QoS for Real Time Applications over Next Generation Data Networks

Project Status Report: Part 1
June 2, 2000

http://www.engr.udayton.edu/faculty/matiquzz/Pres/QoS.pdf

University of Dayton
Mohammed Atiquzzaman
Jyotsna Chitri
Faruque Ahamed
Hongjun Su
Haowei Bai

Ohio State University
Raj Jain
Mukul Goyal
Bharani Chadavala
Arindam Paul
Chun Lei Liu
Wei Sun
Arian Durresi

NASA Glenn
Will Ivancic

New Address: Raj Jain, Washington University in Saint Louis,
jain@cse.wustl.edu, http://www.cse.wustl.edu/~jain
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

Sender

Router1

Router2

Receiver

PATH message

DATA

RESV message
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.
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.
Task 1

Prioritized Early Packet Discard
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 → ATM CBR service.
  - Assured Service → ATM UBR service with CLP=0
  - Best Effort → 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
Steady State Diagram
Steady State Equations

\[ \lambda P_{0,0} = \mu P_{1,0} \]
\[ q\lambda P_{0,1} = \mu P_{1,1} \]
\[ (\lambda + \mu)P_{i,0} = \lambda P_{i-1,0} + \mu P_{i+1,0} + q\lambda P_{i-1,1} \quad 1 \leq i \leq LT \]
\[ (\lambda + \mu)P_{i,0} = (\lambda + p + qh\lambda) P_{i-1,0} + \mu P_{i+1,0} + qh\lambda P_{i-1,1} \quad LT < i \leq HT \]
\[ (\lambda + \mu)P_{i,0} = p\lambda P_{i-1,0} + \mu P_{i+1,0} \quad HT < i < N \]
\[ (\lambda + \mu)P_{N,0} = p\lambda P_{N-1,0} \]
\[ \mu P_{N,1} = \lambda P_{N,0} \]
\[ \mu P_{i,1} = q\lambda P_{i,0} + \mu P_{i+1,1} \quad HT \leq i < N \]
\[ (\mu + qh\lambda) P_{i,1} = q\lambda (1-h) P_{i,0} + \mu P_{i+1,1} \quad LT \leq i < HT \]
\[ (\mu + q\lambda) P_{i,1} = \mu P_{i+1,1} \quad 0 < i < LT \]
\[ \sum_{i=0}^{N} (P_{i,0} + P_{i,1}) = 1 \]
\[ G_h = \frac{\sum_{n=1}^{\infty} nP(W = n, V = 1, U = 1)}{\sum_{n=1}^{\infty} nP(W = n, U = 1)} \]
Queue Occupancy

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

Mohammed Atiquzzaman, University of Dayton, Email: atiq@ieee.org
Goodput versus load for $h=0.5$

Simulation: $N=120, LT=60, HT=80, q=1/6.$
Goodput versus load for $h=0.2, 0.5, 0.8$

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

Mohammed Atiquzzaman, University of Dayton, Email: atiq@ieee.org
Goodput for high priority vs. HT

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

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org
Goodput of high priority vs. $h$

Simulation: $LT=60$

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org
Goodput for high priority versus $LT$

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

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org
OPNET Simulation Configuration

![Diagram showing network nodes and connections with an annotation indicating PEPD applied.]

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org
DS-ATM Protocol Stack

- 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.
Task 2

Mapping of IS over DS
Mohammed Atiquzzaman, University of Dayton, Email: atiq@ieee.org
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

Mohammed Atiquzzaman, University of Dayton, Email: atiq@ieee.org
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>
DS functionality

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

TOS Byte

```
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>DS field</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
</tbody>
</table>
```

DS field

CU
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)
Traffic Conditioning at DS Boundary

BA Classifier

Meter → Marker
Dropper → Shaper

Meter → Marker
Dropper → Shaper

Meter → Marker
Dropper → Shaper

Meter → Marker
Dropper → Shaper

EF Queue-PQ
AF Queue-RIO
BE Queue-RED

Scheduler
Output Link
## 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>

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org
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.
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.
IS-DS Simulation Configuration

EF Sources
1 - 5

AF Sources
6 - 12

BE Sources
13 - 20

Router1

Router2

EF Sinks

AF Sinks

BE Sinks

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org
Interoperability with Aeronautical Telecommunications Networks (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
Model of Transport Layer
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

No. of Octets

- Variable
- 1
- up to 4
- 1 variable
- 1 variable
- 2
- 12 or 24
- 3
- 2
- 8
- 2
- 4

Variable
Comparison of ATN & IP Packets

Email: atiq@ieee.org
Options Field of ATN Packet

Mohammed A. Rezwan, University of Dayton,
Email: atiq@ieee.org
Options Field of ATN (contd.)

- **Security Classification**
  - 0000 0001: unclassified
  - 0000 0010: restricted
  - 0000 0011: confidential
  - 0000 0100: secret
  - 0000 0101: top secret
  - 0000-0110 to 1111 1111: unassigned

- **Security Tag**
  - 0000 0001: Mode S
  - 0000 0010: VDL
  - 0000 0011: AMSS
  - 0000 0100: GateLink
  - 0000 0101: HF

- **Bit Number**
  - 0: ATSC
  - 1: AOC
  - 2: ATN Administrative Comm.
  - 3: General Communications
  - 4: ATN System Management Comm.
  - 5 to 7: reserved for future use & always set to one

- **ATSC Class**
  - 0: A
  - 1: B
  - 2: C
  - 3: D
  - 4: E
  - 5: F
  - 6: G
  - 7: H

Mohammed Atiquzzaman, University of Dayton,
Email: atiq@ieee.org

56
## 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.