Internet Directions

Geoff Huston
Thanks to

- Fred Baker of Cisco for some of the material used in this presentation
It’s a speed thing…

“Man will one day travel faster than a horse can run…”

René Descartes
Internet Backbone Speeds

Internet Backbone Speed (in Mbps)

- T1 Lines
- T3 lines
- OC3c
- ATM-VCs
- IP/λ
- OC12c


MBPS

0 0 1000 10000 100000 1000000 10000000 100000000
Transmission Technologies

Core Networks

- The optical switched backbone
  - Gigabit to Terabit network systems using multi-wavelength optical systems
  - Single hop routing to multi-hop optical Traffic-Engineering control planes

Access Networks

- Access networks are changing…
  - xDSL, cable modem, 3G wireless
  - 100MFE and GigE fibre access systems
Growth of IP Traffic

- Messaging
- Information search/access
- Subscription services/“push”
- Conferencing/multimedia
- Real time Video/imaging
- Entertainment services
- MP3
- DVD

Traffic Projections for Voice and Data

Circuit Switched Voice

Data (IP)

Crossover date varies with measuring point

<table>
<thead>
<tr>
<th>Year</th>
<th>Circuit Switched Voice</th>
<th>Data (IP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Growth of IP Traffic


Traffic Projections

Crossover date

measuring point

Growth of IP Traffic


Traffic Projections

Crossover date

measuring point

Growth of IP Traffic


Traffic Projections

Crossover date

measuring point
Bandwidth Supply and Demand

- Fibre installation is now exceeding Mach 4 per hour for single optical strand equivalent

- Dense Wave Division Multiplexing is lifting per-strand optical capacity
  - from 2.5Gbps to 3.2Tbps (320 wavelengths, each of 10Gbps per lambda) per optical strand

“Raw” Bandwidth will get cheaper per unit

Likely trend from demand pull to massive overhang of excess supply in the wholesale trunk carriage market
“An emerging combination of new technologies, and new service suppliers will create a long-lasting abundance of bandwidth permanently altering the supply-demand equation.”

Forrester Dec 97.

“The potential capacity between major [European] cities will rise one-thousand fold over the next three years”

Yankee Group Aug 98.
High Speed IP Network Transport

Multiplexing, protection and management at every layer

Higher Speed, Lower cost, complexity and overhead
The GigaNet

- An Internet equipped with
  - Gigabit Backbones
  - Gigabit Access
  - Billions of connected devices
Carriage Networks and IP packets

- Each speed shift places greater functionality into the IP packet header and requires fewer services from the carriage system.
- Networks need to get faster, not smarter.

**NETWORK**
- real time bit streams
- network data clock
- end-to-end circuits
- fixed resource segmentation
- network capacity management
- single service platform

**PACKET**
- asynchronous data packet flows
- per-packet data clock
- address headers and destination routing
- variable resource segmentation
- adaptive dynamic utilization
- multi-service payloads
A whole new Terminology Set: Gigabit Networking Technology Elements

- Ethernet packet frames
  - Faster Ethernet: 100mFE, GigE, 10GigE
  - VLANs: 802.1Q
  - Rings (802.17) and T-Bit Fast Switches

- Optical Transports
  - CWDM / DWDM
  - Wavelength-Agile Optical Cross-Connect control systems

- Traffic Engineering
  - Rapid Response, Rapid Convergence IP Routing Systems
  - MPLS to maintain path vector sets
GigNetwork Architecture

Network architectures must be simple in order to be fast
GigNetwork Architecture

- Abundant end-to-end capacity will remain elusive, despite DWDM backbone cores
  - Last mile access deployments are faster and denser than longhaul deployments (the laws of physics and economics still hold)
  - The access / backbone interface will remain a service quality chokepoint
Gigabit networks will bring gigabit applications

As for the future, your task is not to foresee, but to enable it.”
Antoine de Saint-Exupéry
Network Abundance

- **Large edge bandwidth**
  - High speed, always available, fibre and copper delivery systems to home and businesses
    - xDSL copper access
    - HFC cable access
    - FTTB / FTTH fibre access systems

- **Flexible edge bandwidth**
  - **Wireless**
    - IP Mobility - Handsets
    - Fixed Wireless
    - Wireless Service LANs
    - Personal LANS – e.g. Bluetooth
An Abundant Network Will Enable...

- Bandwidth-hungry applications
  - Electronic “mail order” shopping and other commerce
  - MP3 music delivery
  - Mesh DVD delivery
  - Remote Sensing and Imaging apps
  - Wide-scale teleconferencing
    - Remote learning, remote presence
  - Your idea here...

- Massive use in small dedicated applications
  - Online appliances with embedded communications functions
Announcements for just one day...
22nd June 2000

Microsoft, Compaq Computer Corp., and Intel announced Tuesday that they are teaming with San Francisco, California-based Digital Island to build a streaming video network.

The companies say that the network will provide broadcast-scale streaming media for the first time over the Internet, with a reach "roughly comparable" to that of a prime-time TV program.

A couple of Colorado cable cowboys have galloped into the midst of a complex European waltz around the future of broadband access involving a company called Chello.

Chello is the Internet subsidiary of Europe's second biggest cable operator, United Pan-Europe Communications. It was slated to go public twice this spring as Europe's answer to Excite@Home, but the dance has instead been performed in private after two delays in its initial public offering (IPO).

BT Cellnet launched the world's first "always-on" mobile network on Thursday, introducing GPRS technology that is expected to revolutionize the way people use the Internet.

In the corridors of AT&T Labs, Ma Bell is preparing wireless technology that could make today's "wireless Web" look like an old-fashioned telegraph system.

Dubbed "fourth generation," or 4G, the technology is aimed at supercharging wireless access to the Internet over cell phones and other mobile devices. Where today's mobile-phone connections run at about a quarter the speed of dial-up modems, these systems could start about 90 times faster than a dial-up modem and go up from there.

Can a 10th-century king rise from the dead a thousand years later and conquer the world? It sure looks that way. Bluetooth--named after King Harald II of Denmark, who apparently had one bad tooth--is poised to provide broadcast-scale streaming media for the wireless world.

Using radio signals, Bluetooth will let computers and handheld devices talk to each other over a distance of a few yards without the need for wires or cables. That means you'll soon be able to synchronize the information in your cell phone with the database in your Palm Pilot. Or print photos directly from a digital camera. Or use your cell phone as a modem for your laptop.

Eventually, the technology could evolve to the point where consumer swearing a small Bluetooth-enabled device could shop by having their credit information conveyed directly to the store's computer.
It’s a people thing...

Value = Users^2

“The value of a network can be expressed as equal to the square of the number of users…”

Bob Metcalfe
1 Billion Internet Users … or more!

- The true value of a network lies in its ubiquity, not in its functionality
- Ubiquity is where we are heading with the Internet…
Where are these billions of users?

- PCs and the fixed network
- Laptops with wireless lans
- Mobile devices and PDAs
- Appliances with embedded IP

Mobile is coming now
Appliances will come next
1 Billion Mobile Users

“Mobility is hard”
Just about anyone who has worked on IP mobility
Mobile Internet Outlook

Project cellular subscribers
(Nokia 1999)

More handsets than PCs connected
 to the Internet by the end of 2003!

Projected Web handsets
(Nokia 1999)

Projected PCs connected to
the Internet
(Dataquest 10/98)

More handsets than PCs connected
to the Internet by the end of 2003!
The number of i-mode customers exceeded \textbf{13,329,000} as of October 15, 2000.
Fueling the Mobile Market

Consumer End-User Spending Scenario for Mobile Internet

Source: NOKIA
There are Significant Issues, However

“Here there be dragons”

Scott Bradner, V-P Standards, ISOC
GigaNet Service Architecture

- Very large networks introduce new issues in service architectures.
- ‘Flat’ service point address architectures are breaking down – private service identification schemes with translation points are already a large part of today’s internet.
- This is acceptable for client / server, but not for other service models.
Client/Server Architecture is breaking down

- For web-based transactions:
  - Sufficient to allow clients in private address spaces to access servers in global address space

- For telephones and I-Msg
  - You need to use an address when you call them, and are therefore servers in private realm
We need an end to end naming and addressing architecture for agile apps
Big issues in the Big Internet

1: Scale
   - How big can it get?

2: Trust
   - Increasingly, trust is a major issue

3: Predictability
   - Does the network behave as intended?
1 - Scale

“Scaling is the issue for the Internet”

Mike O’Dell, Chief Scientist, UUNET
Growth in BGP Route Table

But they cannot be relied on forever

Projected routing table growth without CIDR

Moore’s Law and CIDR made it work for a while

Deployment Period of CIDR

Source: http://www.telstra.net/ops/bgptable.html
Routing and Addressing in the Billion Node Network

- **Address Efficiency and Route Aggregation**
  - Using addresses more efficiently
  - Adopt hierarchies within addresses allow for remote abstraction of routing information

- **Private Addressing .. Maybe!**
  - Using less public addresses when we can
  - Network Address Translation (NAT) and Real-Specific IP (RSIP)

- **Address extension**
  - Getting more addresses by changing protocol platforms
  - IPv6 and the next address pool
Scale-Related Engineering

- Use **optical switching** to increase versatility of the underlying optical bearers
- **Damp** down transient variations in the routing tables
- Use **Traffic Engineering** to spread network load
- Use **end-to-end IP network architectures** and eliminate per-packet reprocessing in flight by assuring that addresses needed are available
Responding to scaling pressures in the network is a moving target, juggling demands for:

- Addresses
- Routes
- Routing system stability
- Traffic load management
Scale and Constrained Systems

- Scaling pressures will introduce additional constraints into the Internet model
  - Large systems take longer to stabilize and are easier to push into instability
    - Multi-homed networks increase routing instability – multi-homing will be progressively discouraged
    - Address hierarchies will be stricter, and attendant hierarchical business models will become common
    - Congestion events will take longer to resolve – sustained congestion conditions cannot be supported

A very large system is difficult to operate using anarchic principles of distributed control
A new Protocol for the GigaNetwork?

- IP overloads the role of an **address**
  - Identify an attached device
    - NAME
  - Locate an attached device
    - ADDRESS
  - Reach an attached device
    - ROUTE

- In a very large network these concepts may need to be de-coupled:
  - “What is my best ROUTE to reach the current ADDRESS of this NAMEEd device?”
“Fear is driving design behavior on the Internet”

Eric Schmidt, Novell
Trust

- The Internet model is one that has no strict requirement for imposed authority sources.
- The integrity of most Internet infrastructure operations is based on some level of mutual trust:
  - IP address assignment
  - IP routing advertisements
  - DNS integrity
  - End-to-End packet delivery
  - Message delivery systems
Security/Privacy affects Commerce

- Security issues:
  - User: Security by obscurity vs. explicit barriers
  - Service: Authentication services

- Service Attacks exploit trust models
  - Denial of Service
  - Spam
  - Getting Hacked
IETF work in Security

- We have done:
  - Significant work to secure routing and infrastructure
  - Made guaranteed privacy possible via encryption and authentication

- Key issues remain in
  - Software stability
  - Deployment of secure systems
  - Political issues surrounding privacy
Trust and Scale

- The original IP model uses trust at various levels:
  - Domain Name System, Routing, Packet Forwarding, Email, web fetches
- Larger systems require trust to be based on an explicit exchange of credentials and capabilities
  - We have more work to do…
Trust and Scale

- Network designs based on fear of the unknown does not produce rational technology or scaleable networks that can host agile new applications.
3 - Predictability

“If you’re not afraid, you don’t understand”

Mike O’Dell, Chief Scientist, UUNET
What do we mean by “predictability”?

- Includes many factors:
  - Software reliability
  - Traffic flow management
  - Traffic engineering
  - Route exchange control
  - Failure management
Traffic flow management

- Not all applications have the same needs
  - Voice/video needs certain jitter and bandwidth characteristics
  - TCP prefers at most one drop per round trip
- Routing needs differ as well:
  - ISPs want to maximize use of infrastructure
  - Edge networks want to minimize end to end delays
Ongoing work in predictability

- Major research focus
- Product focus from vendors
- Deployment focus by ISPs
  - “If I deploy this will my network crash sometime in the next second?”
Predictability and Scale

- Can a large network service individual service requirements of billions of requests per second?
- Can a very large network with dynamic routing driven from the edges converge to a stable operating state and remain in this state for extended periods of time?
Predictability and Protocols

- Are we expecting too much of the network and thinking too little about the end-to-end protocol?

- The largest network is often the simplest network – that might mean no network level middleware!

- Allowing end-to-end applications to drive a preferred service model across a passive network may well be the only approach that will scale into true Giganets and beyond.
Predictability and Middleware

- Does middleware help or hinder?
  - Is network-level interception and redirection the right tool to allow popular content to be rapidly multi-sourced through local caching? Can it scale?
  - Is the need to introduce network-level interception actions an admission of particularly poor content retrieval protocol design?
    - Would better application level protocols assist in high quality content retrieval with application-level directed middleware?
  - Can active network middleware scale to millions of packets per second in a Giganet architecture?
Going forward

There’s a massive and different “out there” out there.

Somewhere – we just need to know where to look