QoS for Real Time Applications over Next Generation Data Networks

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Outline of Talk

- Present state of the Internet.
- QoS approaches to future data networks.
- Research Issues.
- Progress to date:
  - Task 1: DS over ATM
  - Task 2: IS over DS
  - Task 3: ATN
  - Task 4: Satellite networks
  - Task 5: MPLS
- Conclusions.
Current Internet

- TCP/IP glues together all the computers in the Internet.
- TCP/IP was designed for terrestrial networks.
- TCP/IP does not
  - offer QoS to real time applications, or
  - perform well in long delay bandwidth networks.
Efforts to provide QoS in Internet

- Integrated Services (IS)
- Differentiated Services (DiffServ)
- Explicit Congestion Notification (ECN)
- Multiprotocol Label Switching (MPLS)
- Asynchronous Transfer Mode (ATM)
Integrated Services

- RSVP to reserve resources during connection setup.
- End-to-end QoS guarantees.
- A router has to keep information about all connections passing through the router.
- Gives rise to scalability problem in the core routers.
RSVP Signaling

PATH message

DATA

RESV message

Sender

Router1

Router2

Receiver

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NASA/TM—2001-210904
RSVP Signaling

- Reserves a portion of link bandwidth in each router
- The sender sends a PATH message with resource requirements for a flow.
- Receiver responds with a RESV message
- Each router processes the RESV to reserve the required resources requested by the sender.
- Routers can modify the QoS parameters of the RESV message if enough resources are not available to meet the requirements.
- Each router in the entire path confirms the end-to-end reservation for the flow.
**IS Service Classes**

- **Guaranteed Load Service**
  - Low end-to-end delay, Jitter, Loss.
  - Highest priority service.

- **Controlled Load Service**
  - Network should forward the packets with queuing delay not greater than that caused by the traffic’s own burstiness (RFC 2474).
  - Performance similar to that of an unloaded network.
  - Traffic specifications from the Tspec.

- **Best Effort**
Differentiated Services

- Similar traffic are grouped into classes.
- Resources reserved for classes.
- QoS provided to classes.
  - QoS to individual connections is an open research issue.
- QoS maintained by:
  - Classification
  - Traffic policing
    - Metering, dropping, tagging
  - Traffic shaping
- Per Hop Behavior (PHB)
  - Specifies QoS received by packets i.e. how packets are treated by the routers.

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Asynchronous Transfer Mode

- Strong QoS guarantees; suitable for real time applications.
- High cost prohibits use at the edge network or to the desktop.
- Currently used at the core of the Internet.
Next Generation Internet

- Routers at the edge network will not need to carry too many connections
  - IS can be used at the edge network.
- Core network needs to carry lot of connections.
  - Combination of DS, ATM and MPLS at the core.
- Satellite/Wireless links
  - Remote connectivity and mobility.
Research Issues

- Service mapping between networks.
- Loss and delay guarantees.
- Interoperability among edge and core technologies.
- Interoperability with Aeronautical Telecommunications Network (ATN).
- Operation in satellite environment having high delay and loss.

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Task 1

Prioritized Early Packet Discard

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Asynchronous Transfer Mode (ATM)

- **Service Classes**
  - Constant Bits Rate (CBR)
  - Available Bit Rate (ABR)
  - Unspecified Bit Rate (UBR)

- **CLP in cell header**
  - Determines loss priority of packets
Differentiated Services

- **Service Classes**
  - Premium Service: emulates leased line
  - Assured Service
  - Best Effort Service

- **Various levels of drop precedence.**
  - Need to be mapped to ATM when running DS over ATM.
  - Could be possible mapped to the CLP bit of ATM cell header.
DS over ATM

Possible Service Mappings
• Premium Service $\rightarrow$ ATM CBR service.
• Assured Service $\rightarrow$ ATM UBR service with CLP=0
• Best Effort $\rightarrow$ ATM UBR service with CLP=1

DS packets are broken down into cells at the DS-ATM gateway
• Drop precedence mapped to CLP bit

Buffer Management at ATM switches
• Partial Packet Discard (PPD)
• Early Packet Discard (EPD)
Prioritized EPD

- DS service classes can use the CLP bit of ATM cell header to provide service differentiation.
- EPD does not consider the priority of cells.
- Prioritized EPD can be used to provide service discrimination.
- Two thresholds are used to drop cells depending on the CLP bit.
Buffer Management Schemes

EPD

- $QL < T$
  - Accept all packets.
- $T \leq QL < N$
  - Discard all new incoming packets.
- $QL \geq N$
  - Discard all.

PEPD

- $QL < LT$
  - Accept all packets.
- $LT \leq QL < HT$
  - Discard all new low priority packets.
- $HT \leq QL < N$
  - Discard all new packets.
- $QL \geq N$
  - Discard all packets.
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Steady State Equations

\[
\begin{align*}
\lambda P_{0,0} &= \mu P_{1,0} \\
q\lambda P_{0,1} &= \mu P_{1,1} \\
(\lambda + \mu)P_{i,0} &= \lambda P_{i-1,0} + \mu P_{i+1,0} + q\lambda P_{i-1,1} & 1 \leq i \leq LT \\
(\lambda + \mu)P_{i,0} &= (\lambda p + qh\lambda) P_{i-1,0} + \mu P_{i+1,0} + qh\lambda P_{i-1,1} & LT < i \leq HT \\
(\lambda + \mu)P_{i,0} &= p\lambda P_{i-1,0} + \mu P_{i+1,0} & HT < i < N \\
(\lambda + \mu)P_{N,0} &= p\lambda P_{N-1,0} \\
\mu P_{N,1} &= \lambda P_{N,0} \\
\mu P_{i,1} &= q\lambda P_{i,0} + \mu P_{i+1,1} & HT \leq i < N \\
(\mu + qh\lambda)P_{i,1} &= q\lambda (1-h) P_{i,0} + \mu P_{i+1,1} & LT \leq i < HT \\
(\mu + q\lambda)P_{i,1} &= \mu P_{i+1,1} & 0 < i < LT \\
\sum_{i=0}^{N} (P_{i,0} + P_{i,1}) &= 1
\end{align*}
\]
Goodput

\[ G_h = \frac{\sum_{n=1}^{\infty} nP(W = n, V = 1, U = 1)}{\sum_{n=1}^{\infty} nP(W = n, U = 1)} \]
Queue Occupancy

Simulation: $N=120$, $LT=60$, $HT=80$, $h=0.5$, $q=1/6$.

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Goodput versus load for $h=0.5$

Simulation: $N=120$, $LT=60$, $HT=80$, $q=1/6$.

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Goodput versus load for $h=0.2, 0.5, 0.8$

Simulation: $N=120$, $LT=60$, $HT=80$, $q=1/6$.

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Simulation: $LT=60$, $q=1/6$

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Goodput of high priority vs. $h$

Simulation: $LT=60$

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Goodput for high priority versus $LT$

Simulation: $N=120$, $HT=80$, load=1.6, $q=1/6$.

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OPNET Simulation Configuration

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- AAL Layer marks the End of Packet.

- ATM_layer changes the CLP bit depending on the packet of the DS service.
- Support service differentiation in the ATM switch buffer.
- Change the buffer management scheme in the ATM_switch process to Prioritized EPD.
ATM_Switch Process

Implements the PEPD buffer management to support service differentiation.

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Task 2

Mapping of IS over DS

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Traffic entering DS domain

Packet of size P entering DS domain at boundary node

Is Out-of-profile?

Yes

No

Check for DS field of the packet

No

Shaping

Yes

Insert into EF queue

Discard the EF incoming packet

Insert into AF queue

If buffer occupancy of Q1

No

Push enough EF packets to make space for AF packet

No

Discard the AF incoming packet

Checking for buffer space of Q1

Yes

Yes

Insert into the EF queue

Shaping

Insert into AF queue

Checking for buffer space of Q1

No

End of the EF incoming packet

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Differentiated Services

- **Classification**: Based on IP header field classifies into BA to receive particular per hop behavior (PHB)
- **Metering**: Measuring the traffic against token bucket to check for resource consumption
- **Shaping**: Treatment of out-of-profile traffic by placing it in a buffer.
- **Dropping**: Non-conformant traffic can be dropped for congestion avoidance
- **Admission Control**: Limiting the amount of traffic according to the resources in the DS domain.
  - Implicit Admission Control: Performed at each router
  - Explicit Admission Control: Dynamic resource allocation by a centralized bandwidth broker
Various PHB’s

- Expedited Forwarding (EF PHB)
- Assured Forwarding (AF PHB)
- Best Effort (Default)
Queue Implementation (RED)

- **Incoming**
  - Minimum Threshold
  - Maximum Threshold
  - Packet Drop Probability
  - Queue Size

**RED Region**
QoS Specifications

- Bandwidth:
- Latency:
- Jitter:
- Loss:
Service Mapping from IS-DS

- Provide different levels of service differentiation.
- Provide QoS to multimedia and multicast applications.
- Scalability in terms of resource allocation.
- There is no overhead due to per flow state maintenance at each router.
- Forwarding at each router according to the DSCP code.
- PHB’s along the path provide a scheduling result approximating the QoS requirements and results in IS

<table>
<thead>
<tr>
<th>Integrated Service</th>
<th>Differentiated Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guaranteed Load</td>
<td>Expedite Forwarding</td>
</tr>
<tr>
<td>Controlled Load</td>
<td>Assured Forwarding</td>
</tr>
<tr>
<td>Best effort</td>
<td>Default best effort</td>
</tr>
</tbody>
</table>

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DS functionality

- Per Hop behavior (PHB)
- Behavior Aggregate (BA)
- Differentiated Services Code Point (DSCP)

TOS Byte

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
</table>

DS field

CU

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Guaranteed load - EF PHB

- Guaranteed traffic performance can be met effectively using the EF PHB with proper policing and shaping functions.
- Shaping Delay
- Queuing Delay
- Packets in the Scheduler
Controlled Load - AF PHB

- Classified into delay classes based on the B/R ratio of Tspec for each delay class; Aggregate Tspec is constructed for all the admitted traffic.
- For each delay class, police the traffic against a token bucket derived above.
- Size of the queue is set to limit the queuing delay of AF requirement.
- RIO dropping parameters are set according to the drop precedence of the AF class.
- AF instance service rate is set to bandwidth sufficient enough to meet the delay and loss requirements of the CL traffic.
- Bandwidth distributed between AF and BE to prevent the BF from starvation.
- Scheduling done with WFQ (Weighted Fair Queuing) or WRR (Weighted Round Robin)

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Traffic Conditioning at DS Boundary

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## Mapping Table for IS-to-DS

<table>
<thead>
<tr>
<th>Flow Id</th>
<th>T Spec Parameters</th>
<th>PHB</th>
<th>DSCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R = 400, P = 500, B = 700</td>
<td>AF11</td>
<td>001010</td>
</tr>
<tr>
<td>2</td>
<td>R = 450, P = 550, B = 750</td>
<td>AF32</td>
<td>011100</td>
</tr>
<tr>
<td>3</td>
<td>R = 500, P = 600, B = 800</td>
<td>AF41</td>
<td>100010</td>
</tr>
<tr>
<td>4</td>
<td>R = 550, P = 650, B = 850</td>
<td>EF</td>
<td>000100</td>
</tr>
<tr>
<td>5</td>
<td>R = 600, P = 700, B = 900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>R = 650, P = 750, B = 950</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>R = 700, P = 800, B = 1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>R = 750, P = 850, B = 1050</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>R = 800, P = 900, B = 1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>R = 850, P = 950, B = 1150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Mapping of IS to DS

- Tspec parameters indicating resource reservation taken from RSVP signaling.
- Table entry contains Tspec parameters, flow IDs, PHB groups and DSCP values.
- Measures actual traffic flow rate against a token bucket according to the initial stored table entry.
- If the traffic is in-profile with the requested reservation, it classifies the packet and marks it with the available DSCP, which can approximately assure the requested QoS.
- The out-of profile traffic is stored in a buffer and shaped to be in conformance with the requested traffic profile.
Mapping of IS to DS (contd.)

- Packets are forwarded in the DS domain according to the DSCP value and the PHB group.

- The forwarding treatment is basically concerned with the queue management policy and the priority of bandwidth allocation; these ensure the required minimum queuing delay, low jitter and maximum throughput.

- Depending on the implementations of the PHB’s inside the network, queue management could be RED, WRED, PQ, WFQ.
Interoperability with Aeronautical Telecommunications Networks (ATN)

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Overview of ATN

- Aeronautical Telecommunications Network.
- Supporting data link based ATC application & AOC.
- Integrating Air/Ground & Ground/Ground data communications network into a global internet serving ATC & AOC.
- Introducing a new paradigm of ATC based on data link rather than voice communications.
- Operating in a different environment with different data communication service provider.
- Supporting the interconnection of Ess & Iss using a variety of subnetwork types.
Purpose of ATN

- Using the existing infrastructure.
- High availability.
- Mobile Communications.
- Prioritized end-to-end resource management.
- Scalability.
- Policy based routing.
- Future proofing
QoS of ATN

- Priority
- Transit Delay
- Error Probability
- Cost
- Security
- Reliability

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Model of Transport Layer

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**Structure of TPDU**

<table>
<thead>
<tr>
<th>Octet</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length Indicator Field</td>
</tr>
<tr>
<td>2</td>
<td>CR CDT</td>
</tr>
<tr>
<td>3, 4</td>
<td>DST REF</td>
</tr>
<tr>
<td>5, 6</td>
<td>SRC REF</td>
</tr>
<tr>
<td>7</td>
<td>Class Option</td>
</tr>
<tr>
<td>8</td>
<td>TSAP-ID (Source &amp; Destination Address), TPDU size, Preferred max n, TPDU size, Version number, Security, Checksum, Additional option selection, Alternative protocol class(es), Acknowledge time, Throughput, Residual error rate, Priority, Transit Delay, Reassignment time &amp; Inactive timer</td>
</tr>
</tbody>
</table>

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Variable Fields of TPDU header

- TSAP-ID (Source & Destination Address)
- TPDU size
- Preferred max\(^n\). TPDU size
- Version number
- Security
- Checksum
- Additional option selection
- Alternative protocol class(es)
- Acknowledgement time
- Throughput
- Residual error rate
- Priority
- Transit Delay
- Reassignment time
- Inactivity timer
- Data

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Comparison of ATN & IP Packets
Options Field of ATN Packet

- Padding
- Priority
- QOS
- Security

No. of Octet

No. of Bits

0000-normal
0001-low
0010
0011
0100
0101
0110
0111
1000
1001
1010
1011
1100
1101
1110
1111

S/T: Sequencing vs Transit Delay
C/E: Congestion Experienced
T/C: Transit Delay vs. Cost
E/T: Error Probability vs Transit Delay
E/C: Error Probability vs Cost

Providing traffic type, routing policy & security classification

Globally Unique

0000 Priority 11 0 SST CE T/C E/T E/C 1100 0000 Security

Security Registration ID length (8 bits)
Security Registration ID (V.L)
Security Information length (8 bits)
Security Information (V.L) (Optional)

Tag Set Name length (8 bits)
Tag Set Name (V.L)
Tag Set Length (8 bits)
Options Field of ATN (contd.)

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# TPDU & NPDU Priority Translation

<table>
<thead>
<tr>
<th>Message Categories</th>
<th>Transport layer Priority</th>
<th>Network layer Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network/System Management</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Distress Communications</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Urgent Communications</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>High priority Flight safety Message</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Normal priority Flight safety Message</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Meteorological Communications</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Flight Regularity Communications</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Aeronautical Information Service Message</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Network/System Administration</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Aeronautical Administrative Messages</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>&lt;unassigned&gt;</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Urgent Priority Administration &amp; U.N. Charter Communications</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>High Priority Administrative &amp; State/Government Communications</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Normal Priority Administrative</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Low Priority Administrative</td>
<td>14</td>
<td>0</td>
</tr>
</tbody>
</table>

Priorities above the bold line are for the communications related to safety & regularity of flight.
Conclusions

- Tasks are progressing well and as planned.
- Modeling of Prioritized EPD has been completed.
- OPNET simulation of Prioritized EPD to be continued.
- ns simulation of IS over DS to be continued.
- ATN over DS mapping to be started.