Back to the Future Part 4: The Internet

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IP won the networking race

- Many competitors in the past
  - SNA, DECnet, XNS
  - X.25, ATM, CLNP

- IP provides end-to-end delivery of datagrams, best-effort service only

- IP can use any link-layer technology that delivers datagrams (packets)
IP’s underlying model is a network of queues

- Revolutionary change from the circuit model (Kleinrock 1961)
  - Each packet is routed independently using its destination IP address
  - No concept of a flow between source and destination, no flow state in routers

- Unreliable channels, limited buffer capacity
- Prone to congestion collapse

![Graph showing system throughput vs. offered load](image-url)
Congestion collapse—ALOHA channel

- The ALOHA System (Abramson 1970)
- Poisson process assumption
  - pure ALOHA throughput
    \[ S = G e^{-2G} \] (Abramson)
  - slotted ALOHA throughput
    \[ S = G e^{-G} \] (Roberts)

- ARPANET Satellite System (1972)
Congestion collapse—ALOHA channel (cont.)

- The early ALOHA System was vastly underutilized

- Backoff algorithm for slotted ALOHA (Kleinrock-Lam 1973)
  - Retransmit a collided packet randomly into one of $K$ future time slots
  - Poisson process assumption implies $K \to \infty$
Congestion collapse—ALOHA channel (cont.)

- ASS Note 48 (Lam 1973)

\( K = 15 \)
Congestion collapse—ALOHA channel (cont.)

- Adaptive backoff algorithm (Lam 1974):
  Retransmit a packet with \( m \) previous collisions into \( K(m) \) slots, where \( K(m) \) is monotonically nondecreasing in \( m \)

\[
K(1) = 10 \\
K(m) = 150, \ m \geq 2
\]
Congestion collapse—packet networks

- Network of queues with limited buffers
  - Static window flow control in TCP not sufficient
    (Lam, late 1970s)
Internet congestion control

- Van Jacobson’s algorithms for TCP congestion control (late 1980s)
  - main reason for stability of the current Internet
- UDP does not perform congestion control
  - preferred by voice and video applications
- More and more voice and video traffic will impact Internet stability
  - I believe in differentiating voice and video flows as well as flow admission control
Efforts to extend/replace IPv4 (past 15 years)

- IP multicast
- QoS support - IntServ, RSVP, DiffServ
- Active Networks research program of DARPA
- IPsec - retrofitting IP with security
- IPv6 - replacing IPv4
  - 128 bit IP address
  - flow concept to support QoS
- Mobile IP
- ...

2004 Sigcomm Keynote
S. S. Lam
Don’t mess with IP?

- In recent years, the research community has moved on to other areas
  - P2P overlays
  - Wireless (ad hoc networks, sensor networks, satellite networks)
  - Measurements
- But the IP foundation, currently relying on over-provisioning, still needs work
Is P2P overlay a panacea?

- P2P overlay supports many new distributed applications
- P2P overlay is inefficient in its use of underlying Internet resources
- P2P overlay does not directly address IP’s foundational issues (stability, QoS)
IP as the future universal interface

- Payload in the form of IP packets to enable new applications across different telecom networks
  - analog $\rightarrow$ digital $\rightarrow$ packet

- Recent news
  - Microsoft unveiled plans for developing **IPTV** (October 2003)
  - SBC to invest $6$ billion on fiber to home for TV services (June 2004)
Changing network traffic mix

- Much more voice and video traffic
- Current traffic of a major telecommunications carrier
  - Circuit switched voice 1.2 petabytes/day
  - Internet traffic 1.5 petabytes/day
- Television services over IP
  - Back of the envelope calculation:
    - 4-8 Mbps, 10,000 seconds/day, 10^8 TV sets
    - $500-1000$ petabytes/day to end users
A pragmatic approach

1. Learn from the evolution of Ethernet

   Ethernet technology today is very different from Ethernet technology 20 years ago.
   ○ Transmission rates: 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps
   ○ Switching protocols:
     • CSMA/CD on a cable,
     • CSMA/CD on a hub,
     • collision-free switching,
     • full-duplex point-to-point, both WAN and LAN
   ○ A variety of coding techniques and media

Only the Ethernet frame interface remains the same.
A pragmatic approach (cont.)

2. Accept in some form a competing idea that has been vanquished again and again by IP but refuses to die and go away:

**virtual circuit packet switching**
- X.25 1970s - 1990s [L. Roberts]
- Frame Relay 1980s - present
- ATM early 1990s - present
- Label switching, MPLS late 1990s - present
Real circuit switching also under IP

- IP over SONET

- GMPLS forwarding based on TDM time slot, wavelength, or optical port
  - Nesting of label switched paths (LSPs) reminiscent of multiplexing/demultiplexing hierarchy in telephone networks
IP should be a “big tent”

- To “rule” the world of communications, IP has to attend to the needs of new constituents (voice, video)
  - multiple services to support diverse applications
- For the research community, over-provisioning should be considered a temporary fix, not a permanent solution
- While the core is over-provisioned, access paths to the core are not
The hourglass shape reconsidered

- Although link-layer technologies are diverse, including virtual and real circuits, only best effort service is available to Internet applications
IP needs a broader base

telephony, television, email, WWW, ...

TCP, UDP

IP

best effort

TCP, UDP

IP

best

CoS  Class-oriented Service

FoS  Flow-oriented Service
What is flow-oriented service?

- Dynamic signaling, flow admission control, flow state, quantitative QoS metric
  - Flows subject to admission control rather than random packet drop
  - Make use of virtual or real circuits in link layer

- Am I reviving IntServ?
  - Not exactly

- Per-flow state and dynamic signaling are not scalable!
  - I know
Two good engineering ideas for voice and video

1. Flow aggregation
   - Current examples
     Virtual paths in ATM, Label stacks in MPLS, RSVP aggregation
   - Each flow is routed along a sequence of "virtual channels" each of which carries a flow aggregate
   - Flow aggregation reduces state information and signaling overhead thus improving scalability
     • In the extreme case, a router has just two flow aggregates (voice and video) for each outgoing channel
Two good engineering ideas (cont.)

2. Statistical guarantee

- A natural service guarantee for a voice or video flow is the flow’s loss probability for a given packet delay bound

\[
\text{Prob}[\text{packet delay} > x] < \varepsilon
\]

Very hard problem! Substantial research in the past but needs much more work to be applicable.

- Statistical multiplexing gain from flow aggregation
Major research issues

How to derive service guarantee of a flow from the service guarantee provided to a flow aggregate?

Dynamic configuration and provisioning of virtual channels for flow aggregates.

How to efficiently compute the end-to-end statistical guarantee to a flow, under practical assumptions?

- design, modeling, analysis
- approximation methods
- measurement-based techniques
QoS research is not done

![Diagram showing QoS research efforts and service guarantees.](image)
Inter-provider QoS is a major challenge

- Business and legal issues
- Framework for competitive ISPs to cooperate
  - A quantitative QoS metric for inter-provider agreement
  - A small set of standardized traffic specs for voice and video
  - ...
- It would be nice to have a de facto standard!
How to get one?

- The SSL model
  - Application-driven—the need to secure web transactions
  - Now SSL used for other applications as well

- The FedEx model
  - Profit-driven—someone takes risk

Possible scenario: Some large ISP takes risk and provides QoS services to a large part of the Internet. Success leads to universal global coverage and a de facto standard.
Conclusions

- For the research community, over-provisioning should not be considered a solution.

- To become the universal telecom interface, IP needs to be a “big tent”:
  - A flow-oriented service needed to support television and telephony services.

- QoS research is not done:
  - Flow aggregation and statistical guarantee merit further investigation.
Conclusions (cont.)

- From history
  - Internet—almost 30 years from initial research to commercial deployment
  - Packet radio—about 25 years
  - QoS research began in late 1980s

Widespread commercial deployment of QoS within 10 years!