Modeling the Internet is fun -
but can you make a living?

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Overview

- some history
- successes
  - fluids
  - Poisson
- challenge - model guided measurement
- parting thoughts
Some history

- first network model (Kleinrock, 60s)
- independence assumption
- decomposition
- Poisson

M/M/1
M/G/1
M/M/1/B

...
70s – 80s age of queuing theory

- router/switch models
- flow control
- error control
- non-Poisson arrival processes

- many contributors
  - Lam, Reiser, Schweitzer
Two highlights (70s-80s)

- optimization-based routing (Gallager, 76)
- AIMD congestion control (Jacobsen, 88)
90s - diversification

- network calculus (Cruz, Parekh, Chang, LeBoudec, ...)
- effective bandwidths (Guerin, Kelly, Gibbens, Chang, ...)
- long range dependence (Leland, ...)
- closed loop flow modeling (Firoiu, Padhye, Misra, ...)
- optimization-based resource allocation (Kelly, ...)
- model-based measurement (Bolot, Duffield, Paxson, ...)
- wireless (Gupta, Kumar, ...)
Observations

- models serve different purposes
- performance evaluation
  - configuration
  - comparison of competing designs
- to develop understanding, algorithms, mechanisms
  - “simple as possible, but no simpler” (Einstein)
Observations

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Case studies

- congestion control and TCP
  - models to describe behavior
  - optimization-based models

- model-based measurement
Modeling TCP - an example
Modeling TCP

- background
- TCP friendliness and the IETF
- fluid and Poisson models
- optimization and control
History of TCP

- 1974: first draft of TCP/IP (Cerf, Kahn)
- 1983: ARPANET switches on TCP/IP
- 1986: congestion collapse
- 1988: congestion control for TCP (Van Jacobson)
IETF and TCP friendliness

IETF mandated (mid 90s)

“thou shalt be TCP friendly”

operating definition was

\[ \text{rate} = k \times \frac{MTU}{(R \times \sqrt{p})} \]

\( p \) - loss probability; \( MTU \) - pkt length; \( R \) - round trip time; \( k \sim 1.2-1.4 \)

consequence: 100s papers following party line
Theory vs measurement

- agreement for small $p$
- differences for large $p$
- timeouts play role

![Graph showing theory vs measurement comparison]
PFTK formula

- accounts for timeouts
- drop tail loss assumption
- approximate analysis
  - independence, independence, independence

\[ B(p,R) = \frac{1}{R \sqrt{\frac{4p}{3} + T_0 3\left(\frac{3p}{2}\right)^{1/2} p(1+32p^2)}} \]
Validation

- validated against measurements
- corroborated by many studies
- insensitive to TCP version
- relatively insensitive to loss process (wireless)
Lessons

- be skeptical - don’t accept party line without evidence
- follow discussion of important, timely topics -> good research

TCP friendliness redefined by IETF!

Modeling & validation go hand in hand
Fluid model (Misra)

- losses described by Poisson process
- data as fluid

\[ \frac{dW}{dt} = \frac{1}{R} - \frac{\lambda W}{2} \]

\Rightarrow square root p formula

- transient behavior

(Misra, Gong, Towsley 99)
Fluid model - aftermath

- example of network agnostic model
  - network $\equiv$ loss process
- suggests how to include Poisson driven losses based on network state (routers, flows, ...)

Poisson driven loss process set of differential equations describing flows, routers:

$$\frac{d\bar{W}_i(t)}{dt} = \frac{1}{\bar{R}_i(t)} - \frac{\bar{W}_i(t)\bar{W}_i(t - \tau_i)}{2\bar{R}_i(t - \tau_i)} P_i(t - \tau_i) \quad i = 1, \ldots, K$$

$$\frac{d\bar{q}_v(t)}{dt} = -\text{1}\{\bar{q}_v(t) > 0\} C + \sum_{i=1}^{N} A_{v,i}(t)$$

$$\frac{d\bar{x}_v(t)}{dt} = \frac{\ln(1 - \alpha)}{\delta} \bar{x}_v(t) - \frac{\ln(1 - \alpha)}{\delta} \bar{q}_v(t)$$
Optimization-based Framework

Routing, congestion control: a resource optimization problem:

- allocate resources (e.g., bandwidth) to optimize some objective
- practical routing/congestion control as distributed asynchronous implementations of optimization algorithm
- foundational work
  - Gallager - routing
  - Kelly - congestion control
Model: Congestion Control

- network: links \{l\}, capacities \{c_l\}
- sources \( S \): \((L(s), U_s(x_s)), s \in S\)
  - \(L(s)\) - links used by source \(s\)
  - \(U_s(x_s)\) - utility, strictly concave increasing function of source rate \(x_s\)
Optimization Problem

\[
\max_{x_s \geq 0} \sum_s U_s(x_s) \quad \text{subject to} \quad \sum_{s \in S(l)} x_s \leq c_l, \forall l \in L
\]

- maximize system utility
- constraint: bandwidth used less than capacity

“system” problem

distributed algorithm?
Distributed algorithm

- optimization problem decouples into (Kelly):
  - greedy optimization problem for every session
    \[ \max U_s(x_s) - p_s x_s \]
  - price \( p_s \) given by network as function of rates
  - provides soln. to system problem
- for TCP, price \( \equiv \) loss prob.

what does TCP optimize?

utility function: \(-1/(RTT)^2 x\)
Comments

- TCP is optimal
- TCP no longer a black box
- TCP SETI for large problems?
Aftermath

- new cc algorithms for high speed, small buffers
- application to other resource allocation problems – especially wireless networks
- extensions to multicast
- extensions to routing/rate control

- fluid models right level of abstraction
- Poisson critical model building block
Modeling and measurements
Model-based measurement

measurements

model

estimation

data

Model-based measurement

Model-based measurement
Network Tomography (MINC)

Routing & counting

Data

Internal behavior?

Queuing behavior

Perform inference

Binomial
Topology inference

Power law degree distribution!
Topology inference

sampled traceroutes

exponential degree distr.

data

estimation

?
Topology inference

Power law degree distribution

data

estimated traceroutes

sampled traceroutes

distribution

degree

estimation
Topology inference

sampled traceroutes

graph model
sampling model
estimation

data

distribution

degree
- other examples
  - P2P node up time distributions
  - inter-contact times in DTNs

- models can/should be used to identify bias (and often correct)
Lessons

- many reported measurement results are incorrect due to unintended biases
  (not in SIGCOMM of course)
  ⇒ observations/conclusions may be wrong
- unintended biases introduced due to lack of model
- there always exists model behind measurements
- model needs to be explicit and precise
Parting thoughts: pursuing a PhD

- don’t try to develop new applications

- do try to enable existing and new applications

- application disruption comes from outside community
- technology disruption from within community
Parting thoughts: pursuing a PhD

- take my talk (and others) with a great deal of skepticism
- talk to other disciplines
- ear to the grapevine
... by the way, you can make a living modeling
The end

Thanks!

Slides (will be) available at
http://gaia.cs.umass.edu/towsley/sigcomm08.pdf