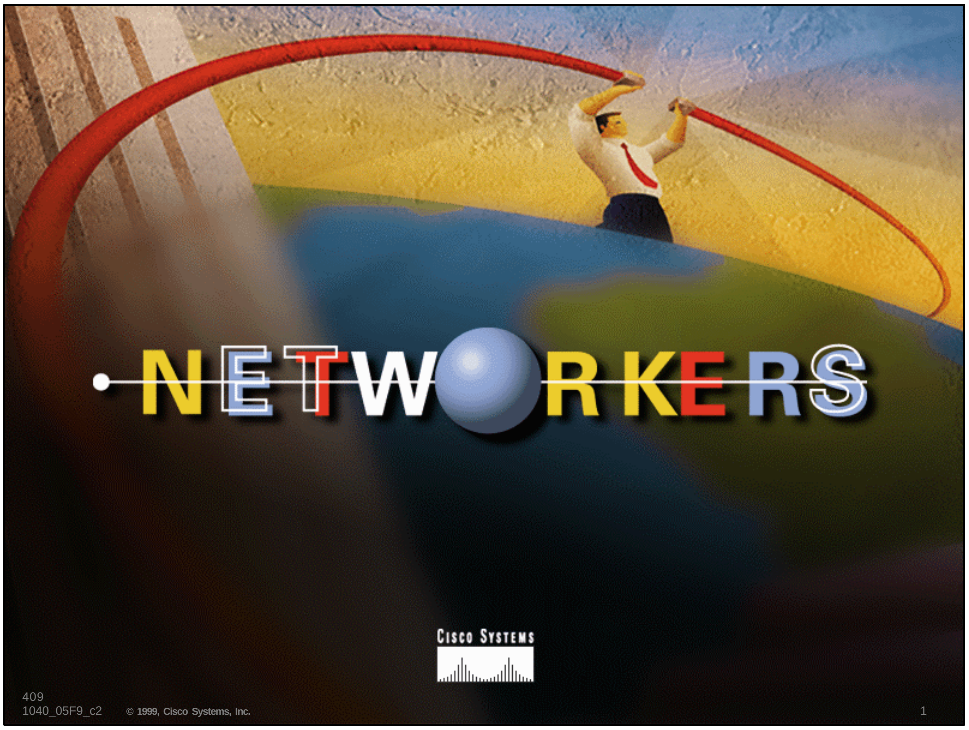

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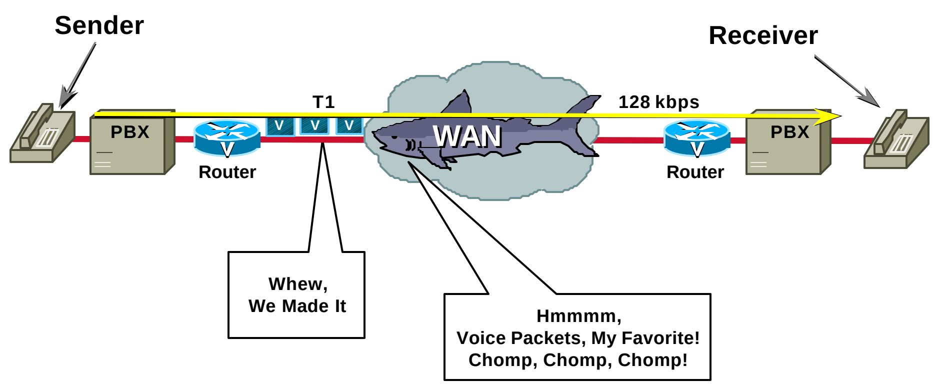
Tuning for Voice Quality

Problem Avoidance

Analyze problem sources and proper design tool/guidelines to ensure voice quality

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

VoIP Packet

Link Header	IP Header	UDP Header	RTP Header	Voice Payload
X Bytes	20 Bytes	8 Bytes	12 Bytes	X Bytes

- 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 50 pps (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 (17k bps)

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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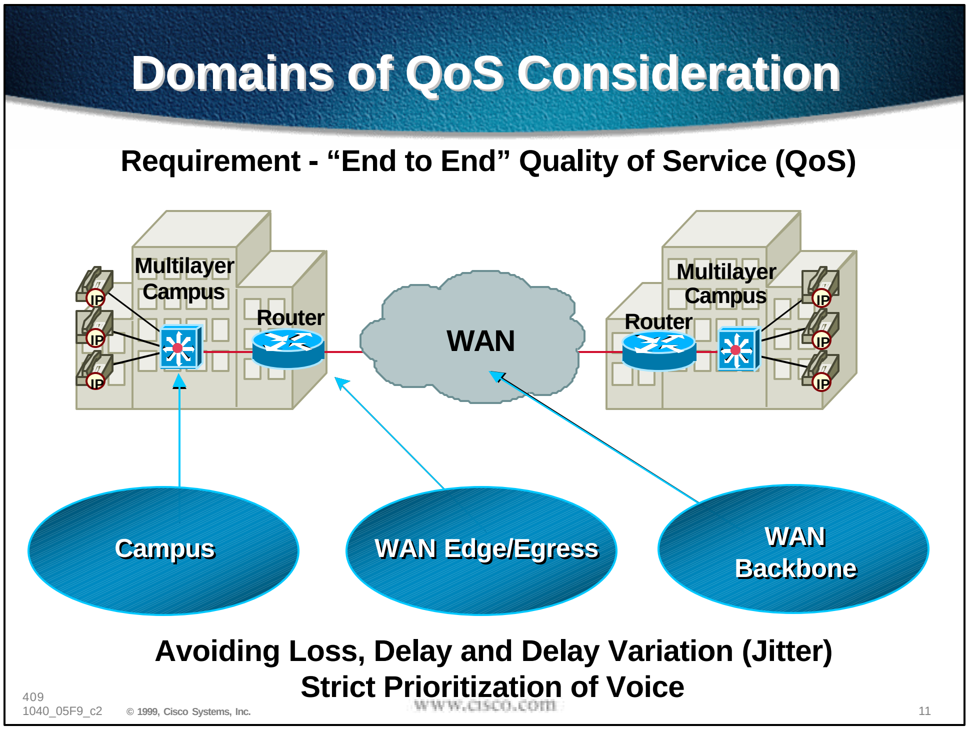

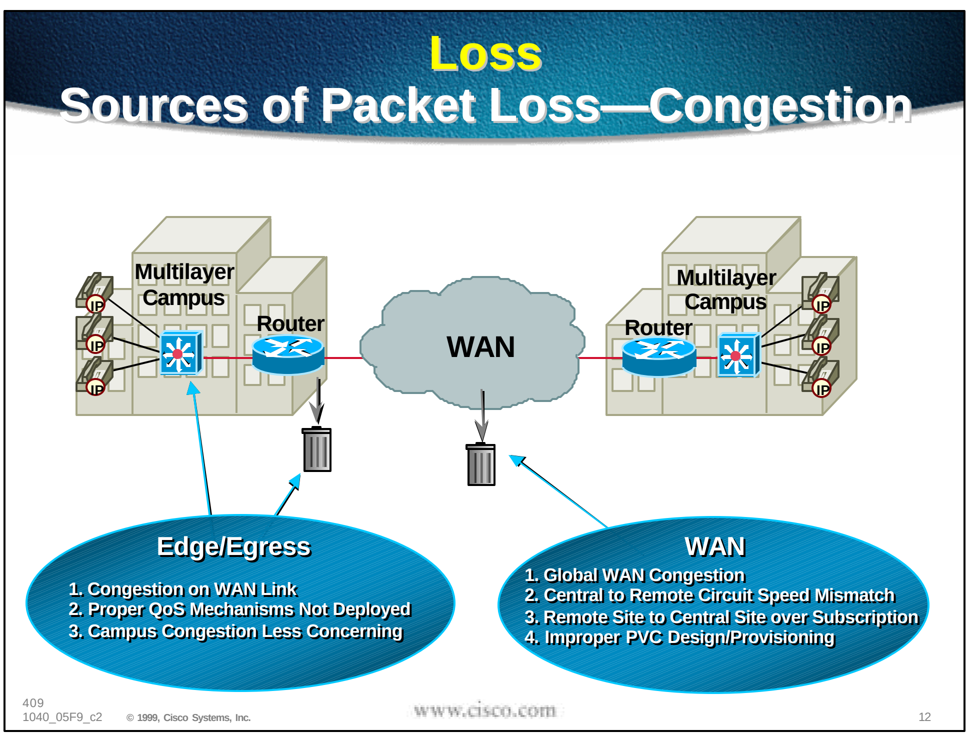

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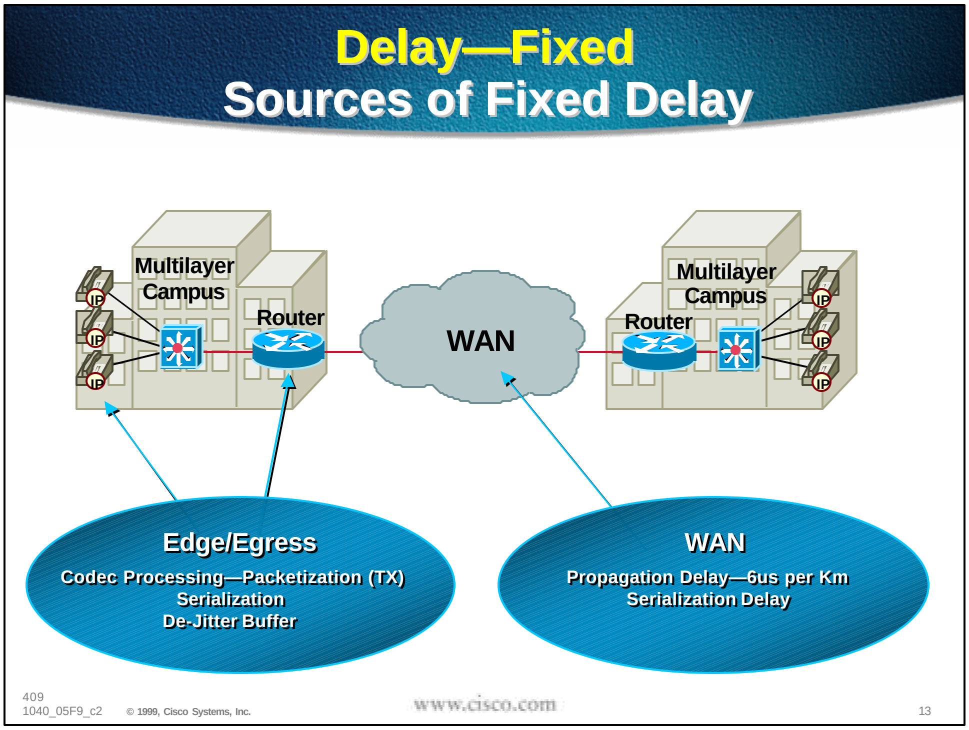

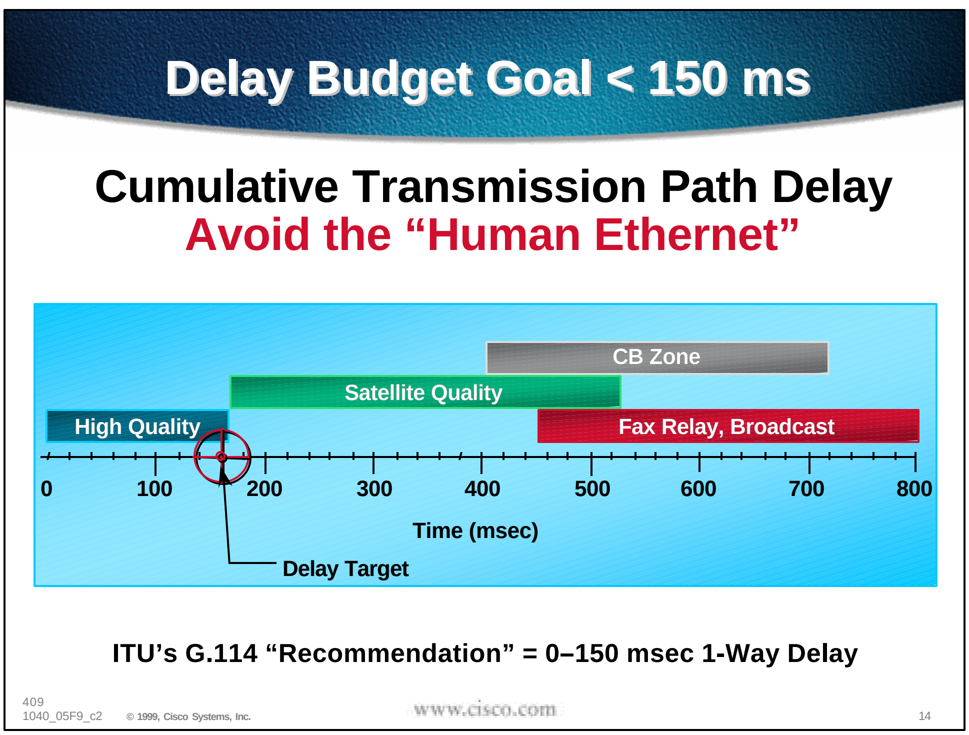

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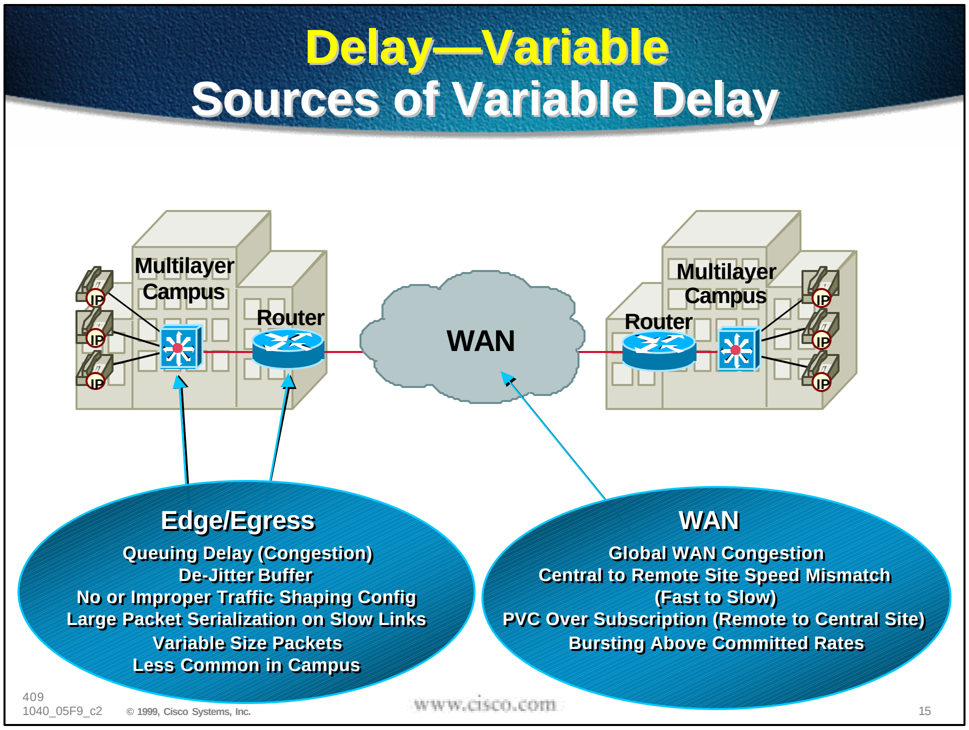

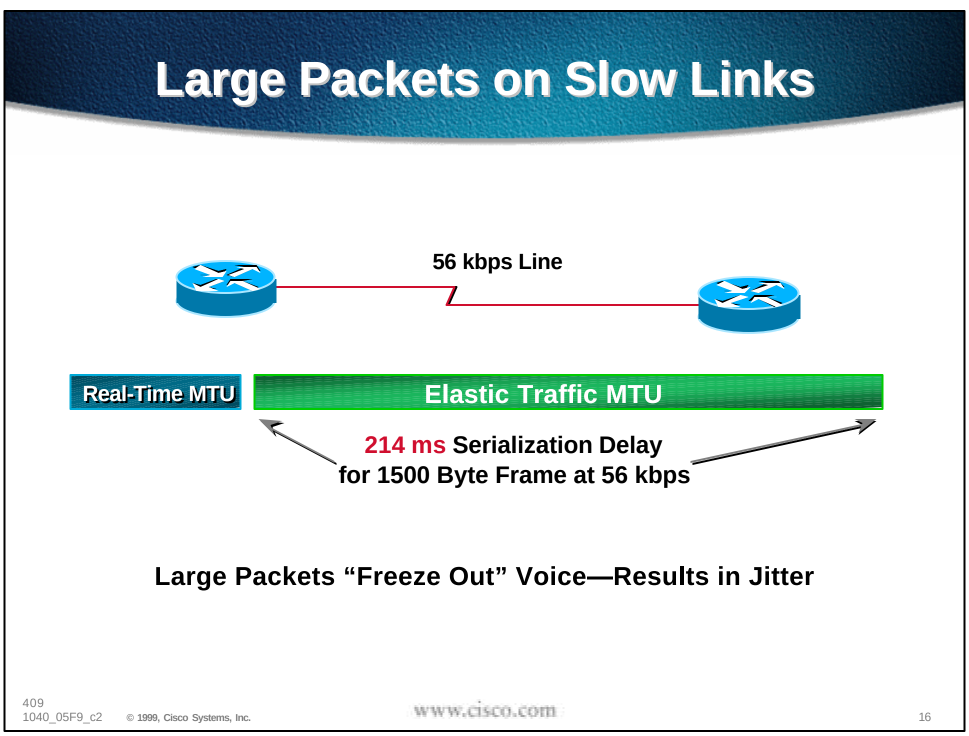

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QoS Needs

- Campus

  Bandwidth minimizes QoS issues

- WAN edge

  QoS “starts” in the WAN—a must

- WAN considerations

  Often forgotten or misunderstood—
  a must

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Agenda

- VoIP Requirements and Challenges
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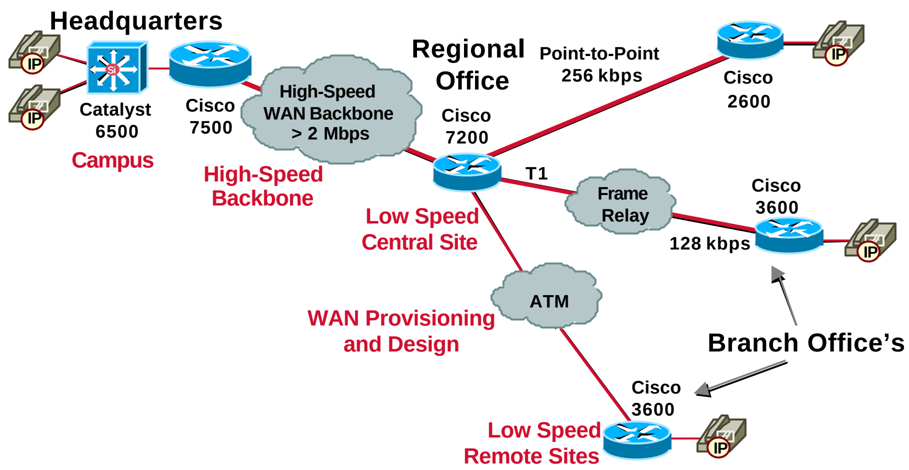
Case Study: End-to-End Quality of Service



Applying Proper Tools in Proper Location

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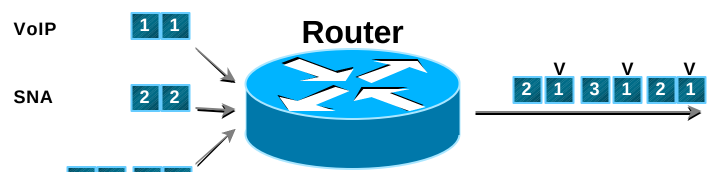
Router/Switch Egress QoS Tools "Three Classes of QoS Tools"



- **Prioritization**
  Low Speed WAN, High Speed WAN, Campus
- **Link Efficiency**
  Fragment and Interleave, Compression, VAD
- **Traffic Shaping**
  Speed Mismatches + To Avoid Bursting

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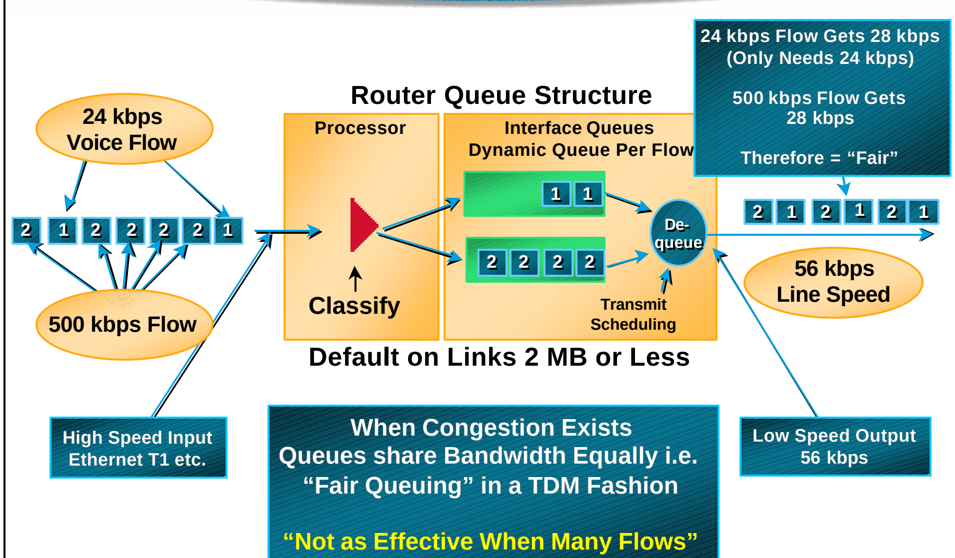
Prioritization
Low Speed WAN Egress QoS

Two MB or Less

- IP precedence
- RSVP
- Class-cased weighted fair queuing - CBWFQ

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



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Displaying WFQ

Emphasizing the "Fair" in Weighted Fair Queuing
Note: The Lower the Weight of a Flow, the More Bandwidth it Gets

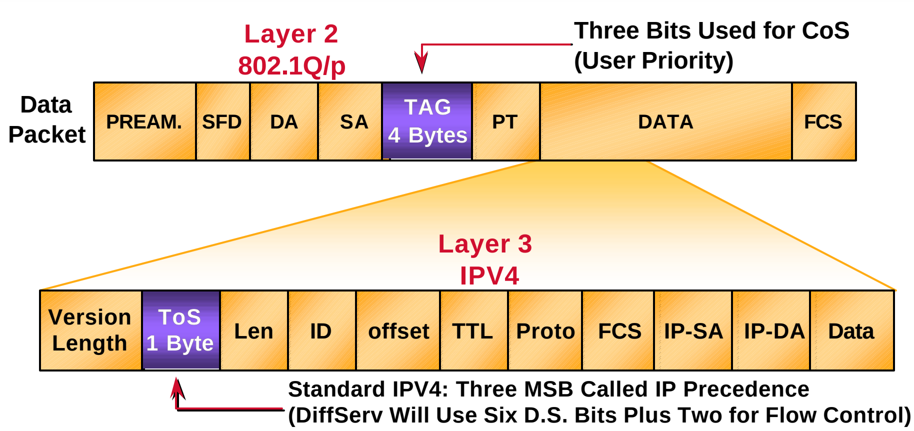
```
HUB3640#show queue se 0/0
 Input queue: 0/75/0 (size/max/drops); Total output drops: 0
 Queuing strategy: weighted fair
 Output queue: 31/64/0 (size/threshold/drops)
   Conversations  2/4 (active/max active)
   Reserved Conversations 0/0 (allocated/max allocated)

 (depth/weight/discards/interleaves) 24/4096/0/0
 Conversation 184, linktype: ip, length: 1504
 source: 10.1.5.2, destination: 10.1.6.1, id: 0x04CF, ttl: 31,
 TOS: 0 prot: 6, source port 1503, destination port 21

 (depth/weight/discards/interleaves) 2/4096/0/0
 Conversation 227, linktype: ip, length: 68
 source: 10.1.1.2, destination: 10.1.1.1, id: 0xFCCF, ttl: 31,
 TOS: 0 prot: 17, source port 49608, destination port 49608
```

Weight = 4096/(1+ IP Prec)

High Bandwidth Flow

VoIP Flow

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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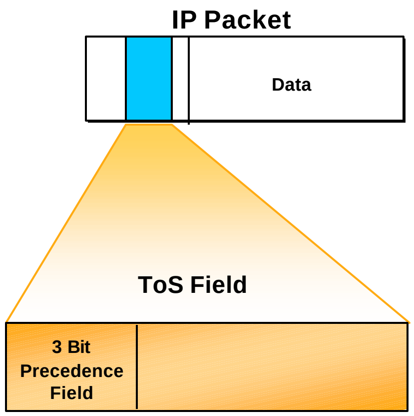
IP Precedence
"Controlling WFQ's De-queuing Behavior"



Weight = $\frac{4096}{(1 + \text{IP Precedence})}$

IP Precedence	Weight
0	4096
1	2048
2	1365
3	1024
4	819
5	682
6	585
7	512

- **IP Precedence**
  - Not a QoS Mechanism turned on in the router
  - "In Band" QoS Signaling—Set in the End Point

Displaying Effects of IP Precedence

This Is Using the "Weight" in Weighted Fair Queuing

```
HUB3640#show queue se 0/0
  Input queue: 0/75/0 (size/max/drops); Total output drops: 0
  Queuing strategy: weighted fair
  Output queue: 9/64/0 (size/threshold/drops)
     Conversations  2/7 (active/max active)
     Reserved Conversations 0/0 (allocated/max allocated)

  (depth/weight/discards/interleaves) 1/585/0/0
  Conversation 90, linktype: ip, length: 68
  source: 10.1.5.2, destination: 10.1.6.1, id: 0x0064, ttl: 255,
  TOS: 192 prot: 17, source port 16384, destination port 16384

  (depth/weight/discards/interleaves) 8/4096/0/0
  Conversation 219, linktype: ip, length: 1504
  source: 10.1.1.2, destination: 10.1.1.1, id: 0x1C7E, ttl: 31,
  TOS: 0 prot: 6, source port 49604, destination port 21
```

VoIP Flow

FTP Flow

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IP Precedence with WFQ

Calculating Given Flow Bandwidth Based on IP Precedence Under Congestion

Flow A BW = (Flow A "Parts" / Sum of all Flow "Parts") X Circuit Bandwidth

Individual Flow "Parts" = 1 + IP Precedence

IP Precedence	Flow "Parts"
0	1
1	2
2	3
3	4
4	5
5	6
6	7
7	8

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IP Precedence Flow Bandwidth Calculation Example

Flow A BW = (Flow A "Parts" / Sum of all Flow "Parts") X Circuit Bandwidth

Example A

56 kbps Link

2—VoIP Flows A+B at 24 kbps (IP Prec 0)
2—FTP Flows at 56 kbps (IP Prec 0)

14 kbps = $\left(\frac{1}{4}\right)$ X 56 kbps

14 kbps Not Suitable for a 24 kbps Flow
Example of Many Flows with WFQ and Equal Precedence Flows

Weighted "Fair" Queuing

Example B

56 kbps Link

2—VoIP Flows A+B at 24 kbps (IP Prec 5)
2—FTP Flows at 56 kbps (IP Prec 0)

24 kbps = $\left(\frac{6}{14}\right)$ X 56 kbps

24 kbps Suitable for a 24 kbps Flow

WFQ Preferring IP Precedence

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IP Precedence
No Admission Control

Moral of the Story: Know Your Environment, Voice Traffic Patterns etc. Recommendations for Certain Bandwidth's to Follow

Example C

56 kbps Link
2—VoIP Flow's at 24 kbps (IP Prec 5)
4—FTP Flows at 56 kbps (IP Prec 0)

21 kbps = $\left(\frac{6}{16}\right)$ X 56 kbps

21 kbps Not Suitable for a 24 kbps Flow

RTP Header Compression Would Help Since it Would reduce VoIP Flow to 11.2 kbps
Also RSVP or CBWFQ

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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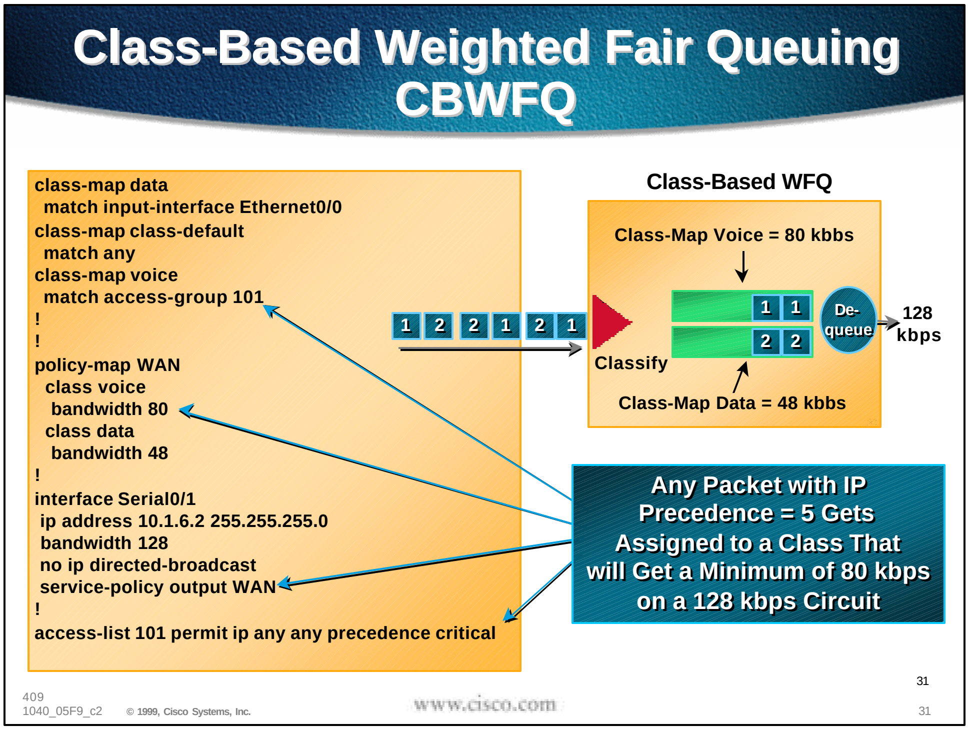

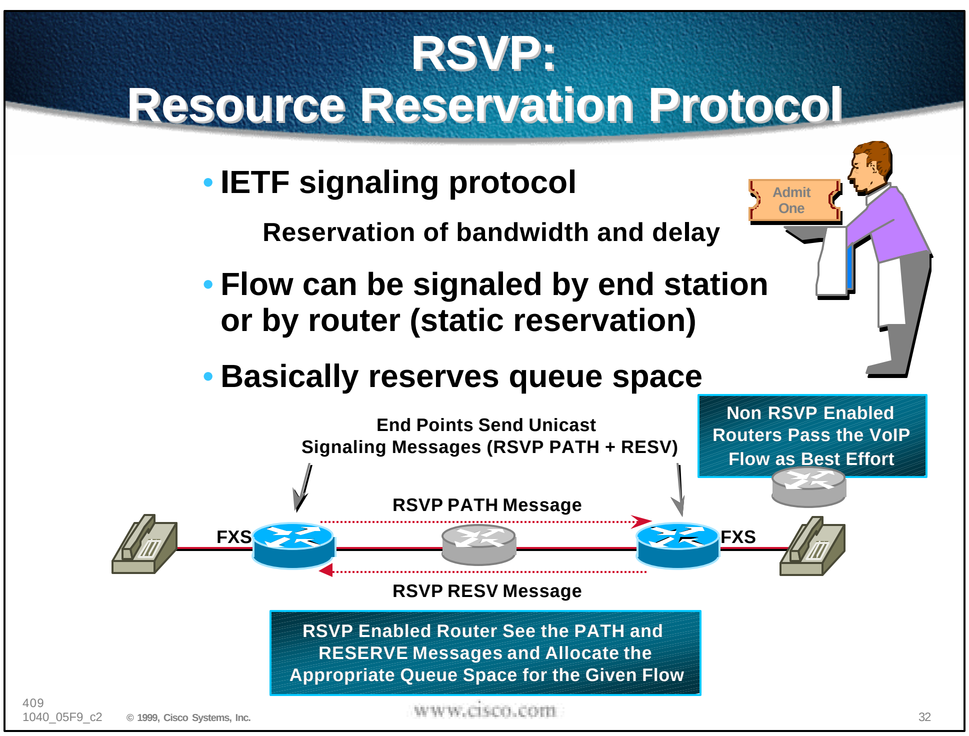

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Configuring RSVP

Interface Command
ip rsvp bandwidth [interface-kbps] [single-flow-kbps]

```
interface Serial0/0
 ip address 10.1.1.2 255.255.0.0
 ip rsvp bandwidth 96 96
 bandwidth 128
 fair-queue 64 256 1000
```

RSVP Flow Weight = Greatest BW Reservation on the link / Conversation BW

Make Sure the Bandwidth Statement Accurately Reflects the Circuit Bandwidth

By Default 75% of the "Bandwidth" Statement Is Reservable

```
bottom#sho ip rsvp installed
BPS    To        From       Protoc  DPort  Sport  Weight Conversation
24K    10.1.1.1  10.1.1.2   UDP     16384  16384  4      264
```


Monitoring RSVP Queue Operation

```
bottom#sho que se 0
  Input queue: 0/75/0 (size/max/drops); Total output drops: 0
  Queueing strategy: weighted fair
  Output queue: 23/64/0 (size/threshold/drops)
     Conversations  3/5 (active/max active)
     Reserved Conversations 1/1 (allocated/max allocated)

  (depth/weight/discards/interleaves) 21/4096/0/0
  Conversation 195, linktype: ip, length: 1504
  source: 10.1.5.1, destination: 10.1.6.1, id: 0xD5E8, ttl: 31,
  TOS: 0 prot: 6, source port 1503, destination port 21

  (depth/weight/discards/interleaves) 2/4/0/0
  Conversation 264, linktype: ip, length: 68
  source: 10.1.1.2, destination: 10.1.1.1, id: 0xAFE9, ttl: 31,
  TOS: 0 prot: 17, source port 16348, destination port 16384
```

FTP Flow

Reserved VoIP Flow

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Prioritization
High-Speed WAN Egress QoS

Greater than 2 MB

- **Distributed weighted fair queuing**
- **WRED**
- **IP to ATM CoS**

At High-Speeds Processor Oriented QoS Mechanisms Not Efficient

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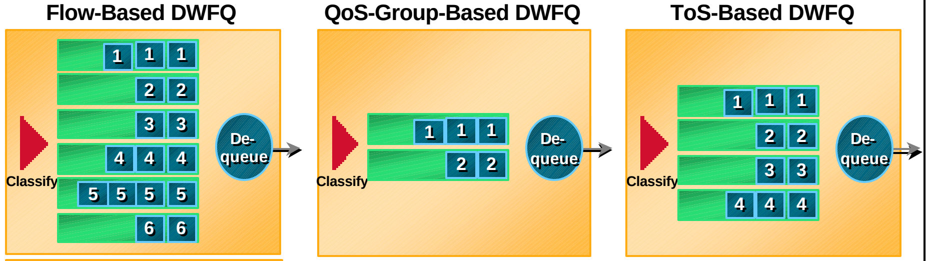
High-Speed Prioritization
Distributed Weighted Fair Queuing (DWFQ)

VIP2-40 or Better (Versatile Interface Processor)

Flow-Based DWFQ | **QoS-Group-Based DWFQ** | **ToS-Based DWFQ**



Flow-Based DWFQ	QoS-Group-Based DWFQ	ToS-Based DWFQ
1 Queue Per Flow IP Precedence Does Not Get Priority (i.e. "Fair Queuing")	Define Queue Classes and weight in Percent Policy Routing Assigns Flows to Queues	4 Queues Based on ToS 2 MSB Can Weight the 4 Queues Accordingly to Percent

- **Cannot be configured on sub-interfaces—yet**

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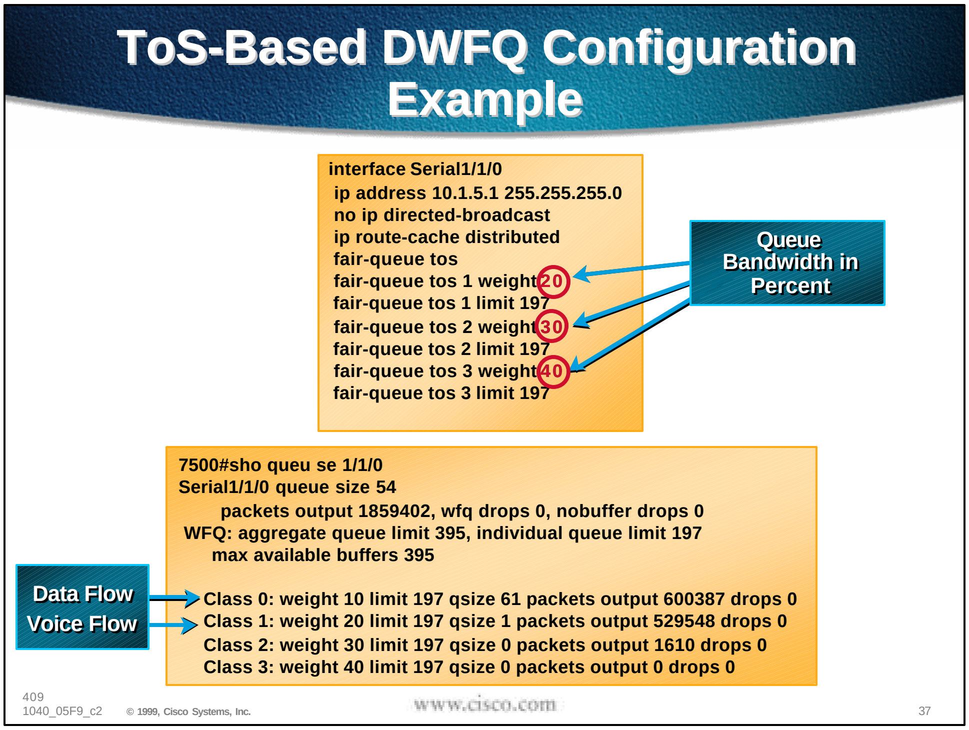

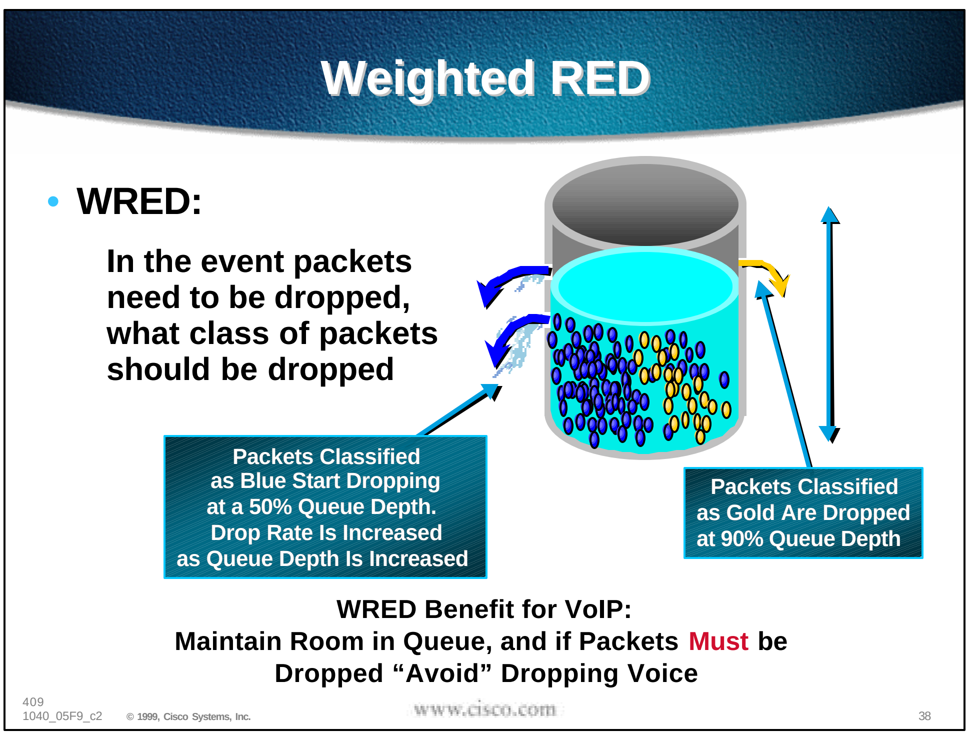

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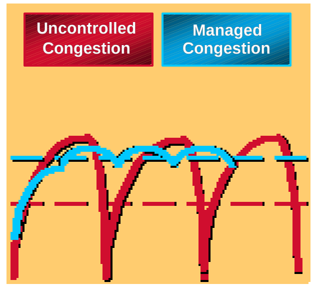
WRED Congestion Avoidance
Maximize Data Goodput

Adjustable Drop Probabilities
(from "show interface")

Queuing strategy: random early detection (RED)
mean queue depth: 56

drops: class	random	tail	min-th	max-th	mark-prob
0	4356	0	20	40	1/10
1	0	0	22	40	1/10
2	0	0	24	40	1/10
3	0	0	26	40	1/10
4	0	0	28	40	1/10
5	0	0	30	40	1/10
6	0	0	33	40	1/10
7	0	0	35	40	1/10
rsvp	0	0	37	40	1/10

Data Flow Prec = 0 (→ class 0)
Voice Flow Prec = 5 (→ class 5)



- **Accommodate burstiness**
- **"Less" drop probability for higher priority flows (VoIP)**
- **Does not protect against flows that do not react to drop**
  - For example, extremely heavy UDP flow can overflow WRED queue

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

- **IP-ATM CoS: Differentiated services over standard ATM**
- **Requires PA-A3/deluxe PA**
  - **IP precedence to ATM CoS mapping**
  - **IP RSVP to ATM services**

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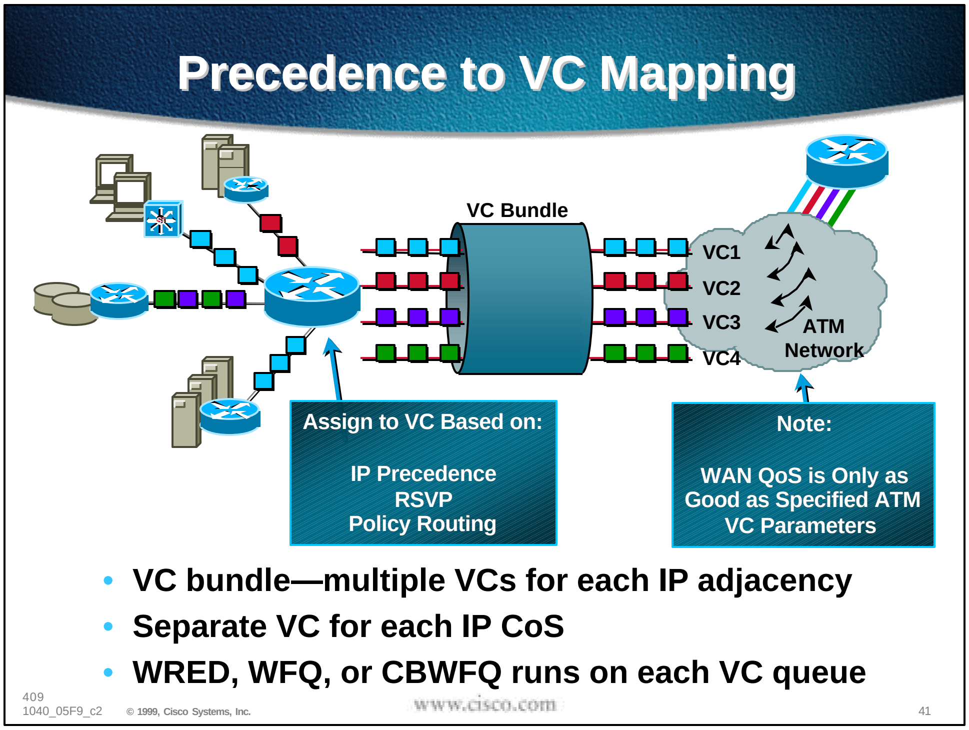

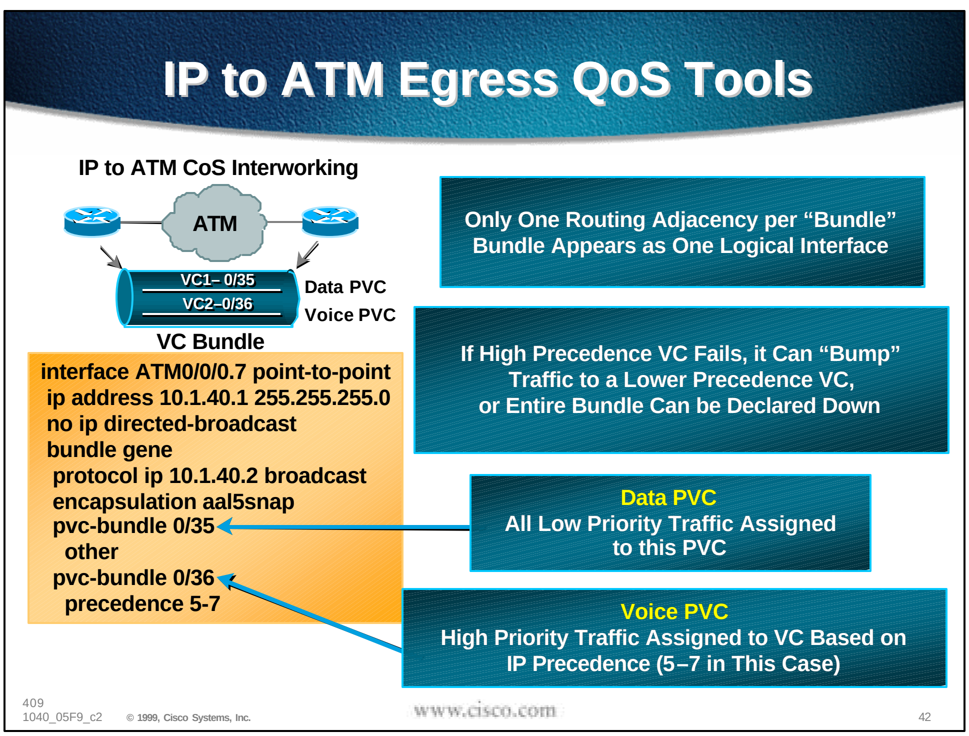

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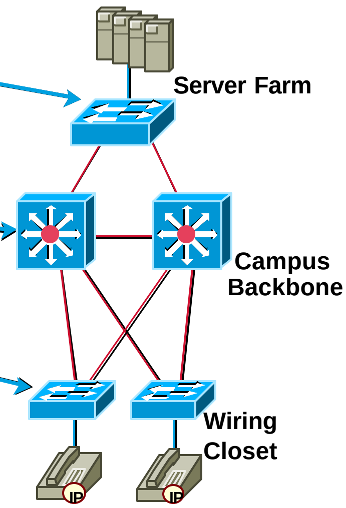
Prioritization
Campus QoS Needs

- **Catalyst 6XXX**
  - Two queues + two drop thresholds per port
  - Classification + policing
- **Catalyst 8500**
  - Four queues
- **Catalyst 5XXX**
  - 1 queue WRED four drop thresholds
  - Reclassification



Campus QoS Need Based on Customer Environment

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Link Efficiency
Low-Speed WAN QoS Tools

- **Fragmentation and interleave (LFI)**
- **RTP header compression (CRTP)**
- **Voice Activity Detection (VAD)**

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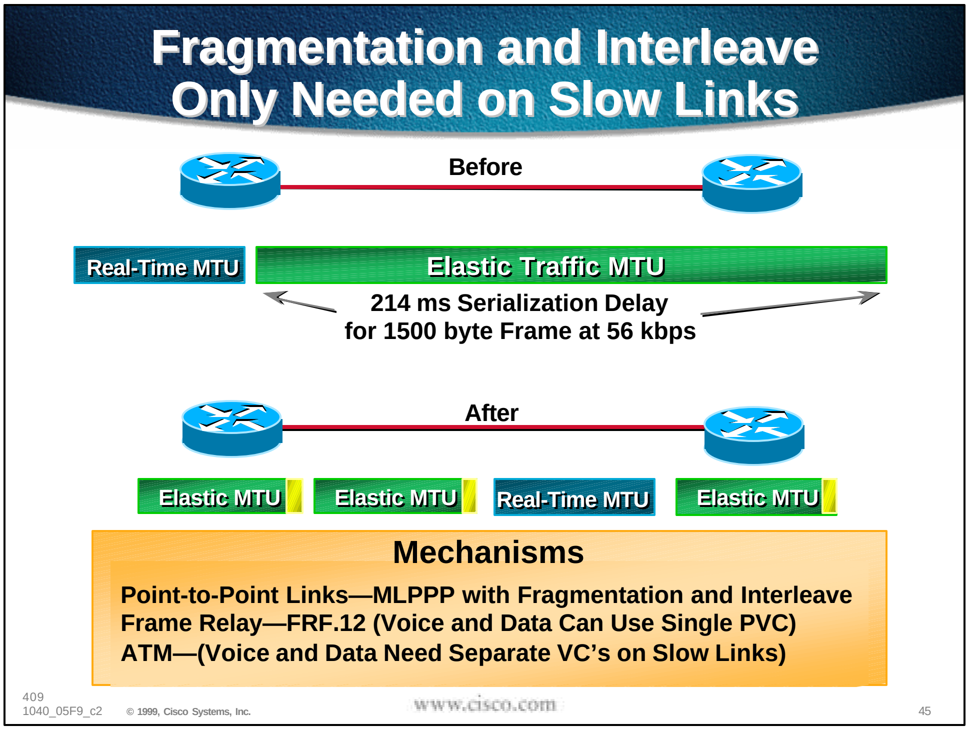

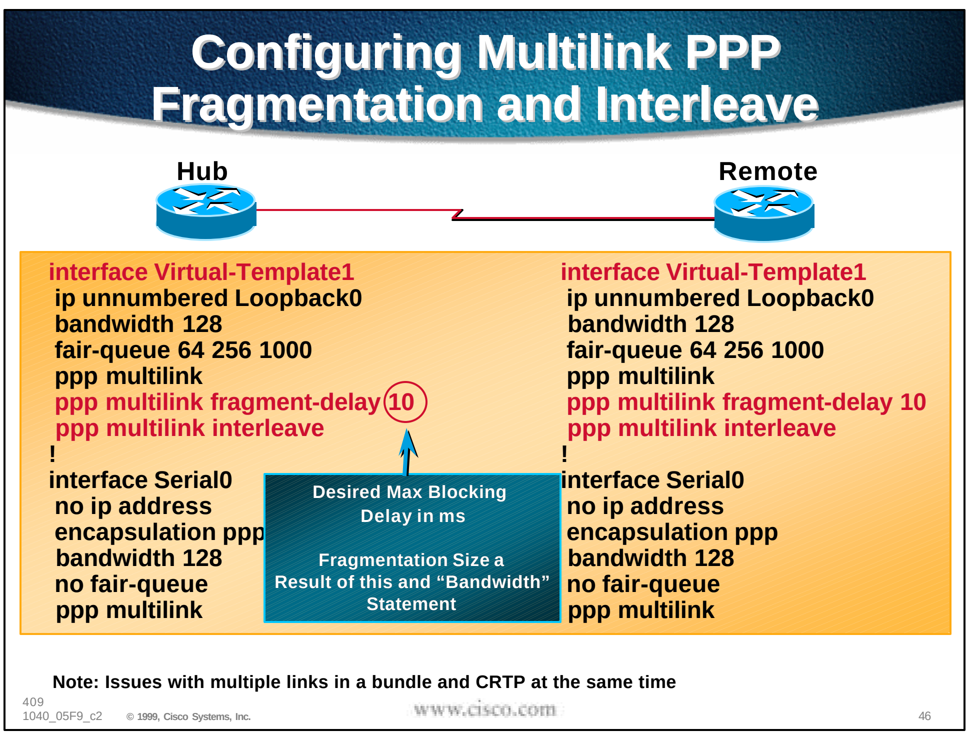

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Low Speed Frame Relay FRF.12 Configuration

Hub3640#

```
interface Serial0/0
 no ip address
 encapsulation frame-relay
 bandwidth 1300000
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 ip address 10.1.1.1 255.255.255.0
 no ip directed-broadcast
 bandwidth 1300000
 frame-relay class gene

map-class frame-relay gene
 frame-relay fragment 70
 no frame-relay adaptive-shaping
 frame-relay bc 2000
 frame-relay mincir 56000
 frame-relay fair-queue
```

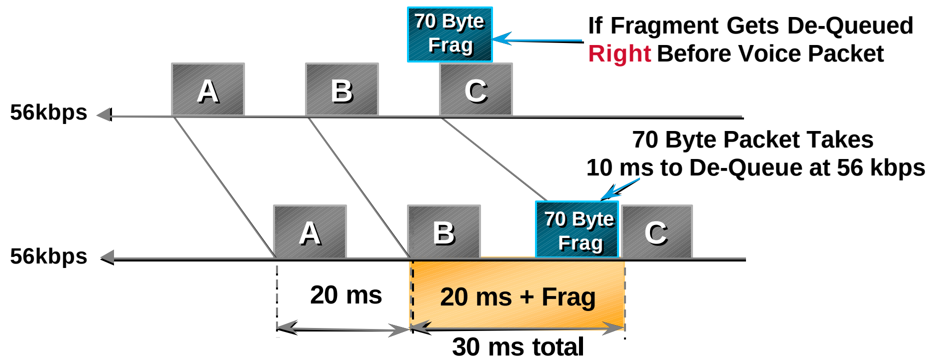
Remote3640#

```
interface Serial0/0
 no ip address
 encapsulation frame-relay
 bandwidth 56000
 frame-relay traffic-shaping
!
interface Serial0/0.1 point-to-point
 ip address 10.1.1.2 255.255.255.0
 no ip directed-broadcast
 bandwidth 56000
 frame-relay class gene

map-class frame-relay gene
 frame-relay fragment 70
 no frame-relay adaptive-shaping
 frame-relay bc 2000
 frame-relay mincir 56000
 frame-relay fair-queue
```

Note: Bc set lower than the default of 1/8th the CIR
Lower interval better on high speed links with low CIR (can result in quicker credit exhaustion)

Setting Fragment Size Based on Minimum Desired Blocking Delay



Note: Blocking delays are always present

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Fragment Size Matrix

Assuming 10 ms Blocking Delay per Fragment

Link Speed	Fragment 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~~

$$\text{Fragment Size} = \frac{10 \text{ ms}}{\text{Time for 1 Byte at BW}}$$

Example: 4 G.729 Calls on 128 kbps Circuit
Fragment Blocking Delay = 10 ms (160 bytes)

Q = (Pv*N/C) + LFI

Q = (480 bits*4/128000) + 10 ms = 25 ms

Worst Case Queuing Delay = 25 ms

Q = Worst Case Queuing Delay of Voice Packet in ms
Pv = Size of a Voice Packet in Bits (at Layer 1)
N = Number of Calls
C = Is the Link Capacity in bps
LFI = Fragment Size Queue Delay in ms

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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	144 ms	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

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RTP Header Compression

- Overhead

  20 ms @ 8 kbps yields
  20 byte payload

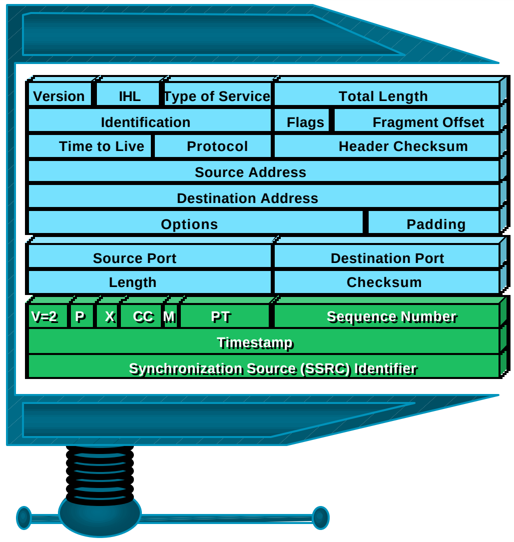
  40bytes per packet IP
  header 20; UDP header 8;
  RTP header 12

  2X payload!

  Header compression
  40 Bytes to 2–4 much
  of the time

  Hop-by-hop on slow links

  CRTP—compressed
  real-time protocol



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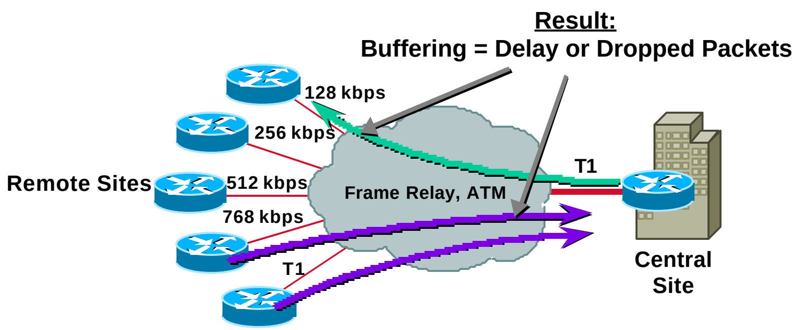
Traffic Shaping
Why?



- 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?

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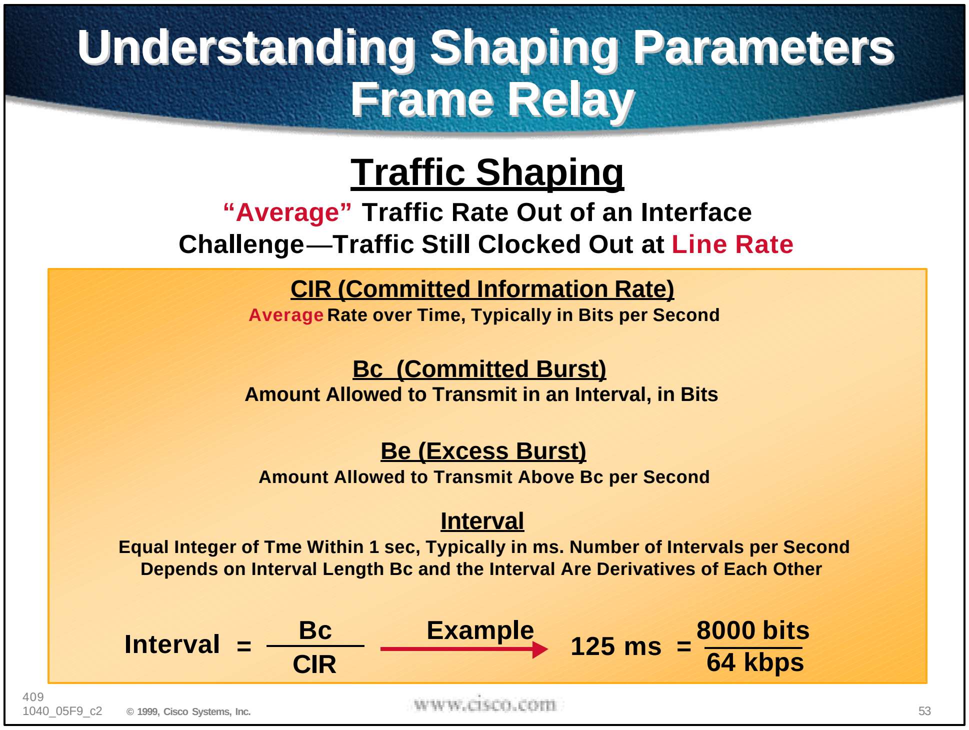

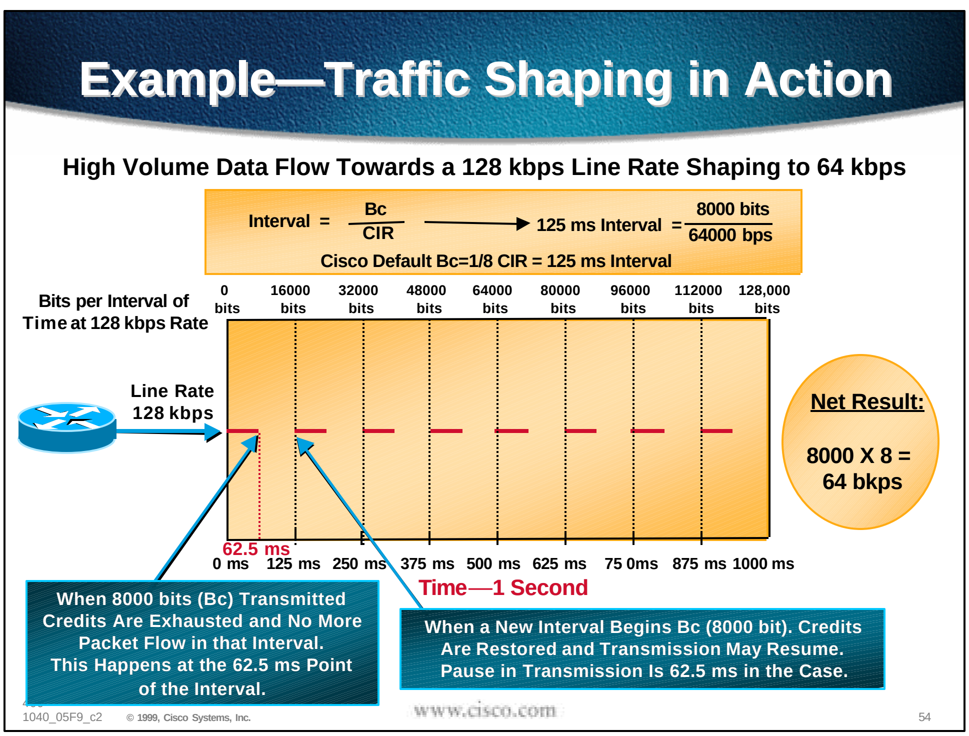

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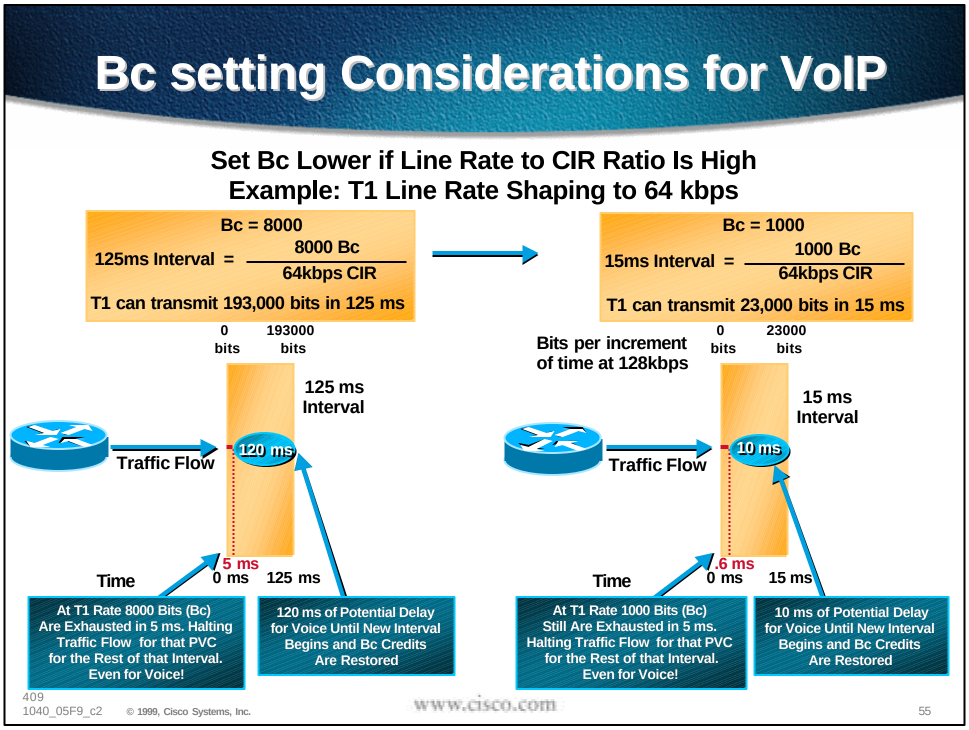

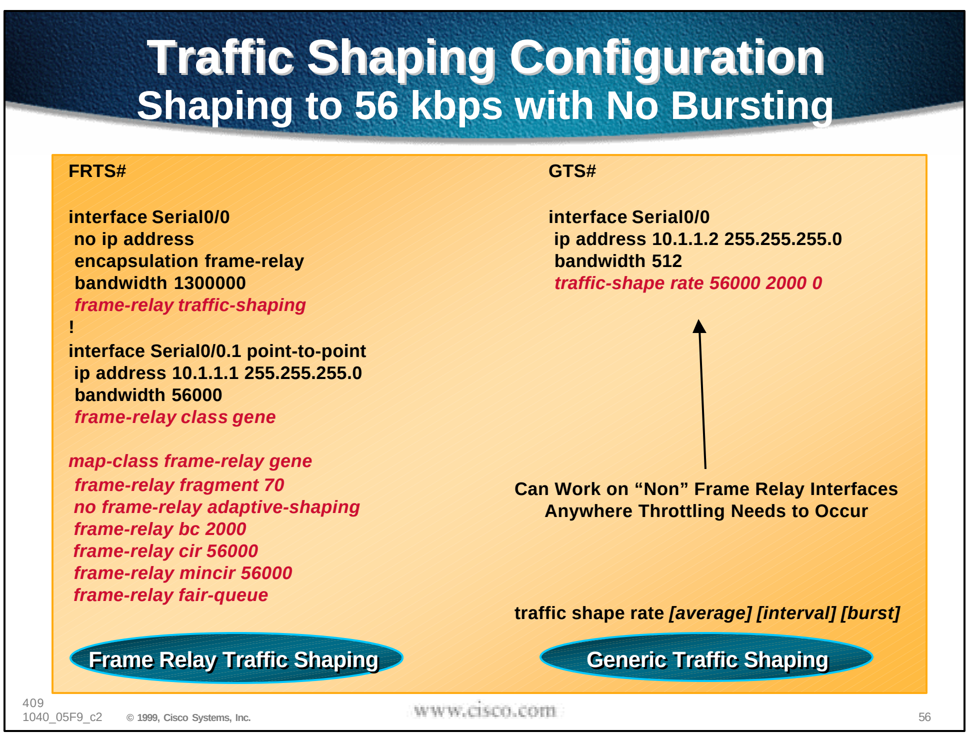

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Verifying Traffic Shaping Operation

```
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 2000     be 0        limit 250    interval 35
  mincir 56000     byte increment 250   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 + Frag—11.3
- Traffic Shaping—11.2
- FRF.12—12.0(4)T
- WRED—12.0
- DWFQ—12.0(3)T
- IP to ATM QoS—12.0(3)T

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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

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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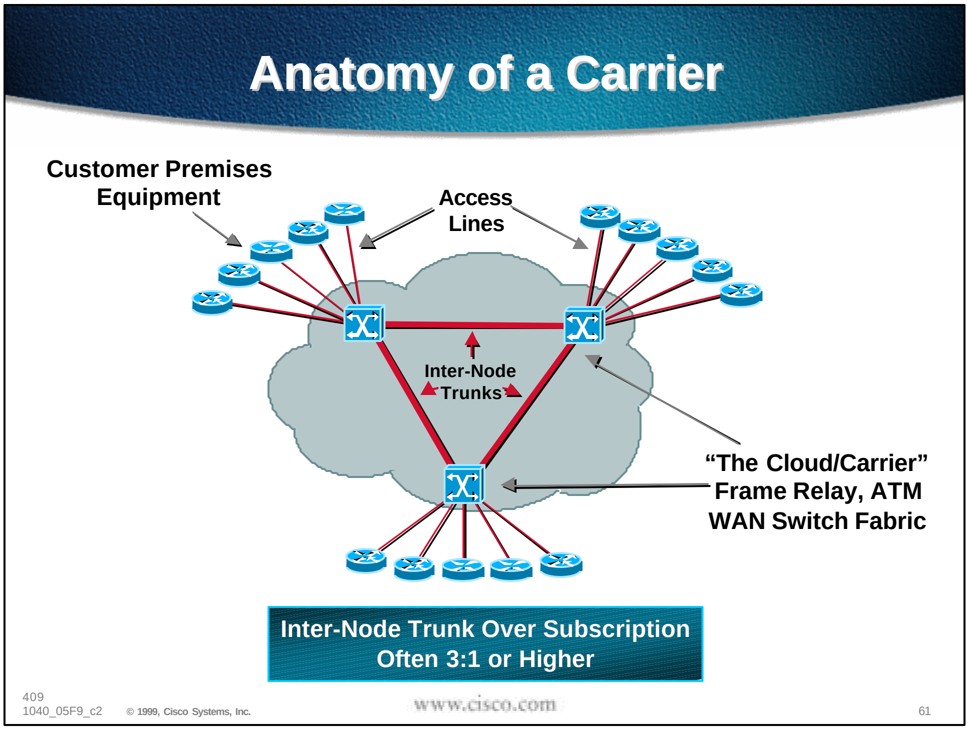

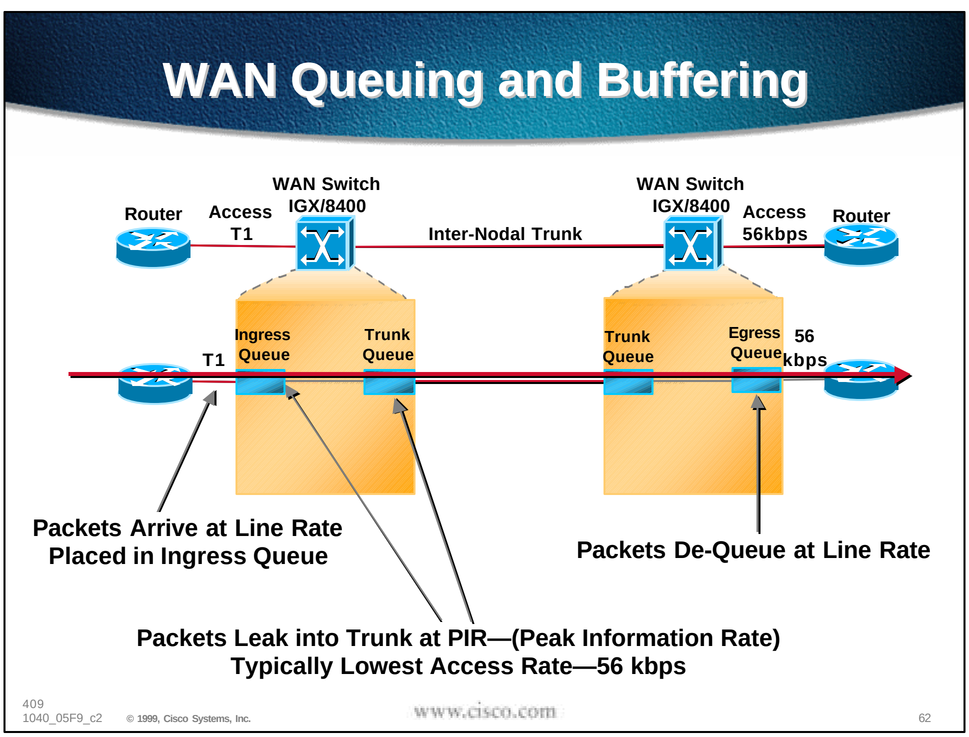

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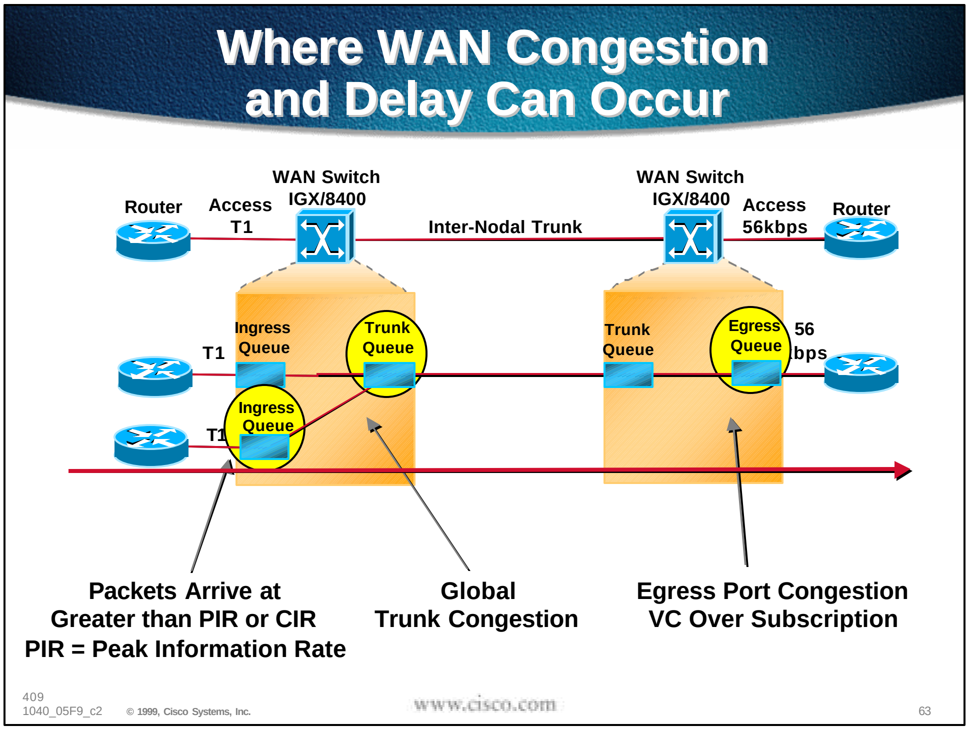

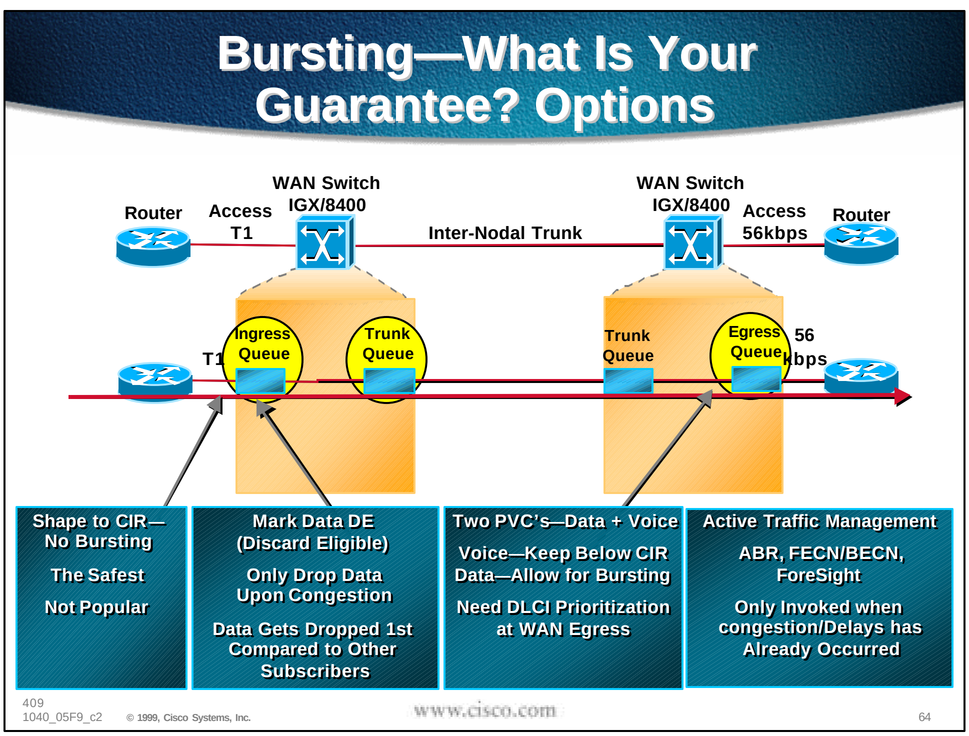

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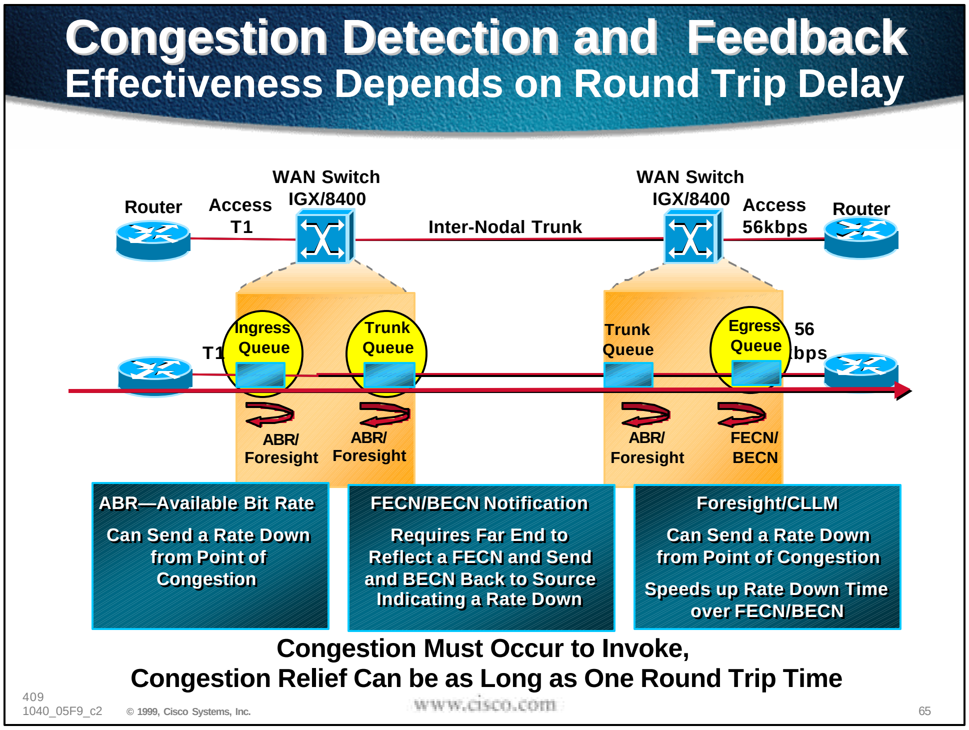

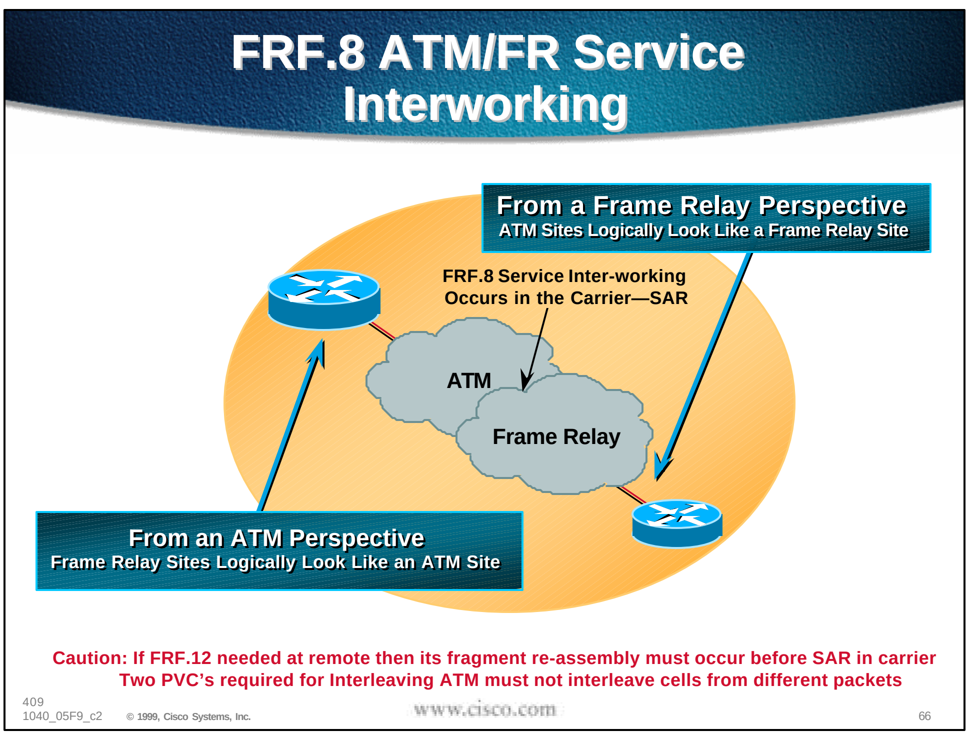

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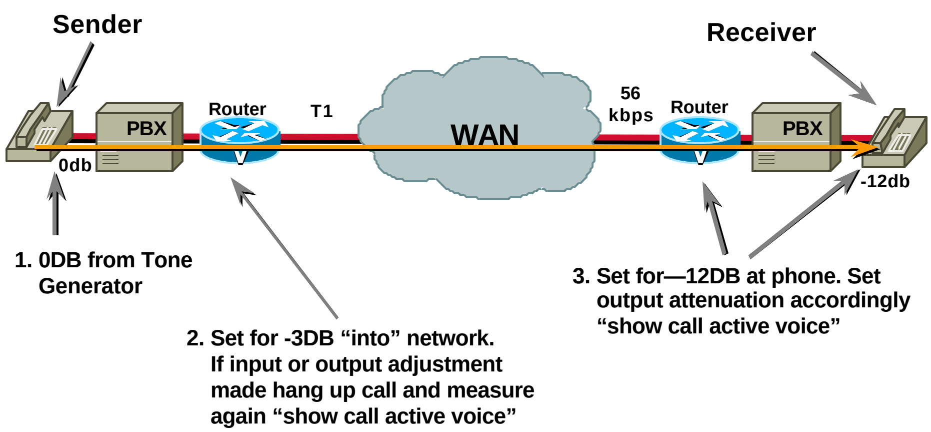
Audio Level Adjustment/Tuning



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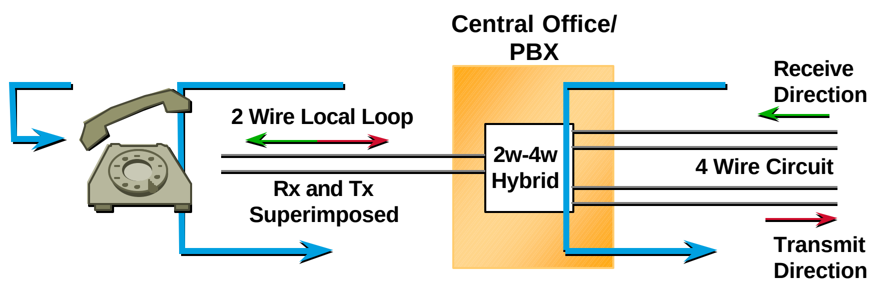
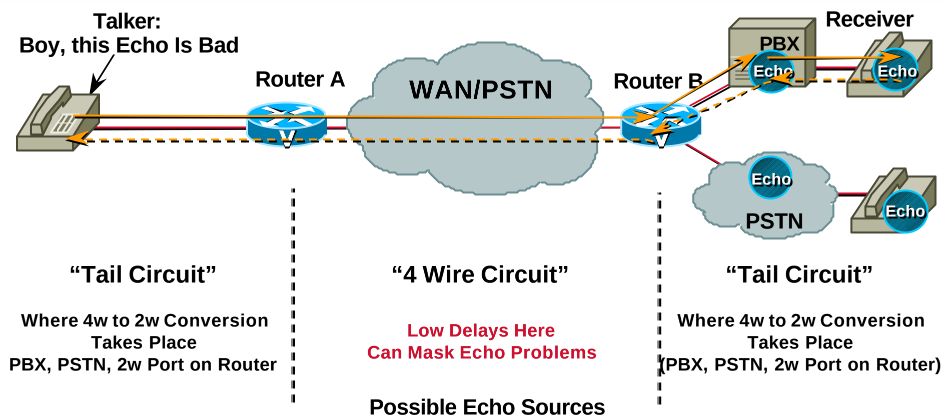
Echo—How Does it Happen? Echo Is Due to a Reflection



- **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**

If "I" Hear Echo, its "Your" Problem



- **ERL (Echo Return Loss)**
  - **ITU-T G.131 states ERL of a device should be greater than 15 dbmo**
  - **Echo cancellers typically give 25 db additional echo reduction**

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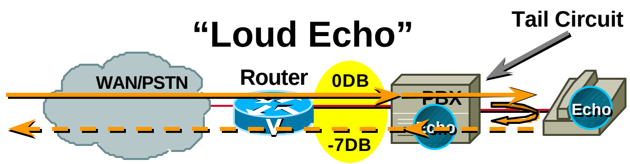
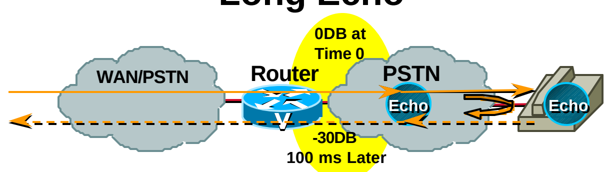
Types of Echo

"Loud Echo"



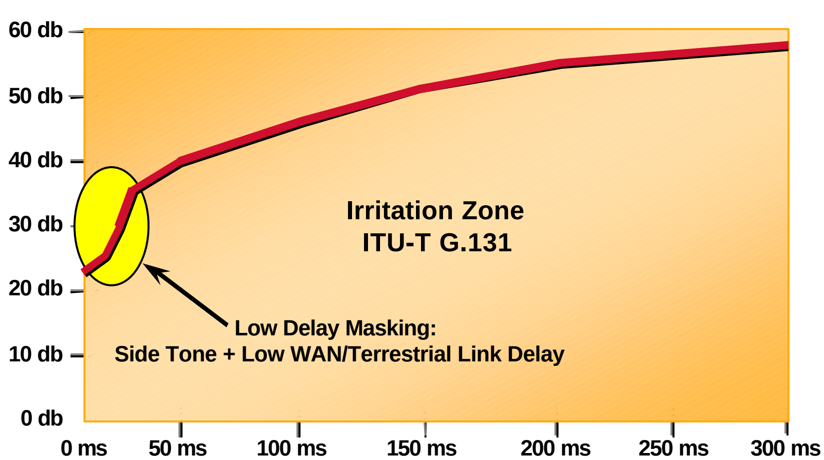
- ERL should be greater than 15 DB
- Typical echo canceller adds about 25 DB of echo reduction
- Solution—fix echo source

"Long Echo"



- Echo exceeds coverage range—Cisco echo coverage is 32 ms

Echo Loudness to Echo Delay Relationship



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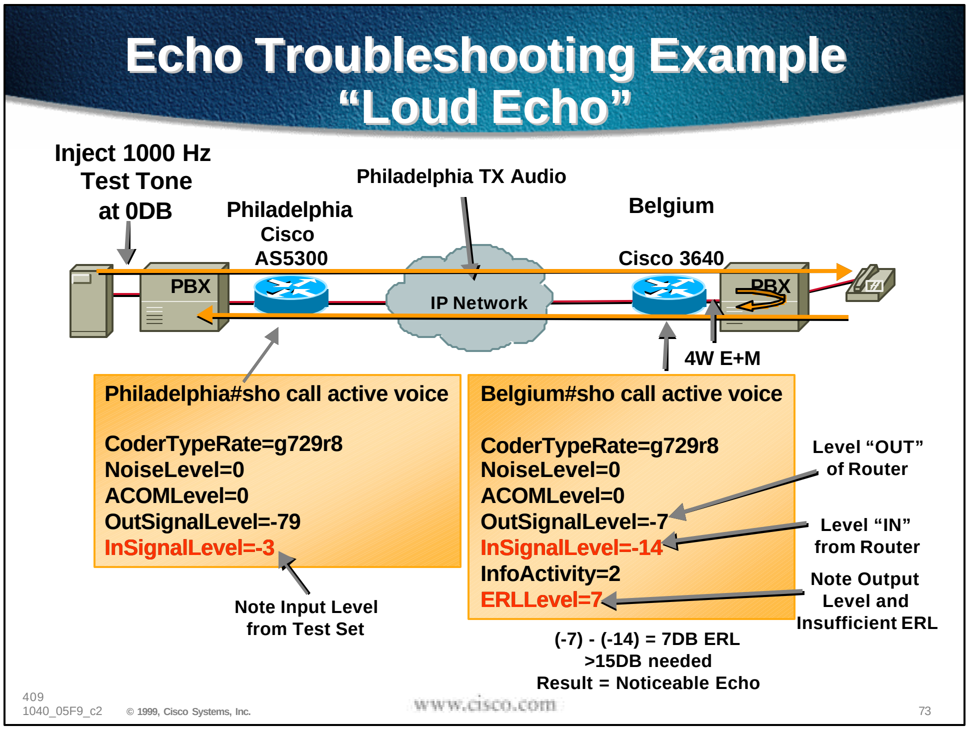

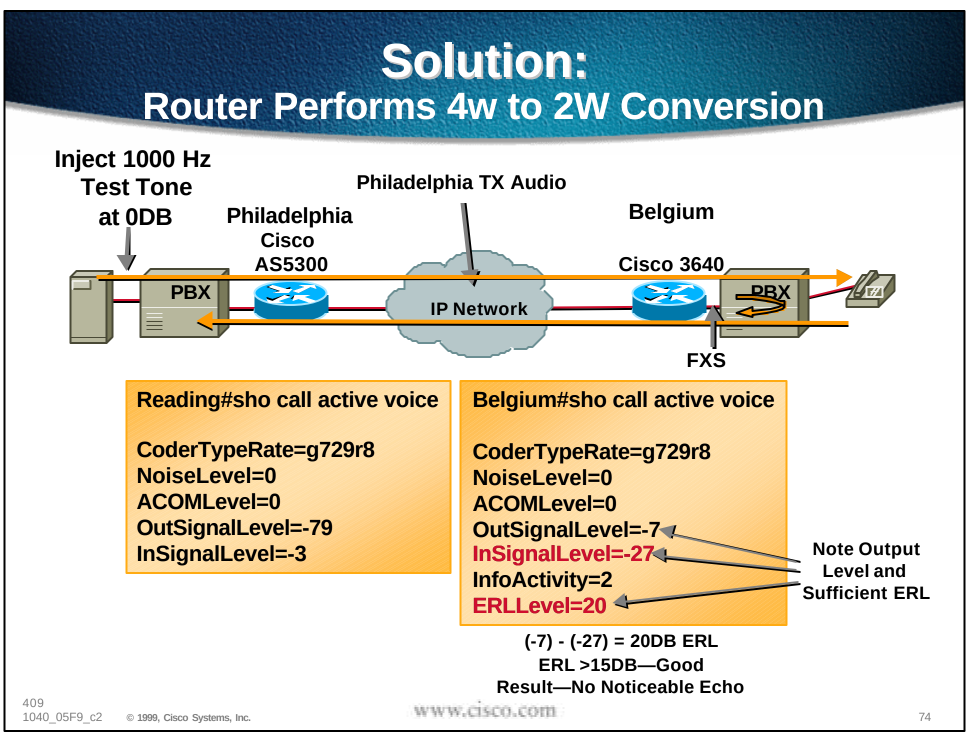

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Agenda

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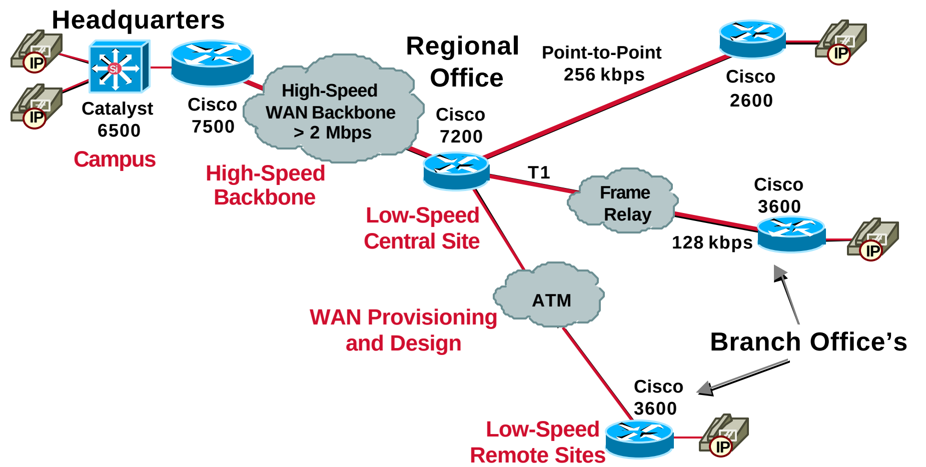
Summary: QoS Best Practice Example



Applying Proper Tools in Proper Location

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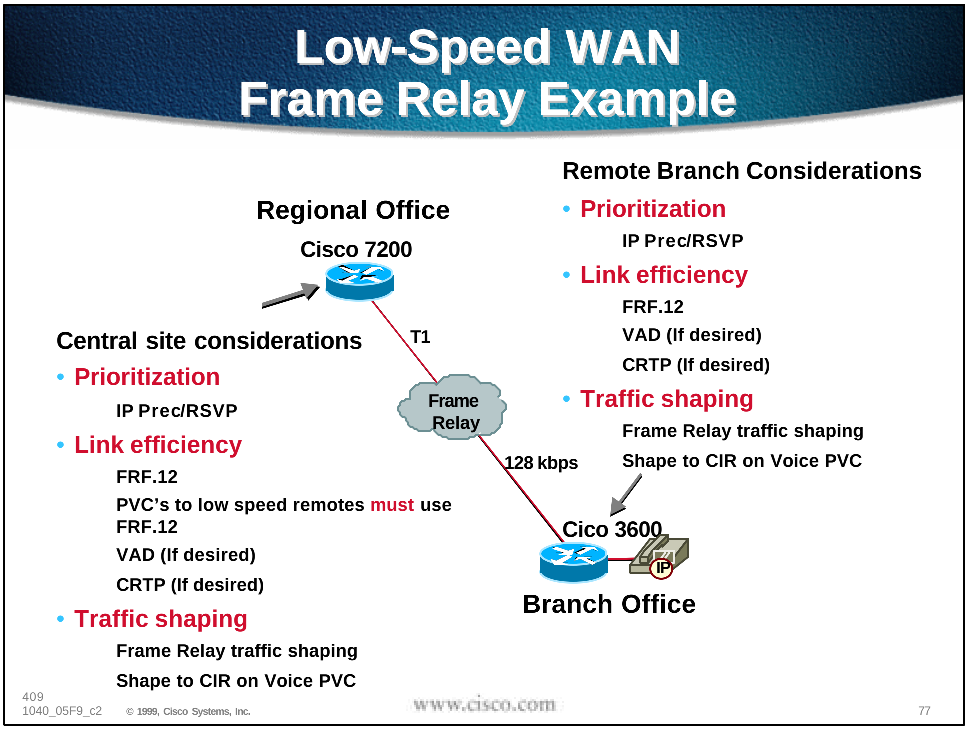

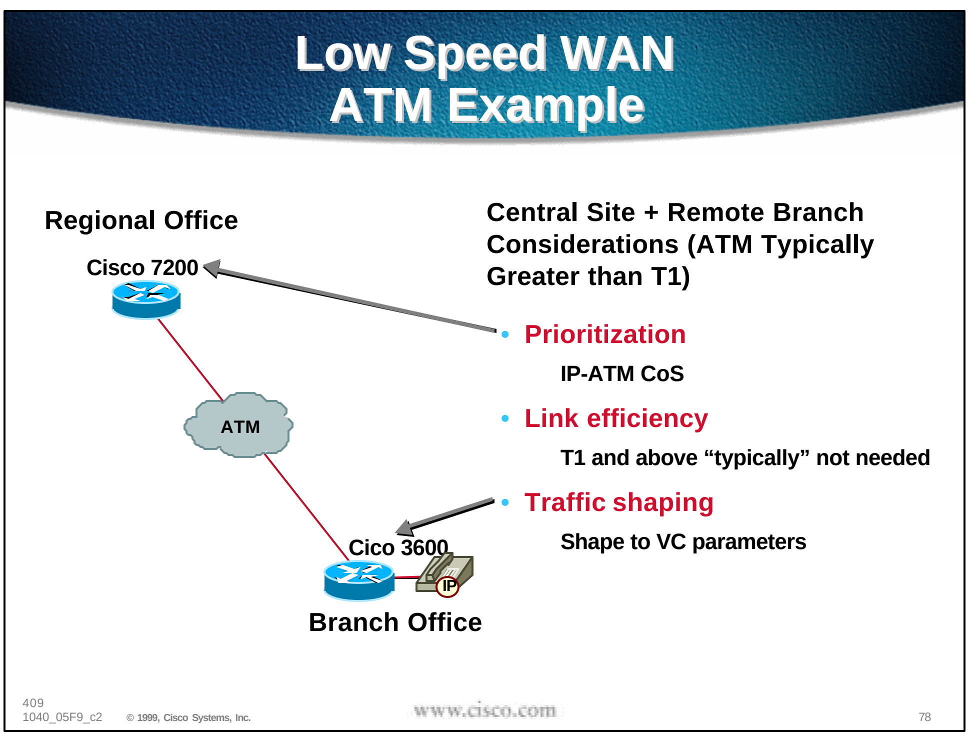

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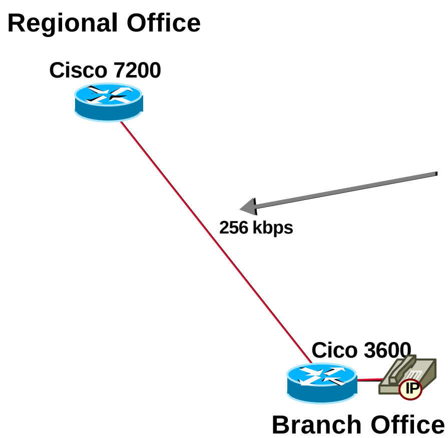
Low Speed WAN
Pt to Pt Example



Point-to-Point Considerations

- **Prioritization**

  IP Prec/RSVP

- **Link efficiency**

  MLPPP with fragmentation and interleave

  VAD (if desired)

  CRTP (if desired)

- **Traffic shaping**

  N/A

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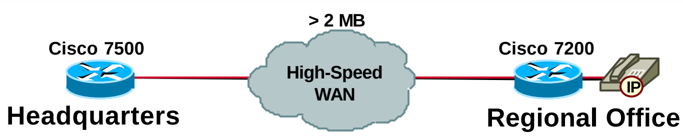
High Speed WAN Backbone
Frame Relay/ATM Example



ATM

- **Prioritization**

  IP-ATM CoS

- **Link efficiency**

  N/A

- **Traffic shaping**

  Shape to VC parameters

Frame Relay

- **Prioritization**

  IP Prec/RSVP

- **Link efficiency**

  FRF.12 if remote low-speed

- **Traffic shaping**

  Frame Relay traffic shaping

  Shape to CIR

Point to Point

- **Prioritization**

  IP Prec/RSVP

- **Link efficiency**

  N/A

- **Traffic shaping**

  N/A

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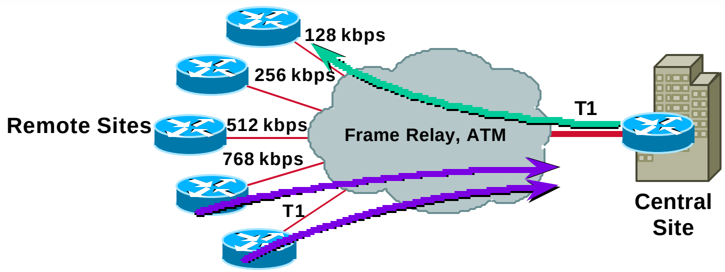
WAN Provisioning/ Design Considerations



Central to Remote Speed Mismatch

Traffic Shaping—Prevents Delay or Loss in WAN—A Must

Remote to Central Over Subscription—Do Not

Add additional T1's at Central Site, or
Traffic Shaping—from Remotes at Reduced Rate (< Line Rate)

Bursting Considerations "Guidelines"

- **Single PVC—limit bursting to committed rate (CIR)**
  - **The safest—you are guaranteed what you pay for**
- **Single PVC—mark data discard eligible**
  - **Your data gets dropped first upon network congestion**
- **Single PVC—utilize BECN's, foresight or ABR**
  - **Only invoked when congestion has already occurred**
  - **Round trip delays—Congestion indication must get back to source**
- **Dual PVCs—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)**
  - **Fragmentation rules still apply for data PVC**

Moral of the Story—"Know Your Carrier"

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In Conclusion

- Prioritization
- Link efficiency mechanisms
- Traffic shape
- Know your WAN!

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