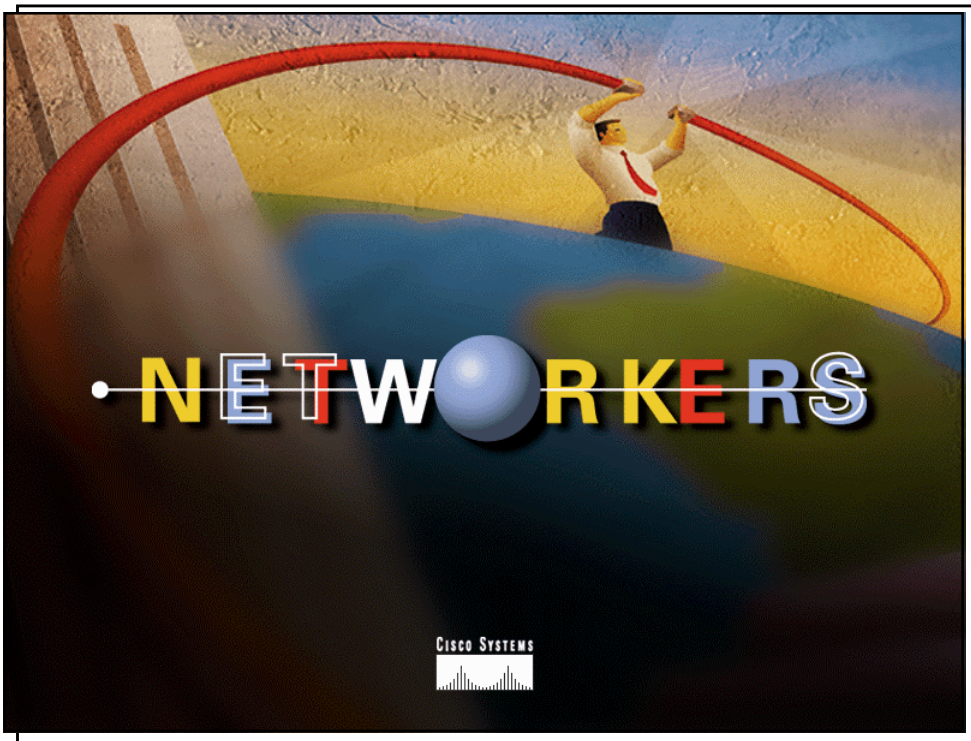
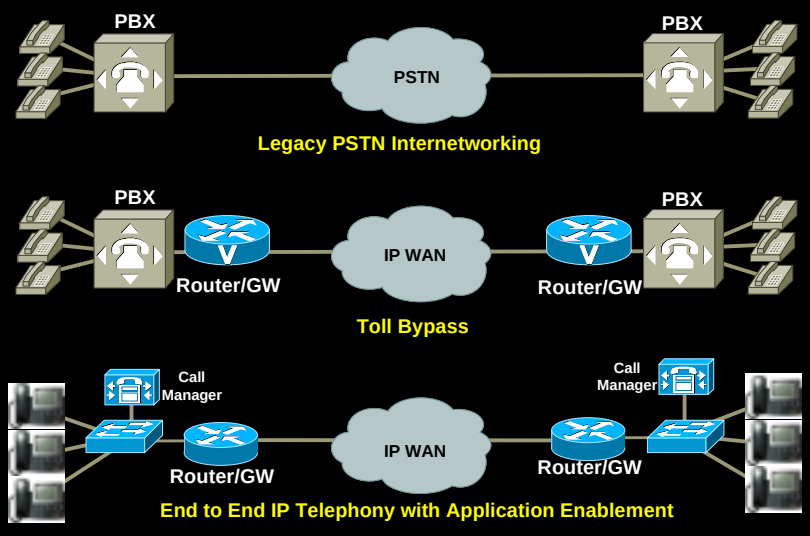


Enterprise Voice Evolution to IP Telephony



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Tuning for Voice Quality

Problem Avoidance

Analyze Problem Sources and Implement Appropriate Tools and Guidelines to Deliver Required Voice Quality

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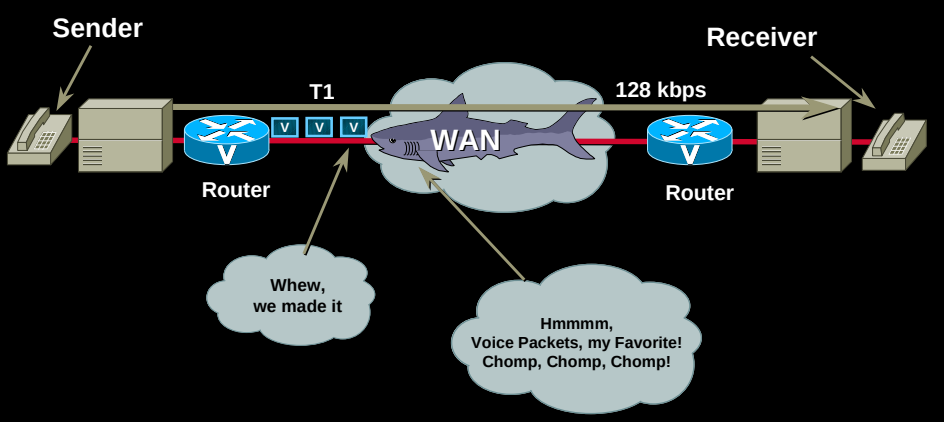
More than Just Providing Router QoS
The World Is Not All Point-to-Point Links



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Agenda

- VoIP Requirements and Challenges
- Router/Switch Egress QoS Study
- WAN QoS Design Considerations
- Tuning—Audio Level and Echo
- Best Practice Recommendations

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Data and Voice Opposite Needs/Behavior

Data

- Bursty
- Greedy
- Drop sensitive
- Delay insensitive
- TCP retransmits

Voice

- Smooth
- Benign
- Drop insensitive
- Delay sensitive
- UDP best effort

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Voice over IP Protocols VoIP Is Not Bound to H.323

(H.323 Is a Signaling Protocol)
Many Other Signaling Protocols—MGCP, SGCP, SIP etc.

Commonality—Voice Packets Ride on UDP/RTP

Voice Payload	G.711, G.729, G.723(.1)
Transport	RTP/UDP
Network	IP
Link	MLPPP/FR/ATM AAL1
Physical	– – –

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"Payload" Bandwidth Requirements for Various Codecs

Encoding/Compression	Resulting Bit Rate
G.711 PCM A-Law/u-Law	64 kbps (DS0)
G.726 ADPCM	16, 24, 32, 40 kbps
G.727 E-ADPCM	16, 24, 32, 40 kbps
G.729 CS-ACELP	8 kbps
G.728 LD-CELP	16 kbps
G.723.1 CELP	6.3/5.3 kbps

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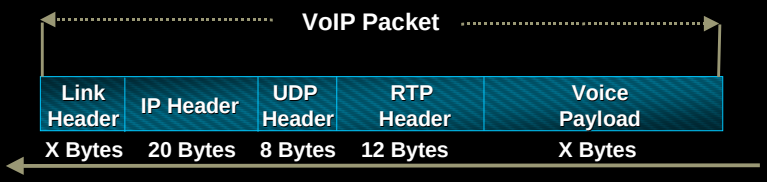
VoIP Packet Format



- Payload size, PPS and BPS vendor implementation specific
- For example:

Not Including Link Layer Header or CRTP

Cisco Router at G.711	= 160 Byte Voice Payload at 50pps (80 kbps)
Cisco Router at G.729	= 20 Byte Payload at 50 pps (24 kbps)
Cisco IP Phone at G.711	= 240 Byte Payload at 33 pps (74.6 kbps)
Cisco IP Phone at G.723.1	= 24 Byte Payload at 33 pps (17 kbps)

Note—Link Layer Sizes Vary per Media

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Various Link Layer Header Sizes "Varying Bit Rates per Media"

Example—G.729 with 60 byte Packet (Voice and IP Header) at 50 pps (No RTP Header Compression)

Media	Link Layer Header Size	Bit Rate
Ethernet	14 bytes	29.6 kbps
PPP	6 bytes	26.4 kbps
Frame Relay	4 Bytes	25.6 kbps
ATM	5 Bytes Per Cell	42.4 kbps

Note—For ATM a Single 60 byte Packet Requires Two 53 Byte ATM Cells

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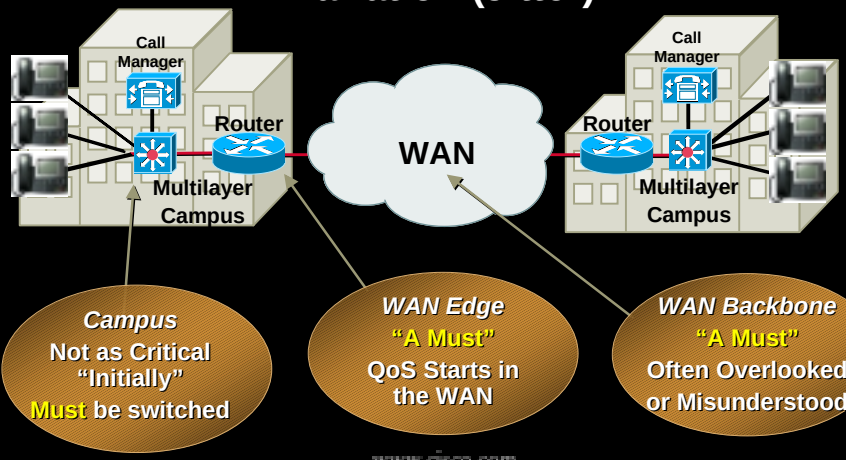
Domains of QoS Consideration Strong as Your Weakest Link

Avoiding Loss, Delay, and Delay Variation (Jitter)



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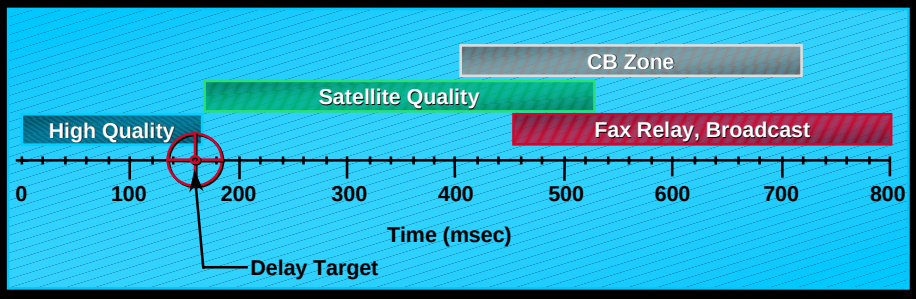
Goals
Consistent Loss Less Packet Delivery

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



Cumulative Transmission Path Delay
Avoid the "Human Ethernet"

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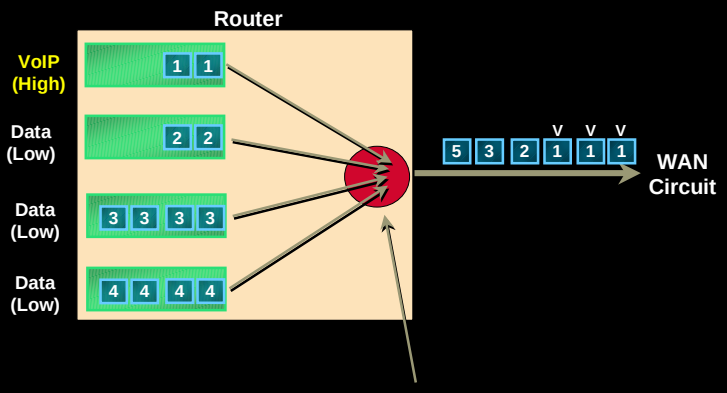
Sources of Trouble
Congestion Points



Results in Buffering (Delay) +
Eventually Dropped Packets (Loss)

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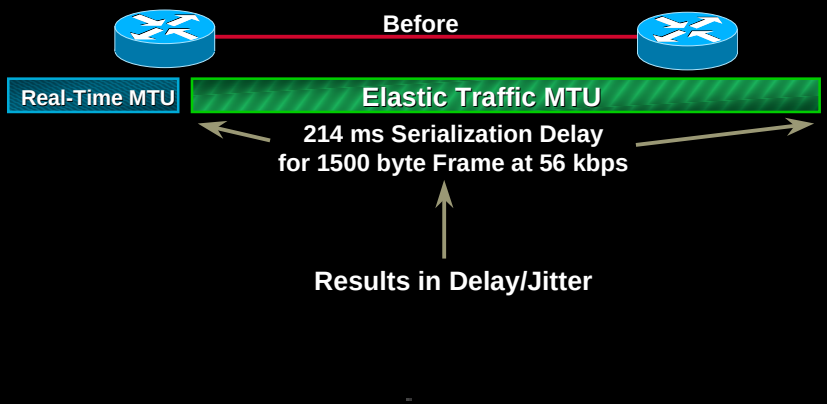
Sources of Trouble
Slow Links



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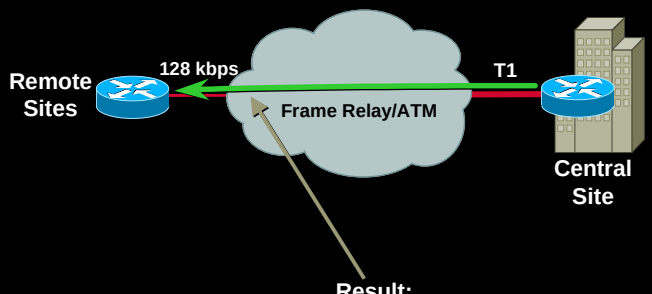
Sources of Trouble
Speed Mismatches



Result:
Buffering which Will Cause Delay
and Eventually Dropped Packets

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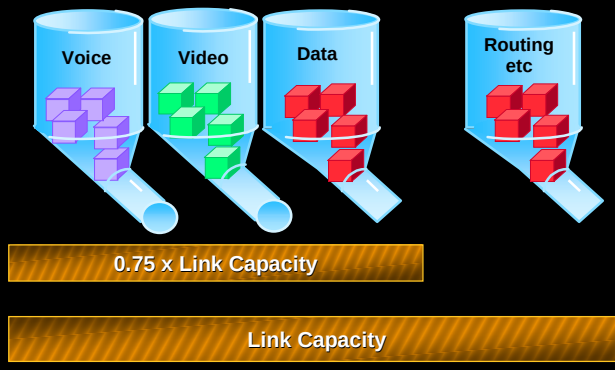
Sources of Trouble Capacity Planning

Voice Is Not Free—Especially on Low-Speed Links—Plan Capacity for Voice



Link Capacity = (Min BW for Voice + Min BW for Video + Min BW for Data)/0.75

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Agenda

- VoIP Requirements and Challenges
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- WAN QoS Design Considerations
- Tuning—Audio Level and Echo
- Best Practice Recommendations

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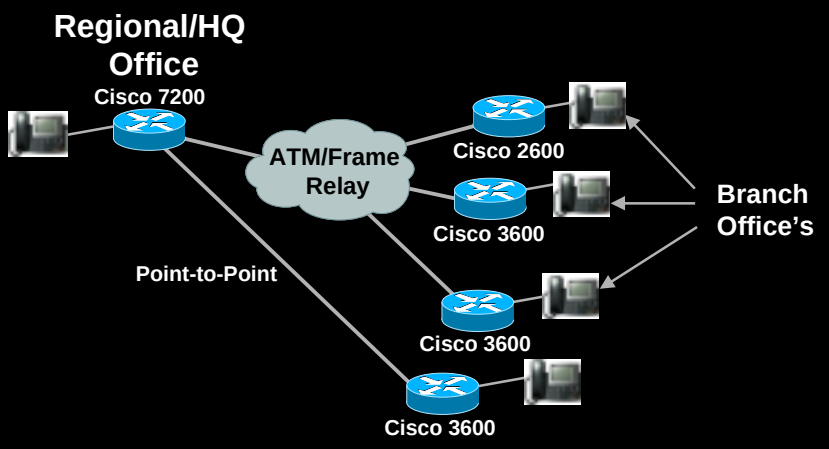
Case Study: End-to-End Quality of Service



Applying Appropriate Tools in Required Location(s)

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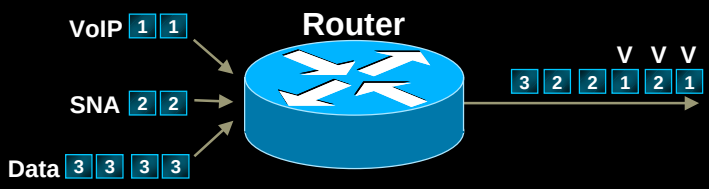
Three Classes of QoS Tools



- **Prioritization**
  - Classification + queuing
- **Slow link efficiency**
  - LFI (Link Fragmentation and Interleave)
  - Compression, Voice Activity Detection (VAD)
- **Traffic shaping**
  - Speed mismatches

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Prioritization
WAN Egress QoS

- **Classification mechanisms**
  - Identifying voice traffic as an important data stream
- **Queuing mechanisms**
  - "Giving" voice priority

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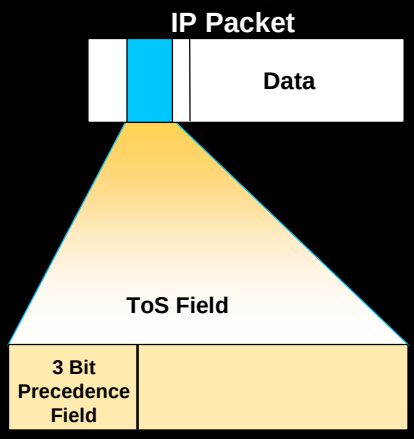
IP Precedence



IP Precedence

Not a QoS Mechanism Turned on in the Router

"In Band" QoS Signaling—Set in the End Point

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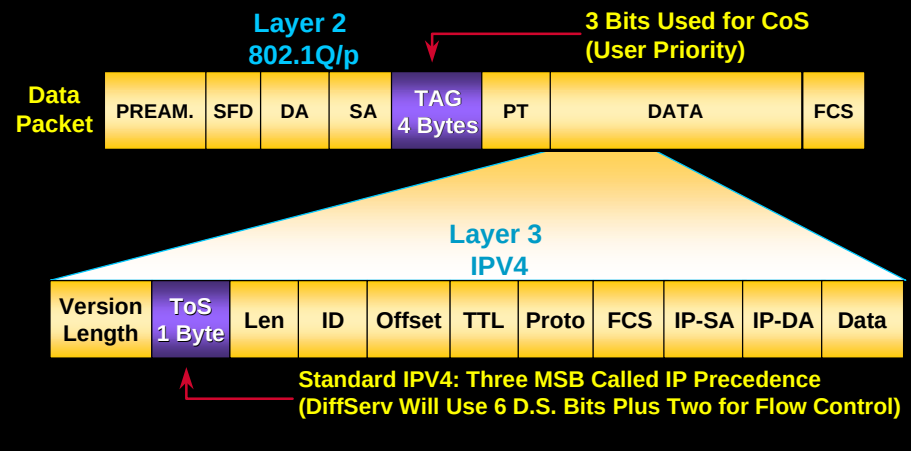
Traffic Differentiation Mechanisms IP Precedence and 802.1p



Layer 2 Mechanisms Are Not Assured End-to-End
Layer 3 Mechanisms Provide End-to-End Classification

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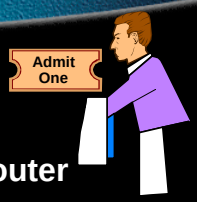
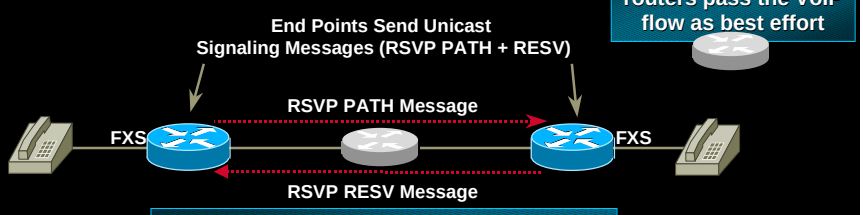
RSVP: Resource Reservation Protocol

- IETF signaling protocol
  - Reservation of bandwidth and delay
- Flow can be signaled by end station or by router (static reservation)
- Basically reserves queue space





RSVP enabled router see the PATH and RESERVE messages and allocate the appropriate queue space for the given flow

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Prioritization
WAN Egress QoS

- **Classification mechanisms**
  - Identifying voice traffic as an important data stream
- **Queuing mechanisms**
  - "Giving" voice priority

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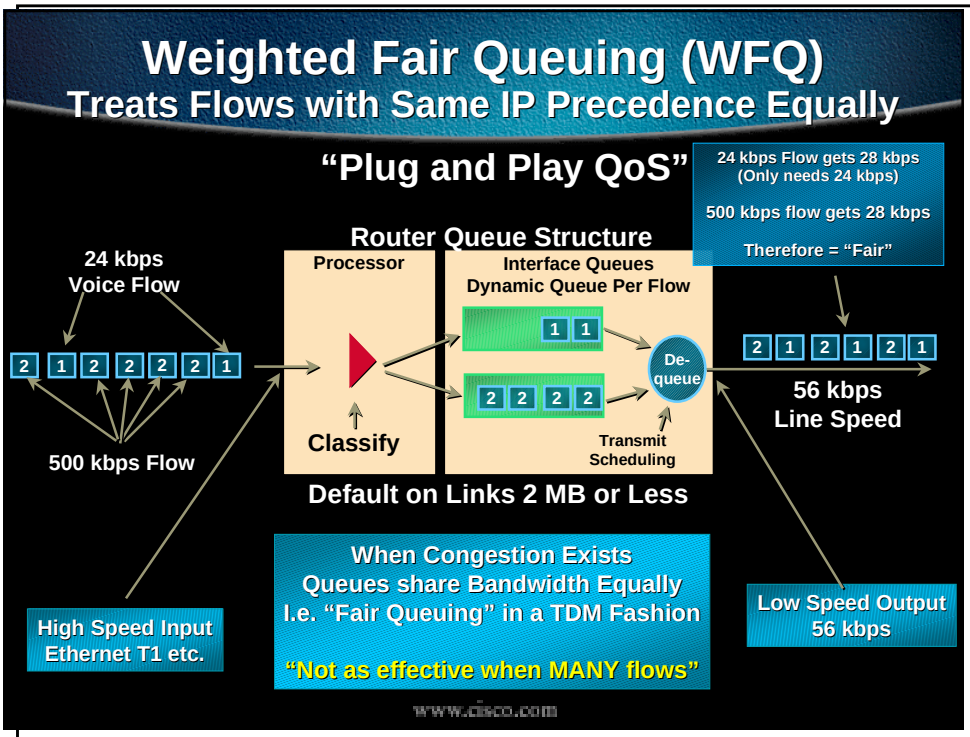
Weighted Fair Queuing (WFQ)
Treats Flows with Same IP Precedence Equally



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Evolving Queuing Mechanisms
Class Based Weighted Fair Queuing—CBWFQ

- Queues represent “classes” that have an associated minimum bandwidth in kbps
- Traffic assigned to classes via a “policy-map”
- Max 64 classes which support:
  - WFQ between classes
  - RED per class

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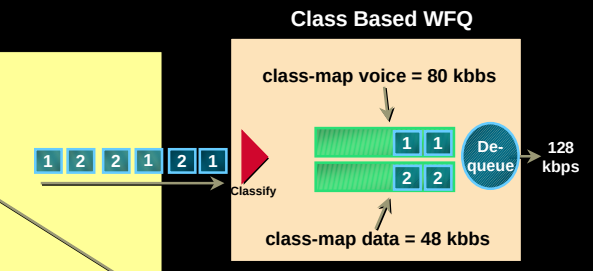
Class Based Weighted Fair Queuing CBWFQ

```
class-map data
  match input-interface Ethernet0/0
class-map voice
  match access-group 101
!
policy-map WAN
  class voice
    bandwidth 80
  class data
    bandwidth 48
!
interface Serial0/1
 ip address 10.1.6.2 255.255.255.0
 bandwidth 128
 no ip directed-broadcast
 service-policy output WAN
!
access-list 101 permit ip any any precedence critical
```



Any Packet with IP Precedence = 5 Gets Assigned to a Class that Will Get a Minimum of 80 kbps on a 128 kbps Circuit

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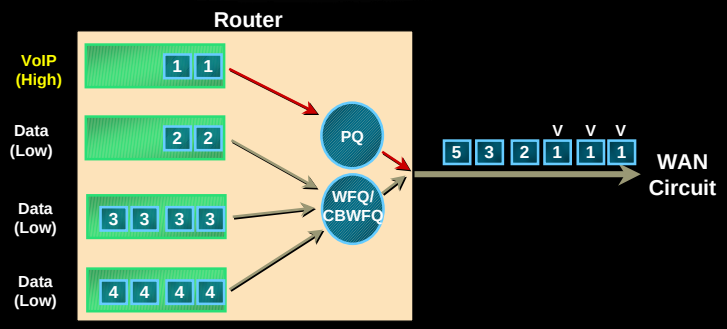
Queuing Enhancements for Voice "IP RTP Priority/Low Latency Queuing"



Identifying and Giving Priority to Voice

Creates Exhaustive Priority Queue for VoIP
Classifies based on UDP port and places in PQ

Point-to-Point Links	-	12.0(5)T
Frame Relay	-	12.0(7)T
ATM	-	12.0(7)T

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IP RTP Priority for Point-to-Point Links

Hub3640#

```
interface Serial0
 bandwidth 56
 no ip address
 encapsulation ppp
 no ip route-cache
 no ip mroute-cache
 no fair-queue
 ppp multilink
 multilink-group 1

interface Multilink 1
 ip address 10.1.1.1 255.255.255.252
 no ip directed-broadcast
 ip rtp priority 16384 16383 26
 no ip mroute-cache
 fair-queue 64 256 1000
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
 multilink-group 1
```

Remote3640#

```
interface Serial0
 bandwidth 56
 no ip address
 encapsulation ppp
 no ip route-cache
 no ip mroute-cache
 no fair-queue
 ppp multilink
 multilink-group 1

interface Multilink 1
 ip address 10.1.1.2 255.255.255.252
 no ip directed-broadcast
 ip rtp priority 16384 16383 26
 no ip mroute-cache
 fair-queue 64 256 1000
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
 multilink-group 1
```

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IP RTP Priority for Frame Relay Links

```
Hub3640#

interface Serial0/0
 bandwidth 1536
 encapsulation frame-relay
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 bandwidth 56
 ip address 10.1.1.1 255.255.255.0
 frame-relay class VoIP-56K
 frame-relay interface-dlci 100
 frame-relay ip rtp header-compression

map-class frame-relay VoIP-56K
 no frame-relay adaptive-shaping
 frame-relay cir 56000
 frame-relay bc 1000
 frame-relay mincir 56000
 frame-relay fair-queue
 frame-relay fragment 70
 frame-relay ip rtp priority 16384 16383 30
```

```
Remote3640#

interface Serial0/0
 bandwidth 128
 encapsulation frame-relay
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 bandwidth 56
 ip address 10.1.1.2 255.255.255.0
 frame-relay class VoIP-56K
 frame-relay interface-dlci 100
 frame-relay ip rtp header-compression

map-class frame-relay VoIP-56K
 no frame-relay adaptive-shaping
 frame-relay cir 56000
 frame-relay bc 1000
 frame-relay mincir 56000
 frame-relay fair-queue
 frame-relay fragment 70
 frame-relay ip rtp priority 16384 16383 30
```

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Make Sure that IP QoS Policies Are Preserved in an ATM Network

- IP-ATM CoS: Differentiated services over standard ATM
- Per VC CBWFQ
  - Requires PA-A3/deluxe PA for Cisco 7200/7500
  - T1 IMA and OC-3 on Cisco 3600

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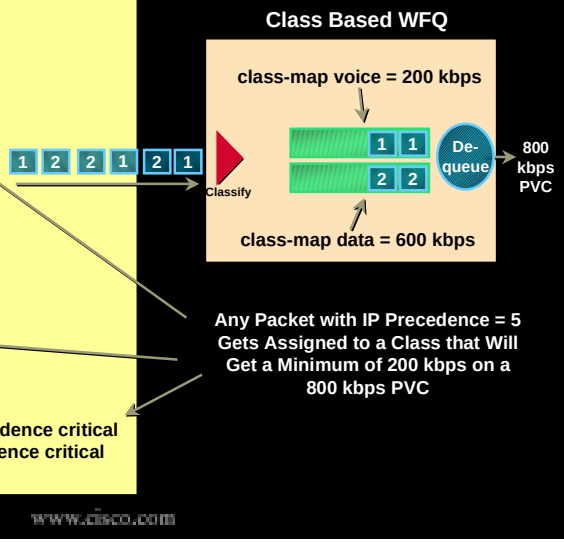
CBWFQ within an ATM PVC

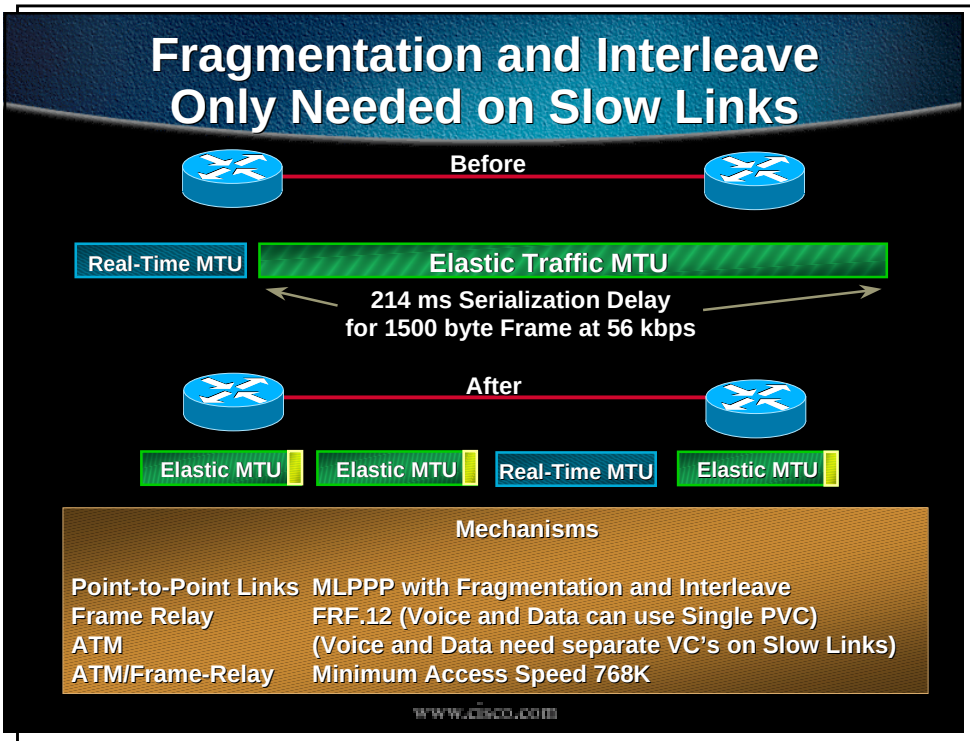
```
class-map data
  match access-group 102
class-map voice
  match access-group 101
!
policy-map WAN
  class voice
   bandwidth 200
  class data
   bandwidth 600
!
interface ATM1/0.16 point-to-point
 ip address 10.1.16.2 255.255.255.0
 no ip directed-broadcast
 pvc 0/35
  service-policy output WAN
  protocol ip 10.1.16.1 broadcast
  vbr-nrt 800 800 1
!
access-list 101 permit ip any any precedence critical
access-list 102 deny ip any any precedence critical
access-list 102 permit any any
```



Link Efficiency
Low Speed WAN QoS Tools

- Fragmentation and Interleave (LFI)
- RTP Header Compression (CRTP)
- Voice Activity Detection (VAD)

Fragmentation and Interleave Only Needed on Slow Links



Mechanisms	
Point-to-Point Links	MLPPP with Fragmentation and Interleave
Frame Relay	FRF.12 (Voice and Data can use Single PVC)
ATM	(Voice and Data need separate VC's on Slow Links)
ATM/Frame-Relay	Minimum Access Speed 768K

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Configuring Multilink PPP Fragmentation and Interleave


```
interface Multilink 1
 ip address 10.1.1.1 255.255.255.252
 fair-queue 64 256 1000
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
 multilink-group 1
!
interface Serial0
 bandwidth 128
 no ip address
 encapsulation ppp
 no fair-queue
 ppp multilink
multilink-group 1
```

Desired Max Blocking Delay in ms

Fragmentation Size a Result of this and "Bandwidth" Statement

```
interface Multilink 1
 ip address 10.1.1.2 255.255.255.252
 fair-queue 64 256 1000
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
 multilink-group 1
!
interface Serial0
 bandwidth 128
 no ip address
 encapsulation ppp
 no fair-queue
 ppp multilink
 multilink-group 1
```

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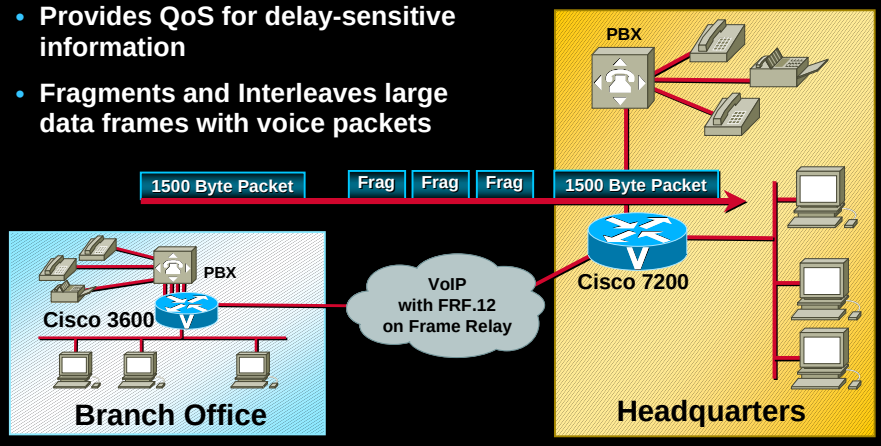
Low Bandwidth Frame Relay FRF.12

- Frame Relay Forum Standard
- Provides QoS for delay-sensitive information
- Fragments and Interleaves large data frames with voice packets



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FRF.12 Configuration

Hub3640#

```
interface Serial0/0
 bandwidth 1300
 no ip address
 encapsulation frame-relay
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 bandwidth 1300
 ip address 10.1.1.1 255.255.255.0
 no ip directed-broadcast
 frame-relay class VoIP-56K

map-class frame-relay VoIP-56K
 no frame-relay adaptive-shaping
 frame-relay cir 56000
 frame-relay bc 1000
 frame-relay mincir 56000
 frame-relay fair-queue
 frame-relay fragment 70
```

Remote3640#

```
interface Serial0/0
 bandwidth 56
 no ip address
 encapsulation frame-relay
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 bandwidth 56
 ip address 10.1.1.2 255.255.255.0
 no ip directed-broadcast
 frame-relay class VoIP-56K

map-class frame-relay VoIP-56K
 no frame-relay adaptive-shaping
 frame-relay cir 56000
 frame-relay bc 1000
 frame-relay mincir 56000
 frame-relay fair-queue
 frame-relay fragment 70
```

Note: Bc set lower than the default of 1/8th the CIR
Bc ideally 1/100 x CIR—(Not always practical)

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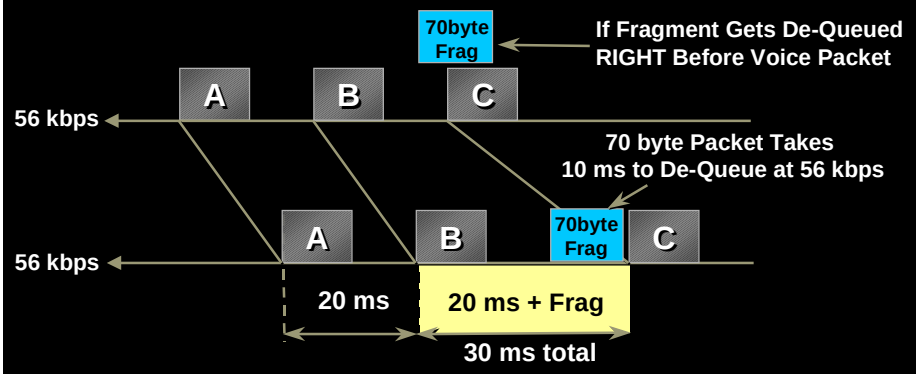
Setting Fragment Size Based on Minimum Desired Blocking Delay



Note: Blocking Delays Are Always Present

Fragment Size Recommendations

This Assumes 10 ms Blocking Delay Per Fragment

Link Speed	Frag Size
56 kbps	70 Bytes
64 kbps	80 Bytes
128 kbps	160 Bytes
256 kbps	320 Bytes
512 kbps	640 Bytes
768 kbps	1000 Bytes
1536 kbs	2000 Bytes

Note:
For Frame Relay PVC's the Fragmentation Size Should Be Set According to the Speed of the PVC

For Example, a 128 kbps PVC on a T1 Would Have the Fragment Size on that PVC Set to 160 bytes for a 10 ms Fragment Size

Avoid "IP MTU Size Reduction" if at All Possible

Prior to FRF.12 was the Only LFI Tool for Frame Relay

- Will drop IP frames with DNF bit set
- Can negatively affect IP applications
- Other "unfragmented" protocols can cause delay—IPX, AppleTalk etc.
- CPU utilization issues

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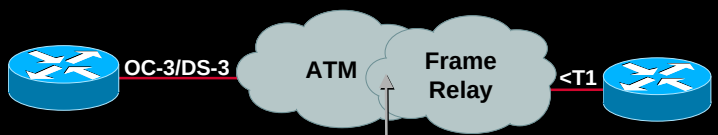
When You "May Have to" Use IP MTU Reduction



FRF.8 Service Inter-working Occurs in the Carrier-SAR

1. For Virtual Circuit Speeds of less than 768K a Link Fragmentation and Interleaving scheme is required. Use a layer 2 LFI scheme if available
2. Where Media combination and platform limitations preclude a layer 2 Link Fragmentation and Interleaving scheme use IP MTU as a last resort

   Increase speed as high as practical to raise MTU size

Understand IP MTU Reduction Issues and Use with Caution
Plan to Migrate to a Layer 2 LFI Scheme when Available

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When Is Fragmentation Needed?

Frame Size

Link Speed	1 Byte	64 Bytes	128 Bytes	256 Bytes	512 Bytes	1024 Bytes	1500 Bytes
56 kbps	143 us	9 ms	18 ms	36 ms	72 ms	144ms	214 ms
64 kbps	125 us	8 ms	16 ms	32 ms	64 ms	128 ms	187 ms
128 kbps	62.5 us	4 ms	8 ms	16 ms	32 ms	64 ms	93 ms
256 kbps	31 us	2 ms	4 ms	8 ms	16 ms	32 ms	46 ms
512 kbps	15.5 us	1 ms	2 ms	4 ms	8 ms	16 ms	23 ms
768 kbps	10 us	640 us	1.28 ms	2.56 ms	5.12 ms	10.24 ms	15 ms
1536 kbs	5 us	320 us	640 us	1.28 ms	2.56 ms	5.12 ms	7.5 ms

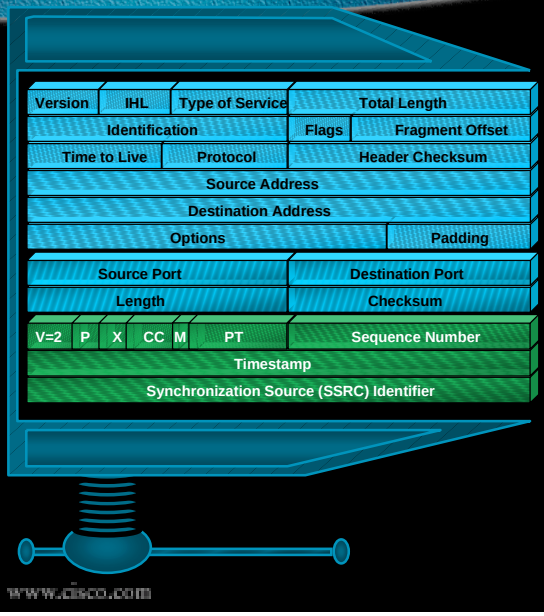
Depends on the Queuing Delay Caused by Large Frames at a Given Speed—Fragmentation Generally Not Needed Above 768 kbps

RTP Header Compression

Overhead

- 20 ms@8 kbps yields 20 byte payload
- 40bytes per packet IP header 20; UDP header 8; RTP header 12

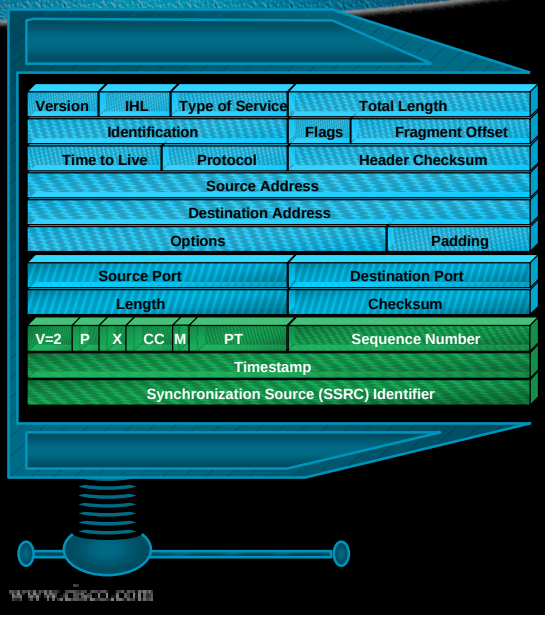
  2X payload!
- Header compression 40 bytes to 2–4 much of the time
- **Hop-by-hop** on slow links point-to-point and Frame Relay
- CRTP—compressed real-time protocol



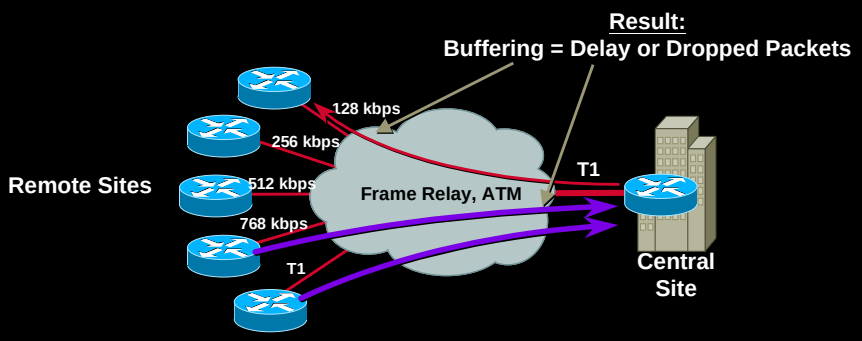
RTP Header Compression

CRTP Status

- Prior to 12.0(7)T
  - Process switched
- 12.0(7)T +
  - Fast switched
  - Express CRTP
- 12.1(2)T
  - 4–5X performance boost
- No CRTP for ATM media



Traffic Shaping Why?



- Central to remote site speed mismatch
- Remote to central site over-subscription
- Prohibit bursting above committed rate
  - What are you guaranteed above you committed rate?

Understanding Shaping Parameters Frame Relay

Traffic Shaping

"Average" Traffic Rate Out of an Interface

Challenge—Traffic Still clocked Out at Line Rate

CIR (Committed Information Rate)

Average Rate over Time, Typically in bits per second

Bc (Committed Burst)

Amount allowed to Transmit in an Interval, in bits

Be (Excess Burst)

Amount allowed to transmit above Bc per Second

Interval

Equal Integer of time within 1 sec, Typically in ms. Number of Intervals per second depends on Interval length Bc and the Interval are derivatives of each other

$$\text{Interval} = \frac{Bc}{CIR} \quad \text{Example} \quad 125\text{ms} = \frac{8000\text{ bits}}{64\text{ kbps}}$$

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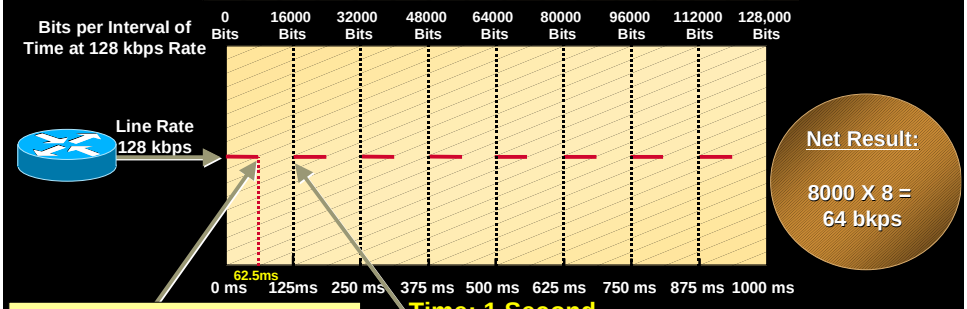
Example—Traffic Shaping in Action

High Volume Data Flow Towards a 128 kbps Line Rate Shaping to 64 kbps

$$\text{Interval} = \frac{Bc}{CIR} \rightarrow 125\text{ ms Interval} = \frac{8000\text{ bits}}{64000\text{ bps}}$$

Cisco Default Bc=1/8 CIR = 125 ms Interval



Net Result:

8000 X 8 = 64 bkps

When 8000bits (Bc) Transmitted Credits are exhausted and no more Packet flow in that Interval This happens at the 62.5ms point of the interval

When a new Interval begins Bc (8000bit) Credits are restored and transmission may resume. Pause in transmission is 62.5ms in the case

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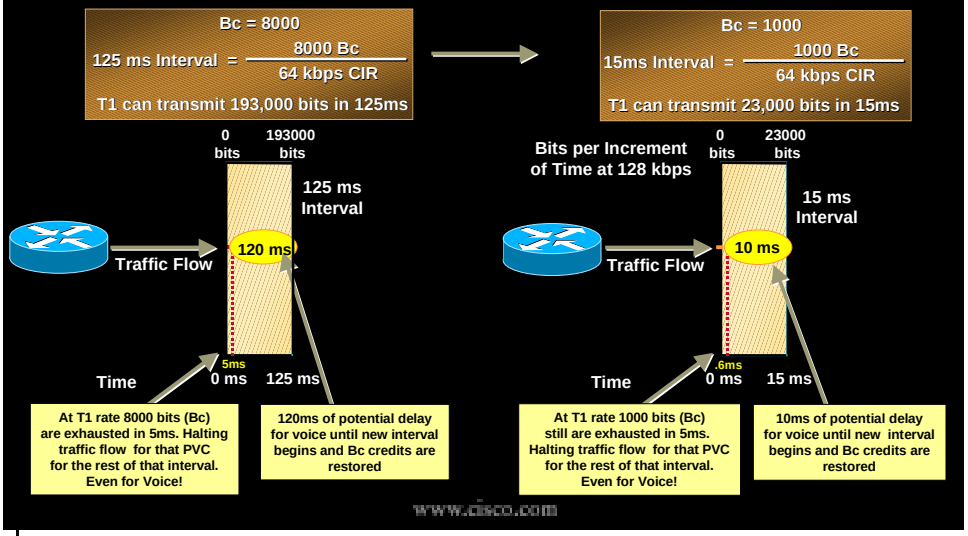
Bc Setting Considerations for VoIP

Set Bc lower if Line Rate to CIR Ratio Is High
Example: T1 Line Rate Shaping to 64 kbps



Traffic Shaping Configuration Shaping to 56 kbps with No Bursting

FRTS#

```
interface Serial0/0
 no ip address
 encapsulation frame-relay
 bandwidth 1300
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 ip address 10.1.1.1 255.255.255.0
 bandwidth 56
 frame-relay class VoIP-56K

map-class frame-relay VoIP-56K
 frame-relay fragment 70
 no frame-relay adaptive-shaping
 frame-relay bc 1000
 frame-relay cir 56000
 frame-relay mincir 56000
 frame-relay fair-queue
```

Frame Relay Traffic Shaping

GTS#

```
interface Serial0/0
 ip address 10.1.1.2 255.255.255.0
 bandwidth 512
 traffic-shape rate 56000 1000 0
```

Can work on "non" Frame Relay Interfaces Anywhere throttling needs to occur

traffic shape rate *[average] [interval] [burst]*

Generic Traffic Shaping

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Verifying Traffic Shaping Operation

```
HUB3640#sho frame pvc 100

PVC Statistics for interface Serial0/0 (Frame Relay DTE)

DLCI = 100, DLCI USAGE = LOCAL, PVC STATUS = STATIC, INTERFACE = Serial0/0.1

  input pkts 149427          output pkts 835851        in bytes 9948250
  out bytes 1042695469       dropped pkts 622090       in FECN pkts 0
  in BECN pkts 0             out FECN pkts 0           out BECN pkts 0
  in DE pkts 0               out DE pkts 0
  out bcast pkts 1325        out bcast bytes 110227
  pvc create time 013442, last time pvc status changed 013145
  fragment type end-to-end         fragment size 70
  cir 56000     bc 1000      be 0         limit 125    interval 17
  mincir 56000     byte increment 125   BECN response no
  pkts 48669     bytes 4146936     pkts delayed 24334     bytes delayed 2072716
  shaping active
```

Byte Increment = Bc

Amount to be Credited to Bc for Next Upcoming Interval.

Value Gets Decreased Upon Receipt of BECN or CLLM Messages. This Is How Router Gets Throttled Back Due to Congestion Indication.

Cisco IOS Support

- WFQ—11.0
- IP Precedence—11.0
- RSVP—11.2
- MLPPP and fragmentation—11.3
- Traffic shaping—11.2
- FRF.12—12.0(4)T
- CBWFQ—depends on platform and media
- IP RTP priority/LLQ
  - Point-to-point—12.0(5)T
  - Frame Relay—12.0(7)T
  - ATM—future—12.0(7)T

Agenda

- VoIP Requirements and Challenges
- Router/Switch Egress QoS Study
- **WAN QoS Design Considerations**
- Tuning—Audio Level and Echo
- Best Practice Recommendations

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WAN QoS Considerations

- High-speed to low circuits
- Remote to central site over subscription
- Over subscription—carrier
- To burst or not to burst?

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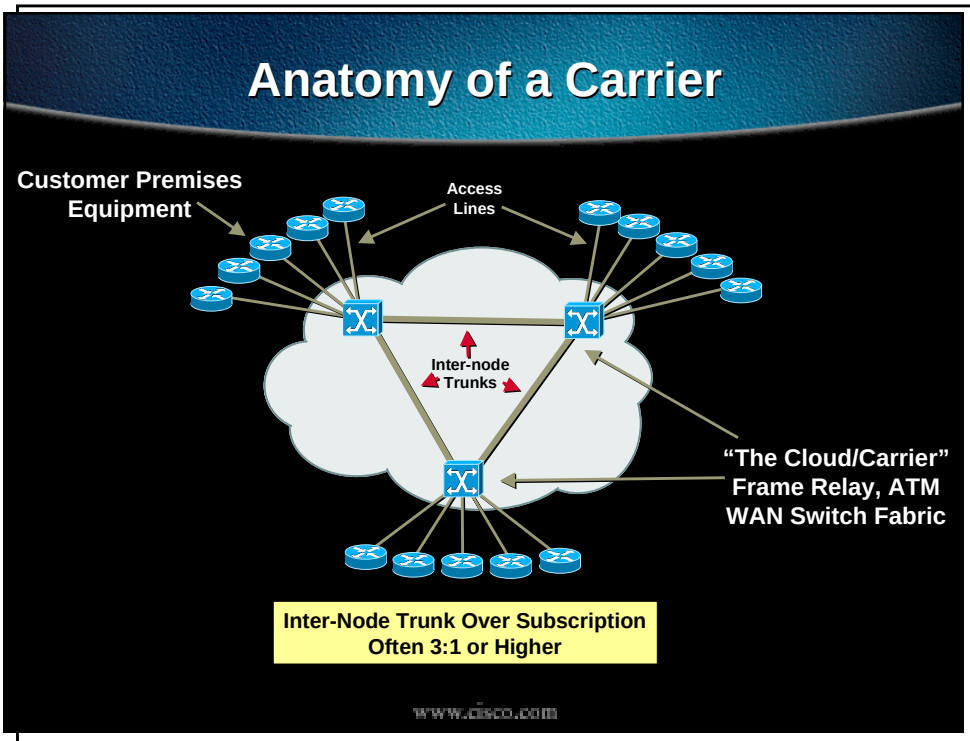
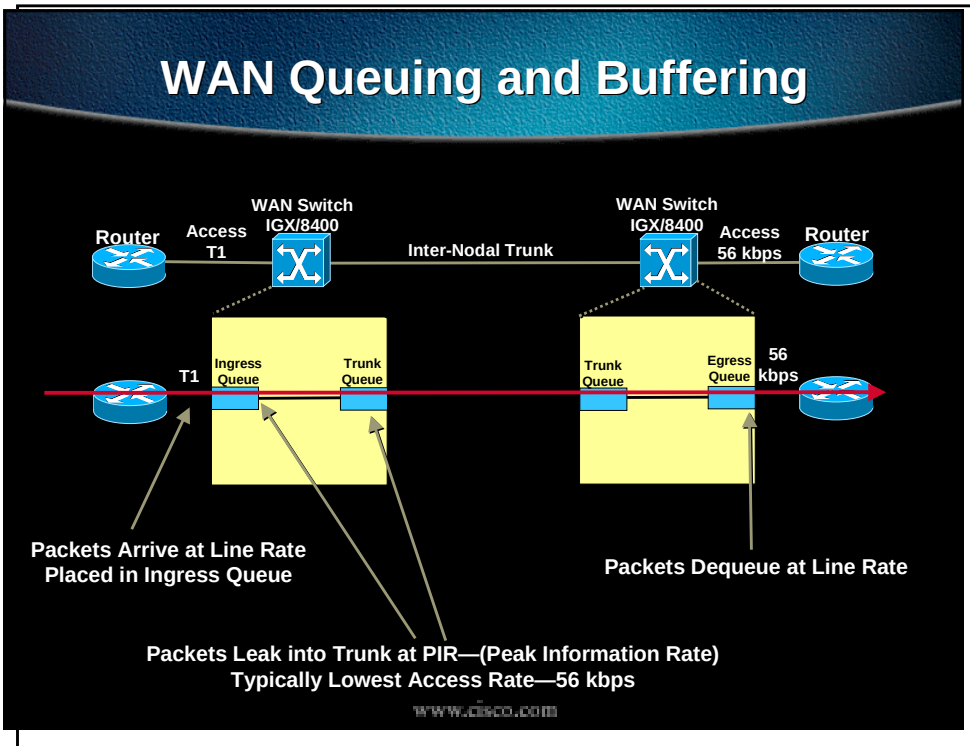
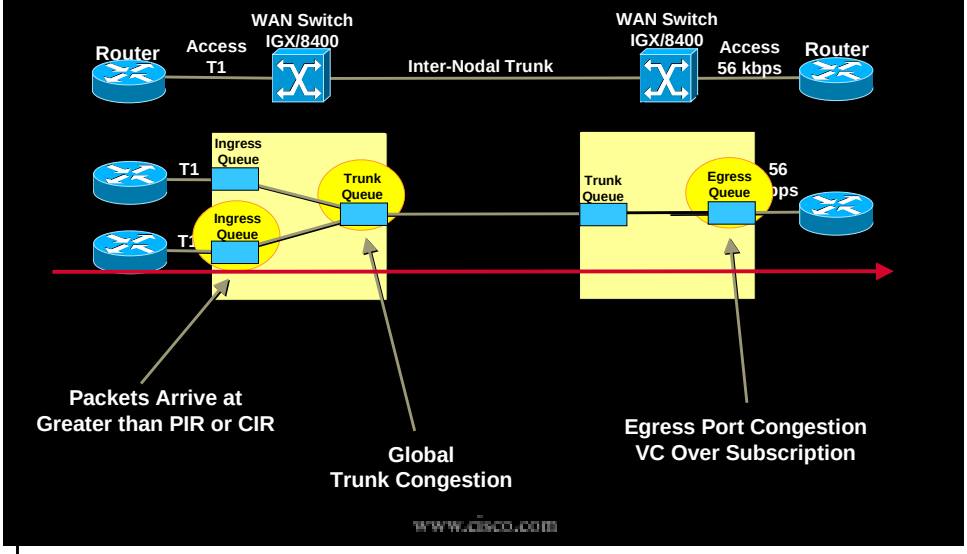
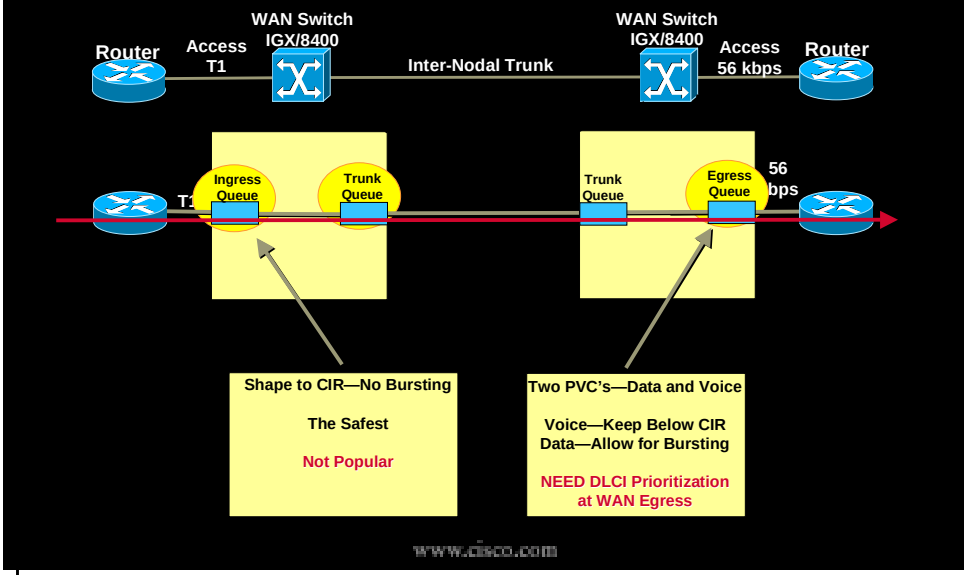




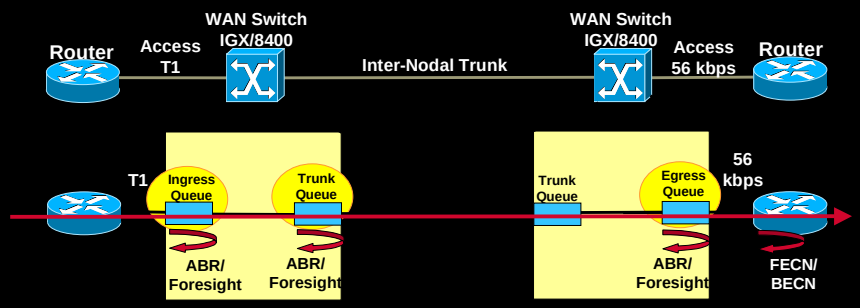
Where WAN Congestion and Delay Can Occur



Bursting—What Is Your Guarantee? Options



Congestion Detection and Feedback Effectiveness Depends on Round Trip Delay



ABR—Available Bit Rate

Can send a Rate Down from Point of Congestion

FECN/BECN Notification

Requires Far End to Reflect a FECN and Send and BECN Back to Source Indicating a Rate Down

Foresight/CLLM

Can Send a Rate Down from Point of Congestion

Speeds up Rate Down Time over FECN/BECN

Congestion Must Occur to Invoke, Congestion Relief Can be as Long as 1 Round Trip Time

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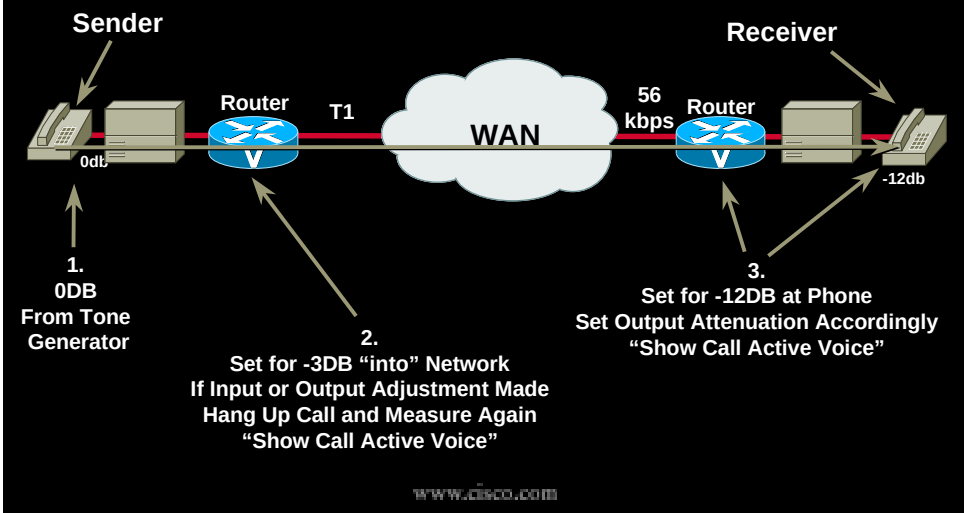
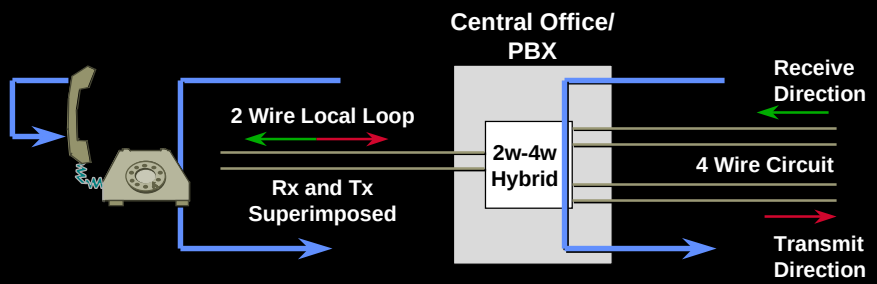
Audio Level Adjustment/Tuning

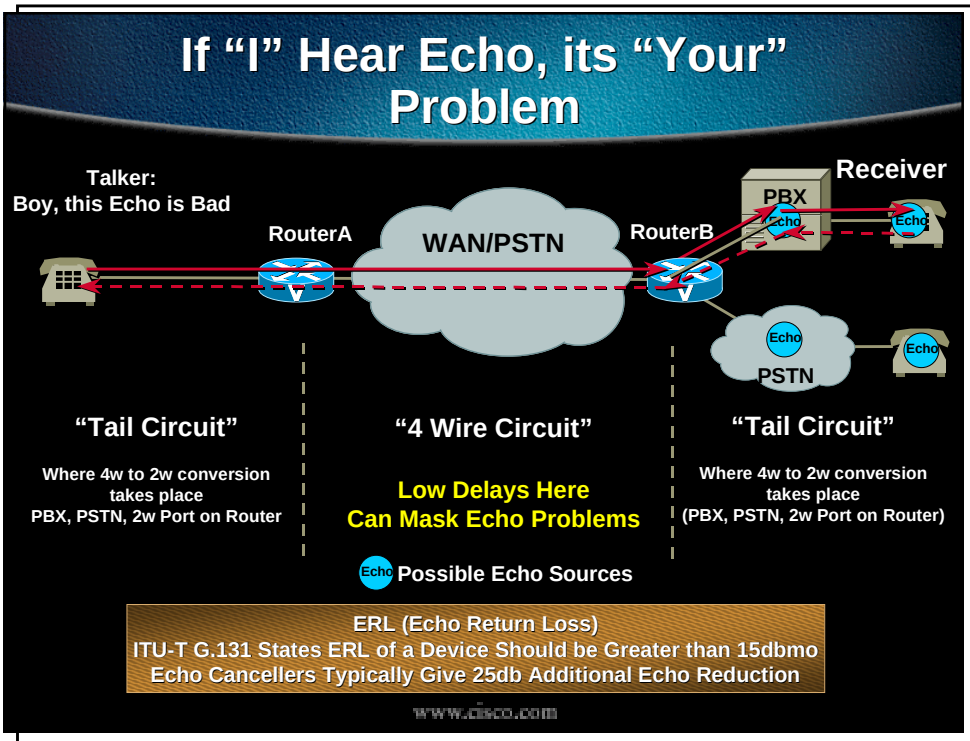


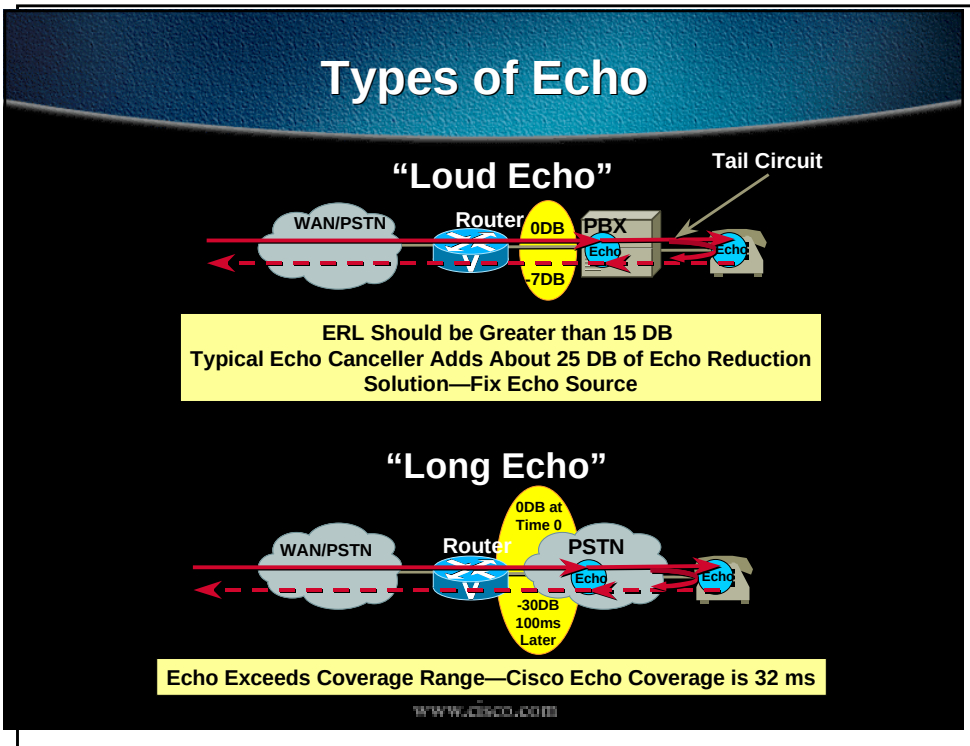
Echo—How Does it Happen?
Echo Is Due to a Reflection



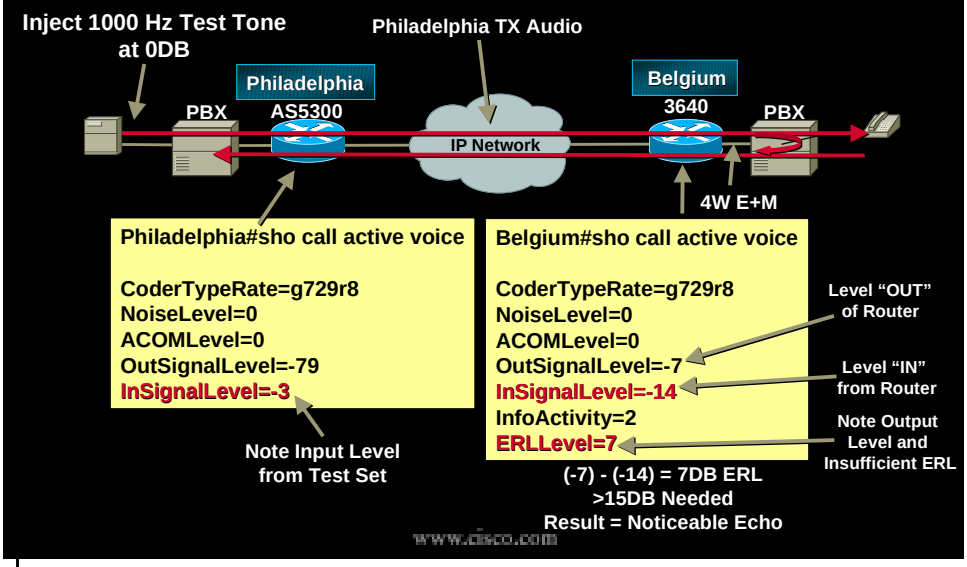
Impedance mismatch at the 2w-4w hybrid is the most common source of echo

Echo is always present
A function of the echo delay, and the magnitude of the echo

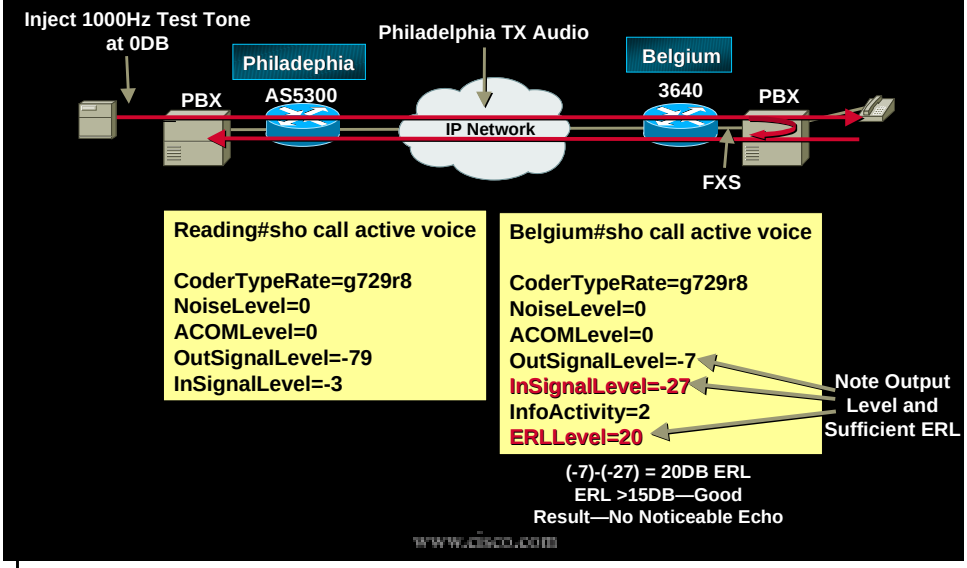




Echo Troubleshooting Example "Loud Echo"



Solution: Router Performs 4w to 2W Conversion



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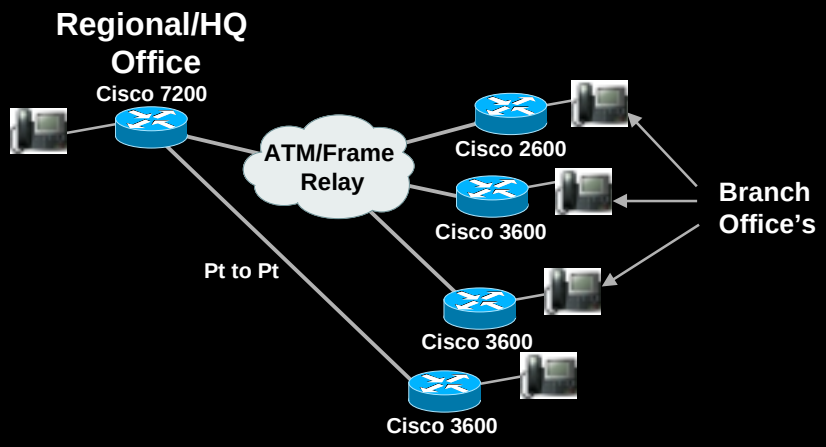
Summary: QoS Best Practices



Applying Correct Tools in Required Location(s)

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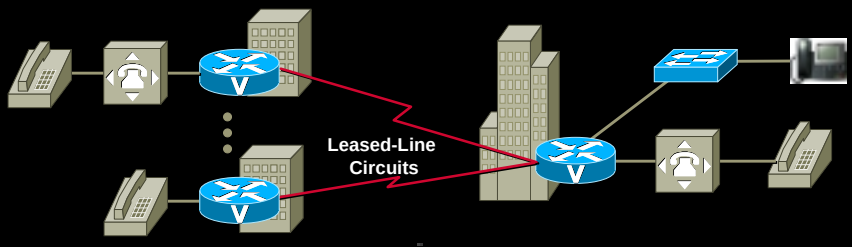
Transport Options
VoIP over Leased-Line 12.0(7)T

Remote Office Network-Side Hardware	QoS and Link Optimization	Head-End Network-Side Hardware
• Low-speed serial interfaces	• IP Prec/DSCP • IP RTP Priority/LLQ • WFQ/CBWFQ • MLPPP • CRTP • Voice compression • VAD • Fax relay	• Low-speed serial interfaces • Multichannel T1/E1 interfaces • Multichannel T3/E3 interfaces



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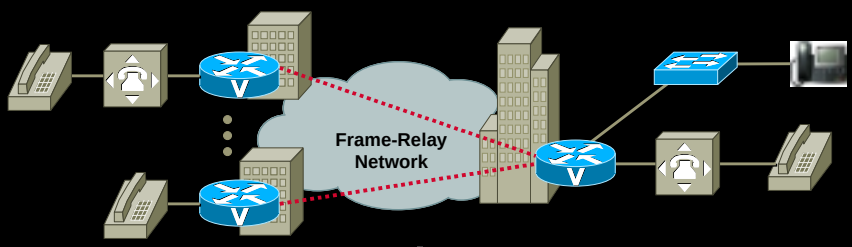
Transport Options
VoIP over Frame-Relay 12.0(7)T

Remote Office Network-Side Hardware	QoS and Link Optimization	Head-End Network-Side Hardware
• Low-speed serial interfaces	• IP Prec/DSCP • IP RTP priority • WFQ • FRF.12 fragmentation • FRTS to CIR • CRTP • Voice compression • VAD • Fax relay	• Low-speed serial interfaces • HSSI interfaces • Multichannel T1/E1 interfaces • MultichannelT3/E3 interfaces



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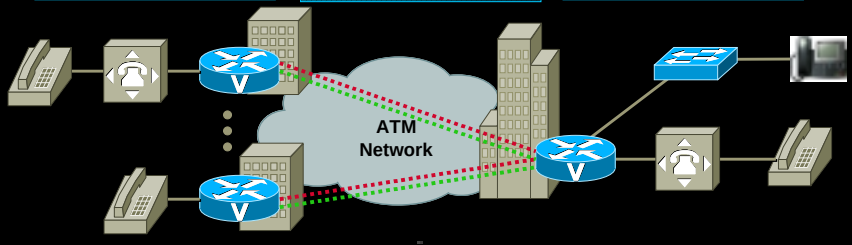
Transport Options
VoIP over ATM 12.0(7)T

Remote Office Network-Side Hardware	QoS and Link Optimization	Head-End Network-Side Hardware
• Low-speed serial interfaces	• IP Prec/DSCP • CBWFQ within a VC • WFQ + IP RTP Priority • Min bandwidth 768K or IP MTU as last resort • Traffic shaping within guaranteed rates • Voice compression • VAD • Fax relay	• T1/E1 IMA interfaces • DS3/E3 ATM interfaces • OC-3 ATM interfaces



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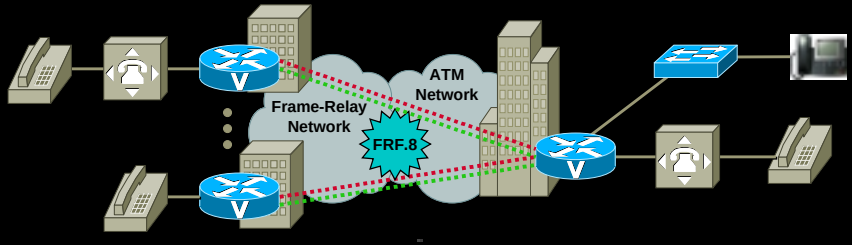
Transport Options
VoIP over Hybrid Networks

Remote Office Network-Side Hardware	QoS and Link Optimization	Head-End Network-Side Hardware
• Low-speed serial interfaces	• IP Prec/DSCP • CBWFQ within a VC • WFQ + IP RTP Priority • Min bandwidth 768K or IP MTU as last resort • Traffic shaping within guaranteed rates • Voice compression • VAD • Fax relay	• T1/E1 IMA interfaces • DS3/E3 ATM interfaces • OC-3 ATM interfaces



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WAN Bursting "Guidelines"

- Single PVC—limit bursting to committed rate (CIR)
  - You are guaranteed what you pay for
- Dual PVC's—one for voice and one for data
  - One for data (may burst), one for voice (keep below CIR)
  - Must perform PVC prioritization in frame cloud—(Cisco WAN gear does)
  - Note—fragmentation rules still apply for data PVC

Moral of the Story—"Know your Carrier"

QoS Summary "Voice Is Not for Free"

- Employ proper WAN edge tools
  - Prioritization, LFI, traffic shaping
- Keep voice within guaranteed rates
  - CIR (Committed Information Rate)
- Manual admission control
  - MAX possible calls do not exceed link speed
  - AVVID remote phones cannot exceed site link bandwidth

Voice Needs…
Planning, Bandwidth, and a QoS Enabled Infrastructure