Voice over IP
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Overview

- new Internet services: “telephone”, “radio”, “television”
- why Internet telephony?
- why not already?
- Internet telephony modalities
- components needed:
  - audio coding
  - data transport
  - quality of service – resource reservation
  - signaling
  - PSTN interworking: gateway location, number translation

The phone works — why bother with VoIP?

<table>
<thead>
<tr>
<th>user perspective</th>
<th>carrier perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>variable compression: tin can to broadcast quality</td>
<td>silence suppression ⇒ traffic ↓</td>
</tr>
<tr>
<td>security through encryption</td>
<td>shared facilities ⇒ management, redundancy</td>
</tr>
<tr>
<td>caller, talker identification</td>
<td>advanced services (simpler than AIN and CTI)</td>
</tr>
<tr>
<td>better user interface</td>
<td>operational advantages</td>
</tr>
<tr>
<td>internat. calls: TAT transatlantic cable = $0.03/hr</td>
<td>cheaper switching</td>
</tr>
<tr>
<td>no local access fees (but ↓ 1c/min.)</td>
<td>fax as data</td>
</tr>
<tr>
<td>easy: video, whiteboard, …</td>
<td></td>
</tr>
</tbody>
</table>
The new phone companies

- separation bit carriage ↔ services
- anybody with Internet connection can provide services (ACD, 800, 900, directory, ...)  
- distinction “in” vs. “out” of network not useful
- incremental start-up investment not large
- new players:
  - cable companies ➤ no new infrastructure, but mostly one-way
  - electric utilities ➤ need line management anyway
  - Qwest, IXC (resell to ISPs), ...

Use VoIP – go to jail

Prohibited: Albania, Bahrain, Botswana, Burundi, Cuba, Cyprus, India, Jordan, Kenya, Mauritius, Mexico, Nepal, Pakistan, Panama, Slovakia, South Africa, Thailand, Turkey, Venezuela, Vietnam, Yemen.

Restricted: Hungary (delay > 250 ms), Brazil, China (China Telecom, 4 spin-offs), Czech Republic (not phone-to-phone), Paraguay (fax only), Poland (p2p for mobile operators)

Allowed: Australia, Canada, European Union, Hong Kong, Japan, New Zealand, Peru, Republic of Korea, Singapore, Switzerland, U.S.
(1999 survey)

Internet telephony as PBX replacement

If global Internet not quite ready ➤ try as PBX
- have mission-critical LAN, PCs anyway
- usually ample (if switched) bandwidth, low latency
- packet switching is cheaper
- network PCs § ISDN phones
- no need for billing

Internet telephony services

- voice mail → email
- calendar integration
- user-programmable call processing logic
- call first available sales person (ACD)
- call whole department
- web IVR
- return web page with favorite “on hold” music
### Internet telephony services

- camp-on without holding a line
- short message service ("instant messaging")
- schedule call into the future
- call with expiration date
- add/remove parties to/from call ➔ mesh
- "buddy lists"

### Switching costs

<table>
<thead>
<tr>
<th>switching method</th>
<th>ports</th>
<th>capacity (Gb/s)</th>
<th>cents/64 kb/s</th>
<th>$/interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/100BaseT Ethernet hub</td>
<td>24</td>
<td>2.40</td>
<td>0.6</td>
<td>10.00</td>
</tr>
<tr>
<td>100BaseTX Ethernet switch</td>
<td>24</td>
<td>2.40</td>
<td>0.9</td>
<td>14.60</td>
</tr>
<tr>
<td>PBX</td>
<td>256</td>
<td>0.02</td>
<td>218.</td>
<td>140</td>
</tr>
<tr>
<td>Lucent 5ESS local (no AIN)</td>
<td>5,000</td>
<td>0.32</td>
<td>469.</td>
<td>300</td>
</tr>
<tr>
<td>Lucent 5ESS local (AIN)</td>
<td>20,000</td>
<td>1.28</td>
<td>273.</td>
<td>175</td>
</tr>
<tr>
<td>Lucent 4ESS toll</td>
<td>100,000</td>
<td>6.40</td>
<td>7.8</td>
<td></td>
</tr>
</tbody>
</table>

### Telephone costs

<table>
<thead>
<tr>
<th>category</th>
<th>cost share</th>
</tr>
</thead>
<tbody>
<tr>
<td>infrastructure</td>
<td>10-23%</td>
</tr>
<tr>
<td>switching and transmission</td>
<td>6%</td>
</tr>
<tr>
<td>overhead</td>
<td>49%</td>
</tr>
<tr>
<td>access</td>
<td>34%</td>
</tr>
<tr>
<td>operations support systems</td>
<td>11%</td>
</tr>
</tbody>
</table>

### Transport costs

<table>
<thead>
<tr>
<th>network</th>
<th>$/min</th>
<th>$/MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>wholesale telephone</td>
<td>0.01–0.02</td>
<td></td>
</tr>
<tr>
<td>U.S. domestic interstate consumer rates</td>
<td>0.05–0.15</td>
<td></td>
</tr>
<tr>
<td>U.S. domestic intrastate consumer rates</td>
<td>0.05–0.25</td>
<td></td>
</tr>
<tr>
<td>modem</td>
<td>0.25 – 0.50</td>
<td></td>
</tr>
<tr>
<td>private line</td>
<td>0.50 – 1.00</td>
<td></td>
</tr>
<tr>
<td>frame relay</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>MCI frame SVC</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Internet</td>
<td>0.04 – 0.15</td>
<td></td>
</tr>
<tr>
<td>Internet modem</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Internet backbone</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

1’ voice = 480 kB w/silence suppr., 1 MB without
Phone usage

“Free” phone calls does not mean unbounded increase:

<table>
<thead>
<tr>
<th>year (millions)</th>
<th>local calls min/day/line (min/day/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>102.2 39</td>
</tr>
<tr>
<td>1988</td>
<td>127.1 39</td>
</tr>
<tr>
<td>1996</td>
<td>166.3 40</td>
</tr>
</tbody>
</table>

Traffic (1998)

Measured in Dial Equipment Minutes (DEM) or bandwidth:

<table>
<thead>
<tr>
<th></th>
<th>GDEM (Gb/s)</th>
<th>bandwidth (Gb/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>2986</td>
<td>364</td>
</tr>
<tr>
<td>U.S. intrastate toll</td>
<td>422</td>
<td>51</td>
</tr>
<tr>
<td>U.S. interstate toll</td>
<td>555</td>
<td>68</td>
</tr>
</tbody>
</table>

PBX: typically, about 10% utilization per phone ➼ 6.4 kb/s per employee (128 Mb/s for 20,000 person campus)

Why aren’t we junking switches right now?

What made other services successful?

email: available within self-contained community (CS, EE)
web: initially used for local information
IM: instantly available for all of AOL

All of these . . .

• work with bare-bones connectivity (≥ 14.4 kb/s)
• had few problems with firewalls and NATs
• don’t require a reliable network

Telephone services are different:

• reliability expectation 99.9% ➼ 99.999%
• PC not well suited for making/receiving calls – most residential handsets are cordless or mobile
• business sets: price incentive minor for non-800 businesses
• services, multimedia limited by PSTN interconnection
• initial incentive of access charge bypass fading (0.5c/min.)
• international calls only outside Western Europe and U.S.
Data vs. Voice Traffic

![Graph showing data vs. voice traffic worldwide traffic (Gb/s) from 1996 to 2002]

August 12, 2001

Internet multimedia protocol stack

![Diagram of the Internet multimedia protocol stack]

August 12, 2001

Internet telephony modes

- tail-end hop off ➞ callee has phone
- front-end hop on ➞ caller uses phone
- Internet in the middle: per-call, multiplexed

August 12, 2001

Internet “signaling”

all non-data (“out-of-band”) functions:

- routing: unicast; DVMRP, PIM, CBT for multicast ✓
- quality of service: RSVP, RTCP, diff-serv ✓
- user Contact: map name to location (IP address)
- call set-up/teardown: SIP, H.323
- policy, billing: “vertical” protocols

August 12, 2001
Architecture

Differences: Internet Telephony ↔ POTS

- separate control, transport (UDP) ➔ no triangle routing
- separate connectivity from resource availability
- separate services from bit transport
- datagram service ➔ less bootstrapping
- in-band signaling ➔ higher speed
- features “network” ➔ end system: distinctive ringing, caller id, speed dialing, number translation, . . . ➔ scaling
- features: intra-PBX = international
- protocols: user-network = network-network signaling

Two Views of Internet Telephony

Internet telephony:
- primarily voice
- look like phone system: ISDN signaling, separate “stack”
- interoperability with SS7
- or SS7 migration to Internet

Internet telephony:
- VoIP = yet another Internet service
- voice = small fraction of traffic in ten years
- SS7 = legacy, to be relegated to edges
- integration with email, web
- multimedia, including non-CM

Architecture

Centrally controlled (master-slave): media gateways controlled by call servers: “connect circuit 17 to IP address 128.59.19.1” ➔ Megaco, MGCP
- all services in server control
- no need to modify end systems
- “pay $4.59/month for call waiting, $7.50 for caller id”

Peer-to-peer: equal participants, end-to-end
- services in proxy servers and end systems
- need to modify software for new services
- “download new software for $19.95”

Connect MGCP islands using SS7 or peer-to-peer protocols
Open Operational Issues

- reliability
- billing
- 911 (emergency) services
- wire tapping (CALEA)
- anonymity and certified identity

Billing

- simplification: email/web delivery, credit card payment
- what to bill for?
  - transport services: volume, time, reserved resources; “free upgrades”
  - signaling services: filtering, forwarding, scripting, mobility, . . .
  - storage services: voice mail
  - gateway services: PSTN gateways
- difficult: settlements between carriers – not simple LEC – IXC – LEC model

Emergency (911) services

- U.S.: dial “911” anywhere → nearest Public Safety Answering Points
- look up street address from telephone company database
- but . . .
  - IP address dynamically assigned
  - may not be correlated to geography
  - dial-in from hotel, remote sites?
  - prevent services: hanging up, transfer, hold, . . .

Emergency services

- advantages:
  - multimedia (video, medical data, . . .)
  - medical database access, with authentication token
  - remote activation of medical devices
- solutions:
  - enclose (signed) location information with call
  - IP address → provider → lookup (RADIUS) needs authenticated protocol
  - GPS
**Lawful intercepts (“wiretapping”)**

- Internet already has remote packet tapping: RMON, telnet + rtdump, . . .
- most intercepts done on local loop → Internet doesn’t change that
- information services exempt from CALEA provisions
- difference between content and “pen register” (signaling) intercept
- see IETF raven mailing list

**Other issues**

- Lots more to talk about (but won’t) . . .
  - carrying ISUP (SS7 signaling) over IP ↦ SCTP
  - using ISUP to set up IP bearers ↦ BICC
  - automatic configuration of IP phones
  - (3G) wireless issues

**Summary**

- transition of separate circuit-switched ↦ IP-based applications
- VoIP: transport + QoS + signaling + services
- packets from the inside out or the outside in?
- Internet telephony or Internet telephony
- stack: IP over ATM, Sonet, WDM?
- role of IPv6 or NATs?
- “the end of distance” or tiered IP service?