Traffic Modeling and Network Simulation

Network Design Problem

Goal

- Given
  - QoS requirement, e.g.,
    - Average delay
    - Loss probability
  - Characterization of the traffic: the input to the network
    - Common traffic characteristics
      - Average interarrival time (arrival rate)
      - Average holding time (message length)
- Design the system
Network Performance Evaluation

Solution methodologies:
- Simulation techniques → good for more detailed analysis
- Mathematical analysis
  - Model this type of process as a Queueing System → good for initial design

Outline

Traffic modeling
- Describes the nature of what is transported over communications networks.
- Understanding traffic can be used to improve network performance
- Traffic is random
  - Time between packet arrivals, interarrival time. Average rate of packet arrivals = \( \lambda \)
  - Packet length
    - Holding time = \( E[L]/R \), e.g., \( E[L] = 1000 \) bits, \( R = 1 \)Mb/s then holding time = 1ms

Simulation
### Application QoS Requirements

<table>
<thead>
<tr>
<th>Application</th>
<th>Data loss</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>file transfer</td>
<td>no loss</td>
<td>elastic</td>
</tr>
<tr>
<td>e-mail</td>
<td>no loss</td>
<td>elastic</td>
</tr>
<tr>
<td>Web documents</td>
<td>no loss</td>
<td>elastic</td>
</tr>
<tr>
<td>real-time audio/video</td>
<td>loss-tolerant</td>
<td>audio: 5kbps-1Mbps, video:10kbps-5Mbps</td>
</tr>
<tr>
<td>stored audio/video</td>
<td>loss-tolerant</td>
<td>same as above</td>
</tr>
<tr>
<td>interactive games</td>
<td>loss-tolerant</td>
<td>few kbps up</td>
</tr>
<tr>
<td>instant messaging</td>
<td>no loss</td>
<td>elastic</td>
</tr>
</tbody>
</table>
Traffic Characterization

Customers request information
Rate of requests = $\lambda$ requests/sec
- Calls/sec
- Packets/sec
- mp3’s/hour
The volume of information requested
- Length of the phone call (sec/call)
- Length of movie (Bytes)
- Size of picture (Bytes)

Traffic Characterization

Traffic characterization describes the user demands for network resources
- How often a customer:
  - Requests a web page
  - Down loads an MP3
  - Makes a phone call
- Size/length (how long you hold network resources)
  - Web page
  - Song
  - Phone call

Sample Realization of an Traffic Process

<table>
<thead>
<tr>
<th>Message number</th>
<th>1</th>
<th>2</th>
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<td>2</td>
<td>--</td>
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<tr>
<td>Length of i^{th} message (seconds)</td>
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<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Traffic:

General Characteristics

Highly variable
Likely to change as new services and applications evolve.
Highly bursty, where one definition of burstyness is:

\[
Burstyness = \frac{\text{Peak rate}}{\text{Average rate}}
\]
Traffic:
General Characteristics

Example: During a remote login connection over a 19.2kb/s modem a user types at a rate of 1 symbol/sec or 8 bits/sec and then transfers a 100 kbyte file. Assume the total holding time of the connection is 10 min.

What is the burstyness of this data session?

Traffic: General Characteristics

The time to transfer the file is

\[(800,000 \text{ bits})/(19,200 \text{ b/s}) = 41 \text{ sec.}\]
So for 600 - 41sec = 559 sec.
The data rate is 8 bits/sec or

4,472 bits were transferred in 559 sec.
Thus in 600 sec. 4,472 + 800,000 bits were transferred, yielding a average rate of:

\[804,472 \text{ bits}/600 \text{ sec} = 1,340 \text{ bits/sec}.\]
The peak rate was 19.2 Kb/s so the burstyness for this data session was:

\[19,200/1,340 = 14.3\]
Traffic: General Characteristics

Asymmetric Nature of Interactive Traffic

User Burst
Think Time
User Burst

Idle Time
Idle Time
Computer Burst
Computer Burst

This Asymmetric property has lead to asymmetric services

Time of Day Variations

From the Internet into Datavision
Mean = 8.876 Mb/s.
Maximum = 18.952 Mb/s

From Datavision out to the Internet
Mean = 5.133 Mb/s.
Maximum = 12.093 Mb/s
Video Traffic

January 2015
Top line (Total) is HTTP+HTTPS
Red is HTTPS
YouTube
Green is Netflix
Blue is Twitch

From: Netflix: Traffic Characterization, Michel Laterman Department of Computer Science, University of Calgary: [https://pages.cpsc.ucalgary.ca/~carey/CPSC641/slides.html](https://pages.cpsc.ucalgary.ca/~carey/CPSC641/slides.html)

In General Traffic

Very bursty

Problems with traffic modeling
- Rapidly evolving applications
- Complex network interactions

Issues:
- Do models match “real” traffic flows?
- Are the performance models based on specific traffic assumption robust
Packet Voice (applies to packet video)

Packet voice/video looks like a steady flow or Constant Bit Rate (CBR) traffic.
However, voice/video can be Variable Bit Rate or VBR:
- “silence detection”
- Variable rate coding

Problem: After going through the network the packets will not arrive equally spaced in time. Thus playback of packet voice must deal with variable network delays.

Packet Voice (applies to packet video)

Example: Parameters for a packet voice system
- 1 source
- Sample rate = 8000 samples/sec (ITU G.711)
- 8 bits/sample (1 byte/sample)
- **8 ms of voice/packet** ← Critical parameter
- Packet size (bytes/packet) = (8ms/packet) * (8000 bytes/sec) = 64 Bytes [assuming no overhead bytes]
- Link rate = 10 Mb/s
- Clocking time/packet (or holding time/packet or service time/packet aka, serialization time)
  = (64 bytes/packet) * 8 bits/byte) / (10 Mb/s) = 51.2us
Voice Traffic: Packet Voice

Transmit at a Constant Bit Rate (CBR)

- 51.2 us

Receive with variable interpacket arrival times

- 51.2 us

X not equal 8ms because of random network delays
If X is too big packet may arrive too late for play out

Assume network delay is uniformly distributed between [25 ms, 75 ms]

- Same as having a fixed propagation delay of 25 ms with a random network delay uniformly distributed between [0 ms, 50 ms]

Note receiver will run out of bytes to playout after 8 ms.

Solution:

- Jitter Buffer Memory to hold 50 ms of the voice signal (or 8 packets or 2.8 Kbits)
- Worst case, receiver will run out of data just as a new packet arrives
Voice Traffic: Packet Voice

New problem: networks delays are unknown and maybe unbounded
A voice packet may arrive at 85 ms and be too late to be played back
- Late packets are dropped
- Last packet may be played out in dead time
Packet voice (video) schemes must be able to deal with variable delay and packet loss (Should voice packets be retransmitted?)

VoIP Quality

The mouth-to-ear delay is the time taken from when a user begins to speak until when the listener actually hears the speech. This one-way latency is known as mouth-to-ear delay.

The E-model (ITU-T Rec. G.107) is a transmission planning tool that provides a prediction of the expected voice quality, as perceived by a typical telephone user.
VoIP - Delay budget
Factors in End to End Delay

Assumption: maximum delay from mouth-to-ear needs to be on the order of 200 -300 ms

ITU G.114
- < 150 ms acceptable for most applications
- [150ms, 400 ms] acceptable for international
- > 400 ms unacceptable

Source -> Network
Codec -> Packetization -> Queue -> Clock Out

Destination
Clock In -> Jitter Buffer -> Codec

Clock Out, aka serialization, modeled by the “server”

Delay & Packet Loss Sources

Clocking time

VoIP - Delay budget
Factors in End-to-End Delay

Example: Delay Budget (depends on assumptions)
- Formation of VoIP packet at TX ~ 30 ms
- Propagation ~ 10 ms
- Network Delays ~ 10 ms
- Extraction of VoIP packet at Receiver ~ 30 ms
- Jitter Buffer ~ 100 ms

Possible trade-offs:
- Jitter Buffer vs voice packet loss
- VoIP packet size vs length of jitter buffer


For examples see: https://www.cisco.com/c/en/us/support/docs/voice/voice-quality/5125-delay-details.html#packetizationdelay

Voice Traffic: Packet Voice

G.723.1 is a voice coding standard, linear prediction compression algorithm

Network Simulation

Outline
- Define network simulation
- Discuss attributes and application of simulation
- Present implementation of simulation systems
- Discuss analysis of simulation results
- Discuss selection of simulation tools
- Provide an overview of ExtendSim. On the start up ExtendSim window there is:
  - A button for tutorials and a video showing how to build models
  - A link to “ExtendSim for DESS Textbook”, a tutorial on the tool.
  - Other useful tools.
  - A link to getting the whole user manual on the class web page.
  (It is long DO NOT PRINT the whole pdf file.)

A Definition of Communication Network Simulation

Communication network simulation involves generating pseudo-random sequences representing network traffic (message lengths and interarrival times or other input processes, e.g. time varying link quality) then using these sequences to exercise an algorithmic description of the network operation.

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Attributes of Simulation

Simulation Is a **Very Flexible** Evaluation Tool
- General Network Characteristics (Sources, Topology, Protocols, Etc.)
- Minute Detail

Simulation Models Can Be **Expensive to Construct**
- Human Effort

Simulation Models Can Be **Expensive to Run**
- Computer Effort

Statistical **Analysis of the Results** Can Be Difficult
- Requires Careful Interpretation

**Difficult to Gain Insight** Into System Behavior
- Simulate Only a Set of Specific Scenarios

When to Use Simulation

Whenever Mathematical **Analysis Is Difficult or Impossible**
- For Studying Transient Behavior of Networks
- For Systems With Adaptive Routing
- For Systems With Adaptive Flow Control
- For Systems With Blocking (Finite Buffers)
- For Systems With General Message Interarrival Statistics

For **Validating Analytic Models** and Approximations
- How Accurate Is the Model?
- Do Approximations Distort the Results?

For **Experimentation Without Disturbing** an Operational System
- Test Possible Modifications and Adjustments
Modeling Elements for Communication Networks

Traffic and Input Processes
- Message Arrival Process
  - Often Interarrival Times (probability density function)
- Message Lengths (probability density function)
- Other Message Attributes
  - Service Class
  - Error models

Algorithmic Descriptions of Network Processing
- Protocols
- Links and Queues
- Routing

Time Step Approach to Network Simulation

Approaches to Discrete Event Simulation
- Time Step Approach (Fixed Increment Time Advance)
- Event-Scheduling Approach

Fixed Increment Time Advance
- Choice of Increment Important
- Too Large: Multiple Events Happen In Single Step
- Too Small: Wasted Processing Time
- Update System States at End of Each Fixed Time Interval
Event Scheduling Approach to Network Simulation

Variable Time Advance
- Advance Time To Next Occurring Event

Update System State Only When Events Occur
- For Example, Arrivals or Departures

Event Calendar
- Events: Instantaneous Occurrences That Change the State of the System
- An Event is Described by
  - The Time the Event is to Occur
  - The Activity to Take Place at the Event Time
- The Calendar is a Time-Ordered List of Events

Event Scheduling Approach: Simplified Flow Control

An Executive (or Mainline) Controls the Selection of Next Event

- Use Event List to determine next event to process
- Advance simulation clock to event time
- Update system state using event routines
- Update event list using event routines
Event Scheduling for Simple Statistical Multiplexer

<table>
<thead>
<tr>
<th>Arrival Packets</th>
<th>Server (b/s)</th>
<th>Departing Packets</th>
</tr>
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<tbody>
<tr>
<td>Buffer (Queue)</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Departure (End of Transmission)</th>
<th>Arrival</th>
</tr>
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<tbody>
<tr>
<td>YES</td>
<td>Use random number generator to obtain next arrival time</td>
</tr>
<tr>
<td>Read &amp; remove from the attributes of a message to send</td>
<td></td>
</tr>
<tr>
<td>Schedule End of Transmission</td>
<td>Transmitter Facility Time</td>
</tr>
<tr>
<td>Add message to buffer (MB)</td>
<td>Transmitter Facility Time</td>
</tr>
<tr>
<td>Change Status of Transmitter Facility to busy</td>
<td></td>
</tr>
<tr>
<td>Schedule End of Transmission of lower message level</td>
<td></td>
</tr>
<tr>
<td>Return</td>
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<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

| Length of i message (seconds) | 1 | 3 | 6 | 2 | 1 | 4 | 2 | 5 | 1 | 1 | 3 |

Verification and Validation of Simulation Models

Model
- Mathematical (Algorithmic) Description of Behaviour of “Real Thing”

Verification
- Determining Whether the Simulation Model Performs As Intended
- In Programming Terminology, “Debugging”
- Example: Is Statistical Multiplexer Model Producing the specified Message Lengths?

Validation
- Determining Whether the Simulation Model Itself Is an “Accurate” Representation of the Communication Network Under Study (the “Real Thing”)
- Example: Is the Assumption the statistical message length model accurate?
Verification Methods

Modular Development and Verification
- Break Large System Into Smaller Components
- Verify Component-by-Component

Structured Walk-Through
- Step-by-Step Analysis of Behavior for Simple Case

Verification Methods

Event Trace
- Detailed Analysis of Model Behavior
- Compare to Walk-Through Analysis

Model Simplification and Comparison to Analytic Results

Graphical Display of Network Status As the Model Progresses
- To “See” What Is Happening As It Happens
Some Comments on Validation

Simulation Models Are Always Approximations
A Simulation Model Developed for One Application
May Not Be Valid for Others
Model Development and Validation Should Be Done Simultaneously
Specific Modeling Assumptions Should Be Tested
Sensitivity Analysis Should Be Performed
Attempt to Establish That the Model Results Resemble the Expected Performance of the Actual System
Generally, Validation Is More Difficult Than Verification

Analysis of Results: Statistical Considerations

Starting Rules
- Overcoming Initial Transients
- An Initial Transient Period Is Present Which Can Bias the Results
- Achieving Steady State
  - Use a Run-in Period:
    - Determine $T_b$ Such That the Long-Run Distribution Adequately Describes the System for $t > T_b$
  - Use a “Typical” Starting Condition (State) to Initialize the Model

Quality of Performance Estimates
- Variance of Estimated Performance Measures
Quality of Performance Estimates

Simulation results are like laboratory measurements, they can be modeled as random variables.
Performance estimates should have acceptable variance.
More observation reduces the variance.

HOWEVER

Often observations, e.g., a sequence of packet delays, taken from network simulation will be correlated.

- Cannot directly apply standard statistical approaches based on iid (Independent, Identically Distributed) observations.

Dealing with Lack of Independence

Replication: Multiple Simulation Runs

- Assume Results for Each Replication Are Independent
- Can be Inefficient Because of Multiple Startup Periods
Criteria for Selecting a Network Simulation Tool

<table>
<thead>
<tr>
<th>Availability</th>
<th>Common Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>ns-3 (<a href="http://www.nsnam.org/">http://www.nsnam.org/</a>)</td>
</tr>
<tr>
<td>Usage</td>
<td>Opnet (<a href="http://www.opnet.com/">http://www.opnet.com/</a>)</td>
</tr>
<tr>
<td>Documentation</td>
<td>QualNet (<a href="http://www.scalable-networks.com">http://www.scalable-networks.com</a>)</td>
</tr>
<tr>
<td>Ease of Learning</td>
<td>ExtendSim</td>
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<tr>
<td>Computation Efficiency</td>
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</tr>
<tr>
<td>Flexibility</td>
<td></td>
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<tr>
<td>Portability</td>
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<tr>
<td>User Interface</td>
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</tr>
<tr>
<td>Extendibility</td>
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</table>

Guidelines to Network Modeling and Simulation

**Things to Know**
- Know the Customer
- Know the Network
- Know the Important Performance Metrics

**Things to Do**
- Establish a Credible Model
- Expect the Model to Evolve ➔ Plan for success
- Apply Good Software Management Techniques
Conclusions

Simulation Can Be an Important Tool for Communication Network Design and Analysis
Care and Thought Must Go Into Construction of Communication Network Models
Care and Thought Must Go Into Interpretation of Model Output

Extend® Overview

Allows Graphical Description of Networks
- Sources, Links, Nodes, Etc.
Data Flow Block Diagrams
Hierarchical Structure to Control Complexity
Be sure and create libraries when creating complex models
Extend® Overview

View Discrete Event Quick Start Videos