What I saw at the Revolution (or) An Abridged History of the Internet

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Background

- I was an early ARPANet user
  - I grew up on a farm in the Central Valley of California, and while in High School was introduced to networking
  - I had an Apple II, and bought a Novation CAT modem and dialed (long distance) into the Ames "TIP" of the ARPANET and explored the Internet
- UC Berkeley taught me "the way"
  - At Cal in 1981, I learned about Unix, the ARPANet and later TCP/IP
  - I worked part time at Lawrence Livermore National Lab on defense programs
  - In both places, I saw how networking could allow computers from different vendors to interoperate – this was not the way most of the world worked
- NASA Ames becomes my home in 1985
  - After Cal, I decided to take a position in a brand new networking group at Ames
  - NASA was mostly a DEC shop running VMS, or IBM mainframes at the manned space centers
  - We replicated the environment at Berkeley, running Unix on Vaxen and TCP/IP on a new sitewide ethernet system
  - Later, my team at Ames was handed the task of extending the Internet to NASA sites
- I get invited to attend the IETF in 1986 (I was 23 yrs old)
  - In those days, anyone who wanted to advance the Internet was warmly welcomed into the family

The first IETF I went to in October of 1986 – 25 years ago

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State of the Net in October of 1986

	ARPANET/MILNET	INTERNET
HOSTS	559	3082*
TACS	126	-
GATEWAYS	102	144*
NETS	-	515
NODES	194	-
DOMAINS	158	

Total Internet hosts	3082*
Total networks	515*
Total Internet gateways	144
MILNET hosts	448
MILNET TACS	111
ARPANET hosts	111
ARPANET TACS	15
MILNET/ARPANET Gateways	102
HOSTMASTER mail	898 messages

*includes MILNET, ARPANET

Issues we were dealing with in 1986

- EGP was having problems and needed fixing
- ARPANet was congested – only 5% of the host-pairs were consuming 50% of the total network capacity!
- The DNS was still in the early stages of deployment – many sites still used hosts.txt for name resolution
- The NSFnet's first backbone, of 56 Kbps links with small DEC LSI-11's acting as routers called "Fuzzballs" was being deployed, as were several regional networks across the US
- Outside the US, most networks ran on top of the old X.25 style "public data networks" and IP over X.25 was not optimal
- The ISO has their own "Internet" protocol stack in development – one that most assumed will replace TCP/IP and the Internet as we knew it
- "Blue sky" thinking about the future

Medium and long term work items

Mid Range IRI Issues

- minimum delay routing
- multi-path routing
- dial-up links
- type-of-service routing
- ISO transition
- null networks
- open management architecture
- congestion control
- size
- speed

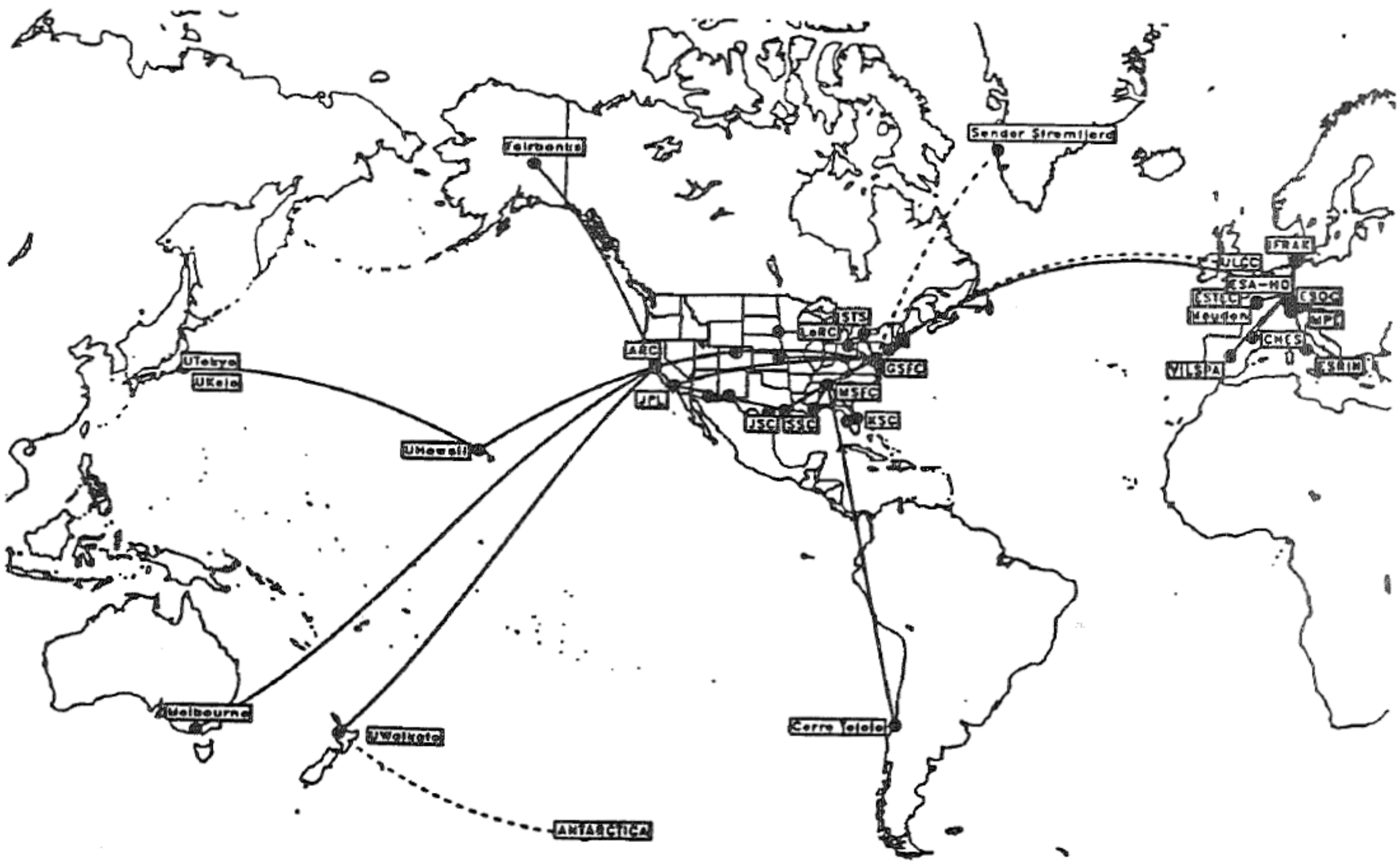
Long Range Blue Sky Visions

- speed (1-100 Gbps medium, 10-100 Mbps to application
- size (up to 200 million endpoints, i.e. approaching telephone)
- dynamics (cf, cellular telephones and human moblity)
- security
- robustness
- resource control
- cost ($100 - $1000 per endpoint)

Backbone networks begin to be constructed

- In 1987, NSF awarded the 2nd NSFNet backbone contract to MERIT, IBM, and MCI and their IBM PC/RT based routers were deployed to connect regional networks and supercomputer centers together in 1988
- NASA built it's own backbone network
  - Ames got the job to build a network to connect the NASA centers to the Internet, as well as a number of science facilities and investigators
  - Initially trunked at 56 Kbps, and later via T1's, it used Proteon routers, and also carried DECNet traffic to help justify the cost of the circuits (after a nasty political fight with the folks at GSFC who ran a DECNet network)
- Department of Energy begins planning it's own IP/DECNet backbone and deploys it in 1988
- Federal networks partnered to jointly connect users – NASA would use NSF's connectivity, and vice versa, etc…
- NASA partnered with Torben Neilsen at the University of Hawaii to connect sites throughout the Pacific in 1989
  - NASA ran a circuit to Hawaii, and then additional circuits were connected to Korea, Japan, Australia, and New Zealand
  - NASA operated and managed the network as part of the agreement
  - NASA allowed non-NASA use of the network on as long as NASA users were connected in country
  - Costs shifted over time as more and more non-science use occured

NASA Science Internet



Interconnection issues

- In 1988, backbones interconnected with each other in haphazard ways, usually through regional networks
- EGP was used between networks, but protocols like RIP and IGRP used inside regional networks did a poor job of passing through backbone routing info – route flapping and other issues routinely affected reliability
- On an evening phone call in 1988, Hans Werner Braun and I were complaining about this and came up with a solution
  - Backbone networks should directly peer with each other at a co-located facility using an 10 Mbps ethernet concentrator
  - Inter-backbone traffic would no longer be routed through regional networks
  - Ames volunteered to host the interconnect, as it had a dedicated secure telecommunications facility, ample trunking to PacBell, and 24x7 onsite support
  - We discussed the idea with our bosses and won immediate approval, NSF would trunk a T1 to an RT located at Ames, and NASA and MILnet already were there
  - DOE and DCA also agreed to extend ESNet and ARPANet to Ames to peer directly
- The interconnect was called the FEBA – the front line of routing and was operational in 1988, and worked so well a 2nd site was selected at SURANet in College Park (FEBA-East)
- The ethernet hub network was accordingly referred to as the DMZ
- Later, for political reasons, the name FEBA was changed to Federal Interconnect eXchange (or FIX)

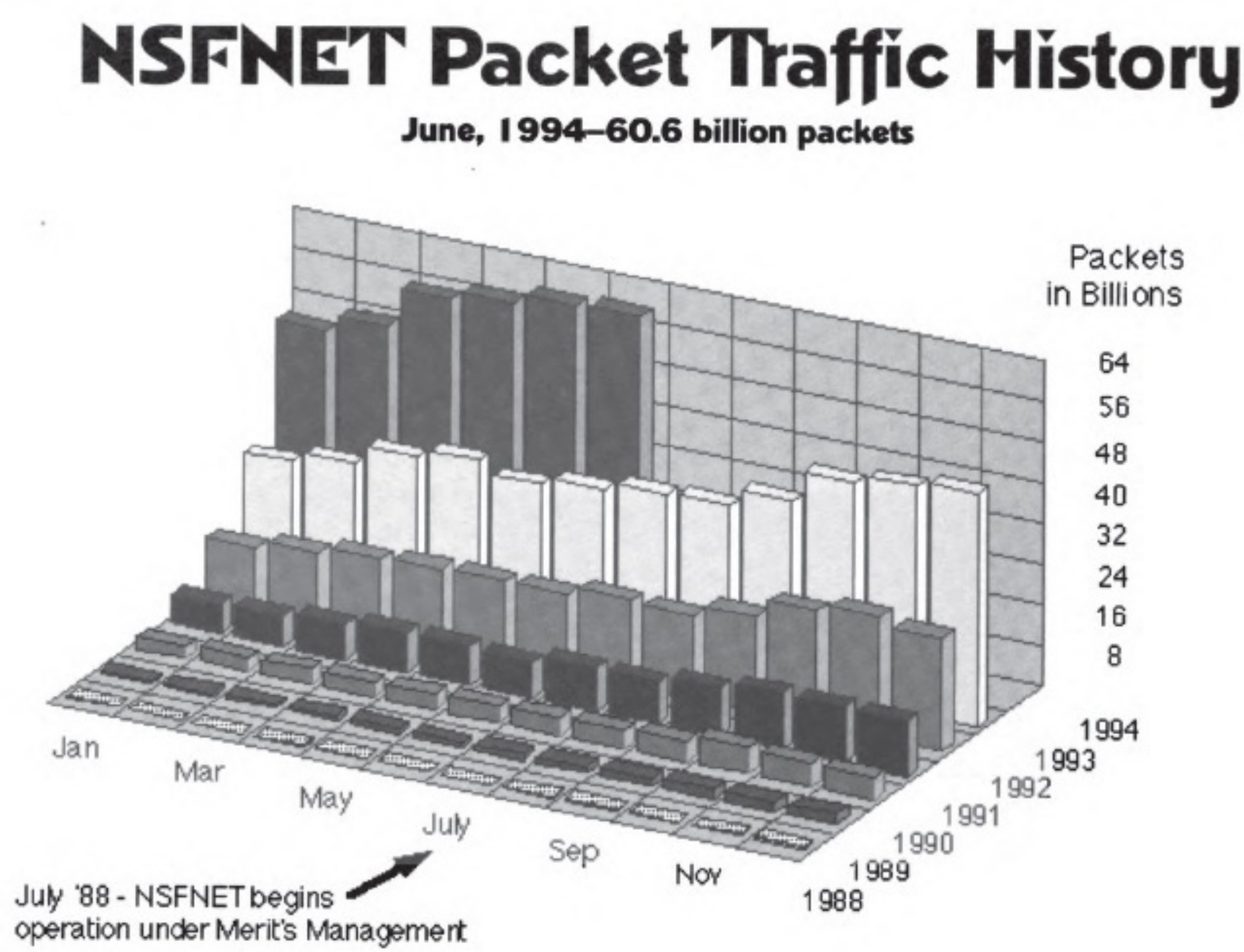
Problems, problems, problems…

- The Morris worm becomes the first DDoS attack on the Internet
  - On November 2nd, 1988, a worm is released that exploits holes in Unix sendmail and other services, and begins to disable machines across the world
  - Ames had a large number of Unix systems, and was hit fairly early
  - We made the painful decision to disable the LAN interfaces of all our backbone routers, cutting off service to field centers and users, but preventing many of them from being infected
  - 36 hours later, the worm was understood, patches were available, and the worst was over
- Security issues
  - Ames ran a root name server, and like many others were the targets of hackers trying to break in
  - While none actually penetrated the machine, NASA practiced aggressive defense of the root, leading to the disabling of machines and the disconnection of Scandinavia
- Porn becomes a nuisance to police
  - Transmitting porn across the Internet was in violation of the NSF and Federal Appropriate Use Policies, but was quite popular when it uploaded, usually in a hidden location
  - We had to police it because we did not want to be written up about federal dollars being used to transport porn (and possibly have federal funding cut off because of it)
  - Our international links were quite modest, and anytime they redlined, porn was often to blame
  - Thanks to the FIX, and a dedicated sparcstation with TCPdump and a homegrown tool, we could identify porn archives and get them removed quickly

The move to DS3 in the early 90's

- Traffic continued to grow and T1's became congested
  - Traffic grew Growth continued aggressively in all areas as more and more LAN's allowed PC's to be connected
  - Even broader use of the Internet occurred after gopher began to see widespread adoption in 1991
- BGP succeeded EGP and supported the rapid addition of new Internet topologies
- Backbone networks all had to move to DS3, but costs were high and equipment was immature
- NSF awarded an upgrade to ANS (Advanced Network and Services – a non-profit comprised of MERIT, IBM, and MCI), and the DS3 based network came up in 1992
- NASA and DOE partnered to upgrade their backbones using a ATM based service
  - We jointly contracted for service after evaluating bids from MCI, AT&T, Sprint and Worldcom
  - Ultimately awarded to Sprint after multiple protests from AT&T delayed the project by over a year
- FIX-W and FIX-E were upgraded to FDDI in order to support the load

Traffic growing rapidly



The Internet turns commercial

- The Internet had grown so fast and was supplanting other networks that commercial interests started getting involved
  - Several commercial internet providers like Alternet (UUnet), PSInet, and Sprintlink had begun operation
  - CIX formed in 1991 to allow commercial operators to interconnect
- ANS requested and received permission to form a for-profit arm called ANS CO +RE, that could sell commercial connectivity as long as the main NSFnet services were not disrupted
- This was perceived as unfair by many parties, and the NSF decided it was time to enable the contracting out of backbone services and reduce the federal role
  - New interconnect points (NAPs) were solicited and awarded
  - Commercial backbones would interconnect at NAPs and could compete for business from regional networks (some of which were also becoming commercial)
- One of the new NAP's (run by PacBell) used an ATM switch that hemorrhaged packets under the slightest load – it was a total disaster
  - In 1994, Sean Doran (Sprint) and Andrew Partan (UUNet) appealed to Ames to open the FIX to commercial exchange because the traffic situation was becoming desperate
  - NASA constructs a Space Act agreement declaring the FIX to be "a unique national asset", and allows commercial use on a cost recovery basis (like a wind tunnel or launch site)
  - A new FDDI ring is established, and commercial networks allowed to co-locate
  - Eventually the new network (MAE-West) is bridged to MFS to allow broader connections

New technologies set the stage for today’s internet

- Netscape is formed after the Mosaic browser is released and empowers nontechnical users to use the web easily
  - The web browser empowers people to trade off ease of use for bandwidth , fueling a massive growth in users, devices, and server based applications
  - The web quickly makes dial-up increasingly slow and opens the door to the broadband revolution
- DWDM begins to dramatically lower the cost of adding bandwidth to fiber systems
  - New optics empower the lowering of the incremental cost of adding capacity dramatically
  - Average cost/bit of transport declines as more and more capacity is added, empowering the Internet to scale without huge increases in cost that would have to be passed on to users
- Moore’s law and Shugart’s law keeps lowering the cost of servers and storage
  - Cost per MIP and Gigabyte declines significantly every year, lowering the cost to deploy the next chunk of compute
  - Average cost declines as more and more capacity is added just like DWDM does for transport, empowering the Internet to scale without huge increases in cost that would be passed on to users
- I am recruited by John Doerr in 1995 to found a new company to bring broadband to the masses using Cable technology – @Home
  - @Home uses all three of these technology advances to empower users to move from the kilobit web to the megabit web

Conclusion

- All of the main technology advances from the mid 90’s are still at work today
  - DWDM and photonics advances are still empowering significant reduction in the cost of transport as speeds increase
  - The cost for incremental additions of server and storage capacity are improving, empowering the construction of massive datacenters and CDN’s that move data closer and closer to users
  - Web browsers continue to advance and empower better and better UI’s with more capabilities to consume content and push state into the cloud
- As long as all of these trends continue, the Internet will continue to scale well