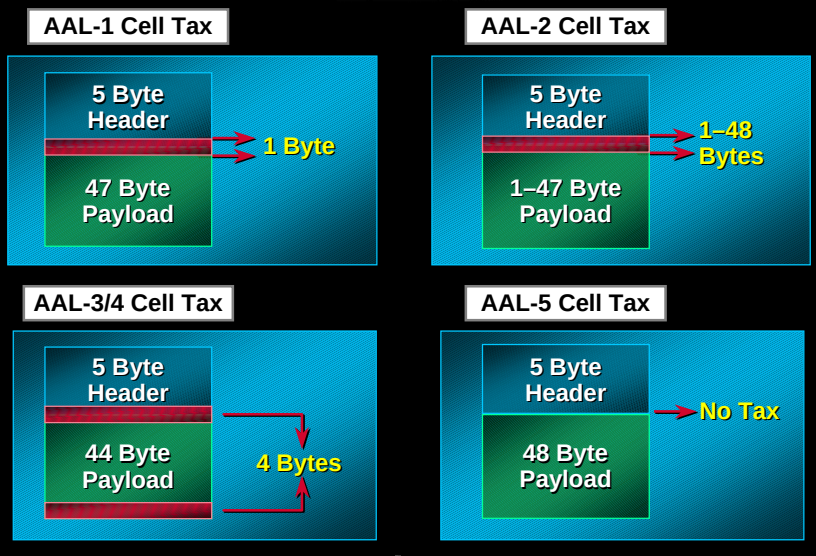
AAL Cell Tax



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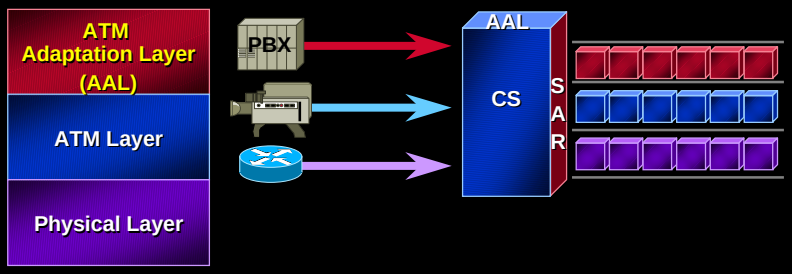
ATM Adaptation Layer—AAL



- AAL = CS + SAR
- CS—cell tax
- SAR—cell <-> packet

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ATM Classes of Service

- **Service criteria**
  - Traffic descriptors
  - QoS parameters
- **Service categories**
  - Constant Bit Rate (CBR)
  - Variable Bit Rate (VBR)
  - Unspecified Bit Rate (UBR)
  - Available Bit Rate (ABR)

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ATM Service Criteria

Traffic Parameters

- **Peak Cell Rate—PCR**—maximum data rate a connection can handle without losing data
- **Sustainable Cell Rate—SCR**—average ATM cell throughput the application is permitted
- **Maximum Burst Size—MBS**—size of the maximum burst of contiguous cells that can be transmitted
- **Minimum Cell Rate—MCR**—rate of an application's ability to handle latency

ATM Service Criteria

QoS Parameters

- Maximum Cell Transfer Delay—**MCTD** how long the network can take to transmit a cell from one endpoint to another
- Cell Delay Variation Tolerance—**CDVT** line distortion caused by change in interarrival times between cells aka jitter

ATM Service Criteria

QoS Parameters

- Cell Loss Ratio—CLR acceptable percentage of cells that the network can discard due to congestion

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ATM Classes of Service

- Service criteria
  - Traffic descriptors
  - QoS parameters
- Service categories
  - Constant Bit Rate (CBR)
  - Variable Bit Rate (VBR)
  - Unspecified Bit Rate (UBR)
  - Available Bit Rate (ABR)

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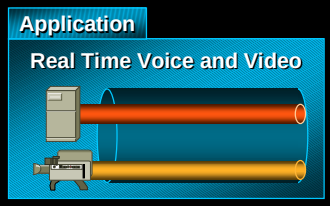
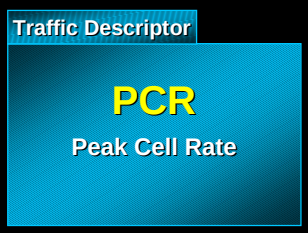
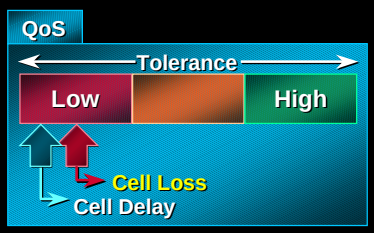
ATM Service Categories

Constant Bit Rate (CBR)

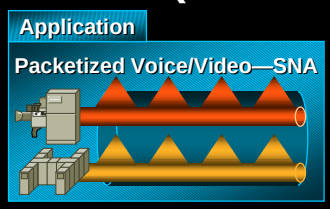


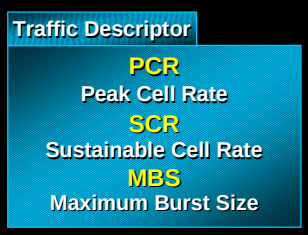


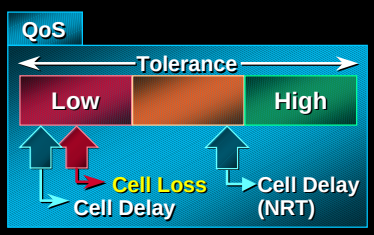


ATM Service Categories

Variable Bit Rate (VBR-RT/VBR-NRT)

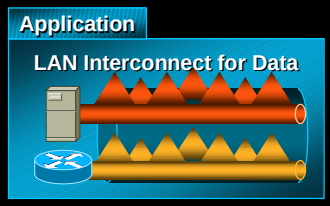


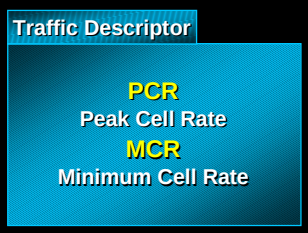


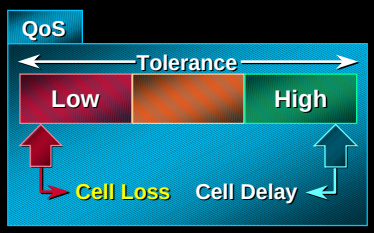


ATM Service Categories

Available Bit Rate (ABR)







Also Uses Congestion Feedback Mechanisms

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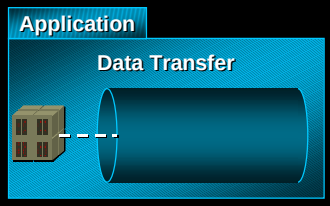
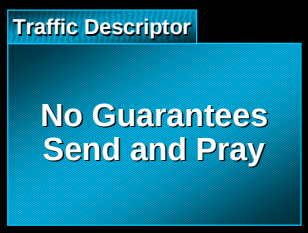
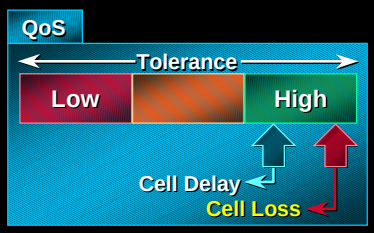
ATM Service Categories

Unspecified Bit Rate (UBR)







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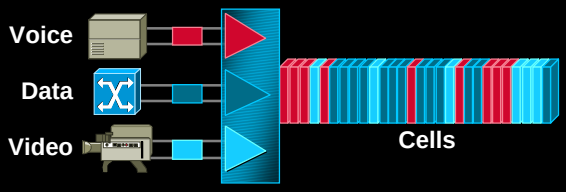
Characteristics of ATM



- Uses small, fixed-sized cells
- Connection oriented
- Supports multiple-service types
- Applicable to LAN and WAN

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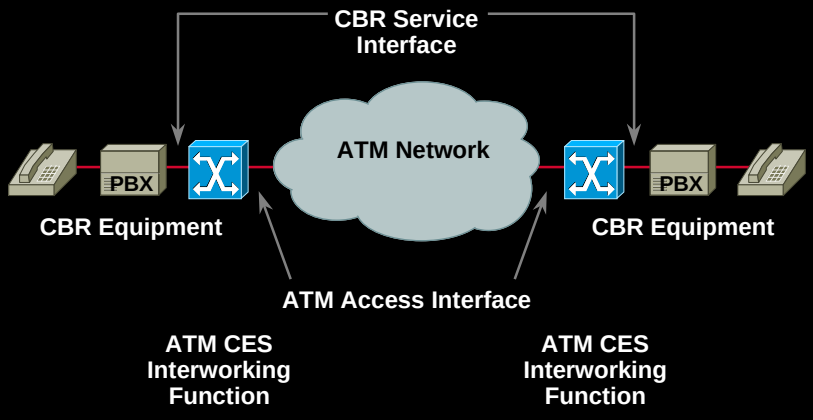
CES Reference Model



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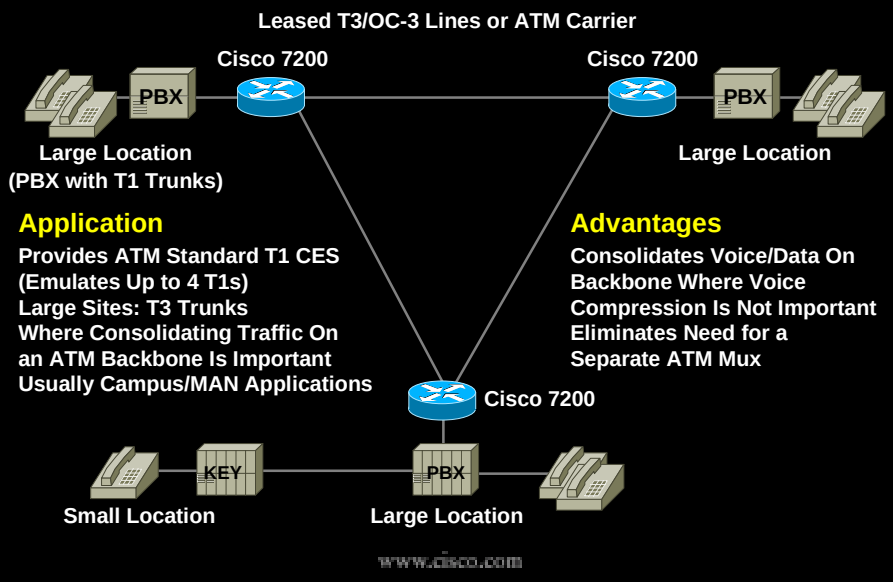
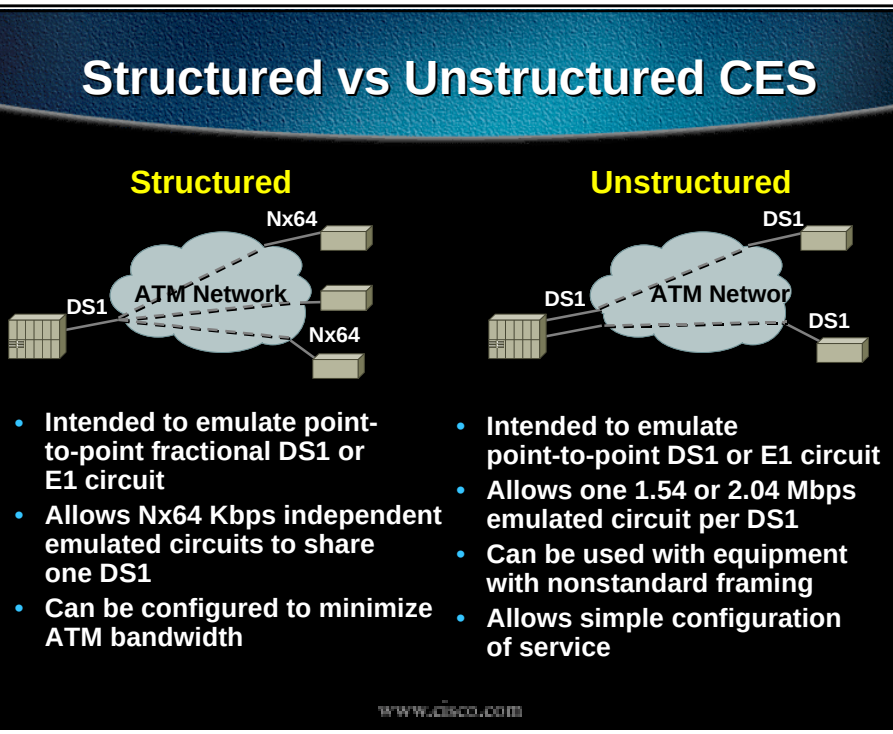
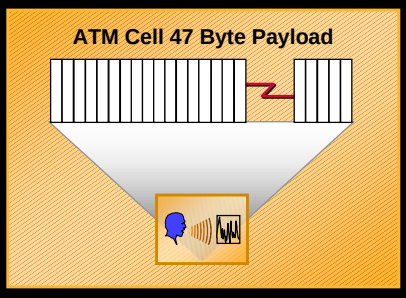
CES Voice Network



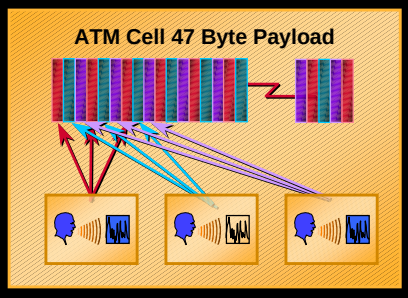
Structured vs Unstructured CES



ATM Voice Transport Choices



- Unstructured circuit emulation service
- Entire payload filled with one voice channel
- Or a continuous stream of bytes from an E1 circuit is placed into cells



- Structured circuit emulation service
- Entire payload filled with many voice channels
- DS0 structure information is maintained

Note: AAL1 Uses One Byte for Overhead

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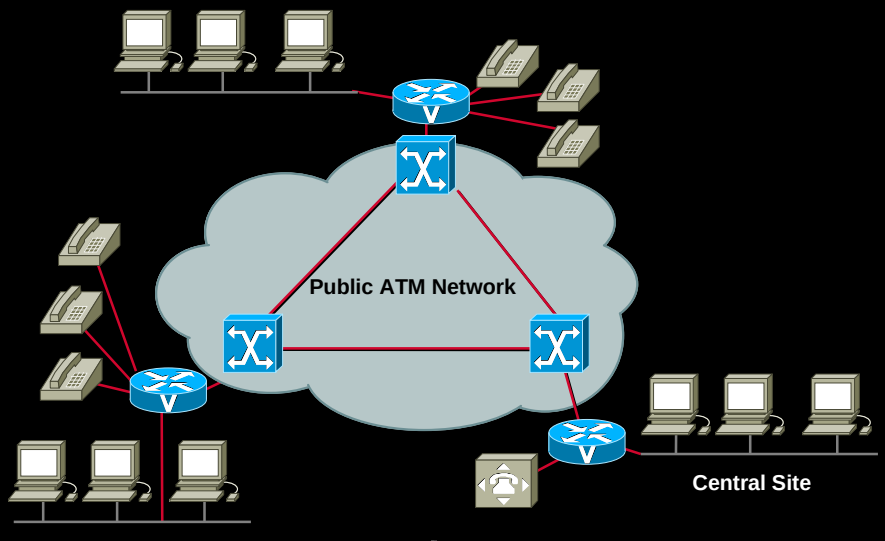
Data/Voice Over ATM (AAL5)



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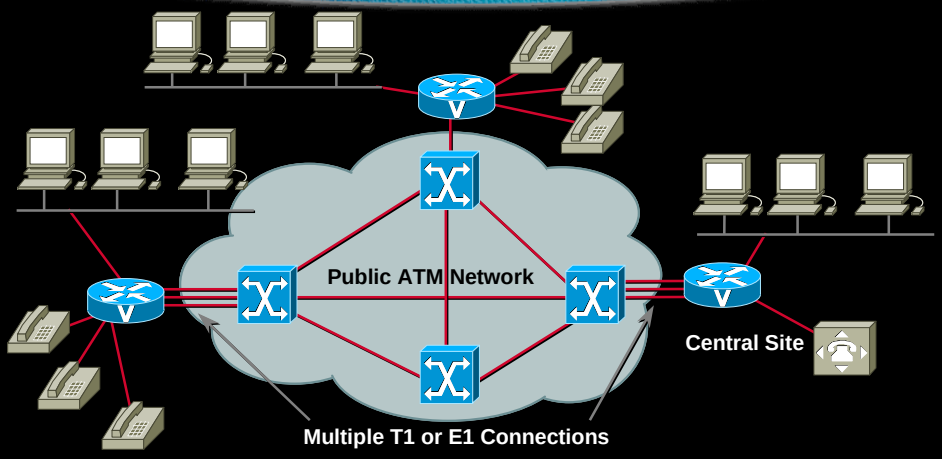
Inverse Multiplexing (IMA)



- Uses AAL5; 48 bytes for data
- Binds multiple PVCs to a single logical interface
- Prioritizes voice cells over data cells

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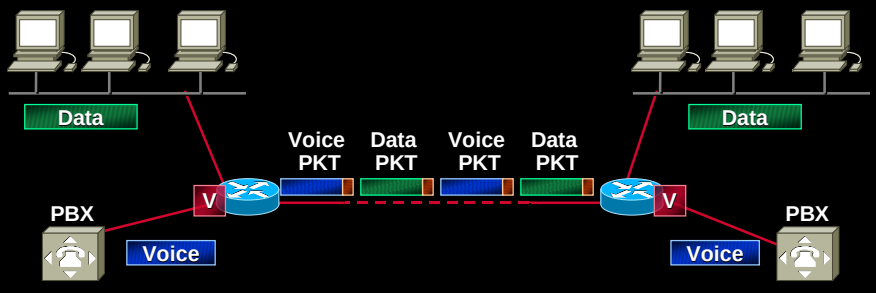
ATM AAL5 Voice and Data Cells



- AAL 5 does not require convergence sub-layer
- 48 Byte payload available for voice/data
- Voice payload = voice sample + padding = 48 bytes
- 5 byte ATM header

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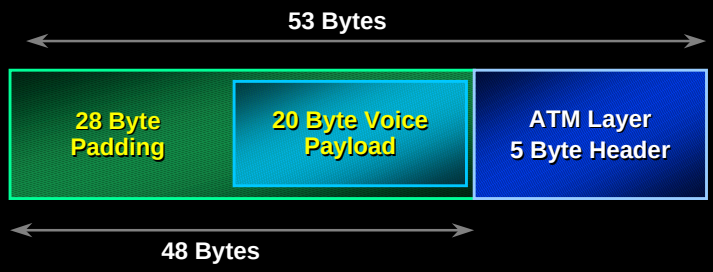
ATM AAL5 Voice Cells



- G.729 compression with 20 ms voice sample
- No AAL5 CS “cell tax”
- 28 Bytes “overhead” due to padding

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VoATM Bandwidth

- Voice payload calculation

  20 msec voice sample * 8 Kbps (for G.729)/8 bits/byte = 20 bytes

  Note: to derive the payload for G.711, substitute 64 Kbps = 160 bytes

- Packet size calculations

  20 byte payload + 28 byte pad +5 byte header = 53 bytes

- Bandwidth calculations

  53 b/voice packet * 8 bits/byte * 50 pps = 21.2 Kbps per call

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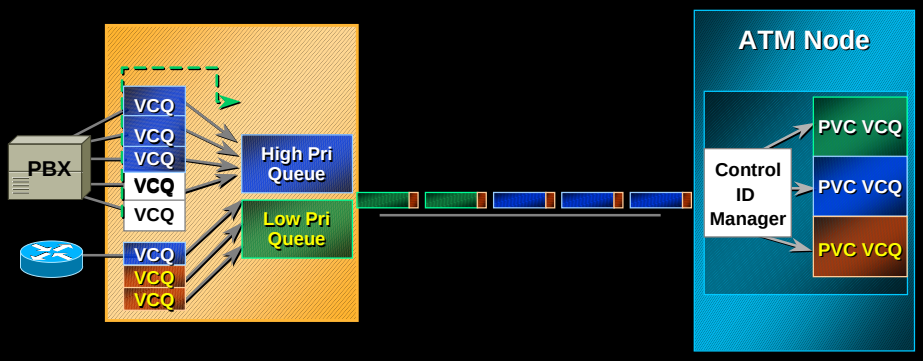
Priority Queuing



Quality of Service (QoS)
Extends Across Entire Network

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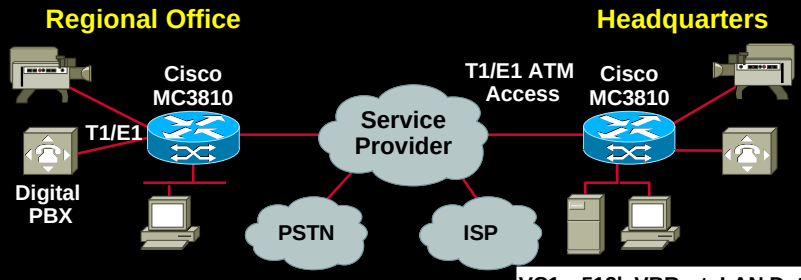
Regional Office—ATM Over T1/E1



- LAN data
- Internet connection
- Voice traffic
- Video application
- C.O. circuit via CES (future)

VC1—512k VBRnrt, LAN Data
VC2—256k VBRrt, 24 Voice Calls
VC3—768k CBR, Video
VC4—VC8 80k CBR, Voice Circuits

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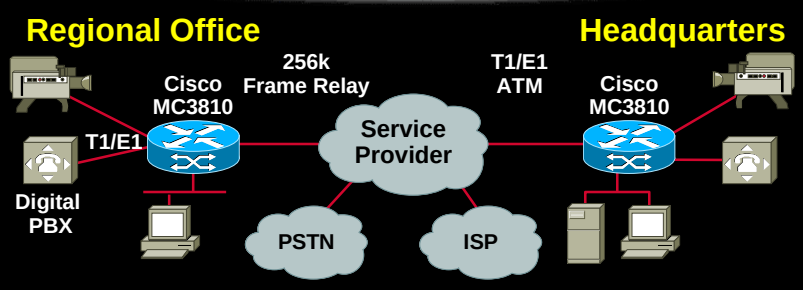
Frame Relay/ATM Interworking



- Network interworking
  - FRF.5
  - Frame Relay encapsulation
- Service interworking compatible
  - FRF.8
  - Carrier compatible

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VoATM—Summary

- ATM reference model
- Fixed size cells—Delay
- Service category—CBR, VBR, ABR
- Service criteria for QoS, SCR, CDVT
- Chose service for requirements—Circuit emulation (AAL1) voice over AAL5
- Combined networks

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References

ATM Forum af-phy-0016.000	DS1 Physical Layer Specification
ATM Forum af-phy-0064.000	E-1 Physical Layer Specification
ATM Forum af-saa-0032.000	Circuit Emulation
ATM Forum af-uni-0010.002	UNI Signaling 3.1
IETF RFC1483	Multiprotocol Over ATM
IETF RFC1577	IP Over ATM
IETF RFC1695	AToM MIB
ANSI T1.630—ITU I.363—I.363.	ATM AAL 1 (Constant Bit Rate)
ANSI T1.635—ITU I.363.5	ATM AAL 5 (Variable Bit Rate)

Web Sites

- Cisco

  http://www.cisco.com
- ATM Forum

  http://www.atmforum.com/