Application Note

ShoreTel

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Configuring WAN Quality of Service for ShoreTel

This application note discusses configuration techniques and settings that can be used to achieve high-quality voice across a Wide Area Network (WAN).

Quality of Service Overview

ShoreTel uses a large number of IP protocols and UDP/TCP ports throughout its distributed VoIP architecture. These include communication protocols for call setup and tear-down, call detail record reporting, communication with ShoreTel's Call Manager application, IP phone display mechanisms and, of course, the Real-time Transport Protocol (RTP) used to carry voice-over-IP packets.

Voice packet media streams (RTP) vary in size from ~26-28 kbps, when using the G.729a codec, to ~274 kbps when using ShoreTel's Broadband Linear codec. On a modern Ethernet LAN, where individual IP phone devices often run at 100Mbps and inter-switch links often run at Gb speeds, there is minimal need for Quality of Service (QoS) configuration. But when that high-speed LAN interconnects to a remote location using a low-speed WAN circuit, such as a 1.5Mb, point-to-point T1 link, congestion will occur, interface buffers will fill up and packets will be discarded.

In order to achieve high-quality voice across a WAN, you need to configure the outbound WAN interfaces on your network equipment to classify and separate voice packets from data packets and then prioritize those voice packets ahead of the data packets. This means that voice packets need to be sent before the data packets (in order to reduce latency) and that, when buffers become full and packets need to be discarded, that data packets are dropped instead of voice packets.

This document will focus on the steps and configurations necessary to mark, classify and prioritize ShoreTel VoIP packets. For simplicity sake, we will provide examples using Cisco IOS commands. These commands can be used across a wide array of hardware devices and software version including many Cisco routers and switches along with other Cisco-like CLI-based routers and switches. Please consult the manuals for your specific equipment in order to implement the ideas and concepts in this Application Note rather than relying on the exact configuration examples provided here.

Quality of Service Mechanisms

Voice packets need to be marked in such a way that they can be identified (or classified) by an edge router. Once identified, they need to be placed into an egress queue that has an elevated level of transmission prioritization and a reduced packet-drop priority. That is to say, the VOICE queue needs to have its packet sent ahead of and with fewer packet drops (during times of high buffer utilization) than the normal, or default, data queue.

Other mechanisms exist to further shape traffic flows through a congested WAN link including link aggregation techniques (such as Multi-Link PPP bundles), packet fragmentation and interleaving (such as Frame Relay Forum standards, FRF.11 & FRF.12 or MLPPP fragmentation and interleaving), TCP header compression, RTP header compression (cRTP), and Random Early Discard (RED & wRED). In this Application Note we will focus only on the marking, classifying and prioritizing of VoIP packets.

WAN QoS for ShoreTel 5

ShoreTel 5's real-time IP Voice communication ports can be summarized in the following table.

Additional traffic is generated within a ShoreTel system but it is not real time and, as such, it is not recommended to include that traffic in any prioritization mechanism. (See ShoreTel Tech Note 152 for a more complete list of protocols and ports used).

TRAFFIC TYPE	TCP/UDP PORT	DESCRIPTION
IP Phone Call Setup	UDP 2427 UDP 2727	MGCP – IP Phone receive port MGCP – ShoreGear Switch receive port
ShoreGear switch-to-ShoreGear switch (Call Setup, ShoreSIP and Bandwidth Reservation)	UDP 5440 UDP 5441 UDP 5442 UDP 5443 UDP 5444 UDP 5445 UDP 5446	Location (LSP) Request & Response ShoreSIP Request & Response Call Routing Service (DRS) Bandwidth Reservation Protocol Request Bandwidth Reservation Service Bandwidth Reservation Protocol Response Call Routing Service (DRS) (Server-only)
ShoreGear Switch (Voice)	UDP 5004	Real-Time Protocol: RTP
IP Phone (Voice)	UDP 5004	Real-Time Protocol: RTP
SoftSwitch (Voice)	UDP 5004	Real-Time Protocol: RTP

Below are examples of Cisco-based IOS commands for two different queuing mechanisms: Priority Queuing (PQ) and Low-Latency Queuing (LLQ). These methods are used predominately on dedicated, point-to-point, T1 circuits using PPP or HDLC layer-2 encapsulation. These commands use an access list to identify all high priority voice traffic on a ShoreTel system and place those packets in a queue on the egress WAN interface that has been configured to send all packets from the "medium" queue ahead of the normal queue.

IOS Commands for Strict Priority Queuing (PQ) using UDP Port Prioritization: Depending on the physical attributes of the router, the WAN interface may have 4 queues to work with: high, medium, normal, and low. With strict priority queuing all packets in a higher queue will be sent prior to servicing any packets from a lower priority queue. We recommend not placing voice packets in the HIGH queue for, though it has the highest transmit priority, it also has the smallest maximum size. Placing voice packets in the medium queue still places them ahead of data traffic (which is placed in the default NORMAL queue) and has a larger total packet allowance than the HIGH queue.

```
access-list 101 remark : ShoreTel Voice over IP Ports
access-list 101 permit udp  any any eq 5004
access-list 101 permit udp  any any eq 2427
access-list 101 permit udp  any any eq 2727
access-list 101 permit udp  any any range 5440 5446

priority-list 1 protocol ip medium list 101
priority-list 1 default normal

interface serial 0/0             ! Substitute your WAN interface
  priority-group 1
```

The IOS Commands for Strict Priority Queuing (PQ) using UDP Port Prioritization (useful for older IOS configurations or non-congested WAN links)

IOS Commands for Low Latency Queuing within Class-based Weighted Fair Queuing (LLQ/CBWFQ) using UDP port prioritization: On links that have a greater need to shape voice traffic along side data traffic it is often better to use a more advanced queuing mechanism than strict priority queuing. Strict priority queuing can have the negative side affect of starving a WAN link of bandwidth for data traffic. ShoreTel uses an Admission Control Bandwidth mechanism to allocate a maximum utilization of VoIP pckets sent between sites but it is not able to be configured with enough granularity to accommodate all types of different WAN topologies perfectly.

Low Latency Queuing offers a method by which only a certain maximum amount of bandwidth is prioritized for packets in the voice queue while still allocating a sufficient amount of bandwidth for other traffic. These configuration commands use the newer Modular QoS Commands in later versions of Cisco IOS which create a class mapping to identify voice packets, then assign that class to a policy-map which defines prioritization behavior and finally that policy map is applied to an egress interface.

(**NOTE:** Not all interfaces, hardware and IOS versions support all of these commands. For example ATM circuits may not allow LLQ commands to be used on sub-interfaces.)

```
access-list 101 remark : ShoreTel Voice over IP Ports
access-list 101 permit udp  any any eq 5004
access-list 101 permit udp  any any eq 2427
access-list 101 permit udp  any any eq 2727
access-list 101 permit udp  any any range 5440 5446

class-map SHORETEL_VOIP    ! Note: some IOS’s will insert a “match-any”
   match access-group 101  ! on this “class-map” command

policy-map VOIP_POLICY
   class SHORETEL_VOIP
       priority percent 75 ! Allows up to 75% of the circuit speed to be used
                           ! for strict priority queing of VoIP packets.
                           ! any bandwidth not used by the VoIP packets is
                           ! usable by any other packets

   class class-default     ! Adjust setting for the default class
       fair-queue          ! Uses Weighted Fair Queuing for other traffic
       random-detect       ! Enables Random Early Discard (RED) for remainder
                           ! of traffic
   interface serial 0/0
       service-policy output VOIP_POLICY
```

IOS Commands for Low Latency Queuing within Class-based Weighted Fair Queuing (LLQ/CBWFQ) using UDP port prioritization (useful for congested WAN links – may require IOS 12.1 or greater)

Differences in ShoreTel 6

ShoreTel has been using SIP for call control between ShoreGear switches since ShoreTel version 4. But ShoreTel 6 introduced SIP-based call control for both IP trunking and for SIP-based end-points such as WiFi handsets, SIP-based conference phones and SIP-based Analog Terminal Adapters (ATAs). SIP requires the use of randomized UDP ports instead of a fixed UDP 5004 scheme that ShoreTel used to use for all RTP packets.

It is recommended that you transition away from prioritizing ShoreTel voice traffic using specific UDP ports as described above and migrate to using ShoreTel’s “Call Control Options” to mark ShoreTel voice packets with a specified Type of Service (ToS) value or Differentiated Services Code Point (DSCP, or DiffServ).

DiffServ / ToS Byte (0-255): **184**

By doing so, all RTP VoIP media stream traffic sourced from any ShoreTel IP phone or IP hardware voice switch (but not including soft switches, see notes below) will be marked with this value in the IP header. Configure your queuing mechanisms based on this value instead of on UDP port 5004.

Differentiated Services Code Points (DSCP)

Briefly, DiffServ is a value placed in the first 6 bits of the “DiffServ/ToS/Precedence” field of an IP packet header. This gives 64 unique code point values (the remaining 2 bits of the byte-long field are set to zero and ignored).

Furthermore, of the 64 possible values only 32 values are standardized and recommended for use. The first three bits are used to establish one of eight priority settings, or precedence levels. The next two bits can be used to establish a “drop priority,” further differentiating the importance of different packets within a priority level. The sixth bit is reserved and is set to zero.

Therefore the commonly used DSCP bits in the DiffServ Field will be in the format of:

`xxxxx000` (5 bits with the trailing three bits always set to zero)

The eight standardized DSCP markings are:

PRIORITY	PRECEDENCE LEVEL	DSCP BITS	DSCP VALUES	DESCRIPTION
Highest	7	111xx000	224 - 248	NETWORK CONTROL: Protocol keep alives
	6	110xx000	192 - 216	NETWORK CONTROL: Routing protocols
	5	101xx000	160 - 184	Express Forwarding (EF)
	4	100xx000	128 - 152	Class 4 (Assured Forwarding, AF4)
	3	011xx000	96 - 120	Class 3 (Assured Forwarding, AF3)
	2	010xx000	64 – 88	Class 2 (Assured Forwarding, AF2)
	1	001xx000	32 – 56	Class 1 (Assured Forwarding, AF1)
Lowest	0	000xx000	0 – 24	Best Effort (BE) (Default)

The eight standardized DSCP markings

For marking ShoreTel VoIP packets we recommend that you choose the highest possible value just prior to Network Control. That means a DiffServ Code Point setting of Express Forwarding (EF): 184

NOTE: Since the DiffServ (DS) Field is technically a full byte long (8 bits) confusion can arise between different vendors and documentation sources. ShoreTel requires that you specify the entire byte-long field. Hence the recommended value of decimal 184 (displayed as 0xB8 in hex or 10111000 in binary). Since the DSCP portion of the DS Field only truly comprises the first 6 bits (with the last 2 bits set to zero's [being reserved for future purposes]) some vendors will occasionally document only these first 6 bits as the DSCP value and display that value as a decimal number. The first six bits of decimal 184 (10111000 in binary) are 101110 which translates to decimal 46. ShoreTel requires a setting of 184 (decimal) for the whole "DS Field" in order to equate to the highest "DSCP value" (decimal 46) which equals the highest 'EF' priority. Please consult your router/switch vendor's documentation on how to best understand their terminology regarding EF-marked traffic.

NOTE: Only RTP voice traffic sourced from a ShoreTel phone (both an IP Phone and an analog phone connected to a ShoreTel switch) will be marked with this DSCP value. RTP voice traffic sourced from a soft switch (i.e. a ShoreTel server's voice traffic such as voice mail, auto attendant, workgroup services, account code collection, etc) will *not* be marked with this DSCP value but instead will be marked with a default value of '0' which equates to 'best effort' forwarding.

NOTE: Changing the DiffServ value within ShoreWare Director will immediately alter the packet markings of all new calls to and from a ShoreGear switch. But IP phones retrieve this value at startup. Therefore all IP phones will need to be rebooted in order to download this new information from the ShoreTel main server (contained in the "shore_sXX.txt" file found in the FTP folder on the server).

WAN QoS for ShoreTel 6

Combining the above descriptions of Low Latency Queuing and altering the classifications to prioritize only DSCP 'EF' marked RTP packets we arrive at the following:

IOS Commands for Low Latency Queuing within Class-based WFQ (LLQ/CBWFQ) using DSCP prioritization: *(See above examples for detailed remarks and comments)*

```
class-map SHORETEL_VOIP
   match ip dscp ef

policy-map VOIP_POLICY
   class SHORETEL_VOIP
      priority percent 75
   class class-default
      fair-queue
      random-detect

interface Serial0/0
   service-policy output VOIP_POLICY
```

But these commands by themselves leave out the other call-setup packets and only prioritize the RTP media streams themselves. It often is desirable to elevate the forwarding of all these packets and not just the RTP packets. In the following example we are examining all packets for a DSCP of 'EF' as well as looking for any of the MGCP and UDP 5440-5446 ports. We have removed UDP 5004 because we are now randomizing UDP ports for our RTP stream.

IOS Commands for Low Latency Queuing within Class-based WFQ (LLQ/CBWFQ) using DSCP prioritization and UDP ports:

```
access-list 101 remark : ShoreTel Voice over IP Ports
access-list 101 permit udp  any any eq 2427
access-list 101 permit udp  any any eq 2727
access-list 101 permit udp  any any range 5440 5446

class-map SHORETEL_VOIP
   match ip dscp ef
   match access-group 101

policy-map VOIP_POLICY
   class SHORETEL_VOIP
      priority percent 75
   class class-default
      fair-queue
      random-detect

interface Serial0/0
   service-policy output VOIP_POLICY
```

This is much better but we still do not have any of the voice packets being sent from the ShoreTel server (i.e. the softswitch) being classified and prioritized. That's because they are not being marked with the DSCP marking – only the ShoreTel hardware devices set this value in the IP header of the RTP packets. To remedy this we must configure the VoIP packets from the IP address of any and all ShoreTel servers to be prioritized as well. All RTP packets from the servers are sourced from the servers IP address and are UDP packets with source and destination UDP ports greater than 1024.

Assuming a ShoreTel server with an IP address of 10.1.1.5 the following configuration, placed on all outbound router interfaces at the headquarters site, will place all voice traffic (both phone-to-phone traffic already marked with the 'EF' DSCP value and voice traffic from the ShoreTel server) into the high priority queue.

In this, the final configuration, we also set the default class map to reset DSCP values in non VoIP packets to the default 'Best Effort' DSCP code point value to ensure that no rogue application attempts to elevate the delivery of its own packets.

IOS Commands for Low Latency Queuing within Class-based WFQ (LLQ/CBWFQ) using DSCP prioritization, UDP ports and UDP prioritization for server-sourced RTP packets:

```
access-list 101 remark : ShoreTel Voice over IP Ports
access-list 101 permit udp  any any eq 2427
access-list 101 permit udp  any any eq 2727
access-list 101 permit udp  any any range 5440 5446

access-list 102 remark : ShoreTel Server VoIP Packets
access-list 102 permit udp  host 10.1.1.5 gt 1024  any gt 1024
                         ! Using the newer ACL 'operator port'syntax
class-map SHORETEL_VOIP
   match ip dscp ef
   match access-group 101
   match access-group 102

policy-map VOIP_POLICY
   class SHORETEL_VOIP
      priority percent 75
   class class-default
      set dscp default
      fair-queue
      random-detect

interface Serial0/0
   service-policy output VOIP_POLICY
```

An alternative method to classifying ShoreTel server traffic is to apply an 'input' service-policy on the Ethernet port that connects directly to the ShoreTel server to automatically adjust the DSCP value for those RTP packets coming from the server. Doing so would simplify the upstream QoS configuration by marking the server RTP traffic at the point of ingress into the network and then relying on the simpler DSCP QoS example from the section above.

IOS Commands to set DSCP value on ingress for RTP traffic from the ShoreTel server:

```
access-list 103 permit udp  host 10.1.1.5  any  range 1025 65535
                             ! Using the older 'range' syntax

class-map SERVER_VOIP
  match access-group 103

policy-map SET_DSCP
  class SERVER_VOIP
  set ip dscp 46             ! Here we use the 6-bit decimal value

interface FastEthernet0/0    ! The interface connected to the server
  service-policy input SET_DSCP
```

WAN QoS for ShoreTel 6 using DSCP over Frame Relay Links

Point-to-point leased circuits (as described above) are dedicated, private, WAN connections giving you complete administrative control over congestion management and packet prioritization. Every packet you send "out" a T1 circuit is guaranteed to be received at the other end in exactly the same order with exactly the same latency with exactly 0% packet loss. But private circuits can be very expensive.

Frame Relay provides a compromise between expense and administrative control. With Frame Relay you order a relatively high-bandwidth circuit (often a full 1.544Mb T1) but only pay for a minimum guaranteed data rate. The guaranteed rate is called the "Committed Information Rate" or CIR. The CIR on a full T1 can vary from 0 kbps to 256 kbps to 1024 kbps or higher.

With Frame Relay you are allowed to send "bursts" of traffic above your guaranteed CIR rate. But the Frame Relay provider (the Telco), during periods of congestion within their network, can (and will) indiscriminately discard packets from your circuit that exceed your CIR.

Therefore, the only way to guarantee successful delivery of ALL your voice packets is to groom and shape your outbound transmission rate to never exceed your CIR.

This defeats some of the benefit of Frame Relay in the first place (i.e. being able to burst) but returns the necessary administrative control over packet loss back to you, the customer, instead of the indiscriminate discard procedures used by your provider.

Below is an example of adding rate shaping on a 256 kbps CIR Frame Relay circuit to the above QoS mechanisms.

Low Latency Class-based Weighted Fair Queuing using DSCP prioritization over Frame Relay Circuits:

```
 map-class frame-relay VOIP_CIR_SHAPING
   frame-relay cir 256000
   frame-relay bc 25600
   frame-relay mincir 256000
   service-policy output VOIP_POLICY   ! from above configurations

interface Serial0/0
   no ip address
   encapsulation frame-relay
   frame-relay traffic-shaping

interface Serial0/0.16 point-to-point
   frame-relay class VOIP_CIR_SHAPING
   frame-relay interface-dlci 16
```

Appendix

Topics *not* covered in this document:

- ATM WAN Circuits
- Frame Relay Fragmentation and Interleaving (FRF.11 & FRF.12)
- Separate PVCs for voice & data
- Internet-based VPN QoS
- MPLS-based QoS
- LAN-based QoS mechanisms, such as:
  - VLAN-based QoS
  - MLS QoS
  - Auto QoS
- CoS-based QoS
- 802.1P-based QoS
- Wireless QoS (802.11e, WMM, WME)
- Security

Useful Cisco IOS "show" Commands:

```
show queueing interface serial 0/0      ! Displays total queue hits
show interface serial 0/0               ! Displays total queue drops
show policy-map interface serial 0/0    ! Displays policy map drops
show ip rtp header-compression          ! Displays IP/RTP Header Compression
                                        !  stats on a PPP or HDLC interface
```

ShoreTel References

ShoreTel 6 Planning and Installation Guide
ShoreTel 6 System Administration Guide
ShoreTel 6 Maintenance Guide
ShoreTel Technical Note 0152: Ports used by the ShoreTel System

Cisco QoS References:

http://www.cisco.com/univercd/cc/td/doc/product/software/ios121/121cgcr/qos_c/qcprt2/qcdconmg.htm#1001203
http://www.cisco.com/univercd/cc/td/doc/product/software/ios121/121cgcr/qos_c/qcprt6/qcdcrtp.htm
http://www.cisco.com/univercd/cc/td/doc/product/software/ios121/121cgcr/qos_c/qcprt6/qcdlfi.htm
http://www.cisco.com/univercd/cc/td/doc/product/software/ios121/121cgcr/qos_c/qcprt4/qcdfrts.htm
http://www.cisco.com/univercd/cc/td/doc/product/software/ios121/121cgcr/wan_c/wcdfrely.htm#1001623

DSCP References:

http://www.cisco.com/en/US/tech/tk543/tk757/technologies_tech_note09186a00800949f2.shtml
http://juniper.net/techpubs/software/junos/junos74/
ftp://ftp.isi.edu/in-notes/rfc2474.txt
ftp://ftp.isi.edu/in-notes/rfc2475.txt

Record of Change

This application note is subject to change. Updates and corrections are always welcome. Please submit any updates or corrections to ProServices@ShoreTel.com.

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