A Brief Prehistory of Voice Over IP Parts 1 & 2

Danny Cohen & Stephen Casner
August 10 & 11, 2010

Google™

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A Brief Prehistory of VoIP

Part-1:
Danny Cohen
SunLab at Oracle

Part-2:
Steve Casner
Packet Design

Both were at the
University of Southern California
Information Sciences Institute
when this work was performed

Google, MTV, CA
Aug/10+11/2010

v20

2

2

A Surprise Quiz

In "*IPv4*", what does the "*v4*" indicate ?

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The Purpose of this Talk ...

... is to describe the roots of VoIP as laid in the 1970's

It is important because:

- VoIP is practically replacing telephony
- VoIP is many $B/Year today

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From the Trade Pubs (1/2)

- "VoIP services market [logged] $30.8 billion in revenue for growth of 33% in 2008. In the first three months of 2009, service providers experienced an average of 40% to 50% year-over-year growth for IP Centrex, so the demand for outsourcing and managed solutions remains 'healthy.' "

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From the Trade Pubs (1/2)

- "SIP trunking service revenue is expected to have an 89% compound annual growth rate in 2008-13."
- "In 2008, there were 106 million residential VoIP subscribers worldwide."
- "Demand for residential and business VoIP services continues to grow through the economic downturn because of the cost savings they provide."

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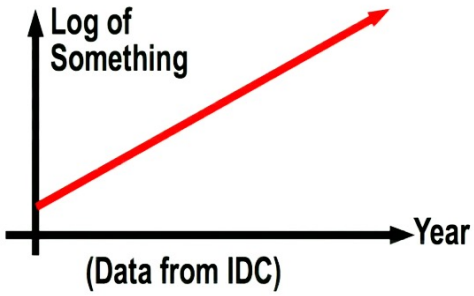
Moore's Law for VoIP



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A Request for a New Program

ADVANCED RESEARCH PROJECTS AGENCY
Washington, D.C. 20301

Program Plan No. 723

Date: 3 June 1968

Program Title: RESOURCE SHARING COMPUTER NETWORKS

Type of Contractor: To be selected from 4 - Industry (Profit)

Project from which Funded: Information Processing Techniques (8D30)

Prepared by: Lawrence G. Roberts
Program Manager

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Objectives of the Program

ADVANCED RESEARCH PROJECTS AGENCY
Washington, D.C. 20301

Program Plan No. 725

Date: 3 June 1968

RESOURCE SHARING COMPUTER NETWORKS

A. Objective of the Program.

The objective of this program is twofold: (1) To develop techniques and obtain experience on interconnecting computers in such a way that a very broad class of interactions are possible, and (2) To improve and increase computer research productivity through resource sharing. By establishing a network tying IPT's research centers together, both goals are achieved. In fact, the most efficient way to develop the techniques needed for an effective network is by involving the research talent at these centers in prototype activity.

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Milestones (written in 6-3-68)

In order to develop an effective store and forward processor, a contractor will be selected competitively to take on the system responsibility for the communications subsystem. The following schedule outlines the expected events:

a. July 1968 -- Award IMP contract

b. March 1969 -- Demonstrate initial net operation with four nodes

c. April 1969 -- Approve design and extend contract to include installation of 19 IMPs

d. December 1969 -- Complete network operational

e. 1970 -- Add communication lines as necessary

f. 1971-1972 -- Arrange with a common carrier the transfer of the communications system

The funds required to implement this plan will not be known precisely until the RFP responses are received. However, it is estimated that the IMPs will cost $50K each and that the contractor will require about $40K per month. Thus the initial phase of the contract will require

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3-Year Budget: 19 IMPs+Comm

5. Cost Estimates.

The interactive network costs fall into two categories: (1) The communications and Interface Message Processor costs, and (2) Costs of communication and resource sharing experiments. The majority of this second class of costs will be borne by each of the computer research contracts now extant. They will vary across a range of extremes bounded by, for example, a single researcher's small experimental program and a group of researchers concerned with studies of on-line documentation. The communications and Interface Message Processor costs are more easily identifiable. The table below shows the commitment requirements.

Year	Costs		
	Communication Line	IMP Contractor	Total
FY 68	0	563K	563K
FY 69	25K	1000K	1025K
FY 70	680K	200K	880K
FY 71	900K	100K	1000K

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Timeline (1/2)

1962 - Packet switching invented

1969 - The ARPAnet was born

1973 - ARPA's crazy idea: Packet Speech
- ARPA initiated the NSC program
- NVP implemented for ARPAnet

1974 - CVSD over the ARPAnet
- LPC over the ARPAnet
- TCP defined (Cerf+Kahn paper)

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Timeline (2/2)

1975 - Voice Message System demonstrated
1976 - CVSD teleconf (ISI,LL,CHI,SRI)
1977 - AT&T packet speech patent (4/77-7/78)
1978 - TCP/IP split, UDP defined, PV movie
1981 - NVP-II defined for use over IP
1995 - The term "VoIP" coined
1996 - RTP specification RFC 1889 published
- IETF began working on SIP

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ARPA's Crazy Idea - 1973

- ARPA suggested to use packet switching networks for real-time interactive speech, for military and civilian applications.
- The Network Secure Communication (NSC) program was tasked to develop packet voice
- Carriers didn't recognize that this would be "disruptive technology"

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The Explicit Objective of NSC

Provide Proof-of-Concept for the use of packet-switching networks for interactive telecommunication among people.

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The Implicit Objectives

- High voice quality (intelligibility, recognition)
- Real-time (low delay, high bandwidth, ...)
- Tele-conferencing
- Multi-media
- Voice-mail
- Interoperability with the telephone network

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ARPA's NSC Program

- Bob Kahn was the PM in charge
- Two-pronged program: speech compression and real-time packet communication
- Contracts: BBN,CHI,ISI,MIT,SCRL,SRI,Utah
- Based on cooperation, not competition: All succeed together or all fail together

This presentation is mostly about the real-time packet communication part of the program.

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Speech Compression

Speech Compression was necessary because the ARPAnet line data rate was only 50Kbps

- CVSD, 8Kbps, domain-independent waveform encoding, light computing
- LPC-10, 2.4Kbps, domain-dependent vocal tract model, heavy computing

Each required about half of a 19" rack for an array processor (SPS-41 or FPS AP-120B)

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The FPS AP-120B (12MFLOPS)

FIGURE 2.36 An overall view of an FPS AP-120B installation. The AP-120B occupies only 29 inches of rack space, and is attached to a PDP-11/34 with two disc units, a tape reader and output printer. The control teletype or vdu is not shown. (Photograph courtesy of D Head and Floating Point Systems, S A Ltd.)

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The ARPAnet

- An IMP per site, up to 64 IMPs each with 4 hosts
- The IMPs interconnected by Bell-303 modems bridging between a 50Kbps digital interface on one side and analog circuits on the other side.
- Addresses were 8=6+2 bits (IMP + host)
- IPv4 uses 32 bits, IPv6 uses 128 bits

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Recommended Reading

Linear Predictive Coding

and the Internet Protocol

Robert M. Gray (2010),

Foundations and Trends® in Signal Processing,

now Publishers, Hanover, MA

ISBN:978-1-60198-348-0

This book is more about audio signal processing and less about packet comm

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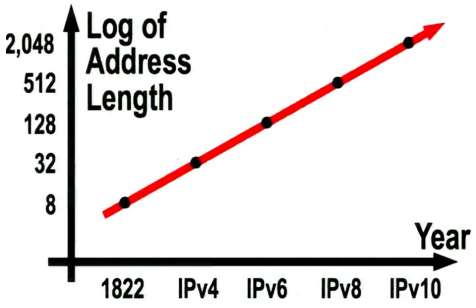
Moore's Law for Addresses



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MIL-SPEC IMP of the ARPAnet

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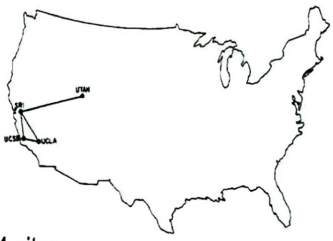
The ARPAnet in December'69



4 sites
4 lines of 50Kbps each

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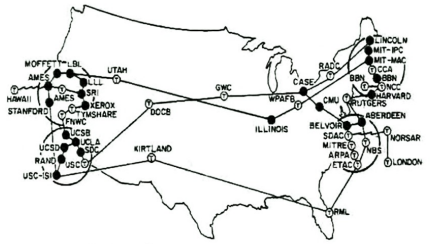
The ARPAnet in June 1974



About 45 sites
3 cross country lines of 50Kbps each

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NCP: Network Control Protocol

- Host-to-Host protocol was NCP; no IP, no TCP, no UDP
- NCP: data integrity, flow control, and error recovery (timeouts+retransmissions), like today's TCP

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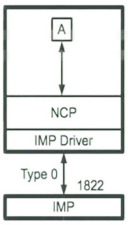
Initial ARPAnet Protocols



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NCP Type of Service

- The NCP provided what everyone wants: a reliable error-free in-order delivery.
- No one wants erroneous data
- No one wants to lose data
- This was the only Type-of-Service offered

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- But it's not good enough for realtime traffic

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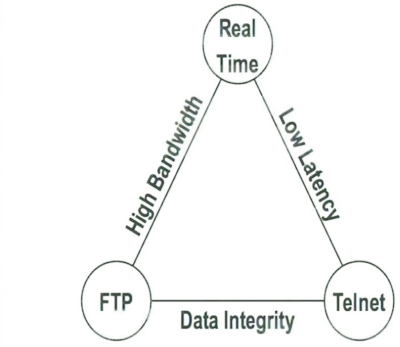
Choose 2 out of 3, No More



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Realtime Communication

- In many cases of realtime communication, new data obsoletes previous data (e.g., weather reading and stock markets).
- Therefore, it does not pay to retrieve lost or damaged data if it causes large delay.
- Realtime is like milk: keep the newest Non-realtime is like wine: keep the oldest

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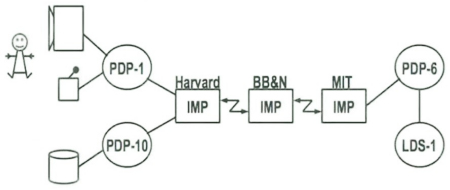
Example for RT-comm (1/1971)



Real-time visual flight simulation at Harvard, Computation (dynamics and visuals) at MIT, Communication over the ARPAnet.

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The Flight-Sim Taught That...

- Low delay and low jitter are essential
- A certain data rate is always needed
- Seq-number and time-stamp are very useful
- Better to drop bad packets than retransmit
- It's helpful to detect no-activity periods
- BER alone is not enough without PER

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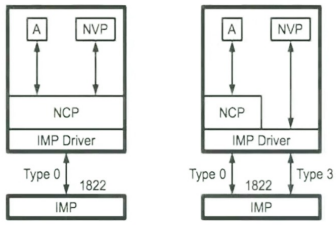
NCP Bypass with Raw Packets

In order to have reasonable delay the NCP was bypassed using raw-packets (type-3)



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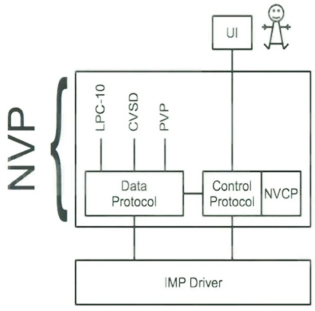
NVP: Network Voice Protocol



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NVCP = NVP + Conferencing

- It provides floor-control and UI extensions.
- UI extensions support voting and invitations
- Also added extensions for voice messaging

PVP = NVP's CP + Video DP

- Used to support MM-tele-conferencing
- Video is treated just as another vocoder(s)
- We dared not dream about storing video files

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Speech Storage Then and Now

Voice messages may be very long (say 60sec) and require more space than locally available, therefore we stored them on the Tera-Bit Datacomputer at CCA with 22GB online.

- 60sec * 2.4Kbps = 144Kb = 18KB
- In June'09, at Best Buy, 500GByte cost $75
- Cost of 60sec is 18KB*$75/500GB=$2.7μ

(two point seven micro-dollar)

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The Internet was Born - 1974

- N networks with O(N) interfaces, not $O(N^2)$
- By replacing the ARPAnet's NCP with TCP, it became possible to create the Internet.
- Initial Internet was ARPAnet plus many networks connected to it.
- 1-1-1983: end of NCP, long live TCP !

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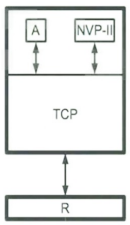
Transmission Control Proto'l (TCP)



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- UDP was added later as its price was right

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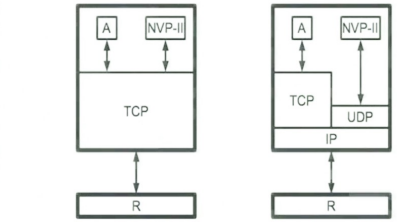
The Split of the Original TCP



- IP = Envelope, TCP = Letter
- UDP was defined for IP-without-TCP
- The split is v4 of TCP (not of IP!).

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In Summary...

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VoIP History a la Google

"The history of VoIP shows that this technology started as far back as 1995 when a small company called Vocaltec released, what was believed to be, the first internet phone software"...,

"This was still a major milestone as it represented the first ever IP Phone"

(Downloaded from Google "VoIP History" on 7-20-2010)

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VoIP or IPuV?

- The name **VoIP** suggests that IP came first and that voice was inserted over IP.
- However, the voice application came first, then IP was created under the voice to support it.
- **IPuV** may be a more appropriate name, but is more difficult to pronounce.

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The IP of VoIP

In the 2000's companies sue for infringement in the 1990's upon patents that were issued in the 1980's about work that we performed in the 1970's, publicly.

This IP was developed and funded by ARPA and put in the public domain

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Conclusion

- VoIP and Packet Video are major components of the the Internet (the "information revolution")
- Their roots were developed and demonstrated publicly by ARPA projects, starting in the 70's
- Advances in computing, communication, and storage made them practical and ubiquitous
- The carriers no longer think we are crazy...

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End

of Part-1

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Tomorrow, Same Time+Place

Steve Casner will show a Jan'78 movie demonstrating a 4-party teleconf using CVSD vocoding, accessing the net either directly or over the STN. He will also discuss the evolution of voice protocols for packet switching networks (like VoIP and Skype), bypassing the entire STN's L/D toll system.

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1974 - CVSD & LPC over the ARPAnet
- LPC over the ARPAnet
- TCP defined (Cerf+Kahn paper)

1975 - Voice Message System demonstrated

1976 - CVSD teleconf (ISI,LL,CHI,SRI)

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Timeline (2/2)

1978 - TCP/IP split, UDP defined, PV movie

1981 - NVP-II defined for use over IP

1992 - IETF AVT WG formed, first audiocast

1994 - MBone carried Hubble repair, Stones

1995 - The term "VoIP" coined
- ITU-T adopted RTP for H.323

1996 - RTP specification RFC 1889 published
- IETF began working on SIP

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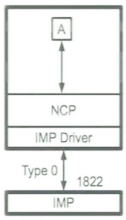

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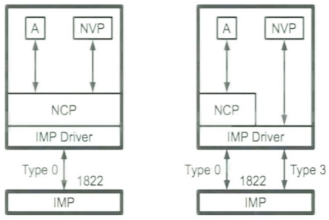

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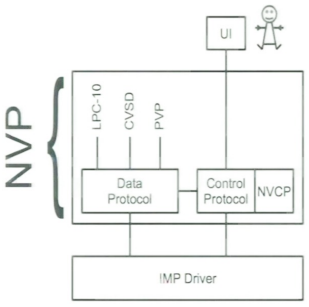

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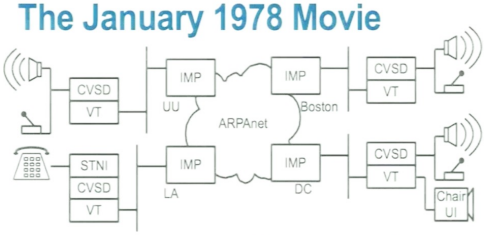
The January 1978 Movie



The movie shows a simulated four-node teleconference with CVSD-vocoded speech.

The movie is available at:
http://www.youtube.com/watch?v=MGat1jRQ_SM

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You may have noticed...

- Occasional screeches: vocoding errors
- Danny's voice sounded funny
- Various user interface devices, incl. phone
- Voting without switching to each participant

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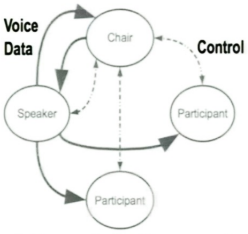
Floor-Controlled Data Paths



- Chairman talks only to the speaker
  - > Only one decoder, so receive one stream
  - > LPC can't encode multiple-speaker audio

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STNI = PSTN Interface

- Interoperability with the PSTN
- Connects any external phone with a local voice terminal (VT)
- Supports DTMF signaling, both ways
- Can be called from any phone, and can call out to any phone, allowing toll bypass
- Note similarity to *SKYPE*

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1982 NSC Program Review

Significant demo events:

- Lincoln Lab packet voice terminals (multi-microprocessor-based, 1.5 ft^3)
- Embedded variable-quality voice coding
- DSP-based LPC encoder/decoder
- 5-party conference, SRI, ISI, 2 @ LL, DCEC (WBnet, PRnet, LEXnet, and STNI to PSTN)

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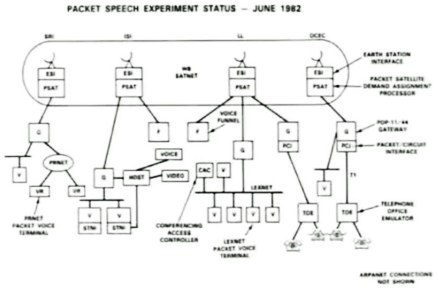
Packet Voice Network



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1982-1992 VoIP "Hibernation"

Packet-speech activities waited for the Internet and computers to become ubiquitous, high-performance, low-cost, and audio-capable.

- Web accelerated Internet popularity & growth
- Workstations gained audio devices
- Commercial parties began to take notice

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We weren't all sleeping...

- Networks evolved from ARPAnet to WBnet to TWBnet and DARTnet and ...
- Packet video developed at ISI
- Packet voice & video conferencing systems simmered in "experimental production"
- Steve Deering developed IP Multicast
- IETF RSVP, IntServ and DiffServ projects prepared the Internet for RT services & QoS

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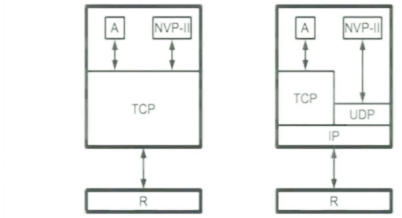
The Split of the Original TCP



- IP = Envelope, TCP = Letter
- UDP was defined for IP-without-TCP
- The split is v4 of TCP (not of IP!).

Pane B19

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3/1992: First IETF Audiocast

- NVP-II over UDP over IP multicast
- DARTnet core of 34-node multicast network
- 20 sites spanning 16 time zones
- Audio outbound from and inbound to meeting
- First meeting of the IETF Audio/Video Transport working group (home of RTP)

Pane B20

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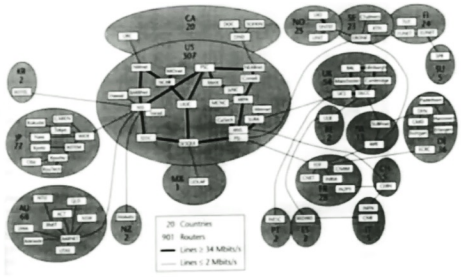
MBone: Multicast Backbone



MBone 1994: 20 countries, 901 routers

Pane B21

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MBone Highlights

- Provided audio-chatroom for network geeks
- Streamed NASA TV of first Hubble repair
- Broadcasted Rolling Stones concert
  - >December 1994 Newsweek article
- Distributed music performance - ACM MM'95
- Session directory sent via IP multicast using Session Announcement Protocol (SAP)

Pane B22

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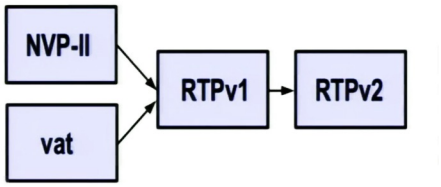
Real-time Transport Protocol



- Concepts from NVP: sequence + timestamp
- Concepts from vat: on-the-fly vocoding switch, source identifiers, start-of-talkspurt bit

Pane B23

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NVP-II Data Protocol Header

- Sequence number and timestamp needed:
  - > Sequence number detects loss
  - > Timestamp indicates intentional gaps
- Header checksum for unreliable transports
- Token length (control tokens are optional)
- Data length comes from lower layer

Pane B24

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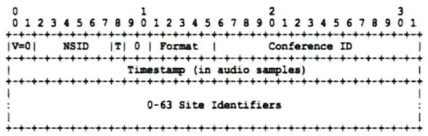
"vat" Data Protocol Header



- Audio format/encoding to switch on-the-fly
- Timestamp in samples facilitates format switch
- Start-of-Talkspurt flag indicates gaps
- 0-63 source identifers for pre-mixed audio
- Conference ID for validation

Pane B25

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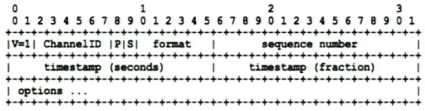
RTP Version 1, November '93



- Timestamp always in [seconds:fraction] for simple inter-media synchronization
- Sequence number (in packets) detects loss
- End-of-sync-unit flag: detection without delay
- Audio format/encoding to switch on-the-fly
- Allowed control tokens as options in data pkts
- Channel ID for multiplexing RTP packets

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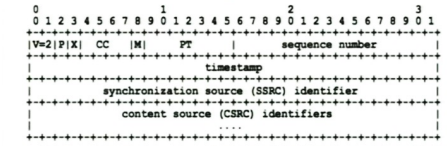
RTP Version 2, 1996 & 2003



- Timestamp in samples facilitates format switch
- Sequence number (in packets)
- Start-of-Talkspurt flag for audio; end for video
- Audio format/encoding to switch on-the-fly
- Source identifer for multiplexing and validation
- 0-15 source identifers for pre-mixed audio

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RTP Version 2 Philosophy

- Separate control and data ports to allow a 3rd-party multicast monitor to get only control
- Fixed 12-byte header, minimal options: fast processing, simple header compression
- Highly scalable for group size, data rate, and any media with inherent notion of real time
- Absolute vs. incremental values for robustness against packet loss

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RTP Version 2 Devolution

In 2009, some backtracking:

- Allow multiplexing RTP and RTCP on one port due to NAT and limited port space
- Header extensions made easier to use, so now multiple options can be chained (but audio & video codecs have options galore anyway)

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Always Another Vocoder

DVI4	12-bit DAT, 20- and 24-bit Linear Sampled Audio
G.722	Adaptive Multi-Rate (AMR)
G.723	Adaptive Multi-Rate Wideband (AMR-WB)
G.726	BroadVoice Speech Codecs
G.728	Enhanced AC-3 (E-AC-3)
G.729	Enhanced Variable Rate Codecs (EVRC)
G.729D	Enhanced Variable Rate Wideband Codec (EVRC-WB)
G.729E	Extended Adaptive Multi-Rate Wideband (AMR-WB+)
GSM	G.711.1
GSM-EFR	G.719
L8	G.722.1
L16	G.729.1
LPC	Internet Low Bit Rate Codec
MPA	MP3 Audio
PCMA	MPEG-4 Audio/Visual streams
PCMU	Selectable Mode Vocoders (SMV)
QCELP	Speex Codec
VDVI	Variable-Rate Multimode Wideband (VMR-WB)
	Vorbis Encoded Audio

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Control Protocol Evolution

- NVP only scratched the surface of the control side of VoIP – rudimentary sessions
- RTP Control Protocol (RTCP) supports only "loosely controlled" sessions without membership control or negotiation
- For a complete VoIP solution, need session signaling for locating participants, negotiating capabilities, billing, ...

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NVP-II Control Protocol

- Series of control tokens with parameters:
  CONNECTION-NAME(address,port,id)
  VOCODING
  I-AM-RINGING
  BYE
  (and several others)
- Provides simple capability negotiation

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RTCP: RTP Control Protocol

- Provides feedback on quality of transmission to sender and other multicast receivers
- Carries persistent identifier for source
- Allows counting participants to scale timers and limit control bandwidth consumption
- Optionally conveys session control info for "loosely controlled" sessions
- Carried on a separate transport-level port

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Sessions: Beginnings of SIP

- Multicast sessions use multicast directory
- P2P calls need explicit session initiation
  - > Addressed in IETF Rem-Conf, ConfCtrl, and MMUSIC working groups
  - > Inputs included Etherphone (PARC), Touring Machine (BellCore), MMConf (BBN), CCP (ISI)
  - > Standardization of multipoint conferencing came later

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History *vs.* Prehistory

Lots of work has been done since early 1990's, sorry we can't cover it all:

- ITU-T adopted RTP for H.323 and defined control protocols to work with it
- SIP development required multiple IETF WGs, is now deployed, and still more to do
- RTSP was developed for streaming

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Conclusion

- VoIP and Packet Video are major components of the the Internet (the "information revolution")
- Their roots were developed and demonstrated publicly by ARPA projects, starting in the 70's
- Advances in computing, communication, and storage made them practical and ubiquitous
- The carriers no longer think we are crazy...

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End

of Part-2

Movie: http://www.youtube.com/watch?v=MGat1jRQ_SM
Or http://ee.stanford.edu/~gray/dv.mpg

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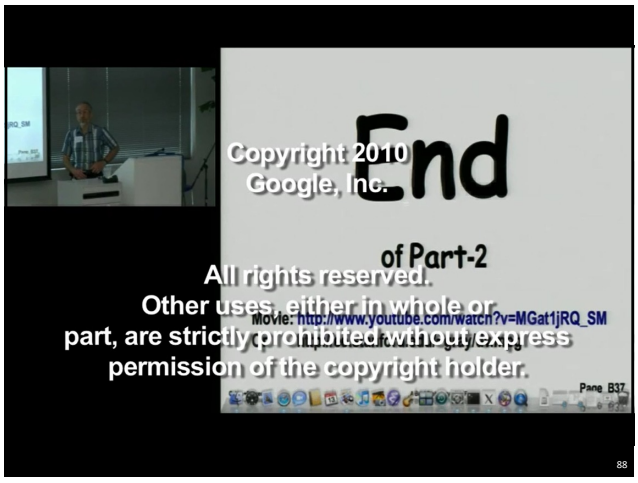

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