Approaches to Real-Time Communications

QoS Service Architectures

- In the early 1990’s, the components of QoS service architectures were defined
- Several architectures were proposed:
  - Tenet
    - Domenico Ferrari at Berkeley led the Tenet Group. This group was part of the Blanca Gigabit Testbed
    - The first paper lays out the architecture for what became later the Tenet Protocol Suite
  - CSZ (Clark/Shenker/Zhang)
    - The paper is also a proposal for a QoS architecture
    - The CSZ paper was very influential in the IETF, and influenced the QoS framework for the Internet
Recall: Design of QoS Networks

- A QoS architecture has the following components

Tenet

- **Goal**: Build a packet networks that can give even stringent QoS guarantees

- **Real-time channel**: a simplex virtual connection in a packet-switched network with QoS guarantees
Tenet - Performance guarantees

- **Deterministic Service**
  - Each channel $j$ has a delay bound $D_j$
  - Let $d_j^k$ be the end-to-end delay of the $k$-th packet from channel $j$. Then
    \[ d_j^k \leq D_j \]

- **Statistical Service**
  - Delay bound is expressed as a statistical bound with
    \[ \text{Prob} \{ d_j^k \leq D_j \} \geq Z \]

- **Best effort**
  - No guarantees

Tenet - Traffic Description

- Traffic from channel $j$:
  - $x_{min}^{j}$ minimum distance between packets from channel $j$.
  - $x_{avg}^{j}$ minimum average packet interarrival time of packet from channel $j$ averaged over an interval of length $I$
  - $I$ averaging interval
  - $s_j$ maximum packet size
Tenet - Scheduling

- A multi-level Earliest-Deadline-Due Scheduling

**Deterministic**

**Statistical**

**Best-effort**

Rule:
- pick "S" packet only if no conflict with "D" packet
- pick "BE" packet only if no conflict with either "S" or "D" packets

Later, the Tenet group added a jitter controlled version of EDD and a static scheduler.

Channel establishment

- Total delay must be less than delays at all nodes
- Assignments of local delay bounds is done in two phases (forward pass, backward pass)

\[ D_j \leq d_{1,j} + d_{2,j} + d_{3,j} \]
Admission Control Tests

- The Tenet suite has the following admission control tests
  - Deterministic Test
  - Delay Bound Test
  - Statistical Test

Deterministic Test

- Can node $n$ keep up with arrivals from connections even if all channels send at their peak rate?

$$\sum_j s_{j,n} / x_{\text{min},j} < 1$$

- Note: A deterministic test effectively enforces a peak rate allocation
- $\rightarrow$ Turns out that this test is not needed
**Statistical Test**

- Performs a test for statistical delay bound guarantees
- Probability $p_j$ that channel $j$ is transmitting packets in interval $I$:
  \[ p_j = \frac{x_{\text{min},j}}{x_{\text{ave},j}} \]

- Given that we have $K$ independent channels, the probability that a subset $C$ is active is given by:
  \[ \text{Prob}(C) = \prod_{j \in C} p_j \prod_{j \not\in C} (1 - p_j) \]

**Statistical Test 2**

- Define overflow combination $h$ as a set of connections such that
  \[ \sum_{j \in h} s_{j,n} / x_{\text{min},j} \geq 1 \]

- Let $H_n$ denote the set of all overflow combinations

- Define $P_{\text{do},n}$ as the probability of “deadline overflow” at node $n$. We have:
  \[ P_{\text{do},n} = \sum_{h \in H_n} P(h) \]
Statistical Test 3

- The statistical test ensures that for all statistical channels \( j \), the following condition holds:

\[
P_{d_{0,n}} = 1 - z_{j,n}
\]

Delay Bound Test

- Tests for possible delay bound violations for both deterministic and statistical connections
- Divide the set of \( K \) channels into two sets \( U \) and \( V \)

\[
U = \left\{ i \mid i = 1, 2, K, u; \ d_{i,n} < \sum_{j=1}^{K} s_{j,n} \right\}
\]

\[
V = \left\{ k \mid k = u + 1, K, K; \ d_{k,n} \geq \sum_{j=1}^{K} s_{j,n} \right\}
\]
Delay Bound Test 2

- Under the assumption that for all $i$:
  \[ x_{\min,i} \geq \sum_{j=1}^{K} s_{j,n} \]

- all deadlines are satisfied if for all $i = 1, \ldots, u$
  \[ d_{i,n} \geq \sum_{j \in A} s_{j,n} + \max_{j \in U} (s_j) \]

Summary on Tenet

- The Tenet group was active from 1990-1995
- The scheme outlined here was refined in many papers
- The first Tenet protocol suite was completed in 1993, with Tenet 2 being the follow-on project

- Concepts pioneered by Tenet:
  - Parameterized QoS
  - Delay guarantees in packet-switched networks
  - Renegotiation of QoS parameters
Clark/Shenker/Zhang

- Goal: Define a QoS architecture for the Internet with focus on application needs
- Network is the current Internet, connectionless datagram network
- “Flows” are end-to-end traffic streams.

Playback Point

- Continuous media (voice, video) is transmitted over a network and played back. By buffering incoming data, the receiver can control the playback point of the data.
Proposed Services

<table>
<thead>
<tr>
<th>Tenet</th>
<th>CSZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deterministic</td>
<td>Guaranteed</td>
</tr>
<tr>
<td>Statistical</td>
<td>Predicted</td>
</tr>
<tr>
<td>Best Effort</td>
<td>Datagram</td>
</tr>
</tbody>
</table>

Applications

- **Which fraction of packets must arrive before playback point and how to set playback point?**

- **Rigid Applications**
  - have an a priori delay bound
  - must keep playback point fixed

- **Adaptive Applications**
  - Can adaptively change playback point
  - delay bound is “de facto” (or, whatever)
  - may experience packet loss
Applications

• How sensitive to interruptions of service?

• Tolerant Applications
  • permit certain interruption
  • Example: Teleconference with Mom

• Intolerant Applications
  • No interruption is permitted
  • Example: Tele-surgery

<table>
<thead>
<tr>
<th></th>
<th>Tolerant</th>
<th>Intolerant</th>
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<tbody>
<tr>
<td>Delay</td>
<td></td>
<td>Guaranteed Service</td>
</tr>
<tr>
<td>Rigid</td>
<td>___</td>
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<tr>
<td>Adaptive</td>
<td>Predicted Service</td>
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</table>
Services

- **Guranteed Service:**
  - Service commitments will be met for all traffic from a network client

- **Predicted Service (definition is vague)**
  1. “If the past is a guide to the future, the network will meet the service characterization”. Indicates that network measurements are used to describe service.
  2. Network attempts to give a service which allows application to minimize playback point

- **Datagram Service**
  - Best effort traffic

Traffic Description

- Leaky Bucket (Here called “Token Bucket”).
- Leaky Bucket is a term from ATM networking.

```
<table>
<thead>
<tr>
<th>Token pool (Bucket)</th>
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<tbody>
<tr>
<td>has depth b</td>
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</tbody>
</table>

Token are added at rate r
(no tokens are added if there are b tokens)

Packet with size p removes p tokens from the pool.
If pool is empty, packet cannot enter
```
Scheduling

- CSZ proposes different scheduling algorithms
  - **Weighted Fair Queueing (WFQ)** for guaranteed service
    - We will study this discipline more. Then it is called Packetized Generalized Processor Sharing
  - **FIFO+** for predicted service

**Weighted Fair Queueing**

- Each flow is allocated a relative share of the link capacity $r_i$.
- If the link capacity is $\mu$, then flow $i$ will get a throughput of not less than:
  
  $\sum_{j \in B} \frac{\mu r_i}{\sum_{j \in B} r_j}$

- **Result from Parekh/Gallager**: With WFQ, the queueing delay of a packet from flow $j$ at a node is bounded by
  
  $b_i / r_i + L / r_i$

  where $b_i$ is the size of the token pool for flow $i$, and $L$ is the maximum packet size.
**FIFO+**

- Tries to give each packet the average delay.

- At each node, measure the average delay of packets in the same class, $d_{\text{avg}}$, and compare it to the actual delay $d_{\text{actual}}$.
- Add $d_{\text{actual}} - d_{\text{avg}}$ as offset to packet header.
- Next node subtracts offset from actual arrival time to calculate “expected arrival time”
- Node transmits packet in the order of “expected arrival times”, i.e., the arrival time that a packet should have had had it been given average delay

**Admission Control**

- Some heuristic rules … not rigorous admission control proposed

- For guaranteed traffic the Parekh/Gallager results give the admission control tests

- Predicted service:
  - Admission control must be based on measurements
  - Many results on this in the last 2-3 years
### Comparison: Tenet vs. CSZ

#### Tenet
- **Services:**
  - deterministic
  - statistical
  - best effort
- **Service Interface:**
  - $x_{\text{min}}$, $x_{\text{ave}}$, $I$, $s$
- **Scheduling:**
  - EDD

#### CSZ
- **Services:**
  - guaranteed
  - predicted
  - datagram
- **Service Interface:**
  - Leaky Bucket $b$, $r$
- **Scheduling:**
  - WFQ
  - FIFO+

#### Tenet
- **Admission control**
  - elaborate set of tests
- **Impact:**
  - Ground-breaking work on real-time communications. Has influenced both ATM and Internet.

#### CSZ
- **Admission control**
  - left vague
- **Impact:**
  - CSZ paper was used by the IntServ working group in the IETF as blueprint to define integrated services for the Internet.