Kungl Tekniska Högskolan

Institutionen för mikroelektronik och informationsteknik

2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

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maguire@it.kth.se
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Practical Voice Over IP (VoIP): SIP and related protocols

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2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Module 1: Introduction

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Welcome to the course!

The course should be fun.

We will dig deeper into Voice over IP - with a focus on SIP and related protocols, but may also examine some of the other protocols which are used.

Information about the course is available from the course web page.

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Welcome to the course!
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Staff Associated with the Course

Instructor (Kursansvarig)

prof. Gerald Q. Maguire Jr. <maguire@it.kth.se>

Administrative Assistant: recording of grades, registration, etc.

Rita Johnsson <ritaj@it.kth.se>

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Staff Associated with the Course
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Practical Voice Over IP (VoIP): SIP and related protocols

Goals, Scope and Method

Goals of the Course

- To understand what Voice over IP (VoIP) systems are, their basic architectures, and the underlying protocols

- To be able to read and understand the literature.

- To provide a basis for your own research and development in this area.

Scope and Method

- We are going to examine the Vovida Open Communication Application Library (VOCAL) system[1] to understand both the details of the system(s) and to abstract from these details some architectural features and examine some places where it can be extended (thus using it as a platform on which you can explore).

- You will demonstrate your knowledge by writing a written report and giving an oral presentation describing your project.

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1. The source code is available from `vovida.org`

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Goals, Scope and Method
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Prerequisites

- Internetwork (2G1305) **or**
- Equivalent knowledge in Computer Communications (this requires permission of the instructor)

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Prerequisites
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Practical Voice Over IP (VoIP): SIP and related protocols

Contents

The focus of the course is on what Voice over IP (VoIP) systems are, their basic architectures, and the underlying protocols. We will primarily focus on the Session Initiation Protocol (SIP) and related protocols.

The course consists of 10 hours of lectures and a project of ~50 hours effort.

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Topics

- Session Initiation Protocol (SIP)
- Real-time Transport Protocol (RTP)
- Real-time Streaming Protocol (RTSP)
- Common Open Policy Server (COPS)
- SIP User Agents
- Location Server, Redirect Server, SIP Proxy Server, Registrar Server, ... , Provisioning Server, Feature Server
- Call Processing Language (CPL)

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Topics
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Examination requirements

- Written and Oral project reports

Grades: U, 3, 4, 5

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Examination requirements
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Practical Voice Over IP (VoIP): SIP and related protocols

Project

Goals: to gain analytical or practical experience and to show that you have mastered some knowledge in this area and to encourage you to find a topic which interests you (since this will motivate you to really understand the material)

- Can be done in a group of **1 to 3** students (formed by yourself). Each student must contribute to the final written and oral reports.

- Discuss your ideas about topics with the instructor **before** starting.

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Project
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Practical Voice Over IP (VoIP): SIP and related protocols

Assignment Registration and Report

- Registration: 10 February 2003, to <maguire@it.kth.se>
  - Group members, leader.
  - Topic selected.

- Written report
  - Length of the final report should be 10 pages (roughly 5,000 words) for each student.
  - Report may be in the form of a collections of papers, with each paper suitable for submission to a conference or journal
  - Contribution by each member of the group - must be clear (in the case where the report is a collection of papers - the role of each member of the group can be explained in the overall introduction to the papers.
  - The report should clearly describe: 1) what you have done; 2) who did what; if you have done some implementation and measurements you should describe the methods and tools used, along with the test or implementation results, and your analysis.

Final Report: written report due **28 February 2003 + oral presentations scheduled 3rd and 4th of March 2003**[1]

- Send e-mail with URL link to <maguire@it.kth.se>

Note that it is OK to start working *well in advance* of the deadlines!

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1. Alternative dates can be scheduled with the instructor's permission.

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maguire@it.kth.se
Assignment Registration and Report
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Literature

The course will mainly be based on the two books:

- Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2.

- Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2

We will refer to other books, articles, and RFCs as necessary. A list of interesting literature will be available on the course web page and in the references and further reading section of each lecture module.

In addition, you will be searching & reading the literature in conjunction with your projects. Please make sure that you properly reference your sources in your report.

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Literature
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Practical Voice Over IP (VoIP): SIP and related protocols

Lecture Plan

- Introduction
  - Course arrangement
  - Set the context of VoIP, both technically and economically
- VoIP details
  - Session Initiation Protocol (SIP)
  - Session Description Protocol (SDP)
  - DNS and ENUM
- Mobility
- Service Creation
- User preferences
- Security, NATs, and Firewalls
- SIP Telephony
- Conferencing
- Mixed Internet - PSTN services
- AAA and QoS
- More than just voice!

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Lecture Plan
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Practical Voice Over IP (VoIP): SIP and related protocols

Voice over IP (VoIP)

First we will set the context, then we will examine the technical details.

VoIP is an End-to-End Architecture which exploits *processing in the end points*.

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Voice over IP (VoIP)
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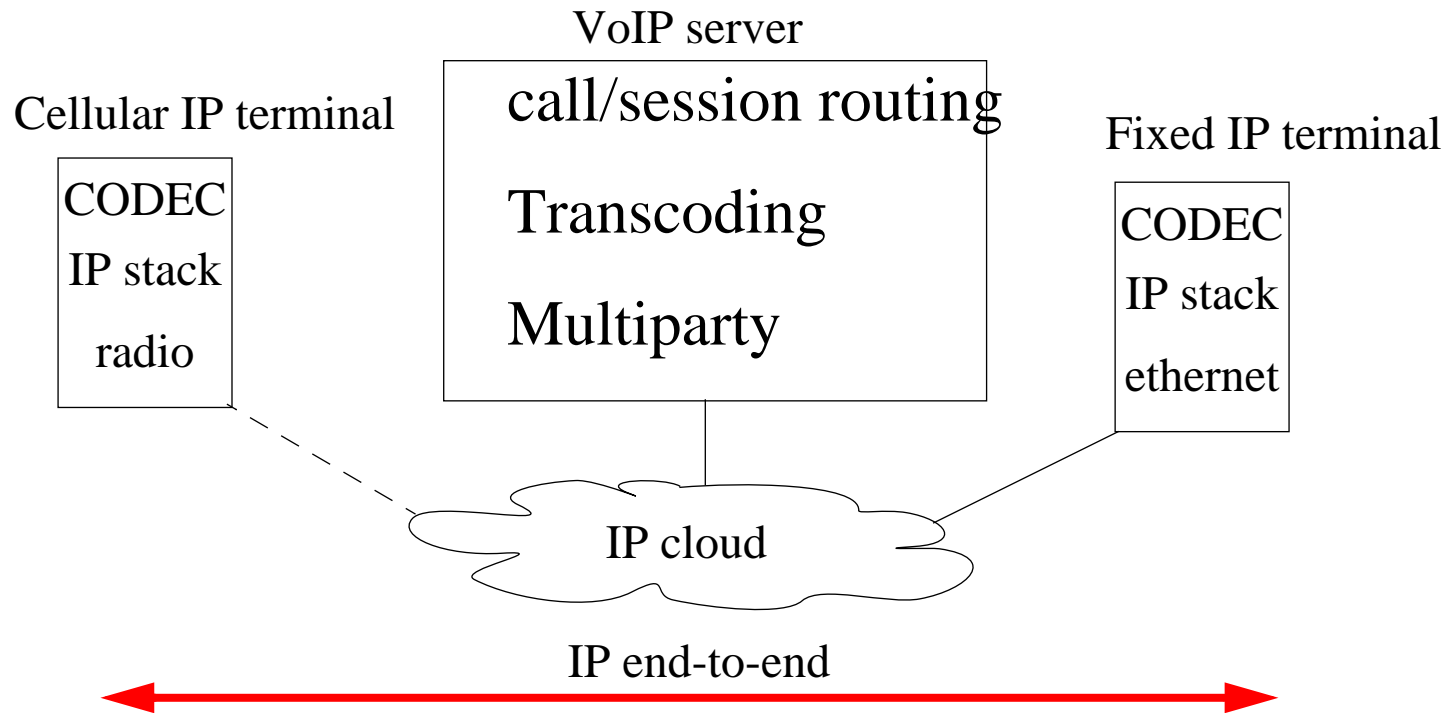
Potential Networks
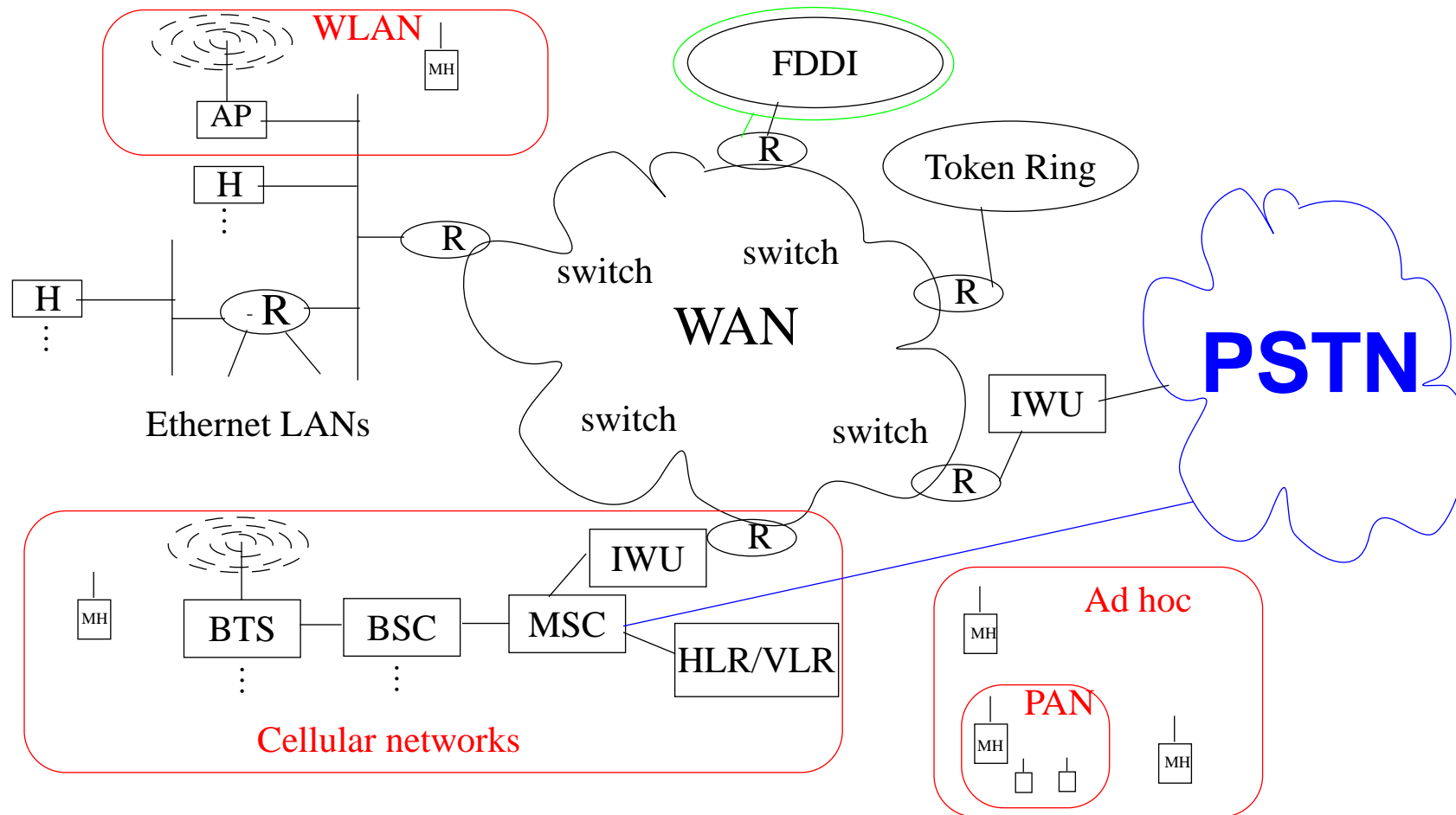
Figure 1: Internet and PSTN

- We will focus on VoIP, largely *independently* of the underlying network, i.e., LAN, Cellular, WLAN, PAN, Ad hoc, … .

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maguire@it.kth.se

Potential Networks
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Network Convergence

In the past we thought about and used many different networks (*each optimized for a specific use*: POTS, data networks (such as X.25), broadcast radio and television, … and each of these in turn often had specific national, regional, or proprietary implementations)

$\Rightarrow$ (Now) we think about a *converged* network which is a *global* network.

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maguire@it.kth.se

Network Convergence

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Internetworking

Internetworking is

- based on the interconnection (concatenation) of multiple networks
- accommodates multiple underlying hardware technologies by providing a way to interconnect **heterogeneous** networks and makes them inter-operate.

Public Switched Telephony System (PSTN) uses a **fixed** sampling rate, typically 8kHz and coding to 8 bits, this results in 64 kbps voice coding; however, VoIP is *not* limited to using this coding and could have **higher** or **lower** data rates depending on the CODEC(s) used, the available bandwidth between the end points, and the user's preference(s).

One of the interesting possibilities which VoIP offers is quality which is:

- better that "toll grade" telephony or
- worse than "toll grade" telephony (but perhaps still acceptable)

This is unlike the *fixed* quality of traditional phone systems.

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maguire@it.kth.se

Internetworking
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Developing as a major market

Voice over IP has developed as a major market - which began with H.323 and has now moved to SIP. There are increasing numbers of users and a large variety of VoIP hardware and software on the market. Some of these, such as Cisco's VoIP phones (as of March 29, 2001) had significant sales. For example,

"... 40,000 IP phones to Dow Chemical (DOW), for instance, and another 8,000 to the New Zealand Ministry of Social Policy. The company says it's installing 2,000 phones each week - but that's a drop in the bucket compared with the number installed by established vendors such as Nortel and Siemens (SI)."

-- Richard Martin, "Cisco Answers the Call of the Phone:The networking giant is getting into an unlikely market: selling telephones", The Industry Standard, March 29, 2001
http://www.thestandard.com/article/0,1902,23203,00.html

Maguire
maguire@it.kth.se

Developing as a major market
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US$1 Billion Market for VoIP handsets!

"According to Cahners In-Stat, the market for voice over IP (VoIP) handsets reached $1 billion in 2001, and will grow to $5 billion by 2006, as IP phone systems replace traditional circuit-switched PBX systems. In 2001, IP phone sales tripled over 2000, and the number of handsets installed per new system doubled, reaching 68 in 2001."

-- Gilda Raczkowski, "The Benefits of Integrated Networks Communications Convergence", in dash30,

http://www1.worldcom.com/us/resources/library/reports/ipcomm/convergence.pdf

Maguire
maguire@it.kth.se

US$1 Billion Market for VoIP handsets!
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Handsets

There are now starting to appear USB attached VoIP handsets:

- TigerJet Network *http://www.tjnet.com/solutions/usb_handset.htm*

WLAN Handsets:

- Symbol Technologies has been selling their NetVision® *Data Phone: Portable Voice and Data Terminal* and NetVision® *Phone* for several years *http://www.symbol.com/products/wireless/voice_over_ip.html*

- Vocera Communications Badge *http://www.vocera.com/*
  - runs speech recognition software in a network attached server
  - unfortunately it uses a proprietary protocol between the handset and their server, but I expect others will make similar devices which will **not** have this **mis-feature.**

Coming are VoIP cellular handsets

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Handsets
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VoIP Chipsets

Agere Systems' VoIP Phone-On-A-Chip - target is **business** telephone **handsets** and **speakerphones** *http://www.agere.com/client/voip_solutions.html*

Two ICs:

- ## T8302 IPT_ARM (Advanced RISC Machine)
  - Up to 57.6 MHz general-purpose processor
  - controls the system I/O: two 10/100Base-T Ethernets, USB, IrDA, SPI, 16 programmable I/O pins (some could be used to interface to an LCD module), …
  - general telephone control features: 7 row outputs and 8 column inputs/outputs to control up to 56 LEDs and scan up to 56 keys, 6 different flash rates, …

- ## T8301 IPT_DSP (digital signal processor)
  - Based on Agere Systems DSP1627 digital signal processor core running at 80 MIPS
  - single-cycle multiply accumulate instruction supports voice compression/decompression and echo cancellation algorithms
  - Includes two 16-bit digital-to-analog (D/A), one 16-bit analog-to-digital converters (A/D), low-pass filters, audio amplifier, lots of buffers (for for input and output)

A special feature is acoustic echo cancellation to enable high quality speakerphone. See also [3].

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VoIP Chipsets
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Deregulation ⇒ New operators

Lots of new actors appeared as operators:

- *WorldCom*
- *Qwest*
- *Level3*
- *Net2Phone*
- …

As of Fall 2002, many of these operators were in bankruptcy, reorganizing, or no longer exist - due to the Telecom meltdown!

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maguire@it.kth.se

Deregulation ⇒ New operators
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Deregulation $\Rightarrow$ New Suppliers

Lots of new actors as equipment suppliers:

- *Cisco*, 3Com, *Nortel Networks*, ...

Traditional telecom equipment vendors buying datacom vendors:

- Lucent buys Prominet, spins out Agere and Avaya
- Ericsson buys ACC, sells off microelectronics division
- Alcatel buys DSC Communications and Packet Engines
- Nortel + Bay Networks becomes *Nortel Networks*: unified networks

Lots of mergers and acquisitions among datacom vendors.

As of Fall 2002, many of these vendors were reorganizing, selling off divisions, reducing staffing, ... -- due to the Telecom meltdown!

For a list of SIP products see: *http://www.pulver.com/products/sip/*

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maguire@it.kth.se
Deregulation $\Rightarrow$ New Suppliers
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Let them fail fast!

We hold that the primary cause of current telecom troubles is that Internet-based end-to-end data networking has subsumed (and will subsume) the value that was formerly embodied in other communications networks. This, in turn, is causing the immediate obsolescence of the vertically integrated, circuit-based telephony industry of 127 years vintage.

Izumi Aizu, Jay Batson, Robert J. Berger, et al.,
Letter to FCC Chairman Michael Powell, October 21, 2002
http://pulver.com/press/powell.html

The extent of this transformation is well described in their complete letter which recommends that the FCC:
- "Resist at all costs the telephone industry's calls for bailouts. The policy should be one of "fast failure."
- Acknowledge that non-Internet communications equipment, while not yet extinct, is economically obsolete and forbear from actions that would artificially prolong its use.
- Discourage attempts by incumbent telephone companies to thwart municipal, publicly-owned and other communications initiatives that don't fit the telephone company business model.
- Accelerate FCC exploration of innovative spectrum use and aggressively expand unlicensed spectrum allocation."

Maguire
maguire@it.kth.se

Let them fail fast!
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Latency
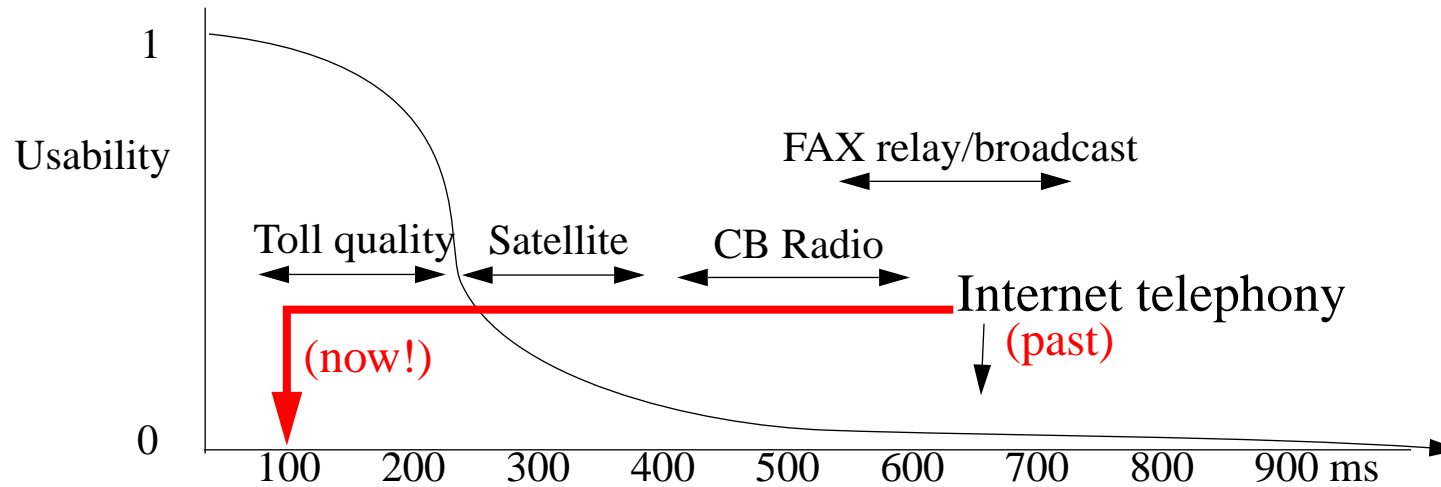
Figure 2: Usability of a voice circuit as a function of end-to-end delay (adapted from a drawing by Cisco[a])

a. (this was at http://www.packeteer.com/solutions/voip/sld006.htm)

For example:

Round-trip times from dumburken.it.kth.se (as of 2002.10.11)	min (ms)	avg (ms)	max (ms)	hops
Local LANs (www.imit.kth.se)	0	0	5	2
to northern Sweden (cdt-lisa.cdt.luth.se)	21	21	21	12
to Austria (www.tu-graz.ac.at)	39	50	61	14
To my machine in eastern US (via an SDSL link)	110	112	119	22
To US west coast (www.stanford.edu)	178	178	179	22
To Australia (www.uow.edu.au)	329	329	332	>22

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maguire@it.kth.se

Latency
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VOIP Modes of Operation

- PC to PC

- PC-to-Telephone calls

- Telephone-to-PC calls

- Telephone-to-Telephone calls via the Internet

- Premises to Premises
  - use IP to tunnel from one PBX/Exchange to another

- Premises to Network
  - use IP to tunnel from one PBX/Exchange to a gateway of an operator

- Network to Network
  - from one operator to another or from one operator's regional/national network to the same operator in another region or nation

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maguire@it.kth.se

VOIP Modes of Operation
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IP based data+voice infrastructure

Public cells

Handset

exchange

E-1 to PSTN

Gateway

IP Phone

FW/Switch

Workstation

Home

Office

Voice Gateway

Workstation

In-building WLAN system

AP

Handset

Handset

Router

AP

Mobile

Internet

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IP based data+voice infrastructure

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Voice Gateway

Use access servers filled with digital modems (currently (formerly?) used for current analog modem pools) as voice gateways or special purpose gateways such as that of Li Wei [4].

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Voice Gateway
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Voice over IP (VOIP) Gateways

Gateways not only provide basic telephony and fax services, but can also enable lots of value-added services, e.g., call-centers, integrated messaging, least-cost routing, … .

Such gateways provide three basic functions:

- Interface between the PSTN network and the Internet

  Terminate incoming synchronous voice calls, compress the voice, encapsulate it into packets, and send it as IP packets. Incoming IP voice packets are unpacked, decompressed, buffered, and then sent out as synchronous voice to the PSTN connection.

- Global directory mapping

  Translate between the names and IP addresses of the Internet world and the E.164 telephone numbering scheme of the PSTN network.

- Authentication and billing

Voice representation

Commonly: ITU G.723.1 algorithm for voice encoding/decoding or G.729 (CS-ACELP voice compression).

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maguire@it.kth.se

Voice over IP (VOIP) Gateways
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Signaling

Based on the H.323 standard on the LAN and conventional signaling will be used on telephone networks.

NB: In conventional telephony networks signalling **only** happens at the *beginning* and *end* of a *call*. See Theo Kanter's dissertation for what can be enabled via SIP so that you can react to **other** events.

Fax Support

Both store-and-forward and real-time fax modes.

- In store-and-forward the system records the entire FAX before transmission.

Management

Full SNMP management capabilities via MIBs (Management Information Base)

- provided to control all functions of the Gateway
- Extensive statistical data will be collected on dropped calls, lost/resent packets, and network delays.

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Voice over IP (VOIP) Gateways
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Compatibility

De jure standards:

- ITU G 723.1/G.729 and H.323
- VoIP Forum IA 1.0

De facto standards:

- Netscape's Cooltalk
- Microsoft's NetMeeting (formerly H.323, now SIP)

Session Initiation Protocol (SIP) [RFC 2543] is much simpler than H.323

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maguire@it.kth.se

Voice over IP (VOIP) Gateways
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Cisco's Voice Over IP

Enables Cisco 3600 series routers to carry live voice traffic (e.g., telephone calls and faxes) over an IP network.

They state that this could be used for:

- Toll bypass
- Remote PBX presence over WANs
- Unified voice/data trunking
- POTS-Internet telephony gateways

Uses Real-Time Transport Protocol (RTP) for carrying packetized audio and video traffic over an IP network.

Cisco 3600 supports a selection of CODECs:

- G.711 A-Law 64,000 bits per second (bps)
- G.711 u-Law 64,000 bps
- G.729 8000 bps

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maguire@it.kth.se

Cisco's Voice Over IP
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Cisco 3800 supports even more CODECs:

- ITU G.726 standard, 32k rate
- ITU G.726 standard, 24k rate
- ITU G.726 standard, 16k rate
- ITU G.728 standard, 16k rate (default)
- ITU G.729 standard, 8k rate

By using Voice Activity Detection (VAD) - you only need to send traffic if there is something to send {Note: telecom operators like this because it enables even higher levels of statistical multiplexing}.

An interesting aspect is that users worry when they hear *absolute* silence, so to help make them comfortable it is useful to play noise when there is nothing useful to output. Cisco provide a "**comfort-noise** command to generate background noise to fill silent gaps during calls if VAD is activated".

Cisco 3600 series router can be used as the voice gateway with software such as Microsoft NetMeeting.

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maguire@it.kth.se
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Cisco 3800 also supports "fax-relay" - at various rates either current voice rate or 2,400/4,800/7,200/9,600/14,400 bps fax rates.

For futher information see

http://www.cisco.com/univercd/cc/td/doc/product/software/ios113ed/113t/113t_1/voip/config.htm

Maguire
maguire@it.kth.se

Cisco's Voice Over IP
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Intranet Telephone System

On January 19, 1998, `Symbol Technologies` and Cisco Systems announced that they had combined the Symbol Technologies' NetVision™ wireless LAN handset and Cisco 3600 to provide a complete wireless local area network telephone system based on Voice-Over-IP technology. (`White Paper`)

The handset uses a wireless LAN (IEEE 802.11) infrastructure and a voice gateway via Cisco 3600 voice/ fax modules. The system conforms to H.323.

> "I believe that this is the first wireless local area network telephone based on this technology" -- Jeff Pulver

Seamless roaming via Symbol's pre-emptive roaming algorithm with load balancing.

Claims each cell can accommodate ~25 simultaneous, full-duplex phone calls.

Ericsson partnered with Symbol, using Ericsson's `WebSwitch2000`

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maguire@it.kth.se

Intranet Telephone System
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Wireless LANs

"The wireless workplace will soon be upon us[1]

Telia has strengthened its position within the area of radio-based data solutions through the acquisition of Global Cast Internetworking. The company will primarily enhance Telia Mobile's offering in wireless LANs and develop solutions that will lead to the introduction of the wireless office. A number of different alternatives to fixed data connections are currently under development and, *later wireless IP telephony will also be introduced.*

…

The acquisition means that Telia Mobile has secured the resources it needs to maintain its continued expansion and product development within the field of radio-based LAN solutions. *Radio LANs are particularly suitable for use by small and medium-sized companies as well as by operators of public buildings such as airports and railway stations.*

Today's radio-LAN technology is based on *inexpensive products that do not require frequency certification.* They are *easy to install* and are often used to replace cabled data networks in, for example, large buildings.

…"

[*emphasis* added by Maguire]

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1. Telia press annoucement: 1999-01-25

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maguire@it.kth.se

Wireless LANs
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Telia's HomeRun

http://www.homerun.telia.com/

A subscription based service to link you to your corporate network from airports, train stations, ferry terminals, hotels, conference centers, etc.

Look for Telia's HomeRun logo:

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Telia's HomeRun
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Ericsson's "GSM on the Net"

- Provide communication services over an integrated GSM- IP (Internet Protocol) network

- support local and global mobility

- support multimedia capabilities and IP-based applications

- uses small radio base stations to add local-area GSM coverage to office LANs

- provides computer-telephony integration: applications include web-initiated telephony, directory-assisted dialing, unified messaging and advanced conferencing and application-sharing using voice datacoms and video.

Maguire
maguire@it.kth.se

Ericsson's "GSM on the Net"
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Gatekeeper

To control an H.323 VoIP network Ericsson has introduced a product called H.323 Gatekeeper. It provides for control of:

- How much traffic is allocated to voice, video, and data;
- Do network bandwidth management;
- Handle routing when there are multiple H.323 Gateways;
- Manage Network Subscriber Access;
- Provides for Charging/Billing Systems;
- Add new Services & Applications;
- Support Network Security and Subscriber Authentication

Gatekeeper uses RAS (Registration, Admission, and Status) for call signalling and its communication.

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maguire@it.kth.se

Gatekeeper
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VOIP vs. traditional telephony

In "*Telcos Hear New Voices*" by Margrit Sessions, Phillips Tarifica Ltd., she predicts that by 2001, Internet telephony could squeeze nearly US$1.2 billion in revenue out of 16 international service providers, while losses due to e-mail (US$463 million) and Internet fax (US$170 million) will be much less.

Expected loss of international call revenue due to: Internet phone, fax, and e-mail, by operator:

Company	Expected Losses (millions of US Dollars)	Loss as a percentage of revenue
AT&T	~350	3.6%
Kokusai Denshin Denwa (KDD) Co. Ltd. (Japan)	~307	10.4%
Deutsche Telekom	~175	4.2%
Telstra Corp. (Australia)	~168	9%
Embratel (Brazil)	~28	11.5%
Bezeq (Israel)	~30	10.7%

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maguire@it.kth.se

VOIP vs. traditional telephony
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Economics

"Can Carriers Make Money On IP Telephony?" by Bart Stuck and Michael Weingarten, Business Communication Review, Volume 28, Number 8, August 1998, pp. 39-44 - *http://www.bcr.com/bcrmag/08/98p39.htm*

"What is the reality in the battle over packet-versus-circuit telephony, and what is hype?

Looking at the potential savings by cost element, it is clear that in 1998, access arbitrage is the major economic driver behind VOIP. By 2003, we anticipate that switched-access arbitrage will diminish in importance, as the ESP exemption disappears and/or access rates drop to true underlying cost.

However, we believe that the convergence between voice and data via packetized networks will offset the disappearance of a gap in switched access costs. As a result, VOIP will continue to enjoy a substantial advantage over circuit-switched voice. Indeed, as voice/data convergence occurs, we see standalone circuit-switched voice becoming economically nonviable."

Note: Enhanced Service Provider (ESP) exemption means that ISPs do not pay access charges to local phone companies {since the ISP just **receives** calls from users}

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maguire@it.kth.se

Economics
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VoIP vs. traditional telephony

Henning Schulzrinne in a slide entitled "Why should carriers worry?"[1] nicely states the threats to traditional operators:

- Evolution from application-specific infrastructure $\Rightarrow$ **Content-neutral** bandwidth delivery mechanism - may take away the large margins which the operators are used to (and **want**!):
    - "GPRS: $4-10/MB
    - SMS: > $62.50/MB
    - voice (mobile and landline): $1.70/MB"
- Only operators can offer services $\Rightarrow$ Anybody can offer phone services
- SIP only needs to handle signaling, not media traffic
- High barriers to entry $\Rightarrow$ No regulatory hurdles

In addition to this we can add: Only vendors can create services $\Rightarrow$ anybody can create a service

---

1. Henning Schulzrinne, "When will the telephone network disappear?", as part of Intensive Graduate Course "Internet Multimedia", University of Oulu, 3-6 June 2002.

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maguire@it.kth.se

VoIP vs. traditional telephony
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Patents

Mixing voice and data in the LAN goes back to at least this patent:

US 4581735 :   Local area network packet protocol for combined voice and data transmission

INVENTORS: Lois E. Flamm and John O. Limb

ASSIGNEES: AT&T Bell Laboratories, Murray Hill, NJ

ISSUED: Apr. 8 , 1986

FILED: May 31, **1983**

ABSTRACT: In order to control the transfer of packets of information among a plurality of stations, the instant communications system, station and protocol contemplate first and second oppositely directed signal paths. At least two stations are coupled to both the first and the second signal paths. A station reads one signal from a path and writes another signal on the path. The one signal is read by an arrangement which electrically precedes the arrangement for writing the other signal. Packets are transmitted in a regular, cyclic sequence. A head station on a forward path writes a start cycle code for enabling each station to transmit one or more packets. If a station has a packet to transmit, it can read the bus field of a packet on the forward path. Responsive thereto, a logical interpretation may

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maguire@it.kth.se

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be made as to whether the forward path is busy or is not busy. If the path is not busy, the packet may be written on the path by overwriting any signal thereon including the busy field. If the path is busy, the station may defer the writing until the path is detected as not busy. In order to accommodate different types of traffic, the head station may write different start cycle codes. For example, a start-of-voice code may enable stations to transmit voice packets; a start-of-data code may enable stations to transmit data packets, etc. for the different types of traffic. Further, the start cycle codes may be written in a regular, e.g., periodic, fashion to mitigate deleterious effects, such as speech clipping. Still further, the last station on the forward path may write end cycle codes in packets on a reverse path for communicating control information to the head station. Responsive to the control information, the head station may modify the cycle to permit the respective stations to, for example, transmit more than one packet per cycle or to vary the number of packet time slots, which are allocated to each of the different types of traffic.

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maguire@it.kth.se

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Deregulation $\Rightarrow$ Trends

- replacing multiplexors with Routers/Switches/… << 1/10 circuit swi. cost
- Standard telco interfaces being replaced by datacom interfaces
- New Alliances:
  - HP/AT&T Alliance, 3Com/Siemens, Bay/Ericcson, Cabletron/Nortel, Alcatel integrating Cisco IOS software technology, Ericsson Radio Systems & Cisco Systems collaborate wireless Internet services, …
- future developments building on VOIP

  ♦ Fax broadcast, Improved quality of service, Multipoint audio bridging, Text-to-speech conversion and Speech-to-Text conversion, Voice response systems, …

  ♦ Replacing the wireless voice network's infrastructure with IP:
  U. C. Berkeley's *ICEBERG*: Internet-based core for CEllular networks BEyond the thiRd Generation

See the Univ. of California at Berkeley ICEBERG project report:
http://iceberg.cs.berkeley.edu/release/

$\Rightarrow$ Telecom (only) operators have no future
$\Rightarrow$ Telecom (only) companies have no future

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Deregulation $\Rightarrow$ Trends
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Carriers offering VOIP

"Equant, a network services provider, will announce tomorrow that it is introducing voice-over-frame relay service in 40 countries, ... The company says customers can save 20% to 40% or more by sending voice traffic over its frame relay network. "This is the nearest you're going to get to free voice," says Laurence Huntley, executive VP of marketing for Equant Network Service. … Equant isn't alone in its pursuit to send voice traffic over data networks. Most of the major carriers are testing services that would send voice over data networks. ... ."[1]

October 2002:

- Verizon offering managed IP telephony via **IPT Watch** for US$3-4/month

- WorldCom offering SIP based VoIP for DSL customers for US$50-60/month for unlimited local, domestic long distance, and data support {price does **not** include equipment at US$200-300 per phone and DSL/Frame relay/ATM connection} The Service Level Agreement (SLA) specifies >99.9% network availability, <55ms round trip latency, and >99.5% packet delivery.

---

1. Mary E. Thyfault, Equant To Roll Out Voice-Over-Frame Relay Service, InformationWeek Daily, **10/21/98**.

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maguire@it.kth.se

Carriers offering VOIP
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WorldCom Connection

Previously

- 3 or more separate networks (often each had its own staff!)
- Duration/geography-based pricing

- Expensive moves, adds, and changes (typically 1^+ move/person/year)
- Standalone applications - generally expensive
- Closed PBX architecture

Today

- via gateway to the PSTN, service expands beyond the LAN to the WAN
- centralized intelligence is offered; customers utilize a Web browser to control and manage their network
- WorldCom incurs the costs of buying major equipment, thus limiting customer's risk and capital investment
- ONE source for all services
- Easy mobility
- Choice of vendors for CPE

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maguire@it.kth.se

WorldCom Connection
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Emulating the PSTN

Many people feel that VoIP will really only "take off" when it can really emulate all the functions which users are used to in the PSTN:

- Integration with the web via: Click-to-connect
- "Dialing" an e-mail address or URL {digits vs. strings}
- Intelligent network (IN) services:
  - Call forward, busy
  - Call forward, no ans.
  - Call forward, uncond.
  - Call hold
  - Call park
  - Call pick-up
  - Call waiting
  - Consultation hold
  - Do not disturb
  - Find-me
  - Incoming call screen/Outgoing call screen
  - Secondary number in/Secondary number out
  - Three-way conference
  - Unattended transfer

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- additional PBX features (which in Sweden means providing functions such as "I'm on vacation and will not return until 31 August 2005")
- Computer-Telephony Integration (CTI), including Desktop call management, integration with various databases, etc.
- PSTN availability and reliability (thus the increasing use of Power over Ethernet for ethernet attached IP phones - so the wall outlet does not have to provide power for the phone to work)
- Roaming - both **personal** and **device** mobility
- **Phone number** portability
- E911 service {How do you handle **geographic** location of the station?}

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maguire@it.kth.se

Emulating the PSTN
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Calling and Called Features

- **Calling** feature - activated when placing a call
  - e.g., Call Blocking and Call Return
- **Called** feature - activated when this entity would be the target of a call
  - Call Screening and Call Forward

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Calling and Called Features
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Beyond the PSTN: Presence & Instant Messaging

- Presence, i.e., Who is available?
- Location, i.e., Where are they?: office, home, traveling, …
- Call state: Are they busy (in a call) or not?
- Willingness: Are they available or not?
- Preferred medium: text message, e-mail, voice, video, …
- Preferences (caller and callee preferences)

This is disucssed in Sinnreich and Johnston's Chapter 11 (Presence and Instant Communications) and is the focus of the course 2G5565 Mobile Presence: Architectures, Protocols, and Applications.

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maguire@it.kth.se
Beyond the PSTN: Presence & Instant Messaging
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Presence-Enabled Services

- Complex call screening
    - Location-based: home vs. work
    - Caller-based: personal friend or business colleague
    - Time-based: during my "working hours" or during my "personal time"

- Join an existing call $\Rightarrow$ Instant Conferencing, group chat sessions, …

- Creating a conference when a specific group of people are all *available* and *willing* to be called

- New services that have **yet** to be invented! (This is a good area for projects in 2G5565 Mobile Presence: Architectures, Protocols, and Applications)

- SIP Messaging and Presence Leveraging Extensions (SIMPLE) Working Group was formed in March 2001

    http://www.ietf.org/html.charters/simple-charter.html

Maguire
maguire@it.kth.se

Presence-Enabled Services
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Three major alternatives for VoIP

- Use *signalling* concepts from the traditional telephony industry $\Rightarrow$ H.323

- Use *control* concepts from the traditional telephony industry $\Rightarrow$ Softswitches

- Use an internet-centric *protocol*: Session Initiation Protocol (SIP) $\Rightarrow$ a change from telephony's "calls" between handsets controlled by the network to "sessions" which can be between **processes** on **any** platform **anywhere** in the Internet and with both **control** and **media content** in *digital* form and hence can be easily manipulated.
  - thus a separate voice network is **not** necessary
  - open and distributed nature enables lots of innovation (since **both** *control* and *media* can be manipulated and "events" are no longer restricted to start and end of calls)

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maguire@it.kth.se

Three major alternatives for VoIP
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Negatives

Although VoIP equipment costs less than PBXs:

- the technology is new and thus upgrades are frequent (this takes time and effort)

- PBXs generally last ~10 years and public exchanges ~30yrs; while VoIP equipment is mostly computer equipment with a ~3 year lifespan

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maguire@it.kth.se

Negatives
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References and Further Reading

IP Telephony (_iptel_)

SIP Forum _http://www.sipforum.org_

A great set of references compiled by prof. Raj Jain is available at:
_http://www.cis.ohio-state.edu/~jain/refs/ref_voip.htm_

[1]   Luan Dang, Cullen Jennings, and David Kelly, _Practical VoIP: Using VOCAL_, O'Reilly, 2002, ISBN 0-596-00078-2.

[2]   Henry Sinnreich and Alan B. Johnston, _Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol_, Wiley, 2001, ISBN: 0-471-41399-2.

[3]   William E. Witowsky, "IP Telephone Design and Implementation Issues", a white paper, Telogy Networks, Inc. A Texas Instruments Company, July 1998, Version 2.2, SPEY004.

   _http://www.telogy.com/our_products/golden_gateway/pdf/IP_Telephone.pdf_

Li Wei, "Gateway between Packet and Switched Networks for Speech Communication".

Maguire
maguire@it.kth.se

References and Further Reading
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[4]   Li Wei, "Gateway between Packet and Switched Networks for Speech Communication", M.Sc. Thesis, KTH/Teleinformatics, September 1994.

Maguire
maguire@it.kth.se

References and Further Reading
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Conferences

VON (Voice on the Net)

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maguire@it.kth.se

Conferences
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- Ulf Strömgren <ustromgr@cisco.com> for sending the Cisco 7960 picture on 2002.10.30
- Henry Sinnreich and Alan Johnston, both of WorldCom, for the wonderful SIP tutorial which Henry sent on 2002.10.30

Maguire
maguire@it.kth.se
Acknowledgements
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Institutionen för mikroelektronik och informationsteknik

2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Module 2: VoIP details

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Telecom Architecture/Approach

- Circuit-switched

- standardized interfaces

- lots of internal state (i.e., each switch and other network nodes)

- long setup times - since the route has to be set up from end-to-end **before** there is any further traffic

- services are built **into** the network
  - **operators** decide what services users can have
  - all elements of the network have to support the service before it can be introduced
  - Application programming interfaces (APIs) are often vendor specific or even proprietary

  $\Rightarrow$ makes it hard to add new services

- clear operator role (well enshrined in *public law*)

- centralized control

- long tradition

- "carrier class" equipment and specifications
  - target: very high availability 99.999% (5 minutes per year of unavailability)
  - all equipment, links, etc. must operate with very high availability

Maguire
maguire@it.kth.se

Telecom Architecture/Approach
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Internet Architecture/Approach [5]

- Packet-switched $\Rightarrow$ connectionless
- standardized **protocols** and packet formats, rather than interfaces
- very limited internal state, the packets are processed as they arrive
  - caches and other state are soft-state and are built dynamically based on traffic
  - no session state in the network
- End-to-End Argument $\Rightarrow$ integrity of communications is the reponsibility of the end node, **not** the network
- Services can be added by anyone
  - since they can be provided by any node attached to the network
  - users control their choice of services
- no centralized control
  - no single point of failure

  $\Rightarrow$ no one can easily turn it off

- a mix of "carrier class", business, and consumer equipment
  - backbone target: high availability >99.99% (50 minutes/year of unavailability)
  - local networks: availability >99% (several days/year of unavailability)
  - However, in aggregate - there is extremely high availability because most of the network elements are **independent**

Maguire
maguire@it.kth.se
Internet Architecture/Approach [5]
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VoIP details: Protocols and Packets

Carry the speech frame inside an RTP packet

IPv4/6	UDP	RTP	CODEC info

20/40 octets   8 octets   12 octets

← 40/60 octets →   ← ~33 octets →
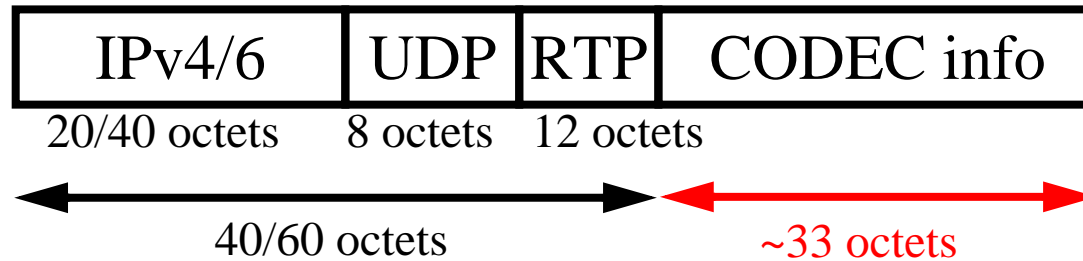
Typical packetization time of 10-20ms per audio frame.

See `http://www.ietf.org/html.charters/avt-charter.html`

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maguire@it.kth.se

VoIP details: Protocols and Packets
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RTP and H.323 for IP Telephony

audio/video applications		signaling and control				data applications
video code	audio codec	RTCP	H.225 registration	H.225 Signaling	H.245 Control	T.120
RTP						
UDP				TCP		
IP						

H.323   framework of a group protocols for IP telephony (from ITU)

H.225   Signaling used to establish a call

H.245   Control and feedback during the call

T.120   Exchange of data associated with a call

RTP   Real-time data transfer

RTCP   Real-time Control Protocol

We will not examine H.323 in much detail, but will examine RTP and RTCP.

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maguire@it.kth.se

RTP and H.323 for IP Telephony
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RTP, RTCP, and RTSP

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maguire@it.kth.se

RTP, RTCP, and RTSP
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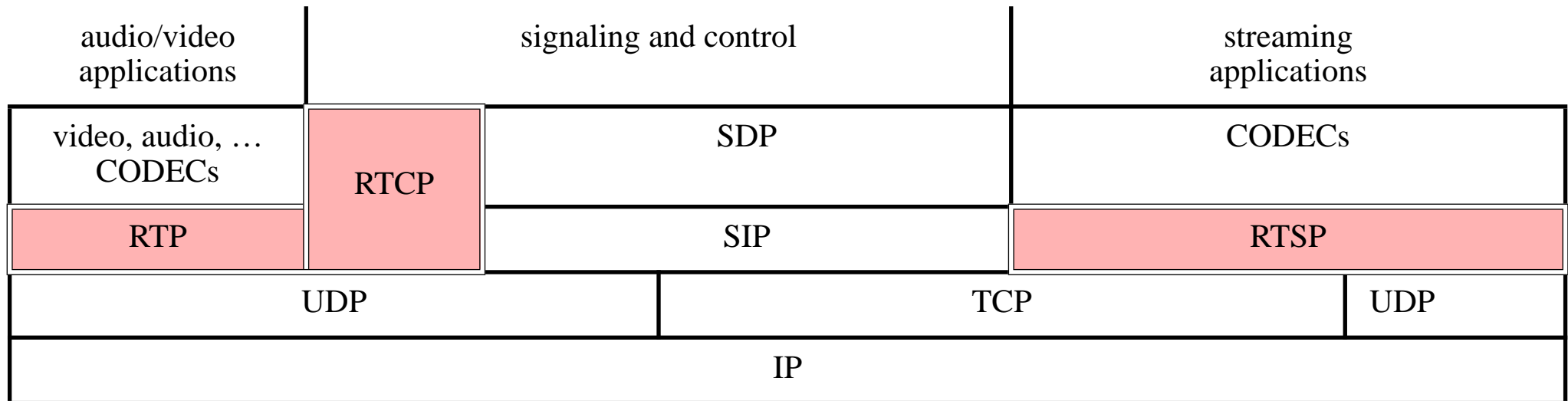
Real-Time Delivery

A real-time application $\Rightarrow$ data must be delivered with the same time relationship as it was created (all be it with a delay)

Two aspects of real-time delivery (for protocols):

Order	data should be played in the same order as it was created
Time	the receiver must know when to play the packets, in order to reproduce the same signal as was input

We keep these separate by using a **sequence number** for *order* and a **time stamp** for *timing*.

Consider an application which transmits audio by sending datagrams every 20ms, but does silence detection and avoids sending packets of only silence. Thus the receiver may see that the time stamp advances by more than the usual 20ms, but the sequence number will be the *expected* next sequence number. Therefore we can tell the difference between *missing packets* and *silence*.

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maguire@it.kth.se

Real-Time Delivery
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Packet delay

A stream of sampled audio packets are transmitted from the source (s_n), received at the destination (r_n), and played (p_n), thus each packet experiences a delay before playout (d_n)
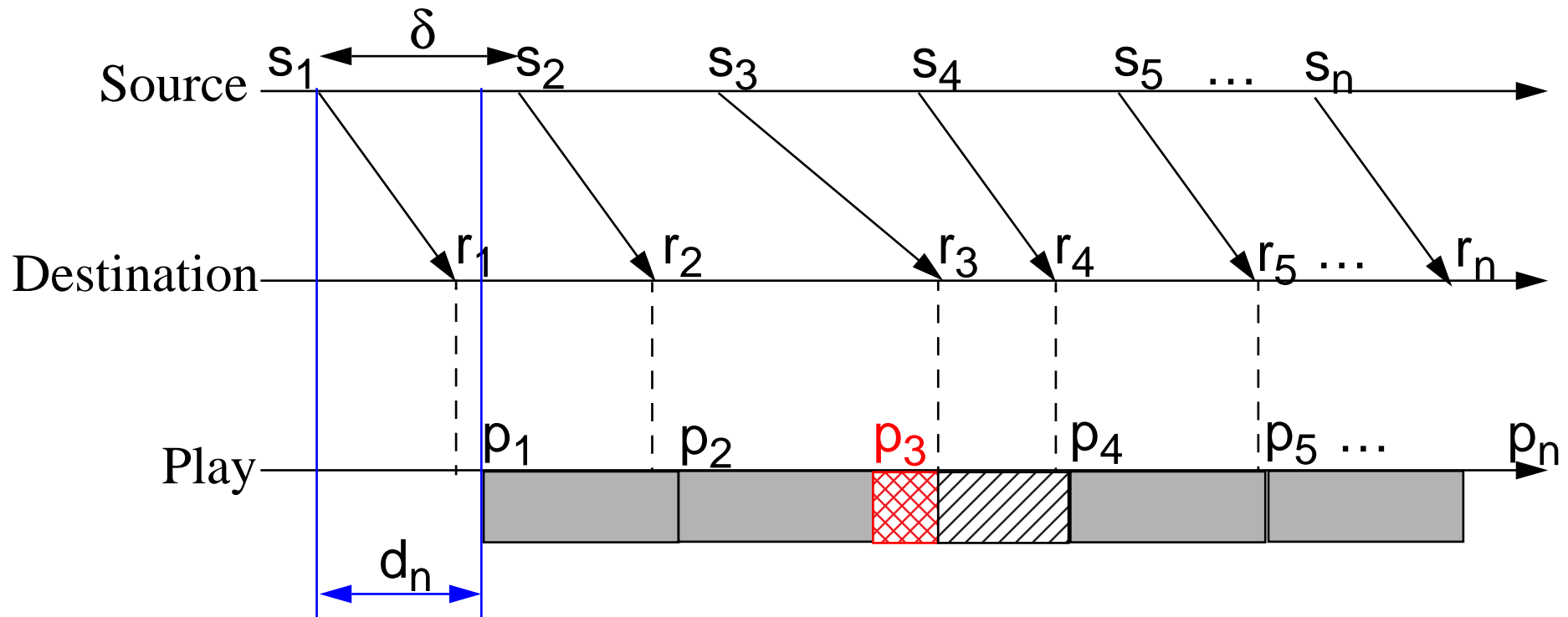
If a packet arrives too late (r_3 arrives after we should have started to play at p_3), then there is a problem (for some or all the third packets audio).

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maguire@it.kth.se

Packet delay
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Dealing with Delay jitter

Unless packets are lost, if we wait **long enough** they will come, but then the total delay may exceed the threshold required for interactive speech! (~180ms)

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maguire@it.kth.se

Dealing with Delay jitter
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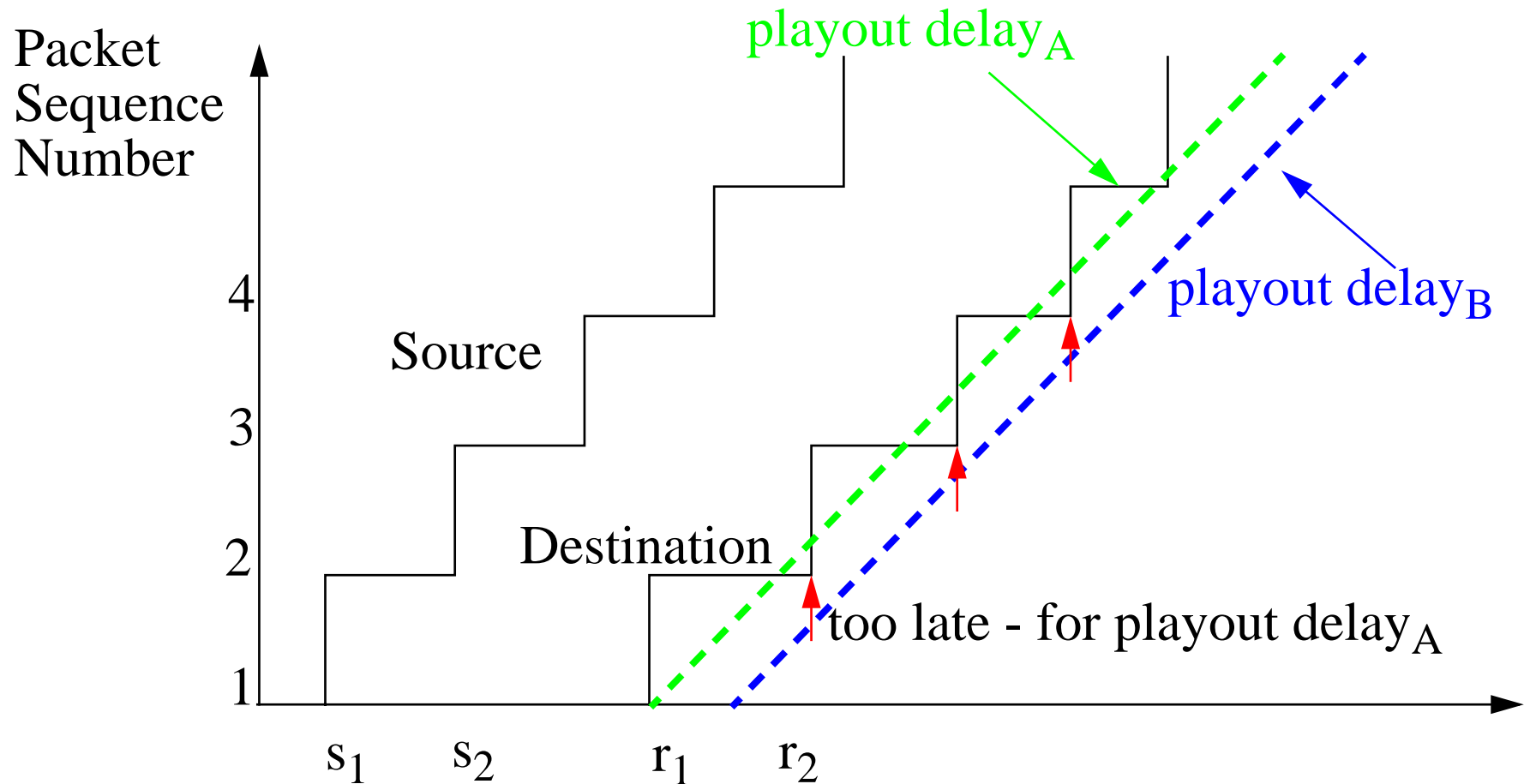
Delay and delay variance (jitter)

The end-to-end delay (from mouth to ear - for audio), includes the encoding, packetization, (transmission, propagation, switching/routing, receiving,)$^+$ dejittering, decoding, playing

To hide the jitter we generally use playout buffer **only** in the final receiver. Note: This playout buffer **adds additional delay** in order to *hide* the delay variations (this is called: **delayed playback**), playback delay > delay variance

There are very nice studies of the effects of delay on peceived voice quality, see R. G. Cole and J. H. Rosenbluth, "Voice over IP Performance Monitoring", Computer Communications Review, Vol. 21, Number 2, April, 2001, pp. 9-24.[7]

- the delay impairment has roughly two *linear* behaviors, thus

$$I_d = 0.024d + 0.11(d - 177.3)H(d - 177.3)$$

$$d = \text{one-way delay in ms}$$

$$H(x) = 0 \quad if(x < 0) \quad else \quad H(x) = 1 \quad when \quad x \geq 0$$

- for delays less than 177ms conversation is very natural, while above this it become more strained (eventually breaking down $\Rightarrow$ simplex)

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maguire@it.kth.se

Delay and delay variance (jitter)
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Playout delay

- Playout delay should track the network delay as it **varies** *during* a session [12][13]
- This delay is computed for each talk spurt based on *observed* average delay and deviation from this average delay -- this computation is similar to estimates of RTT and deviation in TCP
- Beginning of a talk spurt is identified by examining the timestamps and/or sequence numbers (if silence detection is being done at the source)
- The intervals between talk spurts give you a chance to catch-up
  - without this, if the sender's clock were slightly faster than the receiver's clock the queue would build without limit! This is important as the 8kHz sampling in PC's codecs is rarely exactly 8kHz.

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maguire@it.kth.se

Playout delay
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When to play

The actual playout time is **not** a function of the arrival time, only of the end-to-end delay which can be calculated as shown below:

playout time =

sample generation time $+$ local clock synchronization correction $+$ sender packaging delay $+$ network delay $+$ jitter-buffer delay

end-to-end latency
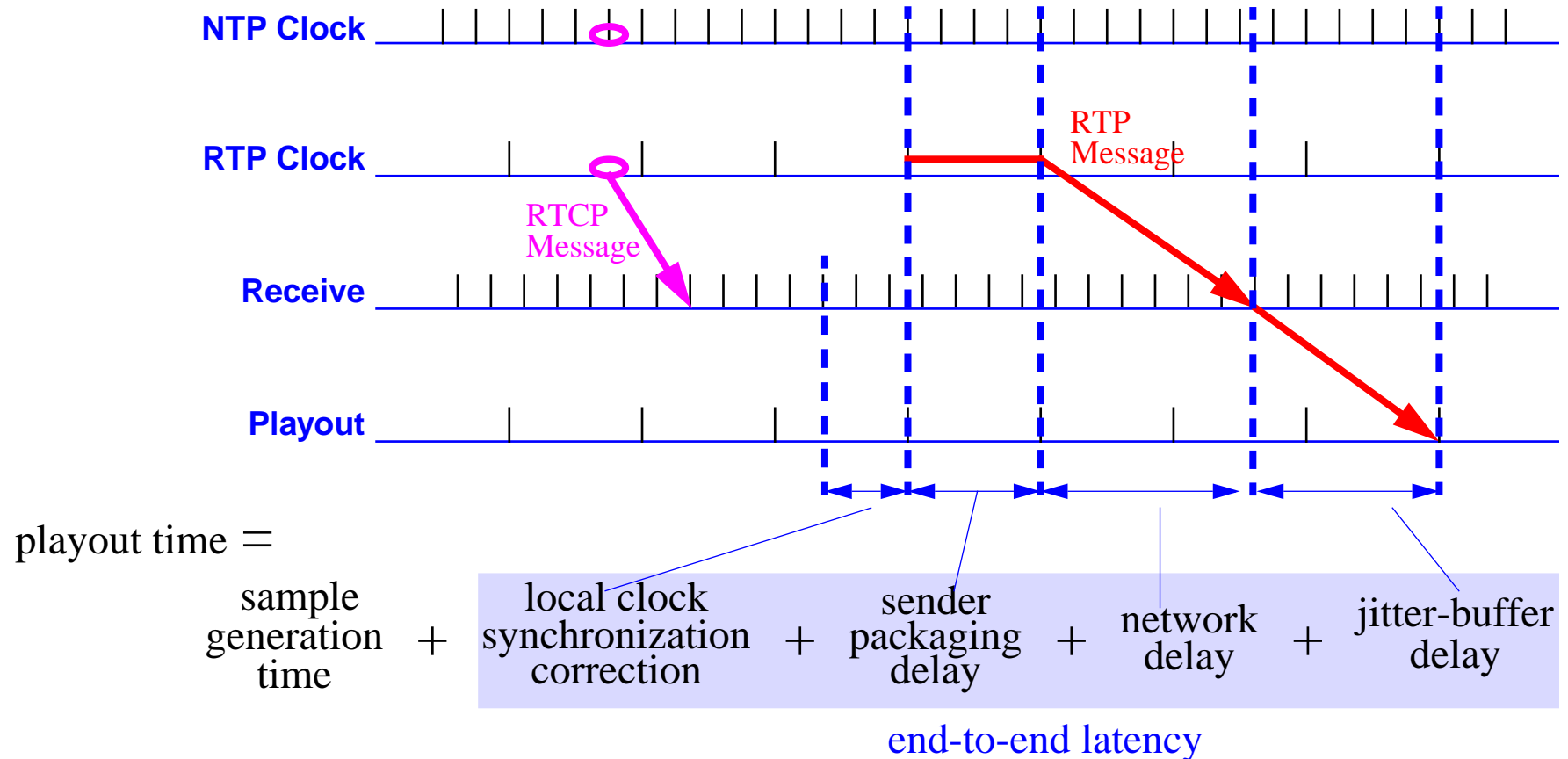
Figure adapted from slide 11 on page 6 of [14].

Maguire
maguire@it.kth.se

When to play
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Retransmission, Loss, and Recovery

For interactive real-time media we generally don't have time to request the source to retransmit a packet and to receive the new copy $\Rightarrow$ **live without it** or *recover it using Forward Error Correction (FEC)*, i.e., send sufficient redundant data to enable recovery.

However, for non-interactive media we can use retransmission at the cost of a longer delay before starting playout

If you do have to generate output, but don't have any samples to play:

- audio
    - Comfort noise: play **white nosie** or play noise like in the last samples {as humans get uncomfortable with complete silence, they think the connection is broken!} [8]
    - if you are using highly encoded audio even a BER of 10^{-5} will produce very noticable errors
- video
    - show the same (complete) video frame again
    - you can drop every 100th frame (for a BER of 10^{-2}), but the user will not notice! [9]

Maguire
maguire@it.kth.se

Retransmission, Loss, and Recovery
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Loss concealment

There are various techniques for loss concealment (i.e., hiding losses), such as those used in the Robust Audio Tool (RAT):

- Vicky J. Hardman, Martina Angela Sasse, Anna Watson, and Mark Handley, "Reliable Audio for use over the Internet", in Proceedings or INET95, Honolulu, Hawaii, Sept. 1995. [10]
  http://info.isoc.org/HMP/PAPER/070/html/paper.html
- Mark Handley, Martina Angela Sasse, and I. Kouvelas, Successful Multiparty Audio Communication over the Internet", Communications of the ACM, Vol. 41, No. 5, May 1998.[11]
- UCL's Robust Audio Tool (RAT) page:
  http://www-mice.cs.ucl.ac.uk/multimedia/software/rat/

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maguire@it.kth.se

Loss concealment
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RTP: Real-Time Transport Protocol

- Defined by RFC 1889 *http://www.ietf.org/rfc/rfc1889.txt*
- Designed to carry a variety of real-time data: audio and video.
- Provides two key facilities:
  - Sequence number for order of delivery (initial value chosen randomly)
  - Timestamp (of first sample) - used for control of playback

Provides no mechanisms to ensure timely delivery.

0 1	2	3	4		8	9		16	
VER	P	X	CC		M	PTYPE		Sequence number	
Timestamp									
Synchronization source identifier									
Contributing source ID ...									
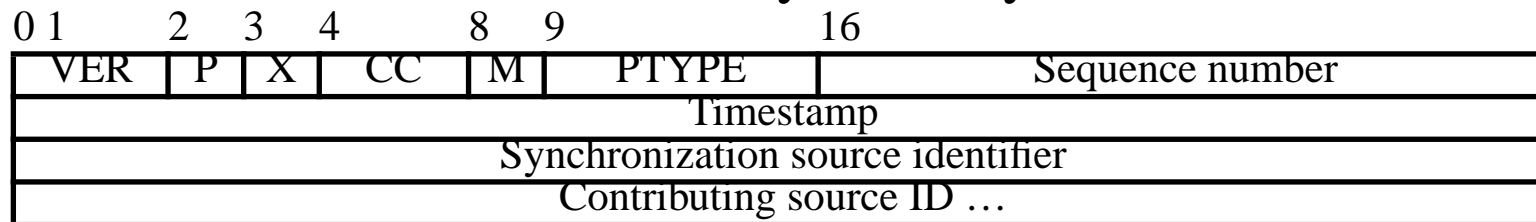
- VER - version number (currently 2)
- P - whether zero padding follows the payload
- X - whether extension or not
- M - marker for beginning of each frame (or talk spurt if doing silence detection)
- PTYPE - Type of payload - defined as Profiles in RFC 1890
  http://www.ietf.org/rfc/rfc1890.txt.

We will address the other fields later.

Maguire
maguire@it.kth.se

RTP: Real-Time Transport Protocol
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Payload types

Payload types (PT) for standard audio and video encodings (Adapted from Table 2 of RFC1990)

PT	encoding name	audio (A)	clock rate (Hz)	channels (audio)	PT	encoding name	video (V)	clock rate (Hz)
0	PCMU	A	8,000	1	16--23	unassigned	A	
1	1016	A	8,000	1	24	unassigned	V	
2	G721	A	8,000	1	25	CelB	V	90,000
3	GSM	A	8,000	1	26	JPEG	V	90,000
4	unassigned	A	8,000	1	27	unassigned	V	
5	DVI4	A	8,000	1	28	nv	V	90,000
6	DVI4	A	16,000	1	29	unassigned	V	
7	LPC	A	8,000	1	30	unassigned	V	
8	PCMA	A	8,000	1	31	H.261	V	90,000
9	G722	A	8,000	1	32	MPV	V	90,000
10	L16	A	44,100	2	33	MP2T	AV	90,000
11	L16	A	44,100	1	34--71	unassigned	?	
12	unassigned	A			72--76	reserved	N/A	N/A
13	unassigned	A			77--95	unassigned	?	
14	MPA	A	90,000	see RFC	96--127	dynamic	?	
15	G728	A	8,000	1				
16--23	unassigned	A						

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maguire@it.kth.se

Payload types
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Audio Encodings

Properties of Audio Encodings (adapted from Table 1 of RFC1990)

encoding	encoding	sample/frame	bits/sample	ms/frame
1016	code-excited linear prediction (CELP) -- Federal Standard FED-STD 1016	frame	N/A	30.0
DVI4	Interactive Multimedia Association's DVI ADPCM Wave Type	sample	4	
G721	ITU' G.721	sample	4	
G722	ITU's G.722: 7 kHz audio-coding within 64 kbit/s	sample	8	
G728	ITU's G.728: Coding of speech at 16 kbit/s using low-delay code excited linear prediction	frame	N/A	2.5
GSM	GSM 06.10: RPE/LTP (residual pulse excitation/long term prediction) coding at a rate of 13 kb/s	frame	N/A	20.0
L8	8 bit linear	sample	8	
L16	16 bit linear	sample	16	
LPC	Linear Predictive Coding	frame	N/A	20.0
MPA	MPEG-I or MPEG-II audio encapsulated as elementary streams, defined in ISO standards ISO/IEC 11172-3 and 13818-3.	frame	N/A	
PCMA	G.711 A-law	sample	8	
PCMU	G.711 mu–law	sample	8	
VDVI	variable-rate version of DVI4	sample	variable	

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maguire@it.kth.se

Audio Encodings
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Timestamps

The *initial* timestamp is to be chosen *randomly* (just as the initial sequence number is selected randomly):

- to avoid replays
- to increase security (this assumes that the intruder does not have access to all the packets flowing to the destination)

The timestamp *granularity* (i.e., the units) are determined by the payload type {often based on the sampling rate}

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maguire@it.kth.se
Timestamps
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Stream translation and mixing

| mixing | combining several RTP streams to produce a single stream |
| translation | converting from one encoding to another (also know as **transcoding**) |

Each source has a unique 32 bit **Synchronization Source Identifier**.

When several sources are mixed the new stream gets its own unique **Synchronization Source Identifier** and the IDs of the contributing sources are included as **Contributing Source IDs**, the number of which is indicated in the 4-bit **CC** field of the header.

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maguire@it.kth.se

Stream translation and mixing
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RTP Control Protocol (RTCP)

[upward] enables endpoints to provide meta-information to the source - this enables the sources to be adaptive to the endpoints. For example, by using an adaptive coding algorithm the source can accommodate the actually data rate of packets arriving at the endpoint.

[downward] enables sources to send the endpoints information about a session

```
0 1      2  3          8              16
+-------+--+--------+-----------+----------------------------+
| VER   |P |  RC    |  PTYPE    |          Length            |
+-------+--+--------+-----------+----------------------------+
|                      Data area  …                          |
+------------------------------------------------------------+
```
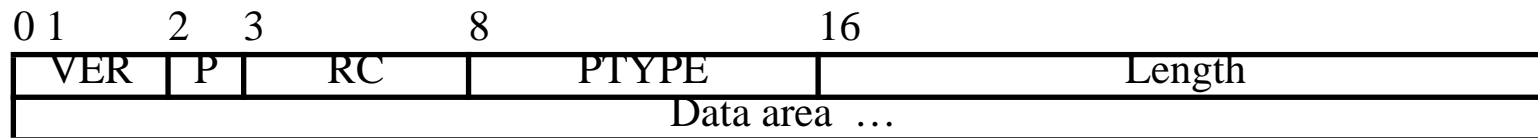
- VER - version number (currently 2)
- P - whether **padding** follows the payload (last octet indicates how much was added)
- RC - **R**eport **C**ount - specifies the number of reports in this packet[1]
- PTYPE - Type of payload

Name	Type		Meaning
Sender Report	SR	200	Time information for each synchronization source and a count of data octets sent
Receiver Report	RR	201	Report of packet loss and jitter, information for timing and round-trip estimation
Source Description	SDES	202	Description of who owns the source
Goodbye	BYE	203	Receiver leaving the session
Application	APP	204	Application-specific report

---

1. RTCP uses compound packets with multiple RTCP messages in a single packet.

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maguire@it.kth.se

RTP Control Protocol (RTCP)
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Compound Reports

If and only if (IFF) the compound packet is to be encrypted: it is prefixed by a random 32-bit quantity selected for each compound packet transmitted.

The first RTCP packet in the compound packet must always be a report packet (either RR or SR). Followed by upto 30 more report packets (as RC is only 5 bits).

This is followed by an SDES packet containing a CNAME item (other information such as NAME, EMAIL, PHONE, LOC {geographic location},TOOL, NOTE, and PRIV {private extension to SDES} are optional).

BYE should be the last packet sent with a given SSRC/CSRC.

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maguire@it.kth.se

Compound Reports
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Proposed RTCP Reporting Extensions

See Friedman, Caceres, Almeroth, et al., "RTCP Reporting Extensions",
Internet-draft, 16 October 2002,

http://www.ietf.org/internet-drafts/draft-ietf-avt-rtcp-report-extns-02.txt

VoIP Metrics Report Block - provides metrics for monitoring VoIP calls.

0		8		16		24	
BT=64		reserved		length=7			
loss rate		discard rate		burst duration			
burst density		gap duration				gap density	
round trip delay				end system delay			
signal power		doubletalk		noise level		Gmin	
R factor		ext. R factor		MOS-LQ		MOS-CQ	
RX Config		JB Nominal		JB Maximum		JB Abs Max	

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maguire@it.kth.se

Proposed RTCP Reporting Extensions
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block type (BT)	the constant 64 = 0x40
reserved	8 bits - MUST be set to zero unless otherwise defined.
length	length of this report block in 32-bit words minus one, including the header; constant 6.
loss rate	fraction of RTP data packets from the source lost since the beginning of reception, as a fixed point number with the binary point at the left edge of the field[a]
discard rate	fraction of RTP data packets from the source that have been discarded since the beginning of reception, due to late or early arrival, under-run or overflow at the receiving jitter buffer, in binary fixed point
burst duration	mean duration of the burst[b] intervals, in milliseconds
burst density	fraction of RTP data packets within burst intervals since the beginning of reception that were either lost or discarded, in binary fixed point
gap duration	mean duration, expressed in milliseconds, of the gap intervals that have occurred
gap density	fraction of RTP data packets within inter-burst gaps since the beginning of reception that were either lost or discarded, in binary fixed point
round trip delay	most recently calculated round trip time between RTP interfaces, in milliseconds
end system delay	most recently estimated end system delay, in milliseconds
signal level	voice signal relative level is defined as the ratio of the signal level to overflow signal level, expressed in decibels as a signed integer in two's complement form
doubletalk level	defined as the proportion of voice frame intervals during which speech energy was present in both sending and receiving directions
noise level	defined as the ratio of the silent period back ground noise level to overflow signal power, expressed in decibels as a signed integer in two's complement form

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maguire@it.kth.se

Proposed RTCP Reporting Extensions
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R factor	a voice quality metric describing the segment of the call that is carried over this RTP session, expressed as an integer in the range 0 to 100, with a value of 94 corresponding to "toll quality" and values of 50 or less regarded as unusable; consistent with ITU-T G.107 and ETSI TS 101 329-5
ext. R factor	a voice quality metric describing the segment of the call that is carried over an external network segment, for example a cellular network
MOS-LQ	estimated mean opinion score for listening quality (MOS-LQ) is a voice quality metric on a scale from 1 to 5, in which 5 represents excellent and 1 represents unacceptable
MOS-CQ	estimated mean opinion score for conversational quality (MOS-CQ) defined as including the effects of delay and other effects that would affect conversational quality
Gmin	gap threshold, the value used for this report block to determine if a gap exists
RX Config	PLC - packet loss concealment: Standard (11)/enhanced(10)/disabled (01)/ unspecified(00); JBA - Jitter Buffer Adaptive: Adaptive (11) / non-adaptive (10) / reserved (01)/ unknown (00). Jitter Buffer is adaptive then its size is being dynamically adjusted to deal with varying levels of jitter;JB Rate - Jitter Buffer Rate (0-15)
Jitter Buffer	nominal size in frames (8 bit)
Jitter Buffer Maximum	size in frames (8 bit)
Jitter Buffer Absolute Maximum	size in frames

a. Here after simply referred to as a binary fixed point number.

b. A burst is defined as a longest sequence of packets bounded by lost or discarded packets with the constraint that within a burst the number of successive packets that were received, and not discarded due to delay variation, is less than some value Gmin.

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maguire@it.kth.se

Proposed RTCP Reporting Extensions
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RTP translators/mixers

Translator   changes transport (e.g., IPv4 to IPv6) or changes media coding (i.e., transcoding)

Mixer   combines multiple streams to form a **combined** stream

Connect two or more transport-level "clouds", each cloud is defined by a common network and transport protocol (e.g., IP/UDP), multicast address or pair of unicast addresses, and transport level destination port.

To avoid creating a loop the following rules must be observed:

- "Each of the clouds connected by translators and mixers participating in one RTP session either must be distinct from all the others in at least one of these parameters (protocol, address, port), or must be isolated at the network level from the others.

- A derivative of the first rule is that there must not be multiple translators or mixers connected in parallel unless by some arrangement they partition the set of sources to be forwarded."

From §7.1 General Description of RFC 1889

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maguire@it.kth.se

RTP translators/mixers
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Synchronizing Multiple Streams

One of the interesting things which RTP supports is synchronization of multiple streams (e.g., audio with a video stream)

0 1	2	3	8	16		
VER	P	RC		PTYPE	Length	
Sender's Synchronization Source ID						
NTP Time Stamp (most significant 32 bits)						
NTP Time Stamp (least significant 32 bits)						
RTP Timestamp						
Sender's Packet Count						
Sender's Octet Count						
First Synchronization Source						
Fraction Lost			Total Packets Lost			
Extended Highest Sequence Received						
Inter-arrival Jitter						
Last Sender Report						
Delay Since Last Sender Report						
…						

- Unfortunately since the time stamps of each stream started at a random number we need some other method to synchronize them!
- Thus we use the Network Time Protocol (NTP) based time stamps - this gives us an absolute timestamp
- Since we now include the stream timestamps we can correlate these to absolute time (and hence from one stream to another)

Maguire
maguire@it.kth.se

Synchronizing Multiple Streams
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RTP Transport and Many-to-many Transmission

RTP uses a connectionless transport (usually UDP):

- Retransmission is undesirable (generally it would be too late)
- Since RTP handles flow control and sequencing we don't need this from the transport protocol
- RTP is packet oriented
- Enables us to easily use multicast (when there are many endpoints that want the same source stream)
  - multicast identifed a **group**
  - these multicast groups can be *dynamic*

Maguire
maguire@it.kth.se

RTP Transport and Many-to-many Transmission
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Sessions, Streams, Protocol Port, and Demultiplexing

Session	All traffic that is sent to a given IP address, port
Stream	a sequence of RTP packets that are from a single synchronization source

Demultiplexing:

session demultiplexing	occurs at the transport layer based on the port number
stream demultiplexing	occurs once the packet is passed to the RTP software, based on the synchronication source identifier - then the sequence number and timestamp are used to order the packet at a suitable time for playback

Maguire
maguire@it.kth.se

Sessions, Streams, Protocol Port, and Demultiplexing
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Further details of RTP and RTCP

See: Chapters 28 and 29 of Douglas E. Comer and David L. Stevens, "Internetworking with TCP/IP, Volume III: Client Server Programming and Applications, Linux/POSIX Version", pp. 467-513 [17].

Maguire
maguire@it.kth.se

Further details of RTP and RTCP
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Real Time Streaming Protocol (RTSP)

Defined in RFC 2326 *http://www.ietf.org/rfc/rfc2326.txt*

- remote media playback control (think in terms of controlling a remote VCR/DVD/CD player)

- similar to HTTP/1.1, but
  - introduces new methods
  - RTSP servers maintain state
  - data carried out of band (i.e., in RTP packets)

- can use UDP or TCP

- Uses Web security methods (see [19])

http://www.ietf.org/internet-drafts/draft-ietf-mmusic-rfc2326bis-01.txt

Maguire
maguire@it.kth.se

Real Time Streaming Protocol (RTSP)
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RTSP session description

```
<title>Twister</title>
   <session>
      <group language=en lipsync>
         <switch>
            <track type=audio e="PCMU/8000/1"
                   src="rtsp://audio.example.com/twister/audio.en/lofi">
            <track type=audio e="DVI4/16000/2" pt="90 DVI4/8000/1"
                   src="rtsp://audio.example.com/twister/audio.en/hifi">
         </switch>
         <track type="video/jpeg" src="rtspu://video.example.com/twister/video">
      </group>
   </session>
```

From figure 6: "Sample RTSP session description" of Henning Schulzrinne,
"A comprehensive multimedia control architecture for the Internet"

http://www.cs.columbia.edu/~hgs/papers/Schu9705_Comprehensive.pdf

Maguire
maguire@it.kth.se

RTSP session description
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[6] Multiparty Multimedia Session Control (mmusic) Working Group
`http://www.ietf.org/html.charters/mmusic-charter.html`

Also important are the measures of delay, delay jitter, throughput, packet loss, etc. IP Performance Metrics (`ippm`) is attempting to specify how to measure and exchange information about measurements of these quantities.

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Maguire
maguire@it.kth.se

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http://info.isoc.org/HMP/PAPER/070/html/paper.html

[11] Mark Handley, Martina Angela Sasse, and I. Kouvelas, Successful Multiparty Audio Communication over the Internet", Communications of the ACM, Vol. 41, No. 5, May 1998.

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http://www.eeng.dcu.ie/~narbutt/UKTS_2001.pdf

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Maguire

maguire@it.kth.se

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http://www.cs.odu.edu/~cs778/jeffay/Lecture9.pdf

RTP and RTCP

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Maguire
maguire@it.kth.se
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RTSP

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Maguire
maguire@it.kth.se

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Institutionen för mikroelektronik och informationsteknik

2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Module 3: SIP

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 *and* Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Session Initiation Protocol (SIP)

Developed by the IETF Multiparty Multimedia Session Control (MMUSIC) working group and since September 1999 in the IETF SIP working group.

SIP is a text-based protocol, similar to HTTP and SMTP, for initiating interactive communication sessions between users. Sessions include: voice, video, chat, interactive games, and virtual reality.

SIP working groups charter "… to maintain the basic model and architecture defined by SIP. In particular:

1 Services and features are provided **end-to-end** whenever possible[1].

2 Extensions and new features must be generally applicable, and not applicable only to a specific set of session types.

3 Simplicity is key.

4 Reuse of existing IP protocols and architectures, and integrating with other IP applications, is crucial.

---

1. The use of end-to-end control is the exact opposite of the centralized control in traditional telecommunication networks.

Maguire
maguire@it.kth.se

Session Initiation Protocol (SIP)
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SIP WG's deliverables

1 A draft standard version of SIP.

2 **callcontrol**: call control specifications, which enables multiparty services, e.g., transfer and bridged sessions

3 **callerpref**: caller preferences extensions, enables intelligent call routing services

4 **mib**: a MIB for SIP nodes

5 **precon**: extensions needed to assure satisfaction of external preconditions, e.g., QoS establishment

6 **state**: extensions needed to manage state within signaling, aka SIP "cookies"

7 **priv**: extensions for security and privacy

8 **security**: security and privacy mechanisms

9 **provrel**: extensions needed for reliability of provisional messages

10 **servfeat**: extensions needed for negotiation of server features

Maguire
maguire@it.kth.se

SIP WG's deliverables
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11 sesstimer: Session Timer extension

12 events: Events extensions (Subscribe/Notify)

13 security: Requirements for Privacy and Security

14 natfriend: Extensions for making SIP a NAT-friendly protocol

Maguire

maguire@it.kth.se

SIP WG's deliverables

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Related working groups

- Session Initiation Proposal Investigation (*sipping*) WG - to analyze the requirements for application of SIP to several different tasks
- SIMPLE WG - using SIP for messaging and presence
  - SIP for Presence
  - IMPP to define payload
- IP telephony (IPTEL) WG
  - Call Processing Language (CPL)
  - Telephony Routing over IP (TRIP)
- SPIRITS - SIP as 'transport' mechanism
- Distributed Call Signaling (DCS) Group of the PacketCable Consortium (*http://www.packetcable.com/*) for distributed telephony services
- 3rd Generation Partnership Project (*3GPP*), 3rd Generation Partnership Project 2 (*3GPP2*), and Mobile Wireless Internet Forum (*MWIF http://www.mwif.org/*) -- various third-generation wireless network efforts

Historic

- There was a PSTN and Internet Internetworking working group (PINT)

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maguire@it.kth.se
Related working groups
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- **old**: http://www.ietf.org/html.charters/pint-charter.html
- origin of SUBSCRIBE/NOTIFY

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maguire@it.kth.se

Related working groups

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Practical Voice Over IP (VoIP): SIP and related protocols

Session Initiation Protocol (SIP)

- Defined in RFC 3261 _http://www.ietf.org/rfc/rfc3261.txt_
- provides application layer signaling
  - Used to **establish**, **modify**, and **terminate** multimedia _sessions_
- can utilize UDP, TCP, TLS, SCTP, … for underlying transport
- HTTP-like
  - uses **textual** rather than binary (ala H.323) messages ($\Rightarrow$ humans can read them)
  - uses Uniform Resource Indicators (URIs) to designate calling and called parties
- target applications : voice, video, gaming, instant messaging, presence, call control[1], …

SIP is an alternative to H.323 proposed by IETF. **Only** covers **signaling** parts of H.323. Does not use RTP itself, but sessions can use RTP.

  - SIP provides ability to **discover** remote users and **establish** interactive **sessions**
  - Does **not** ensure QoS or deliver large quantities of data

SIP uses SDP (Session Description Protocol) to provide information about a call, such as, the media encoding, protocol port number, multicast addresses, etc.

---

1. Largely taken from Advanced Intelligent Network (AIN).

Maguire
maguire@it.kth.se

Session Initiation Protocol (SIP)
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Practical Voice Over IP (VoIP): SIP and related protocols

Is SIP simple?

- 25 RFCs (for SIP and SDP) - total of 823 pages
- RFC3261 is long RFC ever (based on byte count)
- There are claims that one can still build a simple user agent in a (long) evening[30], but there is substantial work required with respect to security (due to TLS, S/MIME, AAA, Denial of Service issues, …)

Maguire
maguire@it.kth.se

Is SIP simple?
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP, RTP, and RTSP

audio/video applications		signaling and control			streaming applications
video, audio, … CODECs	RTCP	SDP			CODECs
RTP		SIP			RTSP
UDP			TCP		
IP					

Maguire
maguire@it.kth.se

SIP, RTP, and RTSP
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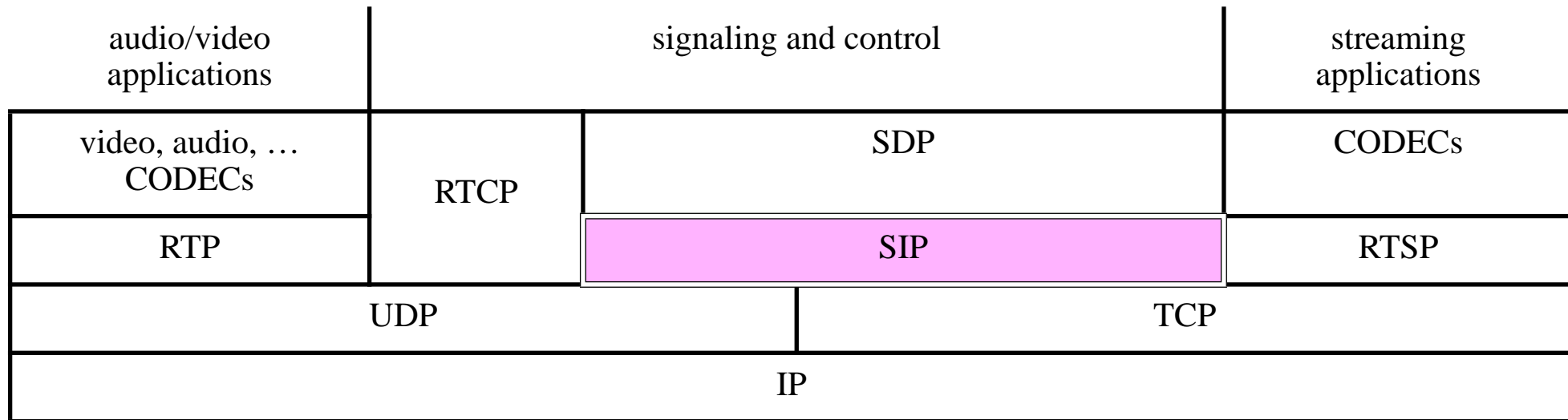
SIP actors

Figure 3: SIP Actors

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maguire@it.kth.se

SIP actors
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SIP Methods

Method	Purpose
INVITE	Invites a user to join a call.
ACK	Confirms that a client has received a final response to an INVITE.
BYE	Terminates the call between two of the users on a call.
OPTIONS	Requests information on the capabilities of a server.
CANCEL	Ends a pending request, but does not end the call.
REGISTER	Provides the map for address resolution, this lets a server know the location of a user.

At least 8 additional methods have been defined see **SIP Method Extensions in other RFCs** on page 156

Maguire
maguire@it.kth.se

SIP Methods
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Status codes

SIP status codes are patterned on and simular to HTTP's status codes:

Code	Meaning
1xx	Informational or Provisional - request received, continuing to process the request
2xx	Final - the action was successfully received, understood, and accepted
3xx	Redirection - further action needs to be taken in order to complete the request
4xx	Client Error - the request contains bad syntax or cannot be fulfilled at this server
5xx	Server Error - server failed to fulfill an apparently valid request (Try another server!)
6xx	Global Failure - the request cannot be fulfilled at any server (Give up!)

Maguire
maguire@it.kth.se

SIP Status codes
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Uniform Resource Indicators (URIs)

URI's have the same basic form as e-mail addresses: user@domain

Two URI schemes:

- SIP URI - introduced in RFC 2543
  - example: `sip:maguire@kth.se`
- Secure SIP URI - introduced in RFC 3261
  - example: `sips:maguire@kth.se`
  - Requires TLS over TCP as transport for security

Two types of SIP URIs:

- Address of Record (AOR) (identifies a user)
  - example: `sip:maguire@kth.se`
  - Need DNS SRV records to locate SIP Servers for kth.se domain
- Fully Qualified Domain Name (FQDN) (identifies a specific device)
  - examples: `sip:maguire@130.237.212.2` or `sip:maguire@chipsphone.it.kth.se`
  - `sip:+46-8-790-6000@kth.se; user=phone` the main KTH phone number in E.164 format via a gateway; note that the visual separators in a phone number (dashes, dots, etc.) are ignored by the protocol

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maguire@it.kth.se

SIP Uniform Resource Indicators (URIs)
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Issues to be considered

- Address Resolution
- Session Setup
- Media Negotiation
- Session Modification
- Session Termination
- Session Cancellation
- Mid-call Signaling
- Call Control
- QoS Call setup

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Issues to be considered
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Practical Voice Over IP (VoIP): SIP and related protocols

Address Resolution

The first step in routing the SIP request is to compute the **mapping** between the **URI** and *a specific user* at *a specific host/address*.

This is a very general process and the source of much of SIP's power.

- providing support for mobility and portability
- Can utilize:
  - DNS SRV lookup
  - ENUM
  - Location Server lookup

We will look at this in detail (see **DNS and ENUM** on page 207), but for now will assume a simple DNS lookup based on the URI.

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Address Resolution
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP timeline

Simple version of Alice invites Bob to a SIP session:

Alice   Invite   Bob

OK,200

ACK

session

Bye
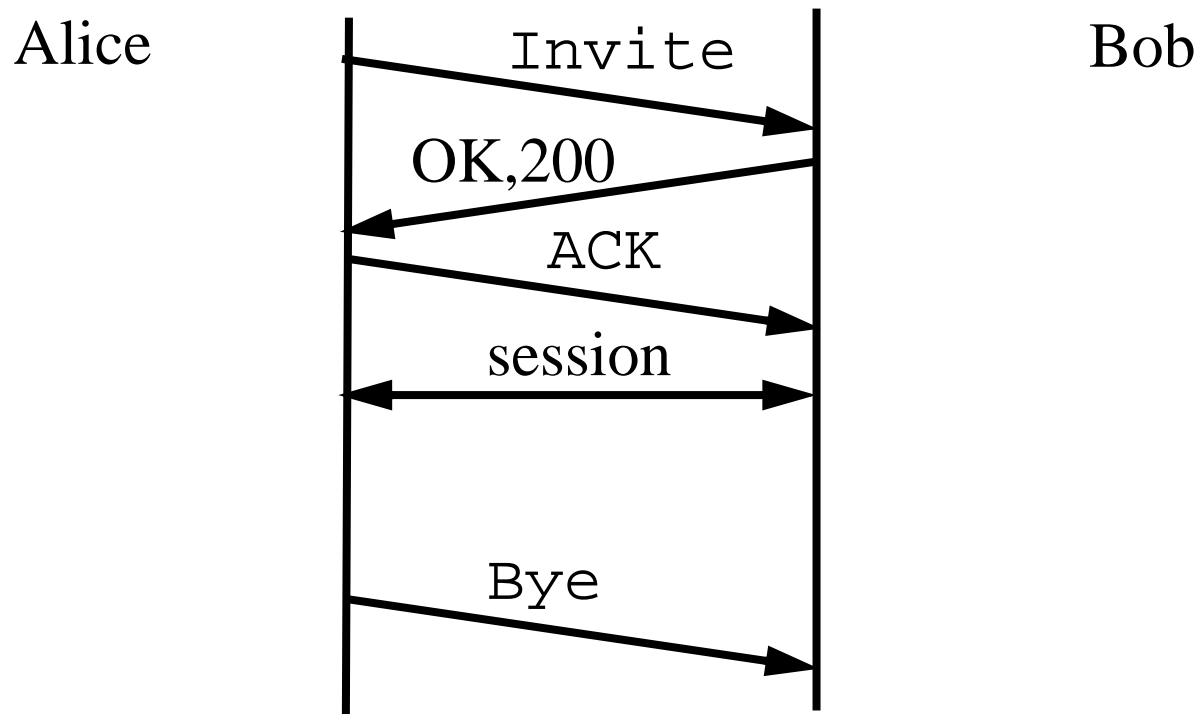
We begin by examining the details of session setup.

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SIP timeline
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Invite[1]

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

SIP is a text-based protocol and uses ISO 10646 character set in UTF-8 encoding (RFC 2279). The message body uses MIME and *can* use S/MIME for security.

The generic form of a message is:

```
generic-message = start-line
                  message-header*
                  CRLF
                  [ message-body ]
```

---

1. Example adapted from draft-ietf-sip-rfc2543bis-06.ps

Bob's response to Alice's INVITE[1]

```
SIP/2.0 200 OK
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
Via: SIP/2.0/UDP
bigbox3.site3.atlanta.com:5060;branch=z9hG4bK77ef4c2312983.1
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bKnashds8
To: Bob <sip:bob@biloxi.com>;tag=a6c85cf
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:bob@192.0.2.8>
Content-Type: application/sdp
Content-Length: 131

(Bob's SDP not shown}
```

---

1. Example adapted from draft-ietf-sip-rfc2543bis-06.ps

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Bob's response to Alice's INVITE
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Practical Voice Over IP (VoIP): SIP and related protocols

ACK

```
ACK sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 ACK
Content-Length: 0
```

A successful set-up sequence was: `INVITE/200/ACK`

A set-up failure would be a sequence such as: `INVITE/4xx`[1]`/ACK`

NB: `INVITE` is the *only* method in SIP that involves a 3-way handshake with ACK

The further setup of the call can proceed **directly** between Alice and Bob, based on the the information (especially that in SDP) which they have exchanged.

Now we will examine the details of these initial SIP messages!

---

1. or 5xx or 6xx

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ACK
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Invite (method/URI/version)

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

Start Line is the first line of a SIP message which contains:

- method or Request type: `INVITE`

- Request-URI which indicates who the request is for:
  `sip:bob@biloxi.com`

- SIP version number: `SIP/2.0`

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SIP Invite (method/URI/version)
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SIP Via

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP proxy.stockholm.se:5060;branch=82.1
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

- **Via** headers show the path the request has taken in the SIP network
  - A Via header is inserted by the User Agent which initiated the request (this will be last in the list of Via headers)
  - Via headers are inserted above this by proxies in the path (i.e., this details the path taken by the request)

- **Via** headers are used to route responses back the same way the request came
  - this allows stateful proxies to see both the requests and responses
  - each such proxy adds the procotol, hostname/IP address, and port number

- The "`branch`" parameter is used to detect loops

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SIP Via
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Practical Voice Over IP (VoIP): SIP and related protocols

Dialog (Call leg) Information

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

- Dialog[1] (formerly "call leg") information is in headers:
  - **To** tag, **From** tag, and **Call-ID** All requests and responses in this call will use this same Dialog information.
  - "**To**" specifies the logical recipient of the message, "**From**" the logical sender
    - the string "Bob" is called a "display name"

- **Call-ID** is unique identifier
  - Call-ID number is arbitrary, but it uniquely identifies this call (i.e., **session**), hence all future references to this session refer to this Call-ID
  - usually composed of pseudo-random string @ hostname or IP Address

---

1. A Dialog formally begins upon receipt of a response containing a tag. It is called an "Early dialog" when the response was a **18x** provisional response.

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Dialog (Call leg) Information
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SIP CSeq

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

- ## Command Sequence (**CSeq**) Number
  - Initialized at start of call (1 in this example)
  - Incremented for each subsequent request
  - Used to distinguish a retransmission from a new request

- ## Followed by the **request type** (i.e., SIP method)

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SIP CSeq
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SIP Contact

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

- **Contact** header contains a SIP URL for direct communication between User Agents
  - If Proxies do not Record-Route[1], they can be bypassed
- **Contact** header is also present in `200 OK` response

---

1. Note that the Record-Route and Route headers approach of RFC 2543 was found not to work.

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SIP Contact
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Content Type and Length

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

- **Content-Type** indicates the type of message body attachment (others could be text/plain, application/cpl+xml, etc.)
  - Here "**application/sdp**" indicates that it is SDP
- **Content-Length** indicates length of the message body in octets (bytes)
  - 0 indicates that there is no message body.

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SIP Content Type and Length
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SIP Max-Forwards

```
INVITE sip:bob@biloxi.com SIP/2.0
Via: SIP/2.0/UDP pc33.atlanta.com:5060;branch=z9hG4bK776asdhds
Max-Forwards: 30
To: Bob <sip:bob@biloxi.com>
From: Alice <sip:alice@atlanta.com>;tag=1928301774
Call-ID: a84b4c76e66710
CSeq: 314159 INVITE
Contact: <sip:alice@pc33.atlanta.com>
Content-Type: application/sdp
Content-Length: 142

(Alice's SDP not shown)
```

- Max-Forwards is decremented by each proxy that forwards the request.
- When count goes to zero, request is discarded and `483 Too Many Hops` response is sent.
- Used for stateless loop detection.

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SIP Max-Forwards
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Other header fields

- **Content-Encoding**:
- **Allow**:
- **Expires**:
- **In-Reply-To**:
- **Priority**: indicated priority of displaying a message to a user
  - Normal
  - Urgent
  - Non-Urgent
  - Emergency
- **Require**: contains a list of options which the server is expected to support in order to process a request
- **Retry after**: number of seconds after which a requestor should try again
- **Supported**: enumerates all the extensions supported the sender (NB: this differs from a "Require" which requires that a destination supports the given extension)

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Other header fields
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Several types of SIP Servers

- **User agent server** runs on a SIP terminal (could be a SIP phone, a PDA, laptop, …) - it consists of two parts:
    - User Agent Client (UAC): initiates requests
    - User Agent Server (UAS): responds to requests
- **SIP proxy** - interprets (if necessary, rewrites specific parts of a SIP request message) before forwarding it to a server closer to the destination:
    - SIP **stateful** proxy server - remembers its queries and answer; can also forward several queries in parallel (can be **Transaction Stateful** or **Call Stateful**).
    - SIP **stateless** proxy server
    - They ignore SDP and don't handle any media (content)
    - Outgoing proxy: used by a user agent to route an outgoing request
    - Incoming proxy: proxy server which supports a domain (receives incoming requests)
- **SIP redirect server** - directes the client to contact an alternate URI
- **Registrar server** - receives SIP REGISTER requests updates LS
- **Location server** (LS) - knows the current binding and queried by Proxies to do their routing
    - SIP can also use DNS SRV (Service) Records used to locate (inbound) proxy.
    - note in RFC 2543: a location server is a generic term for a **database**

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maguire@it.kth.se

Several types of SIP Servers
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SIP Trapezoid[1]

DNS Server

Location Server

Other servers

DNS

SIP

Outbound
Proxy Server

Inbound
Proxy Server

Proxy servers

SIP

SIP

SIP

Media
(RTP)

User Agents

User Agent A

User Agent B
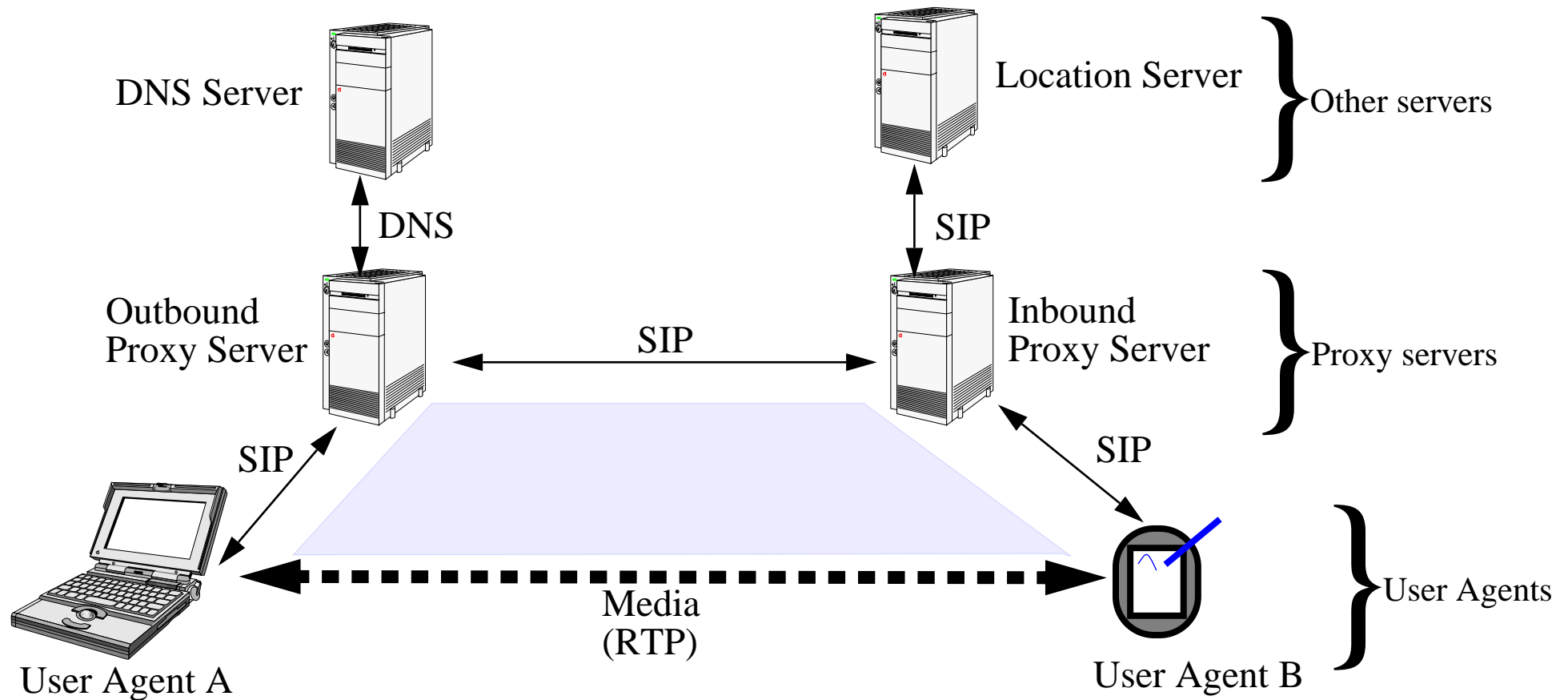
Figure 4: SIP Trapezoid

1. From the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Trapezoid
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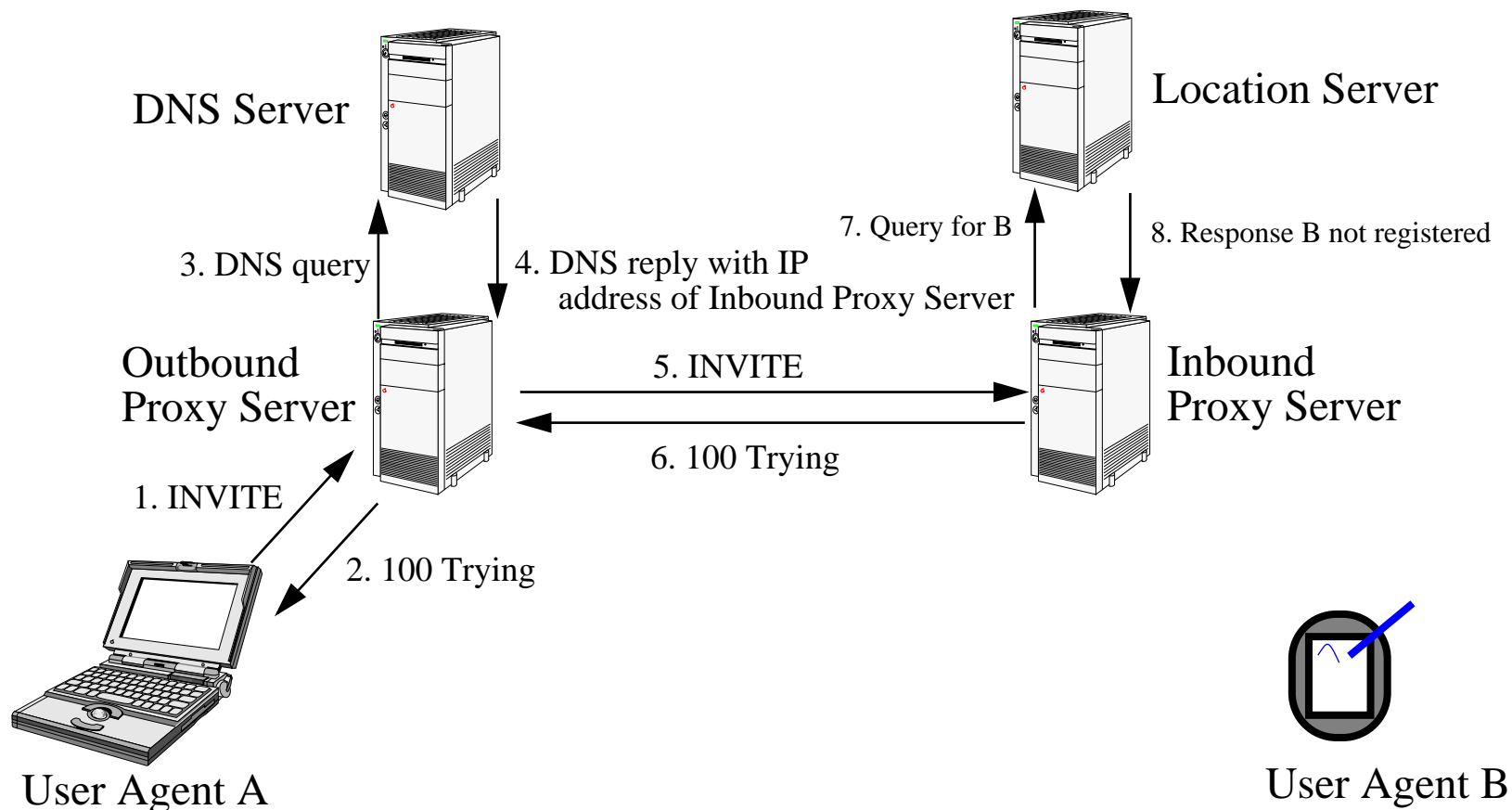
SIP Call Setup[1]

Figure 5: SIP Call Setup - when B has not registered

---

1. From the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Call Setup
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SIP Call Setup Attempt[1]
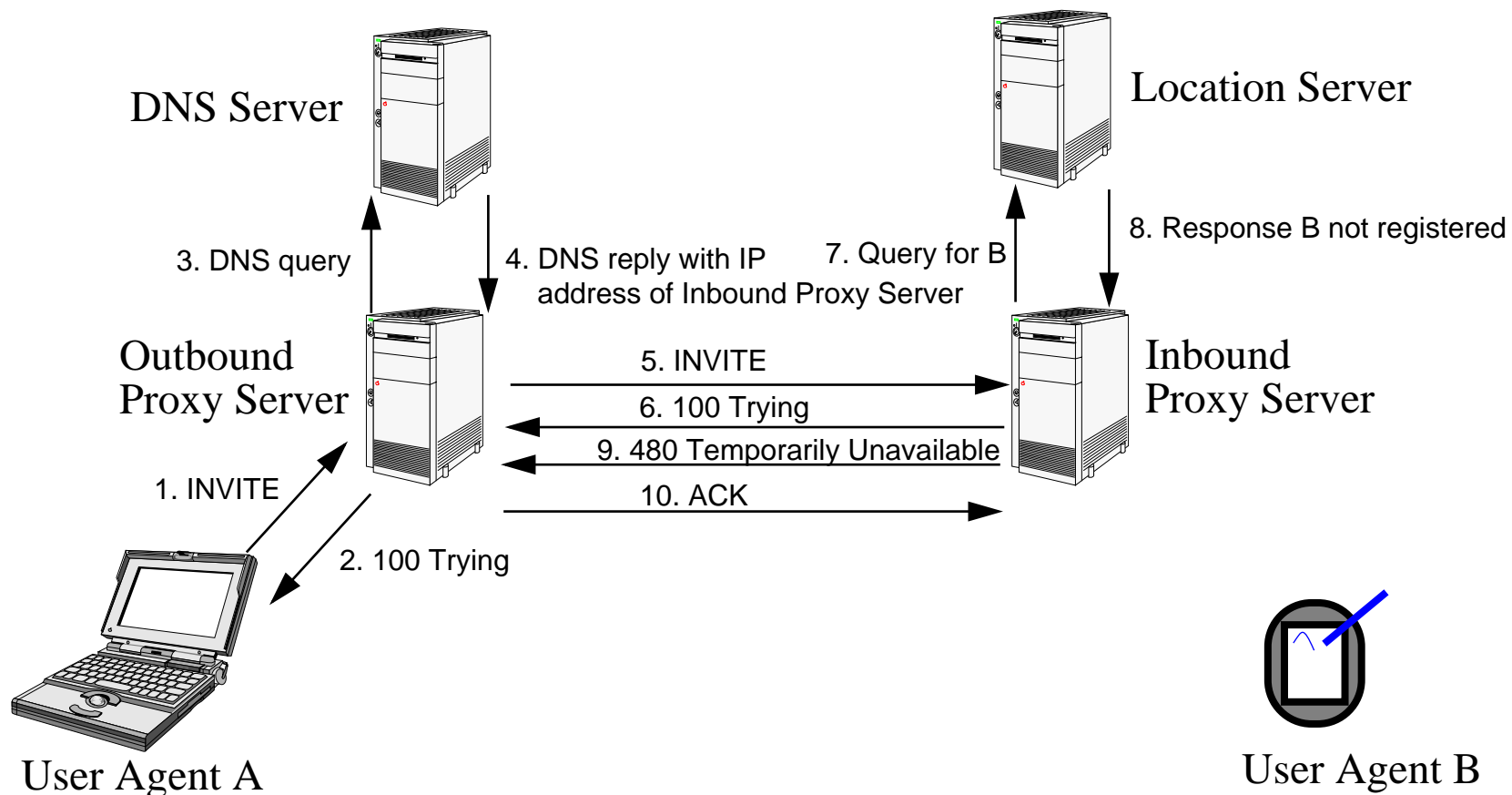
Figure 6: SIP Call Setup Attempt - when B has not registered

---

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Call Setup Attempt
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SIP Call Setup Attempt[1]

DNS Server

Location Server

3. DNS query

4. DNS reply with IP
address of Inbound Proxy Server

7. Query for B

8. Response: B not registered

Outbound
Proxy Server

5. INVITE

6. 100 Trying

9. 480 Temporarily Unavailable

10. ACK

Inbound
Proxy Server

1. INVITE

2. 100 Trying

11. 480 Temporarily Unavailable

12. ACK

User Agent A

User Agent B

Figure 7: SIP Call Setup Attempt - when B has not registered (continued)

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Call Setup Attempt
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Practical Voice Over IP (VoIP): SIP and related protocols
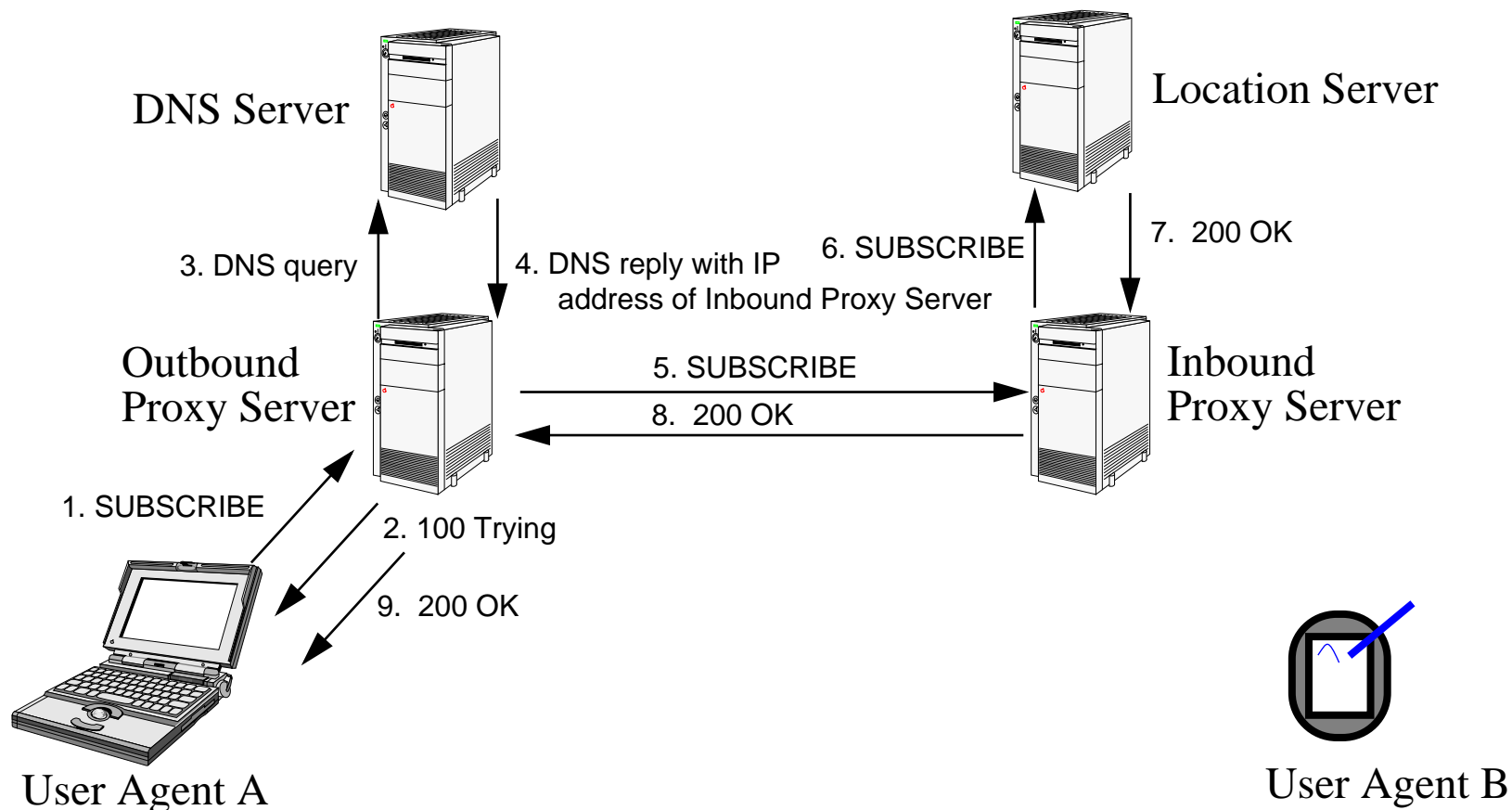
SIP Presence[1]

Figure 8: SIP Presence: A asks to be told when B registers

---

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Presence
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SIP B not Present[1]
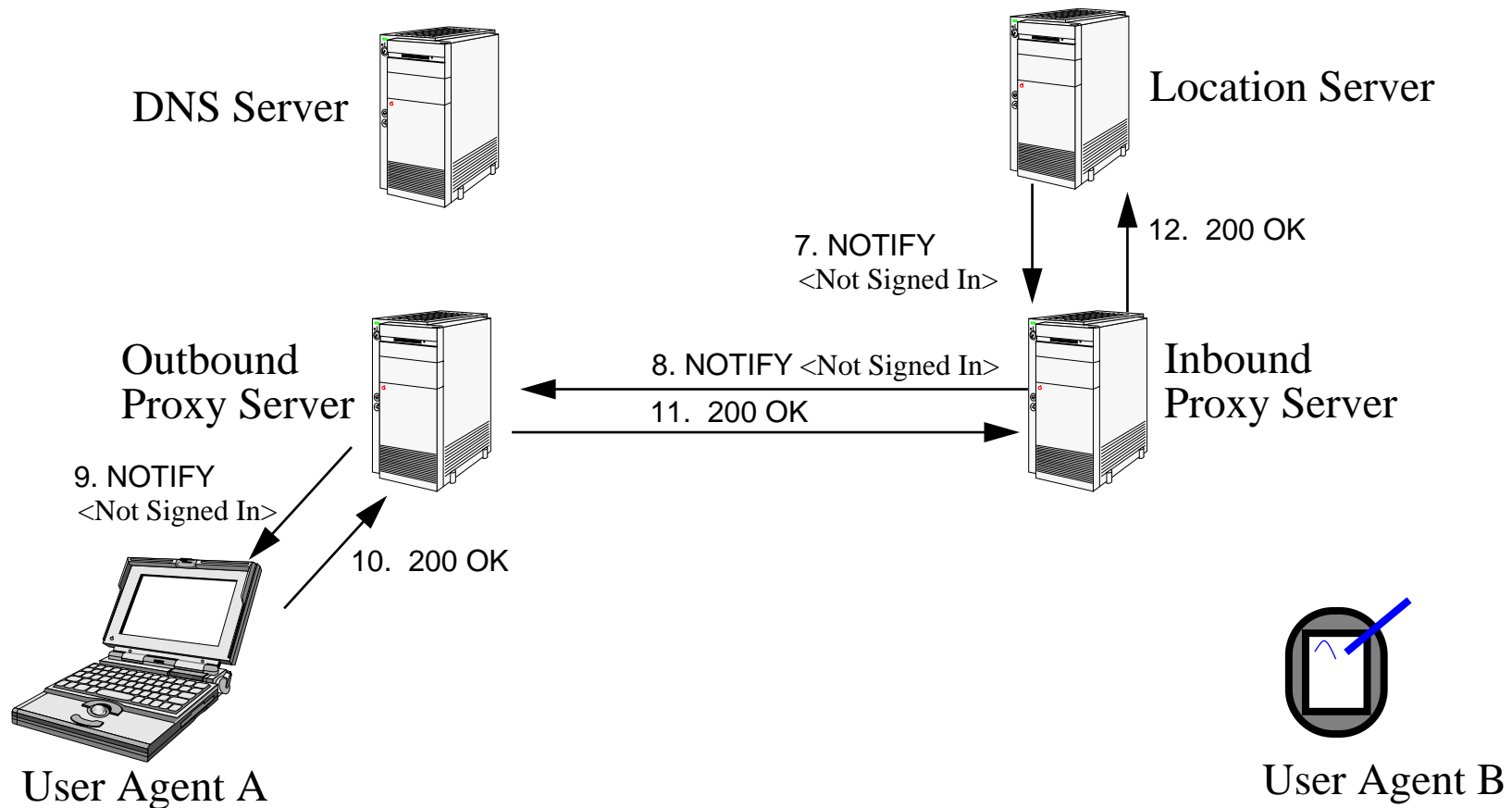
Figure 9: NOTIFY A that B has <Not Signed In>

---

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP B not Present
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SIP Registration Example[1]

DNS Server

Location Server

2. Update DB
B@1.2.3.4

3. 200 OK

Outbound
Proxy Server

Inbound
Proxy Server

4. 200 OK

1. REGISTER
B@1.2.3.4

User Agent A

User Agent B
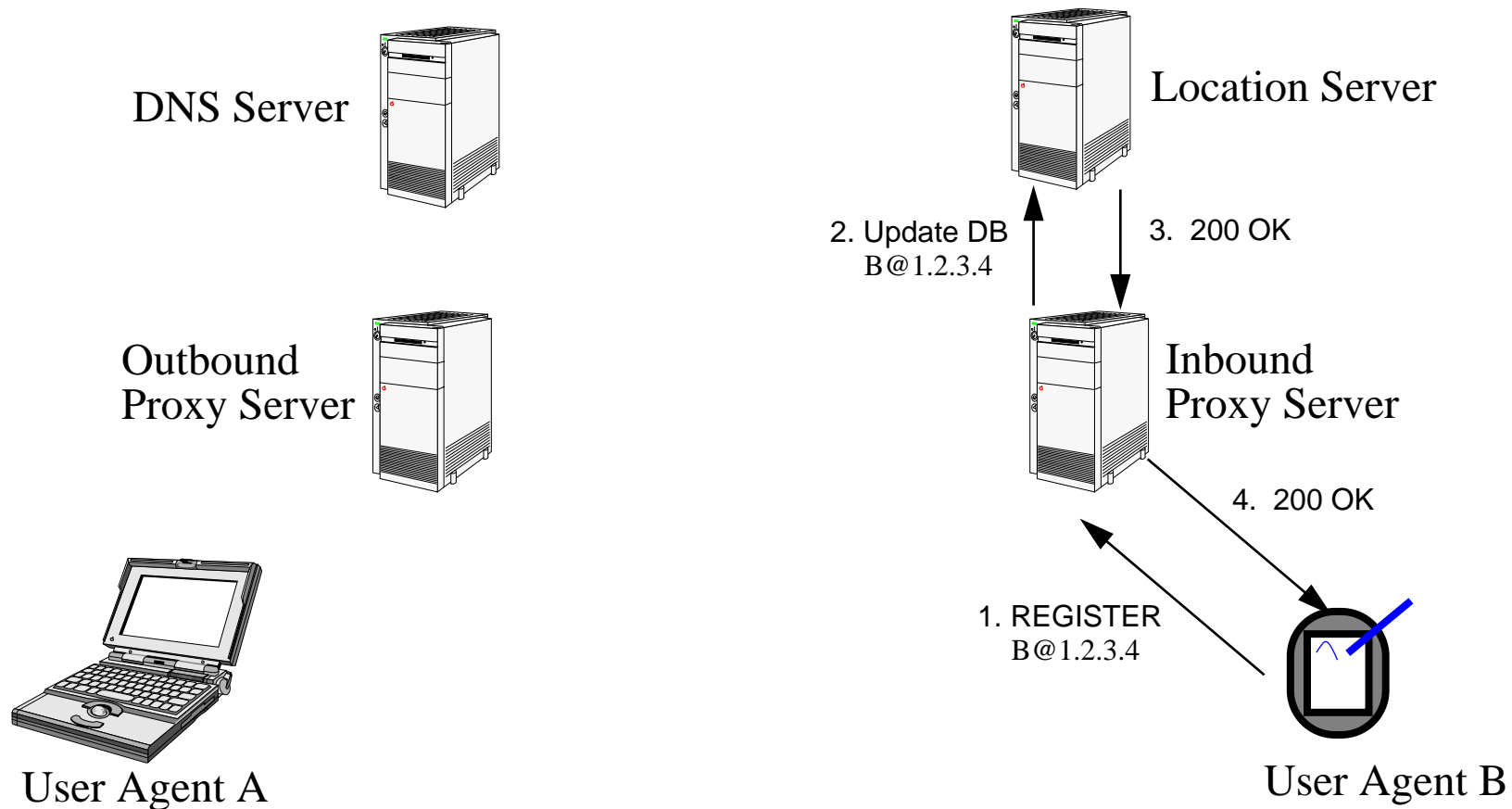
Figure 10: B registers

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Registration Example
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Purpose of registration

User B registers in order to establish their current device and location

- Only *their* location server need know

- Therefore this scales well

- The location server need not disclose this location to "just anyone", but can apply various polices to decide who can learn of it

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Purpose of registration
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Practical Voice Over IP (VoIP): SIP and related protocols

REGISTER**ing**

User Agent (office)   Registrar Server   Location server

1. `REGISTER`

2. `Update (non-SIP)`

User
Agent (home)

4. `200 OK`

3. `Response(non-SIP)`

Registrar updates
location server with
user's location

5. `REGISTER`

6. `Update (non-SIP)`

7. `Response(non-SIP)`

8. `200 OK`

User moves home
and **clears** all their

9. `REGISTER`

10. `Update (non-SIP)`

11. `Response(non-SIP)`

12. `200 OK`

User re-REGISTERs
at home

`REGISTER` request includes one or more `Contact` headers:

```
Contact: <sip:UserA@4.3.2.1>;class=personal
Contact: <sip:UserA-msg-depot@voicemail.provider.com>;feature=voicemail
Contact: <sip:+13145551212@gateway.com;user=phone>;class=business
Contact: <sip:+13145553333@cellphone.com;user=phone>;mobility=mobile
Contact: <tel:+13145551212>
Contact: <mailto:UserA@hotmailer.com>
```

Details at: Sinnreich & Johnston, pp. 78-79 and **User Preferences** on page 235.

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REGISTERing
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SIP Call Setup Attempt[1]
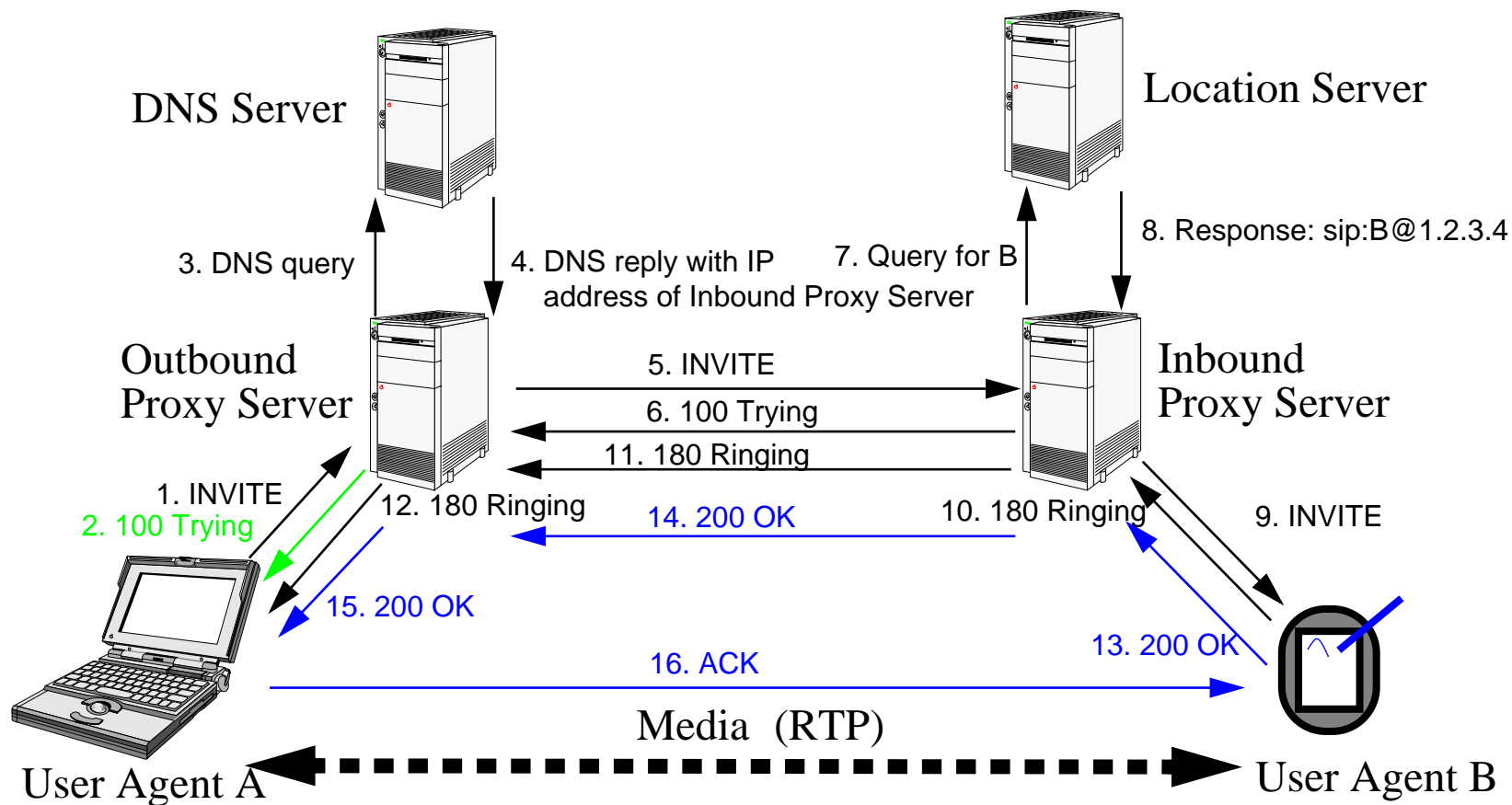
Figure 11: SIP Call Setup Attempt - when B has registered

---

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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SIP Call Setup Attempt
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SIP Session Termination using BYE
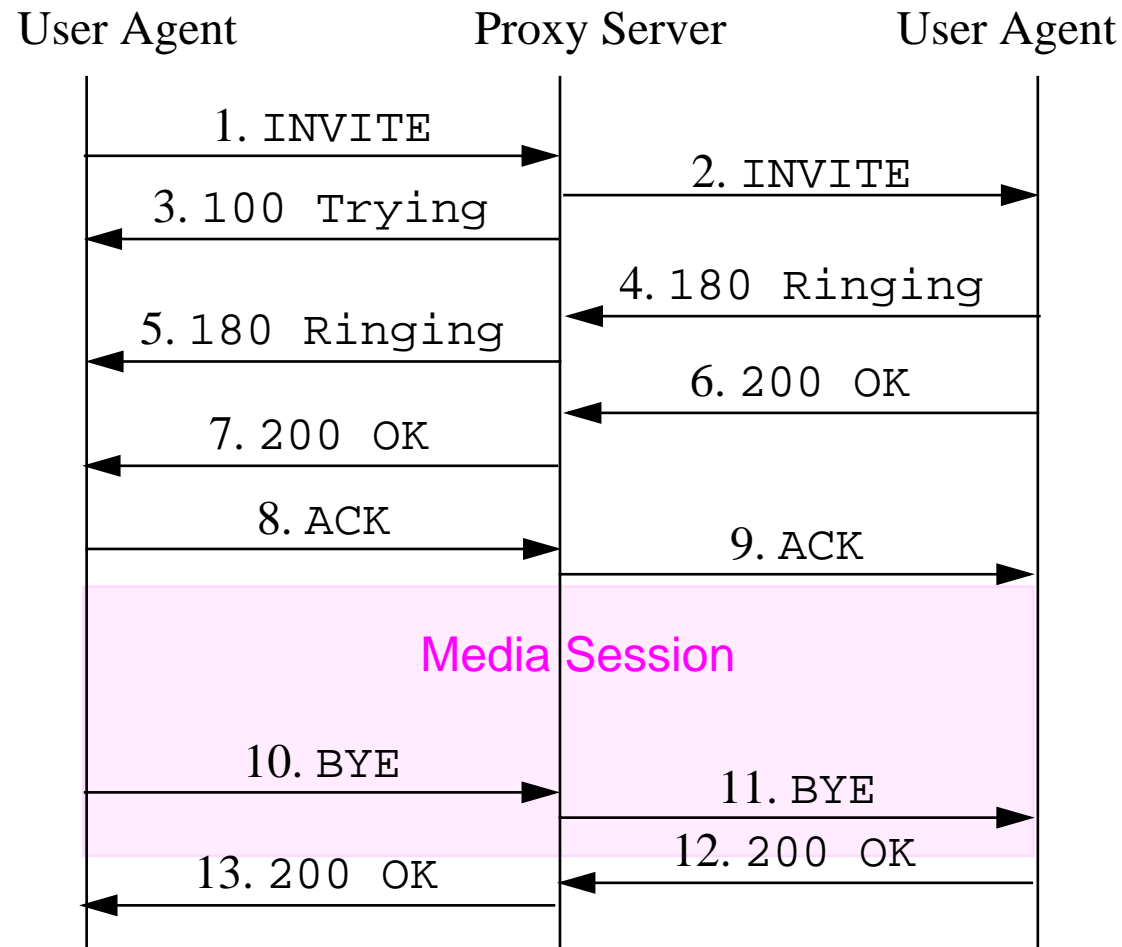
BYE causes the media session to be torn down.

Note: BYE like INVITE is an **end-to-end** method.

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SIP Session Termination using BYE
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SIP Session Termination using CANCEL

CANCEL causes the session to be cancel. Note: If a reply is `481 Transaction Unknown`, then the user agent may need to send a `BYE` since the `CANCEL` was received **after** the final reponse was sent (there was a **race condition**).

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maguire@it.kth.se

SIP Session Termination using CANCEL
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Practical Voice Over IP (VoIP): SIP and related protocols

CANCEL **and** OPTIONS

CANCEL

- In addition to canceling a pending session

- CANCEL can also be sent by a proxy or user agent
  - for example, when a parallel fork has been done, once you have a successful match, then you can cancel the others

OPTIONS

- Used to query a server or user agent for its capabilities

- sometimes used for very simple presence information

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maguire@it.kth.se

CANCEL and OPTIONS
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Practical Voice Over IP (VoIP): SIP and related protocols

Unsuccessful final responses are hop-by-hop

Unsuccessful final responses (3xx, 4xx, 5xx, 6xx) are **always** acknowledged on a *hop-by-hop* basis.

Only 200 OK is *end-to-end*.

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Unsuccessful final responses are hop-by-hop
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Practical Voice Over IP (VoIP): SIP and related protocols

Authentication

Builds upon authentication schemes developed for HTTP (see RFC 2716), for example challenge/response, digest, …

Two forms:

- ## user agent-to-user agent
  - `401 Unauthorized` $\Rightarrow$ Authentication Required

- ## user agent-to-server
  - `407 Proxy Authentication Required` $\Rightarrow$ Authentication Required (reponse sent by a proxy/server)

Note: Any SIP request can be challenged for authentication.

Note: There is **no** *integrity* protection, for additional information see **SIP Security** on page 246.

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Authentication
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SIP Method Extensions in other RFCs

J. Rosenberg and H Schulzrinne, "Guidelines for Authors of Extensions to the Session Initiation Protocol (SIP)", 7 June 2002, *Internet draft*

- ## INFO - Call signaling information during a call
  - S. Donovan, RFC 2976: The SIP INFO Method, October 2000.
- ## PRACK - Reliable ACK
  - J. Rosenberg and H. Schulzrinne, RFC 3262: Reliability of Provisional Responses in Session Initiation Protocol (SIP), June 2002
- ## SUBSCRIBE/NOTIFY
  - A. B. Roach, RFC 3265:Session Initiation Protocol-Specific Event Notification, June 2002.
- ## REFER
  - R. Sparks, "SIP REFER Method", *Internet draft*
  - R. Sparks, "The Referred-By Mechanism", 23 May 2002, *Internet draft*
- ## MESSAGE
  - J. Rosenberg and B. Campbell, SIP Instant Messaging, "Session Initiation Protocol Extension for Instant Messaging", 16 Sept.2002, *Internet draft*
- ## UPDATE - Early media and preconditions
  - J. Rosenberg, RFC 3311: The Session Initiation Protocol (SIP) UPDATE Method. October 2002.

Maguire
maguire@it.kth.se

SIP Method Extensions in other RFCs
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- COMET - Resource Condition Met - preconditions met notification
  - Gonzalo Camarillo, "Confirmation of SDP preconditions", Internet Draft, October 2000, Expired June 2001; F. Haerens, Third Party Call Control for Resource Management. Internet Draft, February 2001, (also expired); W. Marshall, K. Ramakrishnan, E. Miller, et al., "Integration of Resource Management and SIP", Internet Draft, November 2001,

    http://www.ietf.org/proceedings/01dec/I-D/draft-ietf-sip-manyfolks-resource-03.txt.

Maguire
maguire@it.kth.se

SIP Method Extensions in other RFCs
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SIP Extensions and Features

- Method Extensions
  - Unknown methods rejected by User Agent using `405` or `501` response
  - Listed in `Allow` header field
  - Proxies treat unknown methods as a non-`INVITE`

- Header Field Extensions
  - Unknown header fields are ignored by user agents and proxies
  - Some have feature tags registered, these can be declared in a `Supported` or `Require` header field

- Message Body Extensions
  - Unknown message body types are rejected with a `406` response
  - Supported types can be declared with an `Accept` header field
  - `Content-Disposition` indicates what to do with it

- Extension must define failback to base SIP specification.

$\Rightarrow$ No Profiling is needed
  - unlike for example, Bluetooth!

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maguire@it.kth.se
SIP Extensions and Features
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SIP Presence - Signed In[1]
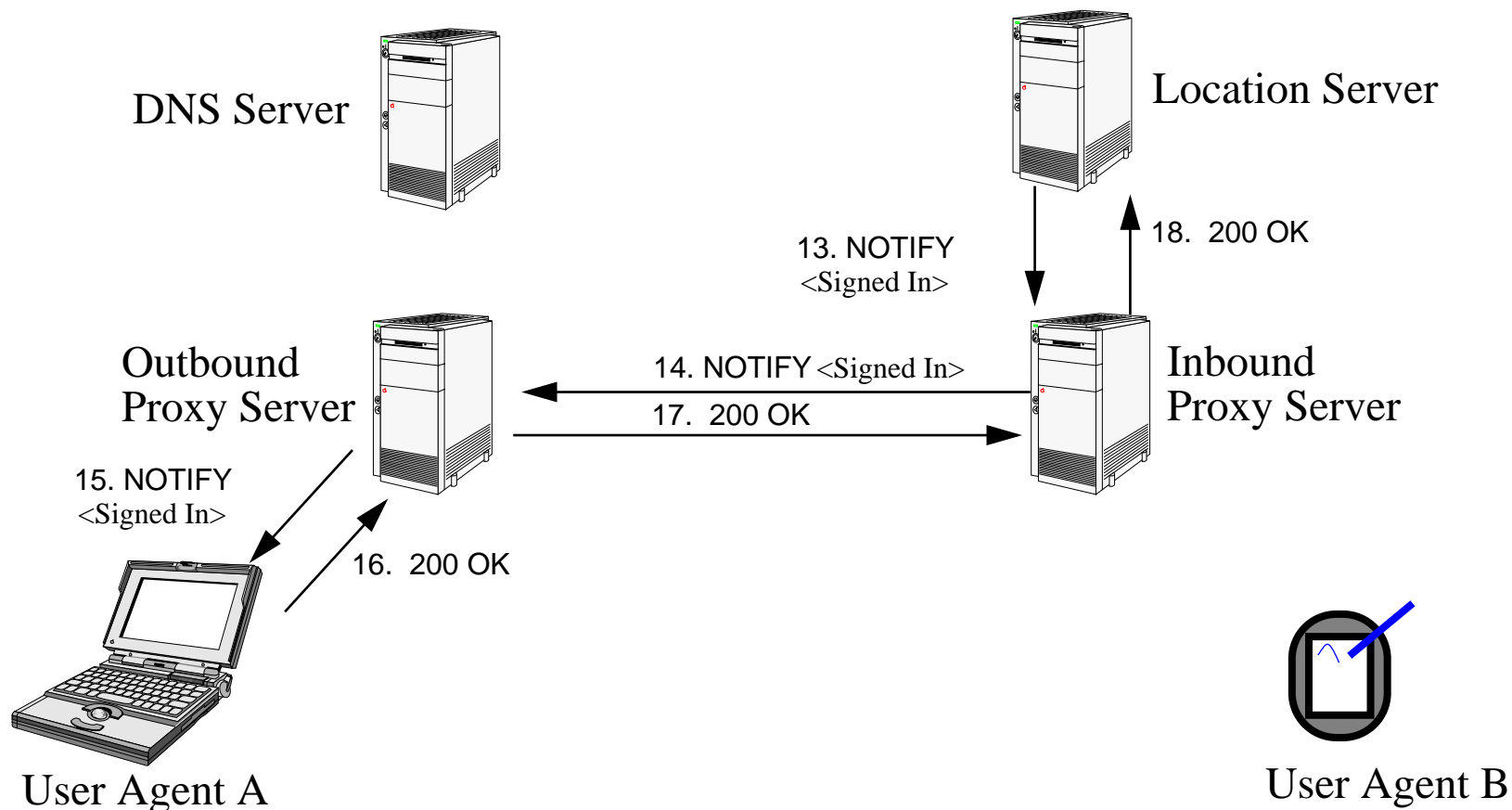
Figure 12: NOTIFY A that B has <Signed In>

---

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
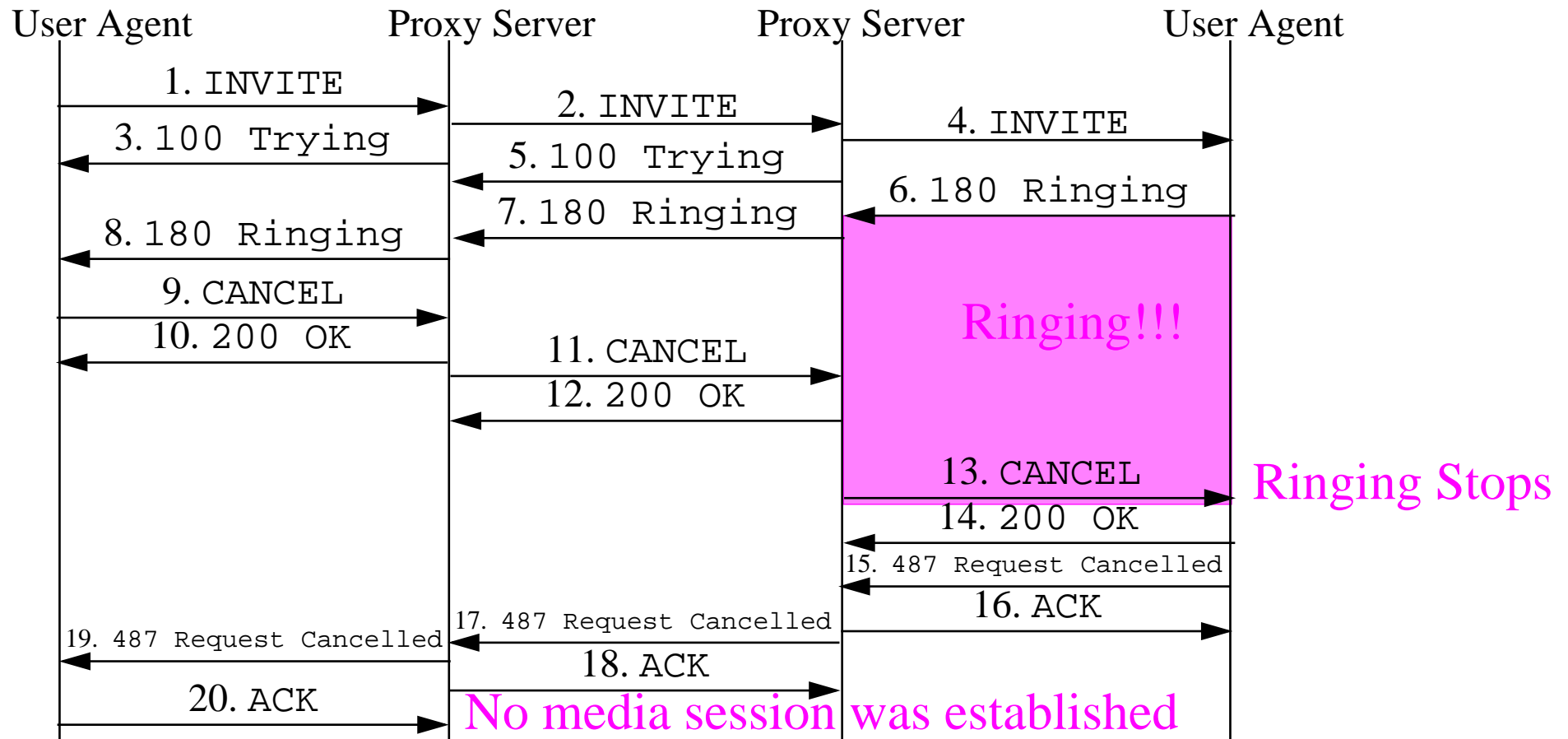*http://smuhandouts.com/8393/SIPTutorial.pdf*

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maguire@it.kth.se

SIP Presence - Signed In
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SUBSCRIBE **and** NOTIFY

User
Agent A

User
Agent B

1. INVITE →

Called party (B) is busy, thus call fails

2. 486 Busy Here ←

3. ACK →

4. SUBSCRIBE →

5. 200 OK ←

Caller requests that they be notified
when the party is no longer busy

6. NOTIFY ←

7. 200 OK →

Called party is no longer busy, so
their UA sends a notification

8. INVITE →

9. 200 OK ←

10. ACK →

Caller calls back and succeeds in
establishing a session.

Media Session

If user B's agent does not wish to provide user A's agent with a notification it sents
a 603 Decline response.

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maguire@it.kth.se

SUBSCRIBE and NOTIFY
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SIP Instant Messaging Example[1]
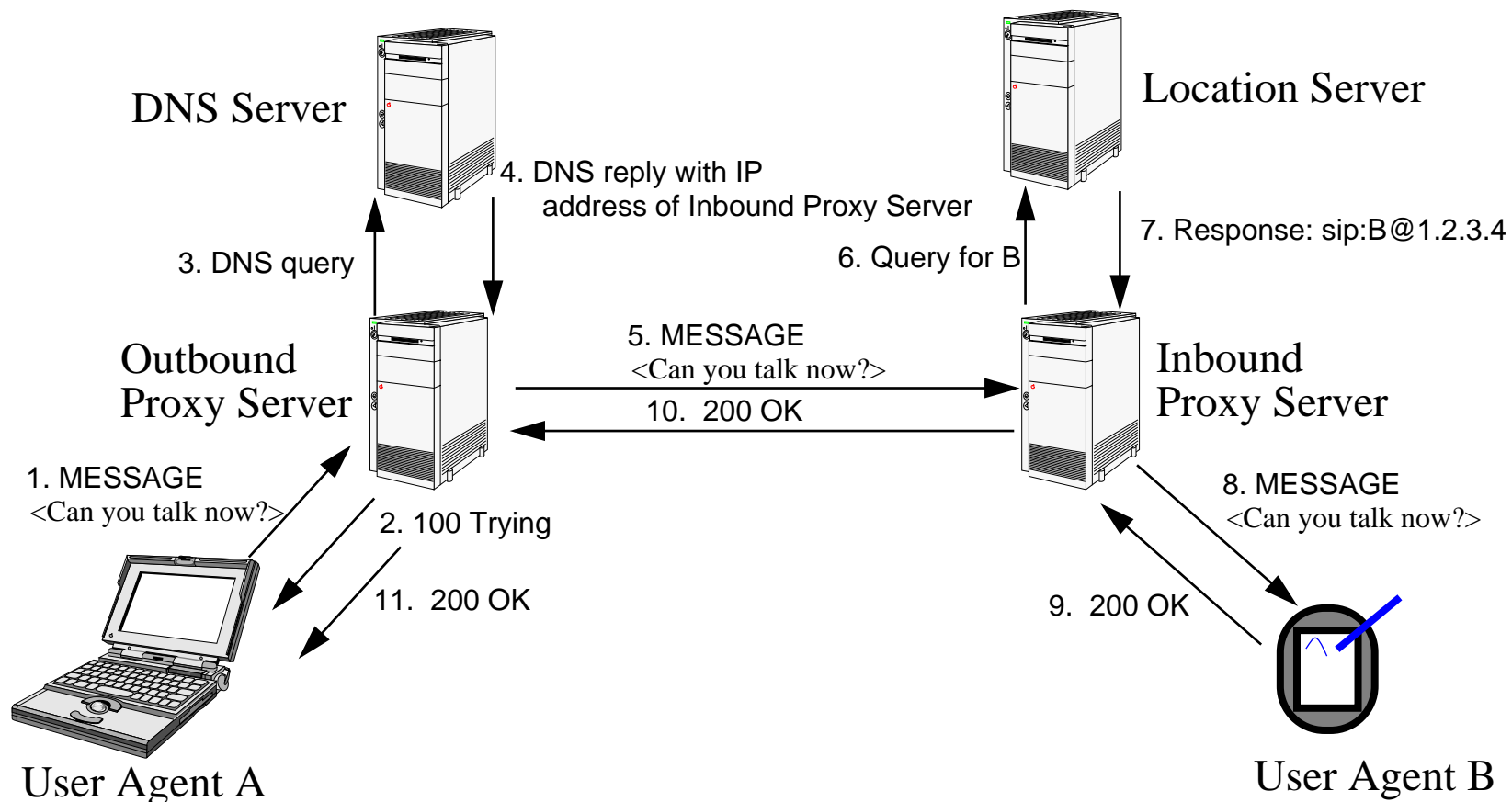
Figure 13: A sends a message to B

---

1. Adapted from the lecture notes "SIP Tutorial: Introduction to SIP" by Henry Sinnreich and Alan Johnston,
http://smuhandouts.com/8393/SIPTutorial.pdf

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maguire@it.kth.se

SIP Instant Messaging Example
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SIP Instant Messaging Example (continued)[1]
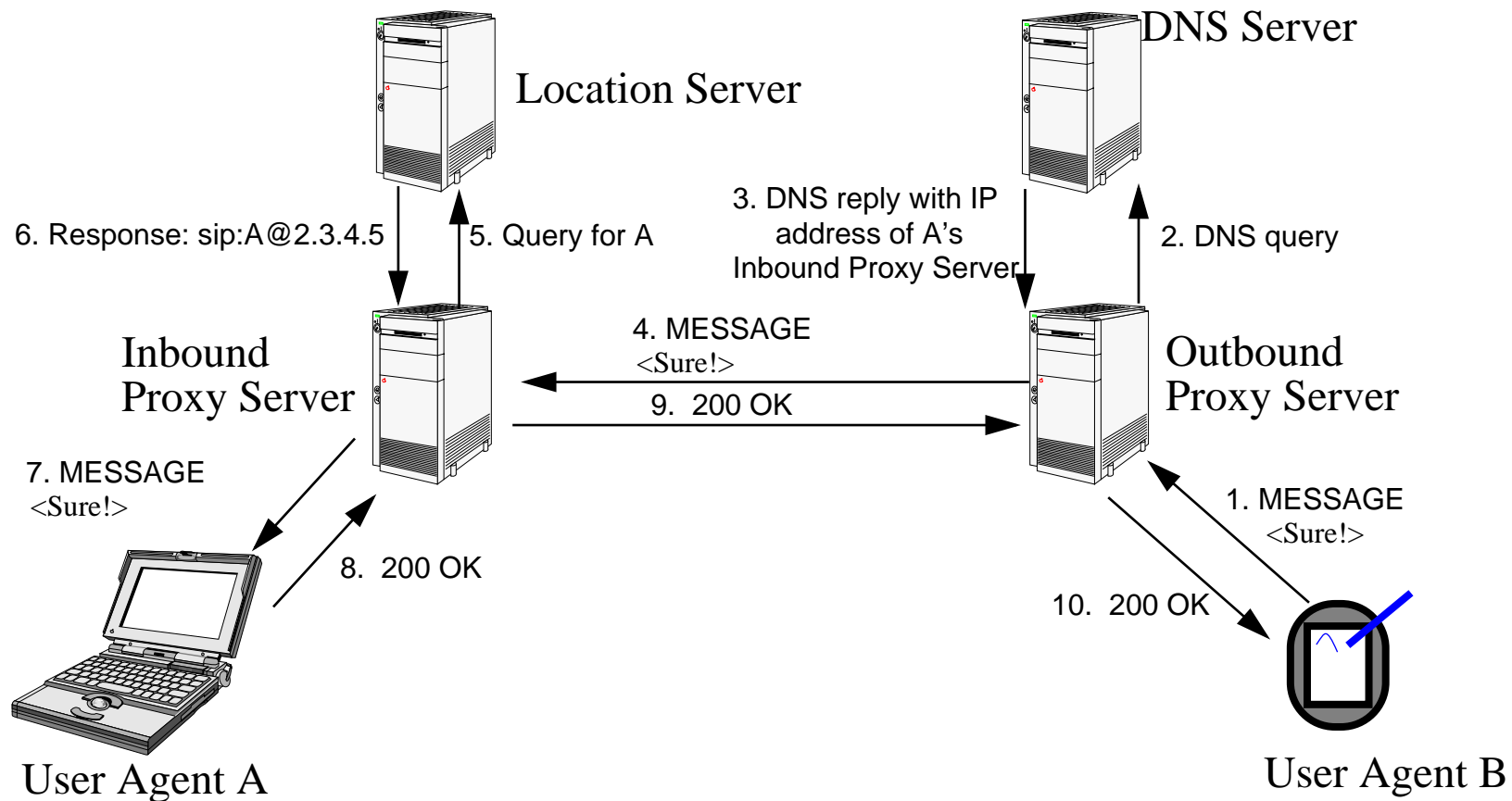
Figure 14: B sends a message to A

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SIP Instant Messaging Example (continued)
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Message example

A simple Instant Message (IM) as SIP:

```
MESSAGE im:UserB@there.com SIP/2.0
Via: SIP/2.0/UDP 4.3.2.1
To: User B <im:UserB@there.com>
From: User A <im:UserA@here.com>
Call-ID: a5-32-43-12@4.3.2.1
CSeq: 1 MESSAGE
Content-type: text/plain
Content-Length: 16

Hi, How are you?
```

The response will be a `200 OK` from B.

Note: the example uses IM URIs instead of SIP URIs.

A `MESSAGE` request can be sent at anytime (even without a session).

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maguire@it.kth.se

Message example
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Midcall signalling

Midcall signalling used when the session parameters don't change, to exchange information between two user agents via the body of an `INFO` message. If the session parameters did change then you would use a re-`INVITE`.
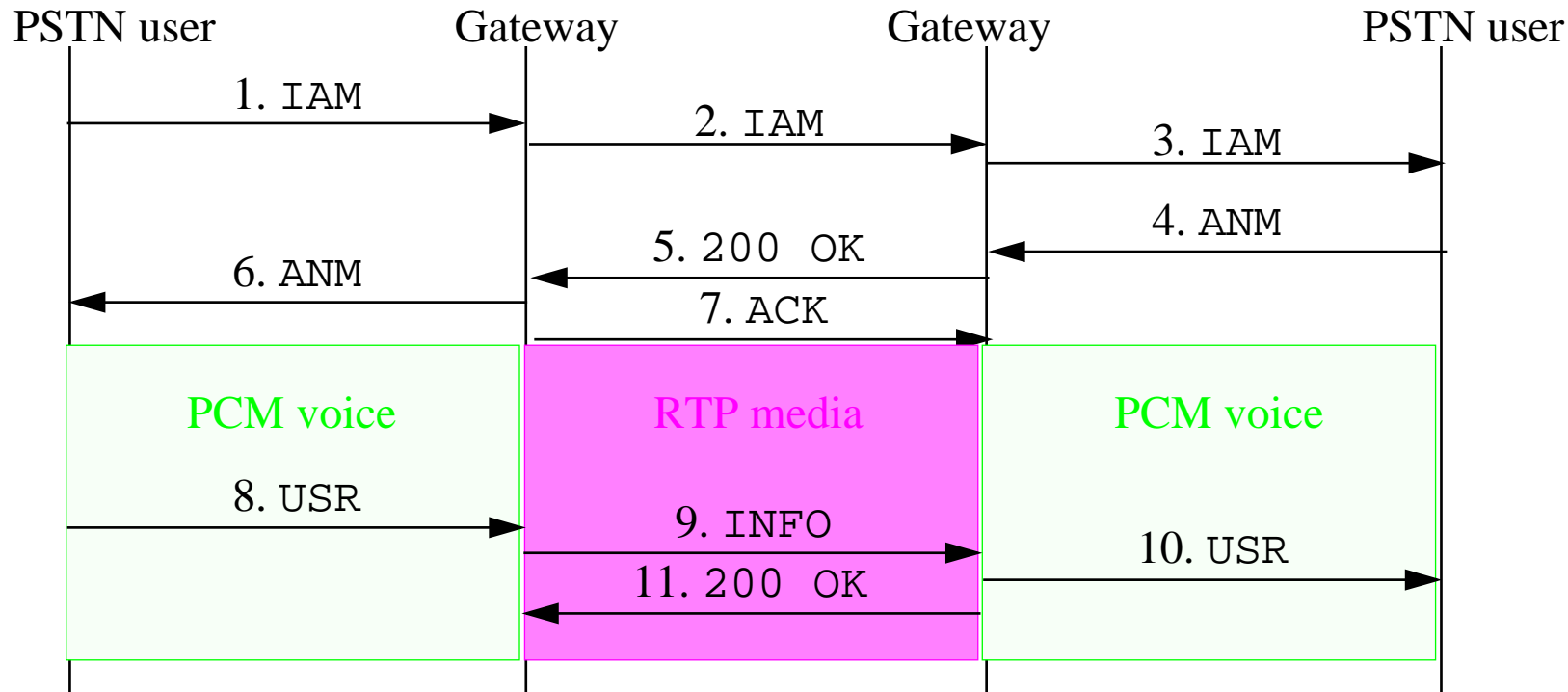
Note in the above figure the ISUP messages: IAM (Initial address message), INM (Answer message), and USR (user-to-user message).

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maguire@it.kth.se

Midcall signalling
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Call Control

SIP is peer-to-peer -- thus a proxy can't issue a `BYE`, only end devices (UAs) can.

To methods for third party call control:

- A proxy passes an invite on, but **stays in the signaling path**
- Use `REFER` to initial third party control (the third party is no longer in the signaling path).

Useful for:

- click-to-call
- Automatic Call Distribution (ACD)
- web call center
- …

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maguire@it.kth.se

Call Control
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Example of using REFER

Third party call control, by User A to set up a session between Users B and C.
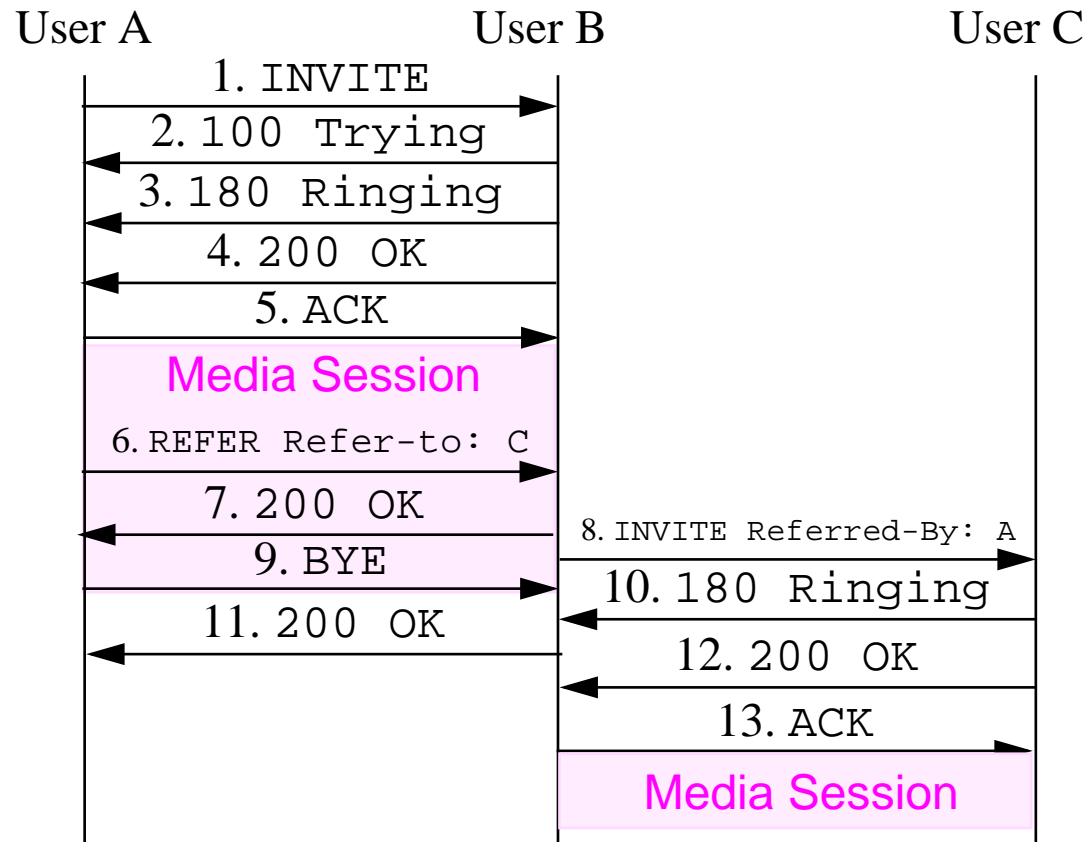
Note: the use by A of an INVITE with a Refer-to header and
the user by B of an INVITE with a Referred-By header.

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Example of using REFER
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QoS and Call Setup

The path which SIP takes may be different that the media path, thus new extensions were added to enable more handshaking:

- Early Media - by allowing SDP to be included in the `183 Session Progress` response (allows establishment of QoS requirements before call is answered) - may also enable one-way RTP {hence the name "early media"}, formally: "media during early dialog"

- Reliable Provisional Responses extension allows detection of a lost `183 Session Progress` response based on using Provisional Response Acknowledgement (`PRACK`)

- UAs can use preCOnditions MET (COMET) method to indicate that the QoS requirements can be met and that the user can be alerted by ringing the phone.

SDP in the `INVITE` contains an attribute-value pair: "`a=qos:mandatory`".

For further details see: RFC3312 [27] and RFC3262 [28]; more about SDP in the next lecture module.

Maguire
maguire@it.kth.se

QoS and Call Setup
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maguire@it.kth.se

QoS and Call Setup
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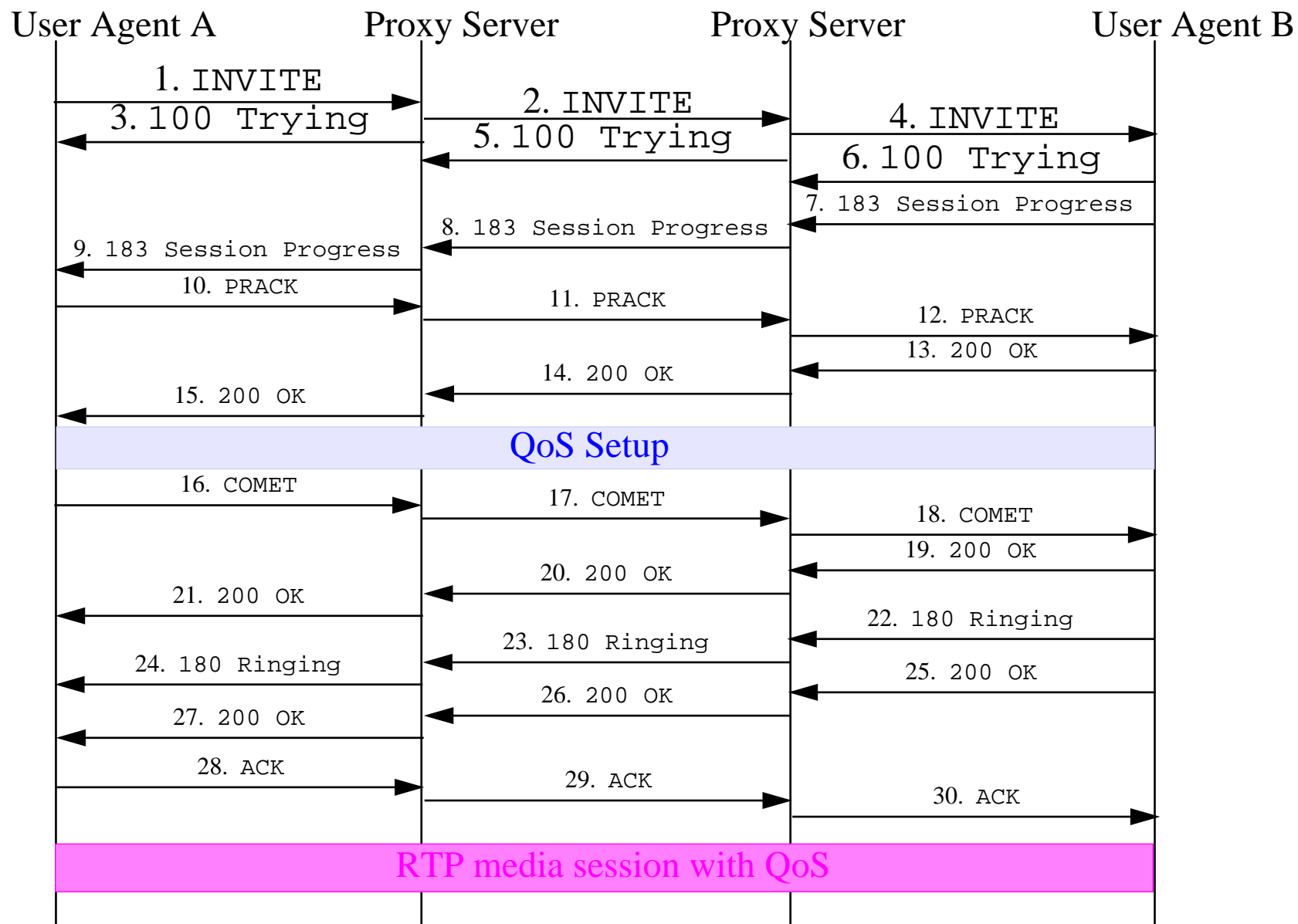
SIP Message retransmission

Timer	default	Purpose
T1	500ms	Set when SIP request is first sent
T2	4 sec.	Longer timeout when a provisional response has been received

If a request is lost, then timeout T1 will generate a retransmission of the request.

If a request is received and a provisional response is received, then sender switches to timeout T2 (to wait for the final response).

`INVITE` is different:

- receiving a provisional response stops all re-transmissions of the `INVITE`;
- however, the sender of the provisional response starts a T1 timer when it sends its final response and if it does not get an ACK in time it retransmits the final response.

If you want/need acknowledgement of provisional responses use `PRACK`.

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maguire@it.kth.se

SIP Message retransmission
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RFC 3261 - Routing Changes

- Introduced "loose routing" vs. RFC 3543's "strict routing"
  - Examples:
    - Pre-loaded (initial `INVITE`) `Route` header can be used instead of the default outbound proxy (DOP)
    - Pre-loaded `Route` header can be used to invoke "home proxy" services (when you are roaming)
    - Additional proxies can be added as needed (for example, adding routing during a call)
- All elements must insert `branch` paramater as a transaction ID in `Via` header fields
- `Contact` header required in all requests that establish a dialog
- `From` and `To` tags are now mandatory
- Recommend users of Fully Qualified Domain Name (FQDN) instead of IP addresses
- `Via` loop detection no longer required of proxies
  - Use of `Max-Forwards` is now manadatory
- `Via` hiding is deprecated (i.e., should no longer be used)
  - because it turned out not to be secure or useful

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maguire@it.kth.se
RFC 3261 - Routing Changes
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RFC 3261 - New Services

- Customized ringing
  - A trusted proxy can insert an `Alert-Info` header field into an `INVITE`
- Screen Pops
  - A trusted proxy can insert an `Call-Info` header field into an `INVITE`
  - URI can be HTTP and can contain call control "soft keys"
- Callback
  - Reply-to and In-Reply-To header - to assist in returning calls
- Annoucement handling
  - UAS or proxy need not make a decision about playing an early media annoucement
    - Error response contains new `Error-Info` header field which contains the URI of the annoucement
  - UAC makes a decision based on the user's interface

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maguire@it.kth.se

RFC 3261 - New Services
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Intelligent Network service using SIP

ITU has defined a set of service features (think of them as primitives which can be use to construct more complex services). These are divided into two sets:

- Capability Set 1: Service Features
- Capability Set 2

J. Lennox, H. Schulzrinne, and T. F. La Porta, "Implementing Intelligent Network Service with the Session Initiation Procol" [31] addresses Capability Set 1:

Abbreviated Dialing (ABD)	Call queueing(QUE)	Off-net calling (ONC)
Attendant (ATT)	Call transfer (TRA)	One number (ONE)
Authentication (AUTC)	Call waiting (CW)	Origin dependent routing (ODR)
Authorization code (AUTZ)	Closed usergroup(CUG)	Originating call screening (OCS)
Automatic callback (ACB)	Consultation calling (COC)	Originating user prompter (OUP)
Call distribution (CD)	Customer profile management (CPM)	Personal numbering (PN)
Call forwarding (CF)	Customer recorded announcement (CRA)	Premium charging (PRMC)
Call forwarding on busy/don't answer (CFC)	Customized ringing (CRG)	Private numbering plan (PNP)
Call gapping (GAP)	Destinating user prompter (DUP)	Reverse charging (REVC)
Call hold with announcement (CHA)	Follow-me diversion (FMD)	Split charging (SPLC)
Call limiter (LIM)	Mass calling (MAS)	Terminating call screening (TCS)
Call logging (LOG)	Meet-me conference (MMC)	Time dependent routing (TDR)
	Multi-way calling (MWC)	

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maguire@it.kth.se

Intelligent Network service using SIP
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Capability Set 1: Services

Abbreviated dialling (ABD)

Account card calling (ACC)

Automatic alternative billing (AAB)

Call distribution (CD)

Call forwarding (CF)

Call rerouting distribution (CRD)

Completion of calls to busy subscriber (CCBS)

Conference calling (CON)

Credit card calling (CCC)

Destination call routing (DCR)

Follow-me diversion (FMD)

Freephone (FPH)

Malicious call identification (MCI)

Mass calling (MAS)

Originating call screening (OCS)[

Premium rate (PRM)

Security screening (SEC)

Selective call forwarding on busy/don't answer (SCF)

Selective call forwarding

Call forwarding on busy

Call forwarding on don't answer (no reply)

Split charging (SPL)

Televoting (VOT)

Terminating call screening (TCS)

Universal access number (UAN)

Universal personal telecommunications (UPT)

User-defined routing (UDR)

Virtual private network (VPN)

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maguire@it.kth.se

Capability Set 1: Services
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Capability Set 2

Wireless services

Inter-network services

Multimedia

Call pick-up

Calling name delivery

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maguire@it.kth.se

Capability Set 2
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Features

List of features adopted from http://www.miercom.com/survey - augmented with my own notes with respect to SIP supporting this feature:

SIP	Feature	Description
✛	911/E-911 support	Emergency services
	Audible message waiting	An audible indicator when there is a new message
	Automated attendant	Answers and routes calls automatically based on caller responses; e.g., via Interactive Voice Response (IVR) or DTMF prompts
✔	Automatic alternate routing	Routes calls automatically based on user-defined routing parameters, priorities, and failover/availability decisions.
✔	Automatic call back	Calls an extention back automatically when a busy signal or no answer is encountered. Also known as Camp on.
	Bridged call appearance	Allows the same phone number to appear and be answered on multiple phone sets.
✔	Call blocking	Selectively blocks calls from user-defined origins

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SIP	Feature	Description
✢	Call conference	An audio path for multiple parties on a single call, established via user keystrokes and no outside intervention.
✢	Call drop	Terminates a call without hanging up the receiver.
✔	Call forward all	Redirects all calls to another station or location.
✔	Call forward on busy	Redirects all calls to another station or location *when the user's is busy.*
✔	Call forward on no answer	Redirects all calls to another station or location *after a specified number of rings.*
✔	Call hold	Places an incoming call on hold or retrieves a call placed on hold.
✔	Call pick-up	Allows a user to place a call on hold, then resume it from another phone in the system.
✢	Call return	Calls back the last incoming number.
✢	Call transfer	Redirects an answered call to another user. see Rick Dean, Billy Biggs, and R. Mahy, "The Session Inititation Protocol (SIP) 'Replaces' Header", Internet Draft, 16 May 2002 -- for 'Attended Transfer' and 'Retrieve from Call Park'
✔	Call waiting	An audible indicator heard when there is another call pending.
✔	Caller ID	Displays the name and/or number of the calling party.

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maguire@it.kth.se

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SIP	Feature	Description
	Call Detail Recording (CDR)	Records call data on a specific extension or group of extensions.
	Class of service	Restricts access to features based upon users' privilege level(s).
	Direct inward system access	Dial-in system station appearance.
✔	Direct transfer to voice mail	Automatically redirects all calls to users' voicemail at the push of a button.
	Directory lookup	Allows users to look up an extension from the corporate LDAP directory.
✔	Distinctive ringing	Uses a different ringtone for different call characteristics, for example, internal vs external calls.
✔	Do not disturb	Makes the phone appear to be out of service.
✔	Follow me	Rings multiple, disparate phones simultaneously when one extension is dialed.
✔	Free seating/Hoteling	Allows a user to move from one location to another, accessing all calls, features, button mappings, etc.
	Hot line	Private line automatic ring-down connection between two phones.
	Hunt groups	Diverts calls to busy extensions to any extension in a pre-defined group.

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maguire@it.kth.se

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SIP	Feature	Description
✢	Intercom - phone-to-phone	An internal intercom that initiates calls within a predefined group or department.
✢	Intercom - phone-to-multi-phone	An internal intercom that initiates voice paging through the speakers of multiple phone systems.
✢	Intrude	Allows specific users to intrude on calls already in progress. See R. Mahy and D. Petrie,"The Session Initiation Protocol (SIP) 'Join' Header", 28 Oct. 2002 - a new header for use with SIP multi-party applications and call control; to logicallyjoin an existing SIP dialog, for: 'Barge-In', 'Message Screening', 'and Call CenterMonitoring'
✢	Last number redial	Redials the last outgoing call.
✔	Least-cost routing	Routes outbound calls to the least expensive alternative, based on user-defined prioritization.
	Leave word calling	Allows internal users to leave short, pre-programmed messages for other internal users.
	Malicious call trace	Allows users to initiate a call trace.
	Message waiting indicator	Visibly indicates when new voicemail arrives, often via a blinking light.
✢	Missed call indicator	Lists missed calls.

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maguire@it.kth.se

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SIP	Feature	Description
	Multiple call appearance	Allows a single phone to have multiple, repeated instances of a single phone extension.
✛	Multiple ring styles	Changes the ringtone based on user preference.
✛	Music on hold	Plays music for the caller when placed on hold.
✛	Mute	Disables the microphone. (This is really just a feature of the client.)
✛	Night service	Changes call coverage based on the time of day, for example, plays a common recording for all calls at night.
✛	One-button send all calls	Automatically redirects all calls to someone else who provides coverage with a single button.
✛	One-button speed dial	Dials a predefined number with a single button.
✔	Personal call routing	Defines routing parameters
	Priority ringing	Uses a different ringtone for specified numbers.
	Recorded announcements	Provides predefined announcements to certain calls, for example, "Your call cannot be completed as dialed".
✔	System speed dialing	Dials frequently-called numbers using an abbreviated access code.
✛	User directory	Allows any system endpoint to browser a database of names, extensions, etc.

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maguire@it.kth.se

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SIP	Feature	Description
	Volume control	Changes the volume individually for the speaker, handset, and ringer.
✛	Whisper page	Allows someone else (such as an assitant) to bridge into a call, allowing only the local party to hear.
✔		Supported by SIP
✛		Supported by SIP + additional methods

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maguire@it.kth.se

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SIP development, evolution, …

In traditional IETF fashion is based on **running code**

- So in your projects you should make sure that what you propose is really feasible by implementing it!
  - should have at least **2 interoperable implementations** for each feature
- See the SIP mailing list (**listen** _until_ you have sufficient knowledge to contribute)
- See the SIP Working Group for what is being worked on by others
- See J. Rosenberg and H. Schulzrinne, "Guidelines for Authors of Extensions to the Session Initiation Protocol (SIP)", Internet draft, 07-JUN-02

    http://www.ietf.org/internet-drafts/draft-ietf-sip-guidelines-05.txt

Maguire
maguire@it.kth.se

SIP development, evolution, …
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Gateways

- **Gateway Location Protocol** (GLP) - a protocol used between Location Server (LSs) {similar to BGP}

- **Signaling Gateway** - to convert from the signaling used in one network to that of the other

- **Media Gateway** - to convert the media format from that used in one network to that of the other

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maguire@it.kth.se

Gateways
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Significance

- In July 2002, 3GPP adopted SIP for their signalling protocol (Release5)
- 3GPP adops SIMPLE as instant messaging/presence mechanism (Release6)

While there are some differences between the 3GPP and IETF points of view

From Henning Schulzrinne, "SIP - growing up", SIP 2003, Paris, January 2003, slide 5.

3GPP	IETF
Network does not trust the user	User only partially trusts the network
layer 1 and layer 2 specific	generic
walled garden	open access

Not suprisingly the 3GPP system for using SIP is rather complex with a number of new components: Proxy Call Session Control Function (P-CSFC), Interrogating Call Session Control Function (I-CSFC), Serving Call Session Control Function (S-CSFC), Home Subscriber Server (HSS), Application Server (AS), Subscription Locator Function (SLF), Breakout Gateway Control Function (BGCF), Media Gateway Control Function (MGCF), and Media Gateway (MGW)

Maguire
maguire@it.kth.se

Significance
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`http://www.ietf.org/rfc/rfc1958.txt`

[21] Multiparty Multimedia Session Control (mmusic) Working Group

`http://www.ietf.org/html.charters/mmusic-charter.html`

[22] Session Initiation Protocol (sip) Working Group

`http://www.ietf.org/html.charters/sip-charter.html`

Also important are the measures of delay, delay jitter, throughput, packet loss, etc. IP Performance Metrics (`ippm`) is attempting to specify how to measure and exchange information about measurements of these quantities.

[23] A great set of references compiled by prof. Raj Jain is available at:

`http://www.cis.ohio-state.edu/~jain/refs/ref_voip.htm`

SIP

[24] Henning Schulzrinne's Session Initiation Protocol (SIP) web page

Maguire
maguire@it.kth.se

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[29] D. Willis and B. Höneisen, Session Initiation Protocol (SIP) Extension Header Field for Registering Non-Adjacent Contacts, IETF RFC 3327, December 2002. `http://www.ietf.org/rfc/rfc3327.txt`

Maguire
maguire@it.kth.se
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[30] Henning Schulzrinne, "SIP - growing up", SIP 2003, Paris, January 2003.

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[32] Study Group 11 of the International Telecommunications Union Telecommunications Standards Sector (ITU-T), ITU-T recommendation Q.1211: Introduction to Intelligent Network Capability Set 1, Annex B

[33] Study Group 11 of the International Telecommunications Union Telecommunications Standards Sector (ITU-T), ITU-T recommendation Q.1221: Introduction to Intelligent Network Capability Set 2.

Maguire
maguire@it.kth.se

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Module 4: Session Annoucement Protocol (SAP)

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 ***and*** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Session Announcement Protocol (SAP)

Defined in RFC 2974[34]

Primarily for **multicast** session announcement. It provides the session setup information to *prospective* participants.

Each SAP announcer periodically multicasts an announcement:

- to a well known multicast address on port 9875
    - IPv4 global scope sessions use multicast addresses in the range 224.2.128.0 - 224.2.255.255 - their SAP announcements are sent to 224.2.127.254
    - IPv4 administrative scope sessions using administratively scoped IP multicast are defined in [x], the multicast address to be used for announcements is the highest multicast address in the relevant administrative scope zone, e.g., if the scope range is 239.16.32.0 - 239.16.33.255, then SAP announcements use 239.16.33.255
    - IPv6 sessions are announced on the address FF0X:0:0:0:0:0:2:7FFE where X is the 4-bit scope value, e.g., an announcement for a link-local session assigned the address FF02:0:0:0:0:0:1234:5678, is advertised on SAP address FF02:0:0:0:0:0:2:7FFE
- has same scope as the session it is announcing (the use of TTL scoping for multicast is discouraged)
- IP time-to-live of 255

Maguire
maguire@it.kth.se

Session Announcement Protocol (SAP)
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Practical Voice Over IP (VoIP): SIP and related protocols

References and Further Reading

SAP

[34] M. Handley, C. Perkins, and E. Whelan, RFC 2974: Session Announcement Protocol, October 2000

Maguire

maguire@it.kth.se

References and Further Reading

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Module 5: Session Description Protocol (SDP)

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Session Description Protocol (SDP)

Maguire
maguire@it.kth.se

Session Description Protocol (SDP)
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Practical Voice Over IP (VoIP): SIP and related protocols

Session Description Protocol (SDP)

Defined by RFC 2327 `http://www.ietf.org/rfc/rfc2327.txt`

- describes media session
- a text-based protocol
- carried in MIME as a message body in SIP messages
- uses RTP/AVP Profiles for common media types

Note: It is more a session description **format** than a **protocol**.

Internet drafts:

- SDP Source-Filters `http://www.ietf.org/internet-drafts/draft-ietf-mmusic-sdp-srcfilter-01.txt`
- SDP: Session Description Protocol -- new:
  `http://www.ietf.org/internet-drafts/draft-ietf-mmusic-sdp-new-10.txt`
- Grouping of media lines in SDP [39]
- Connection-Oriented Media Transport in SDP

  `http://www.ietf.org/internet-drafts/draft-ietf-mmusic-sdp-comedia-04.txt`

- RTCP attribute in SDP `http://www.ietf.org/internet-drafts/draft-ietf-mmusic-sdp4nat-02.txt`

Maguire
maguire@it.kth.se

Session Description Protocol (SDP)
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Practical Voice Over IP (VoIP): SIP and related protocols

- Key Management Extensions for SDP and RTSP

  http://www.ietf.org/internet-drafts/draft-ietf-mmusic-kmgmt-ext-05.txt

Maguire

maguire@it.kth.se

Session Description Protocol (SDP)

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Practical Voice Over IP (VoIP): SIP and related protocols

SDP Message Details

```
v=0
o=Tesla 289084526 28904526 IN IP4 lab.high-voltage.org
s=-
c=IN IP4 100.101.102.103
t=0 0
m=audio 49170 RTP/AVP 0
a=rtpmap:0 PCMU/8000
```

- Version number (ignored by SIP)

- Origin (not used by SIP)

- Subject (ignored by SIP)

- Connection Data
  - connection: network (IN == Internet), Address type (IPv4), and Address

- Time (ignored by SIP): `start stop`

- Media (type, port, RTP/AVP Profile)

- Attribute (profile, CODEC, sampling rate)

Maguire
maguire@it.kth.se

SDP Message Details
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Session description

```
v= protocol version
o= owner/creator and session identifier
s= session name
[i= session information]              { [xx] ⇒ xx is optional}
[u= URI of description]
[e= email address]
[p= phone number]
[c= connection information- not required if included in all media]
[b= bandwidth information]
<< One or more time descriptions (see below) >>
[z= time zone adjustments]
[k= encryption key]
[a= zero or more session attribute lines]*
<< Zero or more media descriptions (see below) >>
```

Time description

```
t= time the session is active
[r= zero or more repeat times]*
```

Media description

```
m= media name and transport address
[i= media title]
[c= connection information-optional if included at session-level]
[b= bandwidth information]
[k= encryption key]
[a= zero or more media attribute lines]*
```

SDP Offer/Response Example

`v=0`	Version of SDP (0)
`o=`	Origin - not use by SIP
`c=IN IP4 130.237.212.6`	Connection INternet, IPv4, address=130.237.212.6
`t=`	Time - not use by SIP
`m=video 4004 RTP/AVP 14 26`	Media **Video**, port=4004, type=RTP/AVP profile, profiles: 14 and 26
`a=rtpmap:14 MPA/90000`	Attribute for profile 14, codec=MPA, sampling rate=90000
`a=rtpmap:26 JBEG/90000`	Attribute for profile 26, codec=JBEG, sampling rate=90000
`m=audio 4006 RTP/AVP 0 4`	Media **Audio**, port=4006, type=RTP/AVP profile, profiles: 0 and 4
`a=rtpmap:0 PCMU/8000`	Attribute for profile 0, codec=PCMU (PCM µlaw), sampling rate=8000
`a=rtpmap:4 GSM/8000`	Attribute for profile 4, codec=GSM, sampling rate=8000

Maguire
maguire@it.kth.se

SDP Offer/Response Example
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SDP Response Example

```
v=0
```
Version of SDP (0)

```
o=
```
Origin - not use by SIP

```
c=IN IP4 130.237.21.87
```
Connection INternet, IPv4, address=130.237.21.87

```
t=
```
Time - not use by SIP

```
m=video 0 RTP/AVP 14
```
Media **Video**, port=0, type=RTP/AVP profile, profiles: 14
Receiver declines the video, indicated by port = 0

```
m=audio 6002 RTP/AVP 4
```
Media **Audio**, port=6002, type=RTP/AVP profile, profiles: 4
Receiver declines the PCM coded audio and selects the GSM coded audio

```
a=rtpmap:4 GSM/8000
```
Attribute for profile 4, codec=GSM, sampling rate=8000

Maguire
maguire@it.kth.se

SDP Response Example
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Session Modification
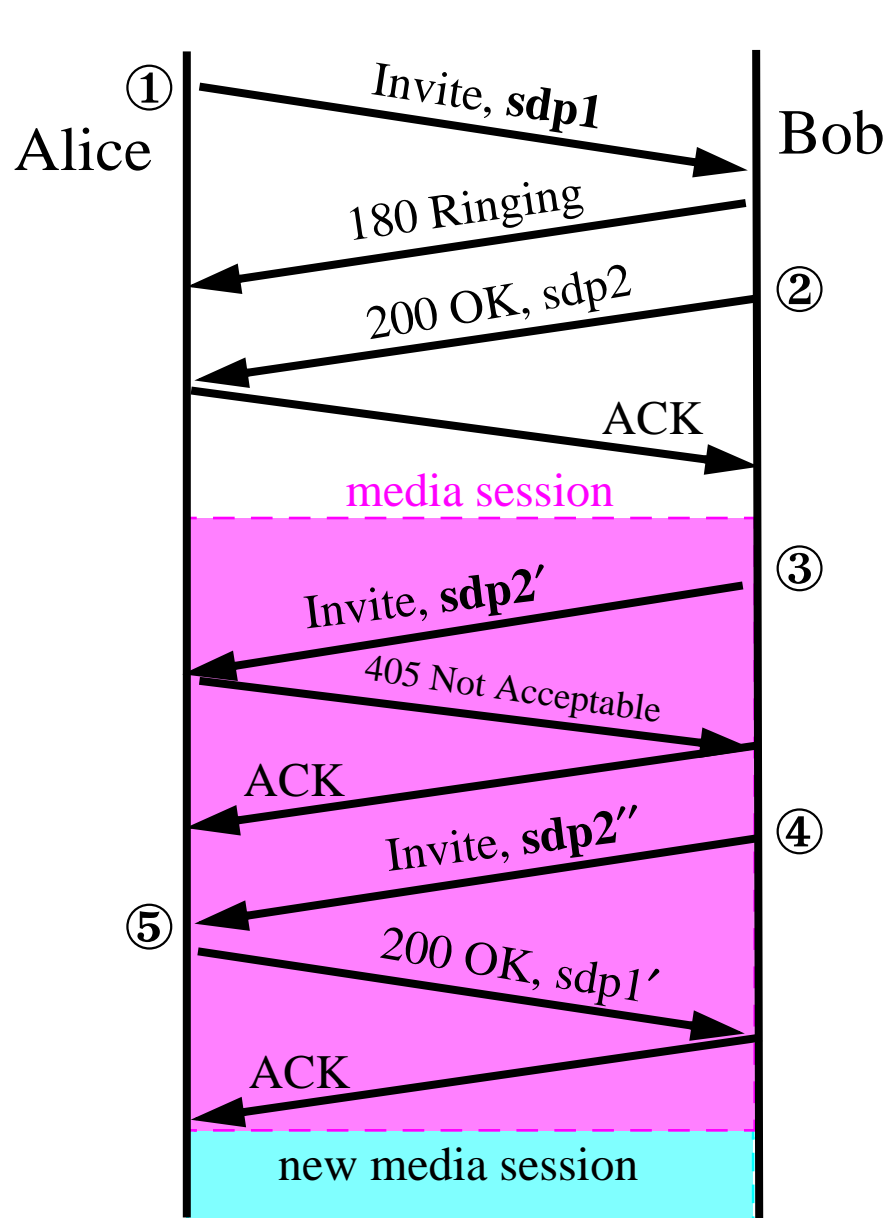
①Alice invite's Bob to a session with the parameters in sdp1

②Bob's modified this in his response sdp2.

They communicate

③ Bob proposes a change in the session (sdp2′), Alice does not accept this change

④ Bob tries with a new proposal (sdp2″)

⑤ Alice accepts with the session description sdp1′

They communication with the new spec.

Maguire
maguire@it.kth.se

Session Modification
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Session modification (continued)

- The re-`INVITE` could have been done by either party - it uses the same `To`, `From`, and `Call-ID` as the original `INVITE`.

- Note that the re-`INVITE`s do not cause a `180 Ringing` or other provisional messages, since communication between Alice and Bob is already underway.

- Note that the first media session continues despite the SIP signalling, until a new agreement has been reached - at which time the new media session replaces the former session.

- The re-INVITE can propose changes of any of the media characteristics, including adding or dropping a particular media stream.
    - this adding or dropping may be because the user has moved from one wireless cell to another, from one network to another, from one interface to another, from one device to another, …

Maguire
maguire@it.kth.se

Session modification (continued)
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Start and Stop Times

Enable the user to join a broadcast sessions during the broadcast.

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maguire@it.kth.se
Start and Stop Times
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Practical Voice Over IP (VoIP): SIP and related protocols

Grouping of Media Lines in the Session Description Protocol (SDP)[39]

Defines two SDP attributes:

- "group" and
- "mid" - media stream identification

Allows grouping several media ("m") lines together. This is to support:

- Lip Synchronization (LS) and
- Flow Identification (FID) - a single flow (with several media streams) that are encoded in different formats (and may be received on different ports and host interfaces)
  - Changing between codecs (for example based on current error rate of a wireless channel)

Note FID does **not** cover the following (but SDP can -- see [39]):

- Parallel encoding using different codecs
- Layered coding

Maguire
maguire@it.kth.se
Grouping of Media Lines in the Session Description Protocol (SDP)[39]
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Lip Synchronization

Example adapted from section 6.1 of [39].

A session description of a conference that is being multicast. First and the second media streams MUST be synchronized.

```
v=0
o=Laura 289083124 289083124 IN IP4 one.example.com
t=0 0
c=IN IP4 224.2.17.12/127
a=group:LS 1 2
m=audio 30000 RTP/AVP 0
```
i=voice of the speaker who speaks in English
```
a=mid:1
m=video 30002 RTP/AVP 31
```
i=video component
```
a=mid:2
m=audio 30004 RTP/AVP 0
i=This media stream contains the Spanish translation
a=mid:3
```

Maguire
maguire@it.kth.se

Lip Synchronization
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Practical Voice Over IP (VoIP): SIP and related protocols

Next generation of SDP (SDPng)

- Designed to address SDP's 'flaws':
  - Limited expressiveness
    - For individual media and combinations of media
    - Often only very basic media descriptions available -- desire for more complex media
  - No real negotiation functionality - as SDP today is a "take it or leave it" proposal
  - Limited extensibility (not nearly as easy to extend as SIP)
  - No semantics for media sessions! Sessions are only implicit.

- SDPng should avoid "second system syndrome"
  - Hence it **should** be simple, easy to parse, extensible, and have limited scope

Session Description and Capability Negotiation

http://www.ietf.org/internet-drafts/draft-ietf-mmusic-sdpng-05.txt

SDPng Transition *http://www.ietf.org/internet-drafts/draft-ietf-mmusic-sdpng-trans-01.txt*

Maguire
maguire@it.kth.se

Next generation of SDP (SDPng)
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Practical Voice Over IP (VoIP): SIP and related protocols

SDPng structure

Uses XML syntax and the following structure

Definitions	optional
	maybe "imported"
Potential and Actual Configurations	SDP m=blocks
	refers to definitions
Constraints	on configurations "optional"
Session Attributes	SDP session attributes +stream semantics

Maguire
maguire@it.kth.se

SDPng structure
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Practical Voice Over IP (VoIP): SIP and related protocols

References and Further Reading

SDP

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[39] G. Camarillo, G. Eriksson, J. Holler, and H. Schulzrinne, Grouping of Media Lines in the Session Description Protocol (SDP), IETF RFC 3388, December 2002 *http://www.ietf.org/rfc/rfc3388.txt*

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Maguire
maguire@it.kth.se
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Maguire

maguire@it.kth.se

References and Further Reading

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Module 6: DNS and ENUM

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Telephony URL and Phone-Context

SIP URIs include Telephony URLs.

A Telephony URL looks like:

```
tel: +358-555-1234567  a telephone terminal
fax: +358-555-1234567  a fax machine
```

Digit seperators of "-" or "." are ignored.

A Phone-Context sets the conditions under which the number can be used, e.g.

```
tel: 1-800-555-1234;phone-content:+1 972
```

- a phone number that can only valid within North America (+1) and within the 972 exchange

- the absense of the "+" in the telephone number indicates that this is a local number, rather than a global number -- but the interpretation of these local numbers is problematic (since there is no assured geographic area nor can one depend on 7 digit numbers being local to a Class 5 exchange {even though this is traditionally the case in North America})

Maguire
maguire@it.kth.se

Telephony URL and Phone-Context
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP URL

used in SIP messages to indicate: originator (From), current destination (Request-URI), final destination (To), and redirection address (Contact)

Examples:

sip:firstname.lastname@company.com	simple example
sip:+1-212-555-1212@gateway.com;user=phone	a call from the Internet to the PSTN E.164 phone number (user=phone is not necessary, but just a hint to parsers that it is a numeric phone number)
sip:+1-212-555-1212@proxy.gateway.com;user=phone	proxy server determines gateway and forwards the request
sip:firstname.lastname@registrar.com;method=register	to register a user at a SIP registrar

Maguire
maguire@it.kth.se

SIP URL
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DNS

Scales well (due to caching)

ENUM typically uses a 3 layer hierarchy

- TLD - top level domain for telephone numbers is: **e164.arpa**
- NAPTR - Naming Authority Pointer [41] - a national EMUM delegation authority (for example zone 1.e164.arpa of +1, i.e., North America)

```
> set querytype=NAPTR
> e164.arpa
Authoritative answers can be found from:e164.arpa
origin = ns.ripe.net
mail addr = e164-contacts.ripe.net
serial = 2002100901
refresh = 14400 (4H)
retry   = 3600 (1H)
expire  = 2419200 (4W)
minimum ttl = 14400 (4H)
```

- Third level **directory server** (such as the Lightweight Directory Access Protocol (LDAP)) or SIP Servers

For details see RFC 2916[42] and RFC 2915[41].

Maguire
maguire@it.kth.se

DNS
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ENUM

IETF's E.164 Number Mapping standard uses Domain Name Server (DNS) to map standard International Telecommunication Union (ITU-T) international public telecommunications numbering plan (E.164) telephone numbers to a list of Universal Resource Locators (URL). SIP then uses those URL's to initiate sessions.

For example, ENUM DNS converts a telephone number in E.164 format, e.g. +46812345, and returns e.g., a Universal Resource Identifier (URI) SIP:olle.svenson@telia.se

Thus a SIP client makes a connection to the SIP gateway telia.se passing the local part olle.svenson.

ENUM can return a wide variety of URI types.

Maguire
maguire@it.kth.se

ENUM
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To find the DNS names for a specific E.164 number

Procedure is:

- Write the E.164 number in its full form, including the countrycode IDDD. Example: +46-8-9761234

- Remove all non-digit characters with the exception of the leading '+'. Example: +4689761234

- Remove all characters with the exception of the digits. Example: 4689761234

- Put dots (".") between each digit. Example: 4.6.8.9.7.6.1.2.3.4

- Reverse the order of the digits. Example: 4.3.2.1.6.7.9.8.6.4

- Append the string ".e164.arpa" to the end. Example: 4.3.2.1.6.7.9.8.6.4.e164.arpa

Maguire
maguire@it.kth.se

To find the DNS names for a specific E.164 number
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ENUM Services

- *www.netnumber.com*

- Neustar (*www.neustar.com*) has their ENUM activity at

  http://www.enum.org/

- EnumWorld (a venture between Network Solutions & Telcordia)

  www.enumworld.com

See also *http://www.enumforums.org/*

Maguire
maguire@it.kth.se

ENUM Services
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP goes beyond ENUM

by offering additional features:

- User preferences

- Personal/Service/… mobility[1]

- Easy and secure updating of information by the end-user

A given User Agent need not directly implement call routing, LDAP lookup, …, but can instead utilize a default SIP outgoing proxy (which in turn does the work).

Call Processing Language (CPL) can be used to support rapid changes in user preferences (see **Call Processing Language (CPL)** on page 225)

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1. See **SIP Mobility** on page 217.

Maguire
maguire@it.kth.se

SIP goes beyond ENUM
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Practical Voice Over IP (VoIP): SIP and related protocols

References and Further Reading

DNS

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ENUM

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Maguire
maguire@it.kth.se

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Module 7: SIP Mobility

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

SIP Mobility

- **Terminal mobility**[1] $\Rightarrow$ the **terminal** moves between **subnets**
    - Note: Mobile IP supports this at the network layer, while SIP supports this at the application layer (*without* requiring Mobile IP be underneath)
- **Personal Mobility** $\Rightarrow$ the **person** moves between **terminals**
- **Service mobility** $\Rightarrow$ the **person** has access to the **same services** *despite* their movement between terminals and/or networks
    - note: the service may be reduced in quality or capabilities subject to the current network's capabilities -- but it is the same service
    - this implies that personalization of services must be distributed to the various terminals that the user wishes to use - see the dissertation of Roch Glitho[45]
- **Session mobility** $\Rightarrow$ the **same session** is maintained despite the user changing from one device to another

---

1. Also known as network-level mobility.

Maguire
maguire@it.kth.se

SIP Mobility
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Practical Voice Over IP (VoIP): SIP and related protocols

Local Number Portability

In the PSTN this means a complex set of lookups for the number, since the number is no longer tied to an exchange.

In SIP the portability occurs because of the lookup of `name@domain`, which can be mapped to whereever the user wants this mapped to! (i.e., fully qualified domain names are *unique*, but are **not** tied to an underlying network address -- it is the name to address mapping which estabilishes this mapping and it is ***always*** **dynamic**).

Maguire
maguire@it.kth.se

Local Number Portability
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References and Further Reading

SIP Mobility

[44] SIP Mobility informal meeting: Unedited Version of SIP-Mobile Minutes, 50th IETF, 730-830pm, March 20th 2001 at Salon A, Minneapolis, Minnesota, *http://www.research.telcordia.com/SIP-mobile/sip-mobile-minutes-50.htm*

Service Mobility

[45]   Roch H. Glitho, A Mobile Agent Based Service Architecture for Internet Telephony, Doctoral Dissertation, Royal Institute of Technology, April 2002.

Maguire
maguire@it.kth.se
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Module 8: SIP Service Creation

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly,
Practical VoIP: Using VOCAL, O'Reilly, 2002, ISBN 0-596-00078-2 ***and***
Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP:
Delivering VoIP and Multimedia Services with Session Initiation Protocol*,
Wiley, 2001, ISBN: 0-471-41399-2.

SIP Service Creation

It is the increased opportunities for the exchange of signaling information via SIP which enables many new features and services.

Maguire
maguire@it.kth.se

SIP Service Creation
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Practical Voice Over IP (VoIP): SIP and related protocols

Services implemented by x

Where x is:

- proxy server,
- called user agent,
- calling user agent, or
- Back-to-Back User Agent (B2BUA)

See examples of call-forward, no-answer service in chapter 6 of Sinnreich and Johnston[2].

Maguire
maguire@it.kth.se

Services implemented by x
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Services implemented by Extensions

i.e., new methods and headers

See the activities of the IETF SIP, SIPPING, and SIMPLE working groups

Proxy servers - simply treat unknown methods as an `OPTION` request, unless there is a `Proxy-Require` header.

User agents return:

`405 Method Not Allowed`	if the method is recognized, but not supported
`500 Bad Request`	if it does not recognize the method
`420 Bad Extension`	if the UAS does not support the requested feature

- All SIP extensions which use the `Require` or `Supported` header[1] **must** be documented as an RFC - to prevent interoperability problems
- All standardized SIP extensions **must** document how the extension interacts with elements that **don't understand** this extension

---

1. See **Other header fields** on page 139

Maguire
maguire@it.kth.se

Services implemented by Extensions
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SIP Service Logic
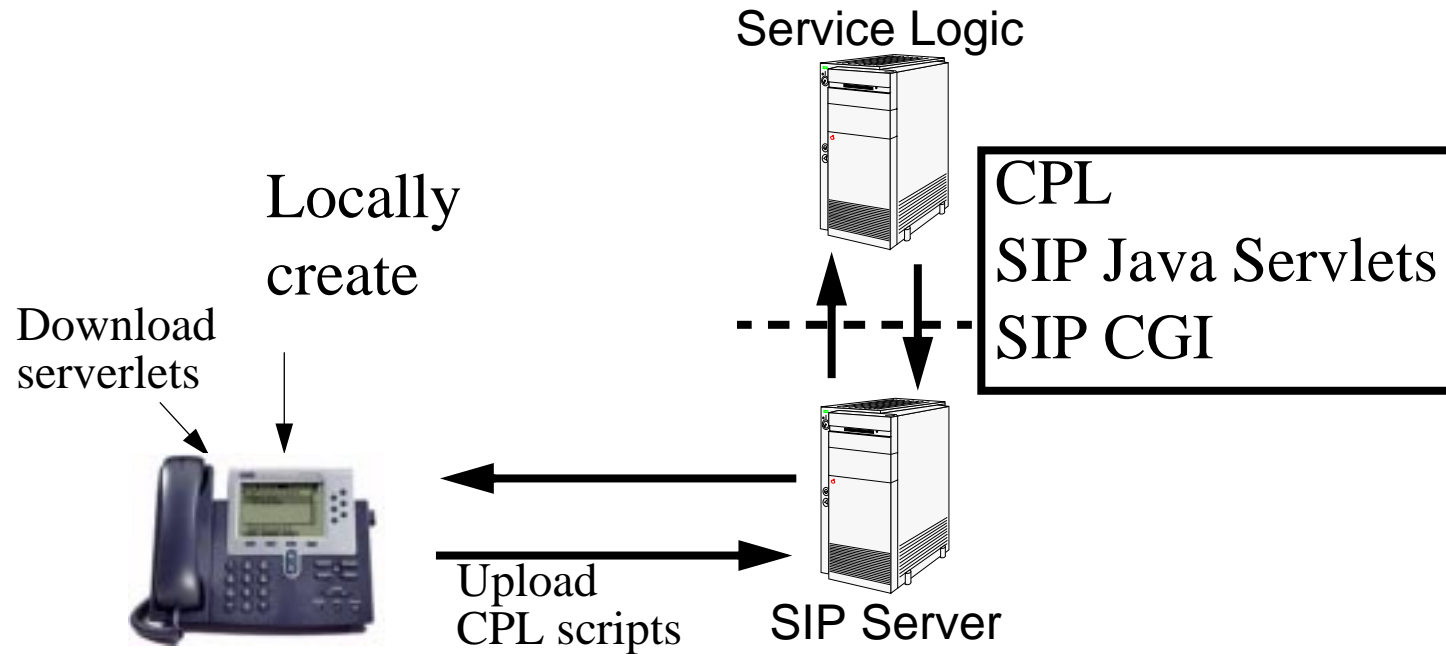
- Call Processing Language (CPL)
- SIP Common Gateway Interface (CGI)
- SIP Java Servlets

Maguire
maguire@it.kth.se

SIP Service Logic
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Practical Voice Over IP (VoIP): SIP and related protocols

Call Processing Language (CPL)

RFC 2824: Call Processing Language (CPL) [46]

An XML-based scripting language for describing and controlling call services.

CPL is a very simple language without variables, loops, or the ability to run external programs! {Hence non-trusted end users can upload services to their SIP server} However, it has **primitives for making decisions** and **acting based on call properties** (e.g., time of day, caller, called party, …).

There is a Document Type Definition (DTD) "cpl.dtd" and strict parsing[1] is done based on this DTD.

Details at:
http://www.ietf.org/internet-drafts/draft-ietf-iptel-cpl-06.txt

See also Chapter 13 of *Practical VoIP: Using VOCAL*[1], this includes an example of developing a feature in CPL

---

1. Thus **any** discrepancies between the script and the scheme are errors.

Maguire
maguire@it.kth.se
Call Processing Language (CPL)
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Common Gateway Interface (CGI)

RFC 3050: Common Gateway Interface for SIP [47]

Similar to HTML CGI, a SIP CGI script resides on the server and passes message parameters via environment variables to a separate process. This process sends instructions back to the server through its standard output file descriptor.

Scripts can be written in Perl, Tcl, C, C++, Java, …

Of course these scripts (being based on general purpose programming languages) do **not** have the limitations of CPL and hence **only trusted users** can be allowed to provide such scripts.

CGI scripts have access to both the request headers and the body and can therefore do general computations based on all this information.

Maguire
maguire@it.kth.se

SIP Common Gateway Interface (CGI)
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SIP Java Servlets

Extends functionality of SIP client by passing messages to the SIP servelets.

Servlets are similar to the CGI concept, but instead of using a separate **process**, the messages are passed to a class that runs within a Java Virtual Machine (JVM) *inside the server.*

Servlets are portable between servers and operating systems, due to the portability of the Java code.

For details see: K. Peterbauer, J. Stadler, et al., "SIP Servlet API Extensions", February 2001, *http://www.cs.columbia.edu/sip/drafts/draft-peterbauer-sip-servlet-ext-00.txt*

SIP Servlets were defined in A. Kristensen and A. Byttner, "The SIP Servlet API", IETF Draft, September 1999,

http://www.cs.columbia.edu/sip/drafts/draft-kristensen-sip-servlet-00.txt

Unfortunately this draft expired and was not carried forward, but is referenced (and large parts included) in subsequent work. See also [48].

Maguire
maguire@it.kth.se

SIP Java Servlets
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JAIN APIs

Providing a level of abstraction for service creation across circuit switched and packet networks, i.e., bridging IP and IN protocols. Goal is provisioning of telecom services by:

- Service Portability: - Write Once, Run Anywhere. (via Java portability)
- Network Convergence: (Integrated Networks) - Any Network
- Service Provider Access - By Anyone!
  - to allow services direct access to network resources and devices

Three SIP APIs within the JAIN initiative:

- JAIN SIP - a low level API that maps directly to RFC 2543
- JAIN SIP Lite - a high-level API, to allow application developers to create applications that have SIP as their underlying protocol **without** needing extensive knowledge of SIP.
- SIP Servlets

The JAIN Service Provider APIs (SPA) are a Java implementation of Parlay APIs.

Maguire
maguire@it.kth.se

JAIN APIs
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Parlay

Parlay Group formed (1998) to specify and promote open APIs that "intimately link IT applications with the capabilities of the communications world".

Goal: to allow applications to access the functionality of the telecoms network in a secure way.

Parlay APIs:

- Service interfaces - provide access to network capabilities and information
- Framework interfaces provide the underlying supporting necessary for the service interfaces to be secure and manageable.

The APIs are defined in Universal Modeling Language (UML).

For further info see: *http://www.parlay.org/* and [52].

Maguire
maguire@it.kth.se

Parlay
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Request-URIs for Service Control

B. Campbell and R. Sparks, "Control of Service Context using SIP Request-URI", IETF RFC 3087, April 2001

Proposes a mechanism to communicate context information[1] to an application (via the use of a distinctive Request-URI).

Using different URIs to provide both state information and the information about lead to this state transition (for example, you were forwarded to the voicemail system because the user did not answer vs. being forwarded to the voicemail system because the user is busy with another call).

---

1. Call state information, such as the calling party, called party, reason for forward, etc.

Maguire
maguire@it.kth.se

SIP Request-URIs for Service Control
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Reason **Header**

Since it is (often) useful to know why a Session Initiation Protocol (SIP) request was issued, the `Reason` header was introduced. It encapsulates a final status code in a provisional response.

This functionality was needed to resolve the "Heterogeneous Error Response Forking Problem" (HERFP).

For details see [53].

Maguire
maguire@it.kth.se

Reason Header
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Voice eXtensible Markup Language (VoiceXML ™)

VoiceXML designed for creating audio dialogs (i.e., audio **in** and **out**) that feature: synthesized speech, digitized audio, recognition of spoken and DTMF key input, recording of spoken input, telephony, and mixed-initiative conversations.

Goal: To bring the advantages of web-based development and content delivery to interactive voice response applications.

For details see: *http://www.w3.org/TR/voicexml*

Open VXI VoiceXML Interpreter (*http://sourceforge.com/projects/openvxi*) - an open source library to interpret VoiceXML.

VoiceXML is designed to go beyond Interactive Voice Response (IVR) systems.

Maguire
maguire@it.kth.se
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JAIN

[49] JAIN website: *http://java.sun.com/products/jain*

[50]   Java Community Process website: *http://jcp.org/*

[51] JAIN SIP 1.0 API specification

Parley

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Maguire
maguire@it.kth.se

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Telecommunication Networks opened by the Parlay Service Interface", M.S. Thesis, Dept. of Microelectronics and Information Technology, Royal Institute of Technology, Sept. 2002

Reason **Header**

[53] H. Schulzrinne, D. Oran, and G. Camarillo, "The Reason Header Field for the Session Initiation Protocol (SIP)", IETF RFC 3326, December 2002

ftp://ftp.rfc-editor.org/in-notes/rfc3326.txt

Maguire
maguire@it.kth.se
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Module 9: User Preferences

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

User Preferences

- ## Caller preference
  - allows caller to specify how a call should be handled
  - to specify media types: audio, video, whiteboard, …
  - to specify languages (of the callee -- consider for example a help desk call where you want to get help in *your* choice of language)
  - do you want to reach the callee at home or only at work?, via a landline or on their mobile phone? …
  - examples: should the call be **forked** or recurse, do you want to use a proxy or redirect, do you want to `CANCEL` 200 messages or not,

- ## Called party preference
  - accepting or rejecting calls: based on time of day, day of week, location of called party, from unlisted numbers, …

Caller/callee different
  - Callee is **passive**, caller is **active**
    - Thus callee's preferences must be defined ahead of time (for example by CPL)
    - However, caller's preferences can be in request
  - Services (usually) run on callee server
  - A given caller might contact any of a large number of number of servers (each of which will have to decide how to process this caller's request)

Conclusion: Include **caller** preferences in request

Maguire
maguire@it.kth.se

User Preferences
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Contact parameters

Values are either pre-set or indicated when a user REGISTER's:

Parameter	Value	example(s)	Explaination of example(s)
class	personal business	class=personal	Call should go the "home" not the office.
duplex	full half send-only receive-only	duplex=full	should be a full duplex call
feature	voicemail attendant	feature=voicemail	Caller wants to be connected to voicemail server
language	language tag	language="en,de,se,!fi"	Connect caller to someone who speaks English, German, Swedish, not Finnish
media	MIME types	media="text/html"	use HTML as the media type
mobility	fixed mobile	mobility=fixed	connect to the callee's fixed rather than mobile terminal
priority	urgent emergency non-urgent	priority=urgent	call is urgent (as seen by the caller).
service	fax | IP | ISDN | PSTN | text	service=IP	use IP rather than fax/ISDN/PSTN/…

Maguire
maguire@it.kth.se

Contact parameters
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Contact header example

```
Contact: maguire <sip:maguire@it.kth.se> ;language="en,de,se,!es"
        ;media="audio,video,application/chat"
        ;duplex="full"
        ;priority="urgent"
```

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maguire@it.kth.se

Contact header example
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Accept/Reject-Contact header(s)

SIP request contains Accept-Contact and Reject-Contact headers

`Reject-Contact` indicates URI's not acceptable

`Accept-Contact` indicates ordered list of acceptable URI's

Indication by means of rules
- set intersection and non-intersection of parameters
- string match of URIs

Example:

```
Accept-Contact: sip:sales@acme.com ;q=0,
    ;media="!video" ;q=0.1,
    ;mobility="fixed"  ;q=0.6,
    ;mobility="!fixed" ;q=0.4
```

In the second example, the caller does **not** want to talk to sales@acme.com, but has a preference for video and somewhat prefers the user's fixed to non-fixed (i.e., mobile) terminal.

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maguire@it.kth.se

Accept/Reject-Contact header(s)
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Callee (i.e., called party) Parameter processing

- Proxy obtains list of URI's and the parameters for each, for callee
- Those that match a rule in Reject-Contact are discarded
- Matching set of URI's determined
- q parameters merged
- Result split into sets of q-equivalency classes
- Parallel search of highest preference q-equivalence class

Maguire
maguire@it.kth.se
Callee (i.e., called party) Parameter processing
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Accept-Contact Example

example from *http://www.ietf.org/proceedings/99nov/I-D/draft-ietf-mmusic-sip-caller-00.txt*

sip:mjh@aciri.org;language=en;media=audio,video;q=.8

sip:m.handley@acm.org;class=business;q=0.3

From Location Service

INVITE
sip:mark.handley@company.co

PROXY

INVITE sip:markh@aol.com
SIP/2.0

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maguire@it.kth.se

Accept-Contact Example
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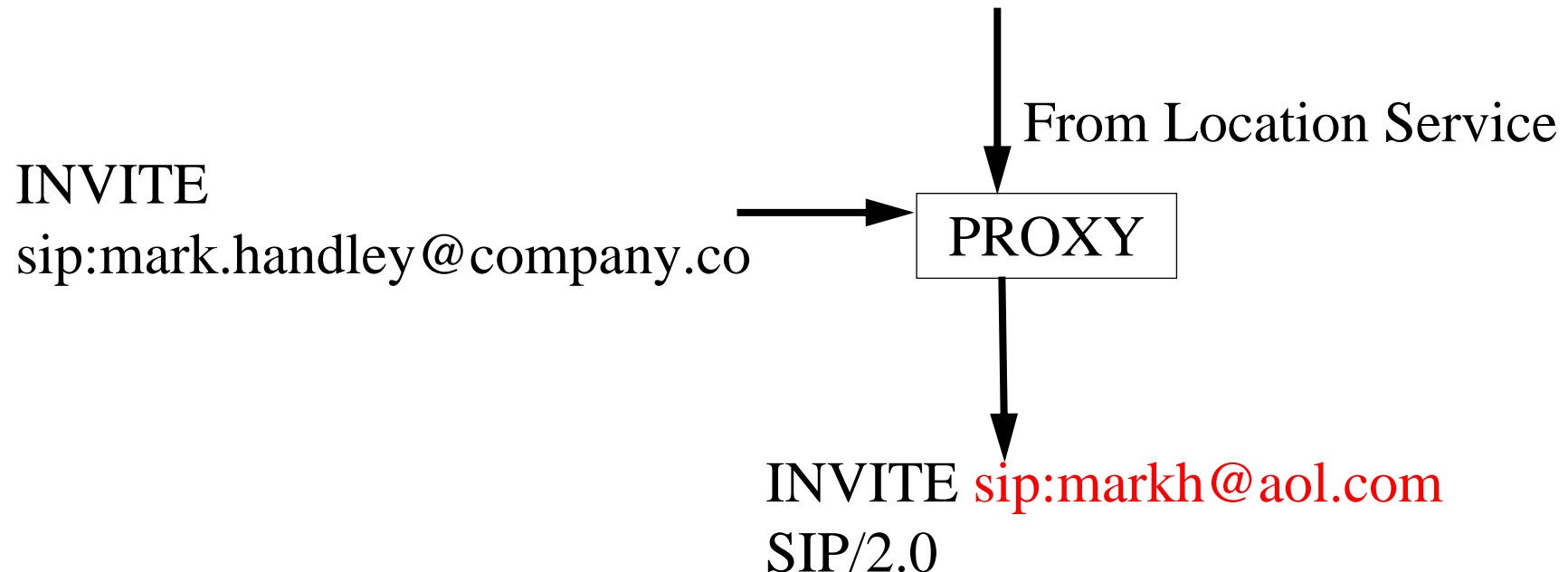
Request-Disposition

Defines services desired from proxy servers

Feature values	Meaning
proxy redirect	whether to proxy or redirect
cancel no-cancel	whether to return just the first 200-class response, or all 2xx responses
fork no-fork	whether to fork or not (i.e., proxy to only a single address)
recurse no-recurse	whether a proxy server upon receiving a 3xx-class response should recurse (i.e., send requests to the addresses listed in the response) or not (i.e., simply forward the list of addresses upstream towards the caller)
parallel sequential	For a forking proxy server, should it send the request to all known addresses at once (parallel), or go through them sequentially, i.e., contacting the next address only after receiving a non-2xx or non-6xx final response.
queue no-queue	If called party is temporarily unreachable, caller can indicate that it wants to enqueue rather than be rejected immediately. Pending call be terminated by a SIP CANCEL or BYE request.

Based on a list of keywords

- **example**: `Request-Disposition: fork, parallel`

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maguire@it.kth.se

Request-Disposition
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SIP Service Examples

Some examples of SIP Services are listed below (from [55])

Call Hold	Single Line Extension
Consultation Hold	Find-Me
Music On Hold	Call Management (Incoming Call Screening)
Unattended Transfer	Call Management (Outgoing Call Screening)
Attended Transfer	Call Park
Call Forwarding Unconditional	Call Pickup
Call Forwarding - Busy	Automatic Redial
Call Forwarding - No Answer	
3-way Conference - Third Party is Added	
3-way Conference - Third Party Joins	

You should compare these to the list we saw earlier: **Features** on page 175

Maguire
maguire@it.kth.se

SIP Service Examples
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User Preferences

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Maguire
maguire@it.kth.se
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Module 10: SIP Security, NATs, and Firewalls

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

SIP Security

SIP Security - RFC 3261 [57]

If you want to secure **both** the SIP and RTP traffic, then you should probably be using an IPSec VPN.

SIP's rich signalling means that the traffic reveals:

- caller and called parties IP addresses
- contact lists
- traffic patterns

For further details concerning how complex it is to protect such personal information see the dissertation by Alberto Escudero-Pascual, "Privacy in the next generation Internet, Data Protection in the context of European Union Data Protection Policy" [68].

For an example of a **call anonymizer service** -- using a back-to-back user agent (B2BUA), see figure 8.6 on page 121 of Sinnreich and Johnston.

Maguire
maguire@it.kth.se

SIP Security
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SIP Digest Authentication

Built upon HTTP's challenge/response mechanism

Challenges:

- `401 Authentication Required` **or**
- `407 Proxy Authorization Required`

Header fields:

Digest	the schema name
username="A"	The user name as specified in the credentials
realm="sip:proxy.com"	realm - copied from the challenge realm indicates the domain for the authentication
nonce="e288df84f1cec4341ade6e5a359"	nonce - copied from the challenge a unique string - typically generated from a timestamp (and possibly a seed), then encrypted with the user's private key
opaque="63632f41"	opaque string which should be returned unchanged to be matched against the challenge (allows for a stateless system)
uri="sip:UserB@there.com"	URI from the `Request-URI`
response="1d19580cd833064324a787ecc"	message digest computed using user's credentials and the nonce

Maguire
maguire@it.kth.se

SIP Digest Authentication
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SIP and S/MIME

RFC 3261 describes the use of Secure MIME (S/MIME) message bodies:

- SIP header fields can be encrypted in an S/MIME message body
- see RFC 2633 [58]

Provides:

- Message integrity
  - Allows detection of any modification of message contents
- Message privacy
  - Private headers protected by S/MIME
- Identity
  - Certificates can be verified to validate identity

Maguire
maguire@it.kth.se
SIP and S/MIME
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SDP & RTP security

As noted earlier SDP enables you to say that you will encrypt the media stream which is sent via RTP - such as DES in CBC Mode (DES-CBC)[1] or AES in f8-mode [60].

This is done via adding to the SDP for each media description:

    k=encryption key

_____

1. All encryption capable RTP clients must support this as their default algorithm. In addition, to prevent known plain text attacks, RTCP headers have a 32 bit random prefix.

Maguire
maguire@it.kth.se

SDP & RTP security
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Secure Real-time Transport Protocol (SRTP)

Provides confidentiality, message authentication, and replay protection for Real-time Transport Protocol (RTP) and RTCP traffic.

Described in an IETF draft "The Secure Real-time Transport Protocol" [63]

http://www.ietf.org/internet-drafts/draft-ietf-avt-srtp-05.txt

Maguire
maguire@it.kth.se

Secure Real-time Transport Protocol (SRTP)
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NATs and Firewalls

Because Network Address Translation (NAT) devices change addresses and sometimes port numbers and because addresses and port numbers are **inside** both SIP and SDP there can be a problem!

Fredrik Thernelius, "SIP, NAT, and Firewalls", looked at this in detail in his M.Sc. thesis[64].

See also the other documents at
`http://www.cs.columbia.edu/sip/drafts_firewall.html`

Note: CNAME's in RTCP may need to be updated by the Network Address Translation (NAT) to **hide** private network addresses.

See also pages 237-239 of *Practical VoIP: Using VOCAL*[1]; particularily the example of using a Cisco ATA (Analog Telephone Adaptor) behind a Linksys firewall (which configures the firewall to pass incoming traffic on port 5060, 4000, and 4001 to the Cisco ATA) - which also refers to `http://www.dyndns.org/`

Maguire
maguire@it.kth.se

NATs and Firewalls
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UDP and TCP Firewall Traversal problems

User Agent A   User Agent B

(outside) Firewall (inside)

1. `INVITE/UDP` →

2. `180 Ringing/UDP` ←

3. `200 OK/UDP` ←

RTP packets/UDP ←

4. `INVITE/TCP` →

5. `180 Ringing/TCP` ←

6. `200 OK/TCP` ←

7. `ACK/TCP` →

RTP packets/UDP →
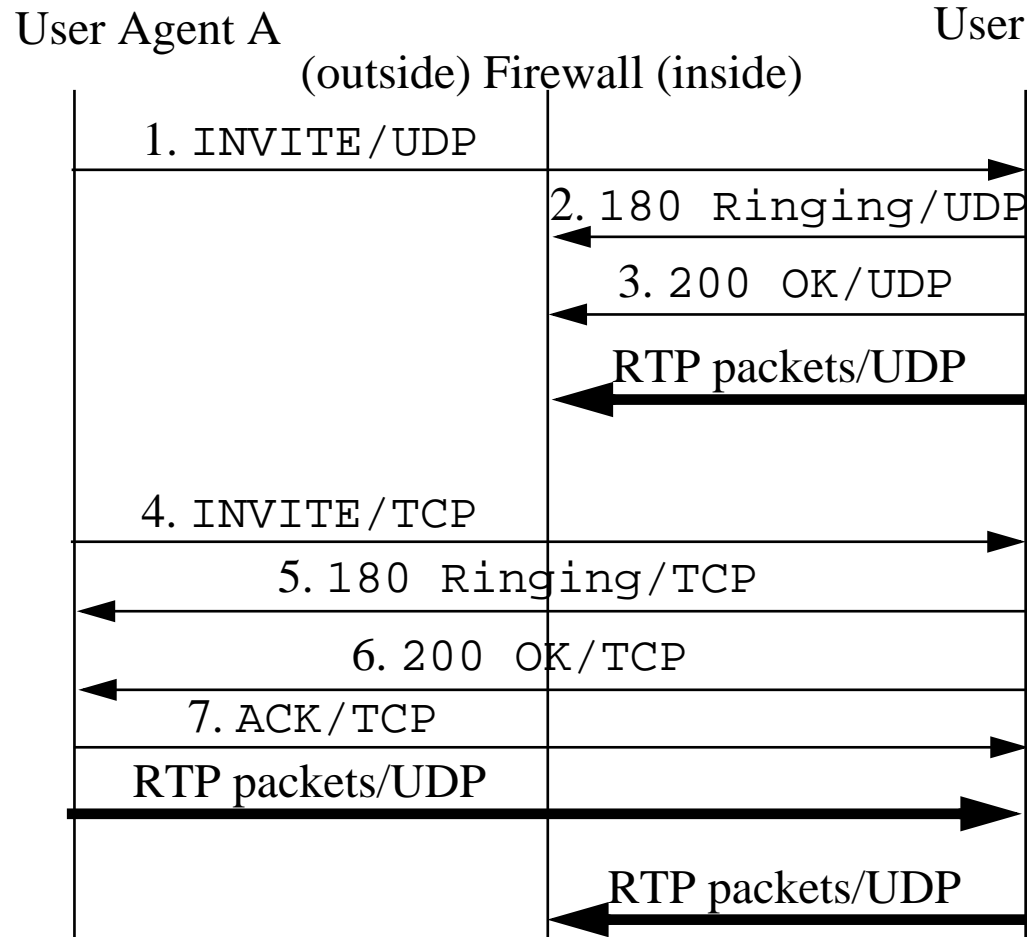
RTP packets/UDP ←

Using UDP all of B's responses and packets are filtered out by the firewall and there is no session!

Using TCP for SIP enables the session to be setup, but B's RTP packets are still filtered out by the firewall!

Maguire
maguire@it.kth.se

UDP and TCP Firewall Traversal problems
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UDP and TCP NAT Traversal problems

User Agent A   (inside)NAT (outside)   **User Agent B**

```
1. INVITE
via:10.1.2.3
Contact: A@10.1.2.3
SDP 10.1.2.3
```

```
2.180 Ringing
via:10.1.2.3; received=1.2.3.4
Contact: B@130.101.102.103
```

```
3.200 OK
via:10.1.2.3; received=1.2.3.4
Contact: B@130.101.102.103
SDP 130.101.102.103
```

```
4. ACK
```

RTP packets to `130.101.102.103`

RTP packets to `10.1.2.3`

BYE A@ `10.1.2.3`

SIP can negociate the NAT, but A's SDP contains a private address

B's RTP packets are directed to a private address and hence can not be routed; similarily B's requests also fail

Maguire
maguire@it.kth.se

UDP and TCP NAT Traversal problems
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SIP Application Level Gateway (ALG) for Firewall Traversal

Use a proxy within the (possibly private) network:
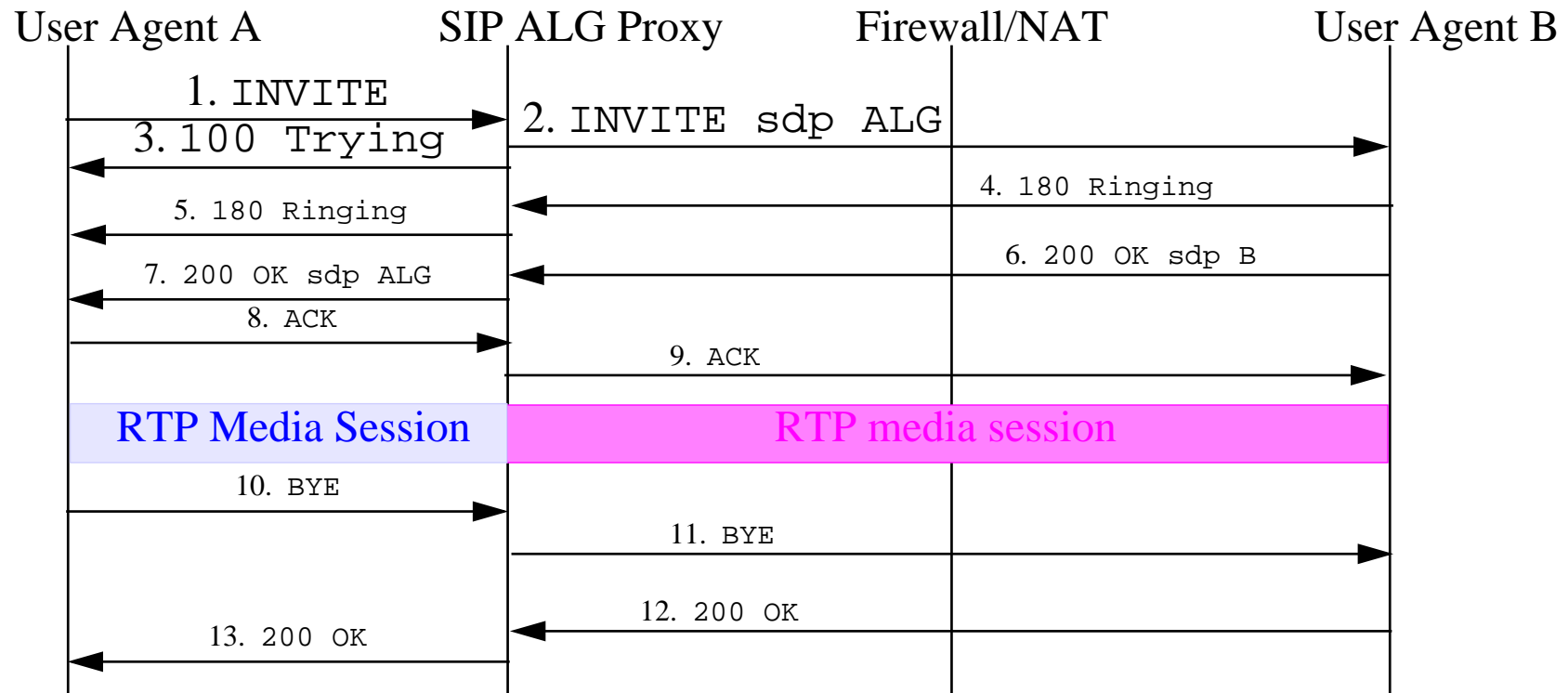
Firewall permits SIP and RTP traffic to/from the Application Level Gateway (ALG) proxy.

Maguire
maguire@it.kth.se
SIP Application Level Gateway (ALG) for Firewall Traversal
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Practical Voice Over IP (VoIP): SIP and related protocols

Middlebox communications (MIDCOM)

User Agent A	Firewall control proxy	Firewall/NAT	User Agent B

1. INVITE →
2. Bind Request →
3. Bind Response ←
4. INVITE →
5. 100 Trying ←
6. 180 Ringing ←
7. 180 Ringing ←
8. 200 OK ←
9. Open Request →
10. Open Response ←
11. 200 OK ←
12. ACK →
13. ACK →

RTP Media Session   **RTP media session**

14. BYE →
15. BYE →
16. 200 OK ←
17. Close Request →
18. Close Response ←
19. 200 OK ←

The generic problem of enabling complex applications through the middleboxes is being addressed by the Middlebox communications (MIDCOM) Working Group, they do so via MIDCOM agents which perform ALG functions, logically external to a middlebox [66].

Maguire
maguire@it.kth.se
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SIP Security

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Maguire
maguire@it.kth.se

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NATs and Firewalls

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Maguire
maguire@it.kth.se
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Maguire
maguire@it.kth.se
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Module 11: SIP Telephony

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly,
Practical VoIP: Using VOCAL, O'Reilly, 2002, ISBN 0-596-00078-2 **and**
Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP:
Delivering VoIP and Multimedia Services with Session Initiation Protocol*,
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SIP Telephony

SIP Telephony (SIP-T) -- for details see RFC 3204 [71].

Gateway between the SIP world and the PSTN world looks like a SIP user agents to other SIP entities and like a terminating telephone switch to the PSTN.

Advantages	Provides ISUP transparency (by carrying ISUP message as multipart MIME messages in the SIP messages between SIP-T gateways)
Disadvantages	Does **not** interwork with SIP
	Perpetuates ISUP!

Maguire
maguire@it.kth.se

SIP Telephony
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Telephony Routing over IP (TRIP)

- TRIP[72] is a gateway to Location Server (LS) protocol
- Designed for an interdomain gateway
- Allows the gateway to advertise what PSTN number range it is a gateway for

For within a domain there is a version for between a gateway and a proxy: TRIP-lite

A Location Server is responsible for a Internet Telephony Administrative Domain (ITAD).

See also: **Telephony Routing over IP (TRIP)[88]** on page 277

Maguire
maguire@it.kth.se

Telephony Routing over IP (TRIP)
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Practical Voice Over IP (VoIP): SIP and related protocols

Call Control Services

Generally include advanced telephony services such as:

- Call Transfer, both Attended and Unattended
- Call Park/Un-Park
- Multistage Dialling
- Operator Services
- Conference Call Management
- Call Mobility
- Call Pickup

See the slides starting on **Intelligent Network service using SIP** on page 172.

Maguire
maguire@it.kth.se

Call Control Services
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Practical Voice Over IP (VoIP): SIP and related protocols

Call Center Redesign using SIP

- Replace the call center switch via VoIP

- Interactive Voice Response (IVR) - using a media server (for pre-recorded clips) and SIP signalling

- Automatic Call Distribution (ACD) - replace with scripts using Call Processing Language (CPL)

- Agent Workstation - a PC with a SIP client

- The agent has access via Web and various databases to information, which can be indexed by the agent using information from the SIP request.

Maguire
maguire@it.kth.se

Call Center Redesign using SIP
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Additional SIP Telephony services

- SIP for the Hearing Impaired
- Emergency Services
- Precedence signalling (military, government, emergency services, …)
- Message Waiting, Voice Mail, and Unified Messaging
- Call Waiting

Maguire
maguire@it.kth.se

Additional SIP Telephony services
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Practical Voice Over IP (VoIP): SIP and related protocols

Emergency Services (E911)

We need to support 3 things[69]:

- There must exist an emergency address (similar to 911, 112, help, …)
- find Public Safety Answering Point (PSAP)
    - outbound proxy -- only if there is a well bounded geographic area servered by this proxy
    - use DNS where the user or device enters a relevant name: e.g., pittsburgh.pa.911.arpa
    - SLP - but scope not likely to coincide with ESR
    - call volume:
        - Sweden: SOSAlarm.se has 20 call centers distributed aound Sweden with ~18 million calls/year with ~20% of them calls to 112 the rest are automatic alarms;
        - US: National Emergency Number Association (NENA) reports >500,000 calls/day or 190 million a year (more than 80% are not emergencies $\Rightarrow$ 311 non-emergency number)
- obtain caller's **identity** and **geographical address**
    - this is done to minimize prank calls
    - caller provides in request
        - Geographic position: N 59° 24.220' E017° 57.029' +/- 77m and/or
        - Geographic Location: "5th floor, Isafjordsgatan 22, Kista, Stockholm, Sweden"
    - or PSAP queries caller
    - or PSAP queries third party based on caller identity

note: Enhanced 911 (E911) - mandated by FCC for cellular phones in US

Maguire
maguire@it.kth.se

Emergency Services (E911)
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Practical Voice Over IP (VoIP): SIP and related protocols

Public Safety Answering Point (PSAP)

For example MapInfo has an E911 database called "PSAP Pro" which contains the following PSAP information for the U.S. :

- 10-digit emergency numbers
- Address information
- Administrative phone number
- Fax number
- Contact person
- Latitude and longitude
- Jurisdictional boundaries

~4,400 records: both primary PSAPs and sheriff's departments and offices in areas not served by a PSAP.

from *http://www.mobileinfo.com/news_2001/issue03/mapinfo_psap.htm*

So finding the nearest one can be done based on geography, but is it the most relevant or useful one?

In Sweden SOS Alarm works with the digital maps of CoordCom.

Location Interopeability Forum: *http://www.locationforum.org/*

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maguire@it.kth.se
Public Safety Answering Point (PSAP)
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Emergency services

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SIP Telephony

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Maguire
maguire@it.kth.se
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Module 12: SIP Conferencing

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 *and* Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Conferencing

- Multimedia conferencing
  - Synchronized Multimedia Integration Language (SMIL) to enable other media (e.g., text, graphics and URLs) to be added to audio/video streams for synchronized display[78]
  - SMIL documents are XML 1.0 documents

- Multipoint conferencing
  - can exploit multicast where available

- Call control for conferencing

Maguire
maguire@it.kth.se

Conferencing
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Practical Voice Over IP (VoIP): SIP and related protocols

Conferencing Models [74]

Type of Conference	Description	Scale
Endpoint mixing	One end point acts as a mixer for all the other end points	small
SIP Server and distributed media	Central SIP server establishes a full mesh between all participants - each participant does their own mixing	medium
Dial-in conference	All participants connect to a conference bridge which does the mixing for each participant	medium
Ad hoc centralized conference	Two users transition to a multiparty conference, by one of them using third-party signaling to move the call to a conference bridge	medium
Large multicast conference	user join the multicast based on the multicast address (which they got via: • annoucement on the web • e-mail • Session Annoucement Protocol (SAP) [77]	small to very large

Commercial conference bridge authenticate the users joining the conference.

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maguire@it.kth.se
Conferencing Models [74]
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SIP Conferencing

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Maguire
maguire@it.kth.se

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SMIL

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Maguire

maguire@it.kth.se

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2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Module 13: Mixed Internet-PSTN Services

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Mixed Internet-PSTN Services

- PSTN and Internetworking (PINT)
- Servers in the PSTN Initiating Requests to Internet Servers (SPIRITS)
- Telephony Routing over IP (TRIP)

Maguire
maguire@it.kth.se

Mixed Internet-PSTN Services
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Practical Voice Over IP (VoIP): SIP and related protocols

PSTN and Internetworking (PINT)[79]

Action from the internet invokes a PSTN service (note: this is **one way** invocation)

Examples

- Request to Call $\Rightarrow$ "Click to Connect" from a web page
- Request to Fax Content $\Rightarrow$ "Click to FAX"
- Request to Speak/Send/Play Content
- …

Based on SIP extensions (SIPext), which in actuality are SDP extensions (i.e., the body of SIP messages). Redefines some methods (`INVITE`, `REGISTER`, and `BYE`) and introduces three new methods:

- `Subscribe` - request completion status of a request
- `Notify` - receive status updates
- `Unsubscribe` - cancel subscriptions

PINT extensions to SDP: Network type (TN) and Address type: RFC2543 (SIP)

Maguire
maguire@it.kth.se

PSTN and Internetworking (PINT)[79]
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Practical Voice Over IP (VoIP): SIP and related protocols

Servers in the PSTN Initiating Requests to Internet Servers (SPIRITS)[82]

Implementing a family of IN services via internet server (rather than in the PSTN)

For example, internet call waiting (ICW) - calling a busy phone in the PSTN network could pop up a call waiting panel on the client that is using this telephone line, this replaces earlier solutions such as:

- for example, Ericsson's PhoneDoubler, Ericsson Review, No. 04, 1997
  http://www.ericsson.com/about/publications/review/1997_04/article55.shtml
- PDF of the entire article:
  http://www.ericsson.com/about/publications/review/1997_04/files/1997041.pdf

SPIRITS protocol *http://www.ietf.org/internet-drafts/draft-ietf-spirits-protocol-02.txt*

SPIRITS unlike PINT allows **two way** interaction between Internet and PSTN.

See also [89].

Maguire
maguire@it.kth.se
Servers in the PSTN Initiating Requests to Internet Servers (SPIRITS)[82]   Module 13:   276 of 280
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Practical Voice Over IP (VoIP): SIP and related protocols

Telephony Routing over IP (TRIP)[88]

Finding a route from the Internet to a gateway nearest to where the call should be terminated

Telephony Routing Protocol is modeled after the Border Gateway Protocol (BGP)

Maguire
maguire@it.kth.se

Telephony Routing over IP (TRIP)[88]
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Practical Voice Over IP (VoIP): SIP and related protocols

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Maguire
maguire@it.kth.se

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Maguire
maguire@it.kth.se

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Maguire
maguire@it.kth.se

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Module 14: AAA and QoS for SIP

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 **and** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Authentication, Authorization, Accounting (AAA)

This become a major issue especially in conjunction with QoS since for better than best effort service, someone probably has to pay for this high QoS - AAA is necessary to decide who you are, if you are allowed to ask for this service, and how much you should be charged. See [94] and "Authentication, Authorization and Accounting Requirements for the Session Initiation Protocol"

`http://www.ietf.org/internet-drafts/draft-ietf-sipping-aaa-req-00.txt`

Maguire
maguire@it.kth.se

Authentication, Authorization, Accounting (AAA)
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Practical Voice Over IP (VoIP): SIP and related protocols

SIP Accounting

For definition of terms see RFC 2975

Purposes:

- controlling resource usage (for example, gateways to PSTN from which someone could place a very expensive international call)
- real-time
  - fraud detection
  - pre-paid subscriptions
- off-line
  - monthly/quarterly billing
  - deriving usage patterns $\Rightarrow$ planning upgrades (resource dimensioning) , input for fraud detection, …

Resources to account for:

- resources used by SIP itself
- resource consumed once initiated by SIP
- services initiated and controlled by SIP {voice mail, media translation/transcoding, …}

Maguire
maguire@it.kth.se
SIP Accounting
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Practical Voice Over IP (VoIP): SIP and related protocols

Open Settlement Protocol (OSP)

(mostly) off-line settlement between operators based on Call Detail Records

Open Settlement Protocol developed as part of ETSI project TIPHON (Telecommunications and Internet Protocol Harmonization Over Networks) [92]

Based on exchange of Extensible Markup Language (XML) messages via HTTP

```
<!DOCTYPE Message [
    <!ELEMENT Message(( PricingIndication |
                        PricingConfirmation|
                        AuthorisationRequest |
                        AuthorisationResponse |
                        AuthorisationIndication |
                        AuthorisationConfirmation|
                        UsageIndication |
                        UsageConfirmation |
                        ReauthorisationRequest |
                        ReauthorisationResponse )+ ) >

               ... ]>
```

Maguire
maguire@it.kth.se

Open Settlement Protocol (OSP)
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Practical Voice Over IP (VoIP): SIP and related protocols

Achieving QoS

- ## Over provision!
  - Simplest approach
- ## If this fails, then use TOS field or Diffserv
  - Much of the problem is on the access network - hence TOS or Diffserv even only on these links may be enough
- ## If this fails, then use RSVP
  - Much more complex - especially when done over several operator's domains

Maguire

maguire@it.kth.se

Achieving QoS

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Practical Voice Over IP (VoIP): SIP and related protocols

Some measured delays

Actual performance of SIP phone to SIP phone and software applications over a LAN, shows that the performance of SIP phones is well within acceptable delay.

Measurements of mouth to ear one-way delay, from "Aside: SIP phone QoS" slide 15 of [30]

end-point A	end-point B	A⇒B	B⇒A
GSM	PSTN	115 ms	109 ms
3Com	Cisco	51 ms	63 ms
NetMeeting	NetMeeting	401 ms	421 ms
Messanger XP	Messanger XP	109 ms	120 ms

Maguire
maguire@it.kth.se

Some measured delays
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Voice Quality

Two major tests:

- ## Mean Opinion Score (MOS)
  - ITU test based on using 40 or more people fro different ethnic or language backgrounds listening to audio samples of several seconds each
  - Human listeners rating the quality from 1 to 5; 5 being perfect, 4 "toll-quality", …

- ## Perceptual Speech Quality Measurement (PSQM)
  - A computer algorithm - so it is easy to automate
  - test tools from Agilent[96], QEmpirix, Finisar, … - cost US$50k and up

One approach is to occasionally ask IP phone users to indicate how the quality of their call was at the end of the call $\Rightarrow$ MOS scoring!

Another is exemplified by Susan Knott, global network architecture for PricewaterhoursCoopers:

> "But I've found that if my vice president of finance can talk to my CIO [over a VoIP connection], and they both say the quality of the connection is OK, then I say that's good enough."
>
> Phil Hochmuth, "Quality question remains for VoIP", NetworkWorld, Vol. 19, Number 40, October 7, 2002, pp. 1 and 71, quote is from page 71.

Maguire
maguire@it.kth.se

Voice Quality
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Practical Voice Over IP (VoIP): SIP and related protocols

QoS Proprietary vs. Standards based

Past

Agere Systems, Inc. VoIP "Phone-On-A-Chip" used a proprietary voice packet prioritization scheme called Ethernet Quality of Service using BlackBurst (EQuB), an algorithm (implemented in hardware) ensures that voice packets are given the highest priority in their collision domain.

2002

Their Phone-On-A-Chip solution now implements a software-based IEEE 802.1q tagging protocol (i.e. Virtual local area network (VLAN) tagging) for outgoing Ethernet frames.[1]

---

1. Agere Systems. T8302 Internet Protocol Telephone Advanced RISC Machine (ARM®) Ethernet QoS Using IEEE® 802.1q, Advisory July 2001.

Maguire
maguire@it.kth.se

QoS Proprietary vs. Standards based
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Practical Voice Over IP (VoIP): SIP and related protocols

QoS for SIP

SDP can be used to convey conditions which must be met:

- direction for QoS support: send, receive, or bidirectional
- along with a "strength" parameter: optional or mandatory

If conditions can be met then a `COMET` is sent.

Maguire

maguire@it.kth.se

QoS for SIP

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Practical Voice Over IP (VoIP): SIP and related protocols

Application Policy Server (APS)

Gross, et al. proposed the use of an Application Policy Server (APS) [95]
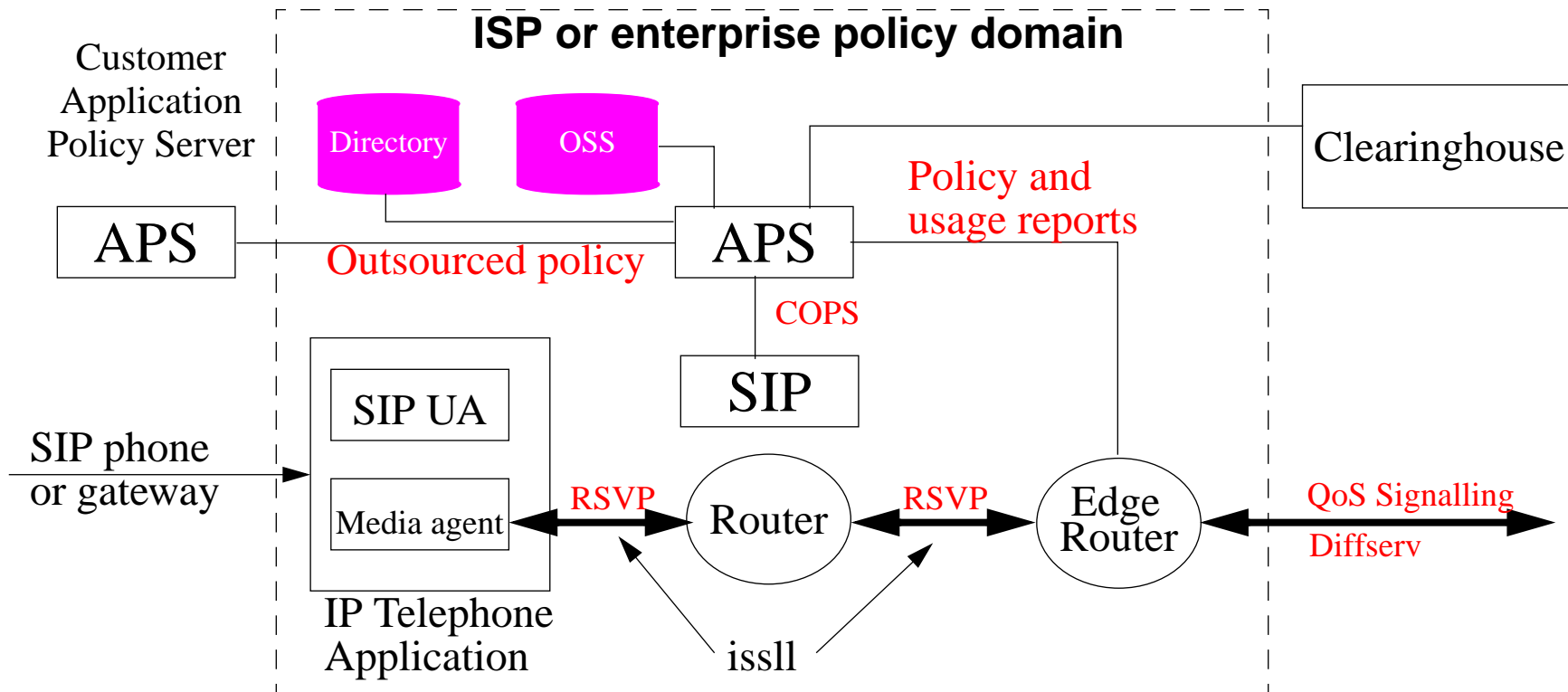
IETF Integrated Services over Specific Lower Layers (issll) Working group (*http://www.ietf.org/html.charters/issll-charter.html*) is defining protocols to control the link layer.

Maguire
maguire@it.kth.se

Application Policy Server (APS)
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Maguire
maguire@it.kth.se

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Maguire
maguire@it.kth.se

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Module 15: SIP Applications

Lecture notes of G. Q. Maguire Jr.

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Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP:
Delivering VoIP and Multimedia Services with Session Initiation Protocol*,
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Session Initiation Protocol Project INvestiGation (SIPPING)

Documents the use of SIP for several applications related to telephony and multimedia, and develops requirements for any extensions to SIP needed for them.

One of the significant features of using SIP for building applications is that it is much easier to build **open, distributed,** and **scalable services** that the traditional method of Intelligent Networks (IN); thus putting services into the hands of user!

The specific tasks for SIPPING will be:

1 PSTN and/or 3G telephony-equivalent applications that need a standardized approach
  - informational guide to common call flows
  - support for T.38 fax
  - requirements from 3GPP for SIP usage
  - framework of SIP for telephony (SIP-T)
  - call transfer and call forwarding
  - AAA application in SIP telephony
  - mapping between SIP and ISUP

Maguire
maguire@it.kth.se
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Practical Voice Over IP (VoIP): SIP and related protocols

2   Messaging-like applications of SIP

- support for hearing-/speech-impaired calling
- development of usage guidelines for subscribe-notify (RFC 2848, SIP events) to ensure commonality among applications using them, including SIMPLE WG's instant messaging.

3   Multi-party applications of SIP

- the working group will review a number of technical pieces

including call transfer, subscribe-notify, SIP features

negotiation, and session description protocol (SDP) capability

negotiation, and will develop requirements and an initial design

or framework for multi-party conferencing with SIP.

4   SIP calling to media servers

- develop a requirements draft for an approach to SIP interaction with media servers, e.g., whether a voicemail server is just a box that a caller can send an INVITE to.

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maguire@it.kth.se

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SIPPING Internet-Drafts

Models for Multi Party Conferencing in SIP

http://www.ietf.org/internet-drafts/draft-ietf-sipping-conferencing-models-01.txt

ISUP to SIP Mapping *http://www.ietf.org/internet-drafts/draft-ietf-sipping-isup-06.txt*

Using ENUM SIP Applications http://www.ietf.org/internet-drafts/draft-ietf-sipping-e164-01.txt

Mapping of ISUP Overlap Signalling to the Session Initiation Protocol

http://www.ietf.org/internet-drafts/draft-ietf-sipping-overlap-03.txt

SIP Service Examples *http://www.ietf.org/internet-drafts/draft-ietf-sipping-service-examples-02.txt*

SIP Support for Real-time Fax: Call Flow Examples And Best Current Practices

http://www.ietf.org/internet-drafts/draft-ietf-sipping-realtimefax-00.txt

A Multi-party Application Framework for SIP

http://www.ietf.org/internet-drafts/draft-ietf-sipping-cc-framework-01.txt

Best Current Practices for Third Party Call Control in the Session Initiation
Protocol *http://www.ietf.org/internet-drafts/draft-ietf-sipping-3pcc-02.txt*

Maguire
maguire@it.kth.se
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Short Term Requirements for Network Asserted Identity

http://www.ietf.org/internet-drafts/draft-ietf-sipping-nai-reqs-02.txt

The Session Initiation Protocol (SIP) and Session Description Protocol (SDP) static dictionary for Signaling Compression (SigComp)

http://www.ietf.org/internet-drafts/draft-ietf-sipping-sigcomp-sip-dictionary-04.txt

A Message Summary and Message Waiting Indication Event Package for the Session Initiation Protocol (SIP) *http://www.ietf.org/internet-drafts/draft-ietf-sipping-mwi-00.txt*

Requirements for Content Indirection in Session Initiation Protocol (SIP) Messages *http://www.ietf.org/internet-drafts/draft-ietf-sipping-content-indirect-02.txt*

NAT and Firewall Scenarios and Solutions for SIP

http://www.ietf.org/internet-drafts/draft-ietf-sipping-nat-scenarios-00.txt

A Session Initiation Protocol (SIP) Event Package for Dialog State

http://www.ietf.org/internet-drafts/draft-ietf-sipping-dialog-package-00.txt

A Session Initiation Protocol (SIP) Event Package for Conference State

http://www.ietf.org/internet-drafts/draft-ietf-sipping-conference-package-00.txt

Session Initiation Protocol PSTN Call Flows

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maguire@it.kth.se

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Practical Voice Over IP (VoIP): SIP and related protocols

http://www.ietf.org/internet-drafts/draft-ietf-sipping-pstn-call-flows-00.txt

Session Initiation Protocol Basic Call Flow Examples

http://www.ietf.org/internet-drafts/draft-ietf-sipping-basic-call-flows-01.txt

Session Initiation Protocol Torture Test Messages

http://www.ietf.org/internet-drafts/draft-ietf-sipping-torture-tests-00.txt

SIP Generic Request History Capability - Requirements

http://www.ietf.org/internet-drafts/draft-ietf-sipping-req-history-00.txt

Authentication, Authorization and Accounting Requirements for the Session Initiation Protocol

http://www.ietf.org/internet-drafts/draft-ietf-sipping-aaa-req-00.txt

Maguire
maguire@it.kth.se

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Practical Voice Over IP (VoIP): SIP and related protocols

SIPPING Request For Comments

User Requirements for the Session Initiation Protocol (SIP) in Support of Deaf, Hard of Hearing and Speech-impaired individuals (RFC 3351)

http://www.ietf.org/rfc/rfc3351.txt

Session Initiation Protocol (SIP) for Telephones (SIP-T): Context and Architectures (RFC 3372) *http://www.ietf.org/rfc/rfc3372.txt*

Maguire
maguire@it.kth.se

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Practical Voice Over IP (VoIP): SIP and related protocols

Application Service Components

Maguire
maguire@it.kth.se

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Practical Voice Over IP (VoIP): SIP and related protocols
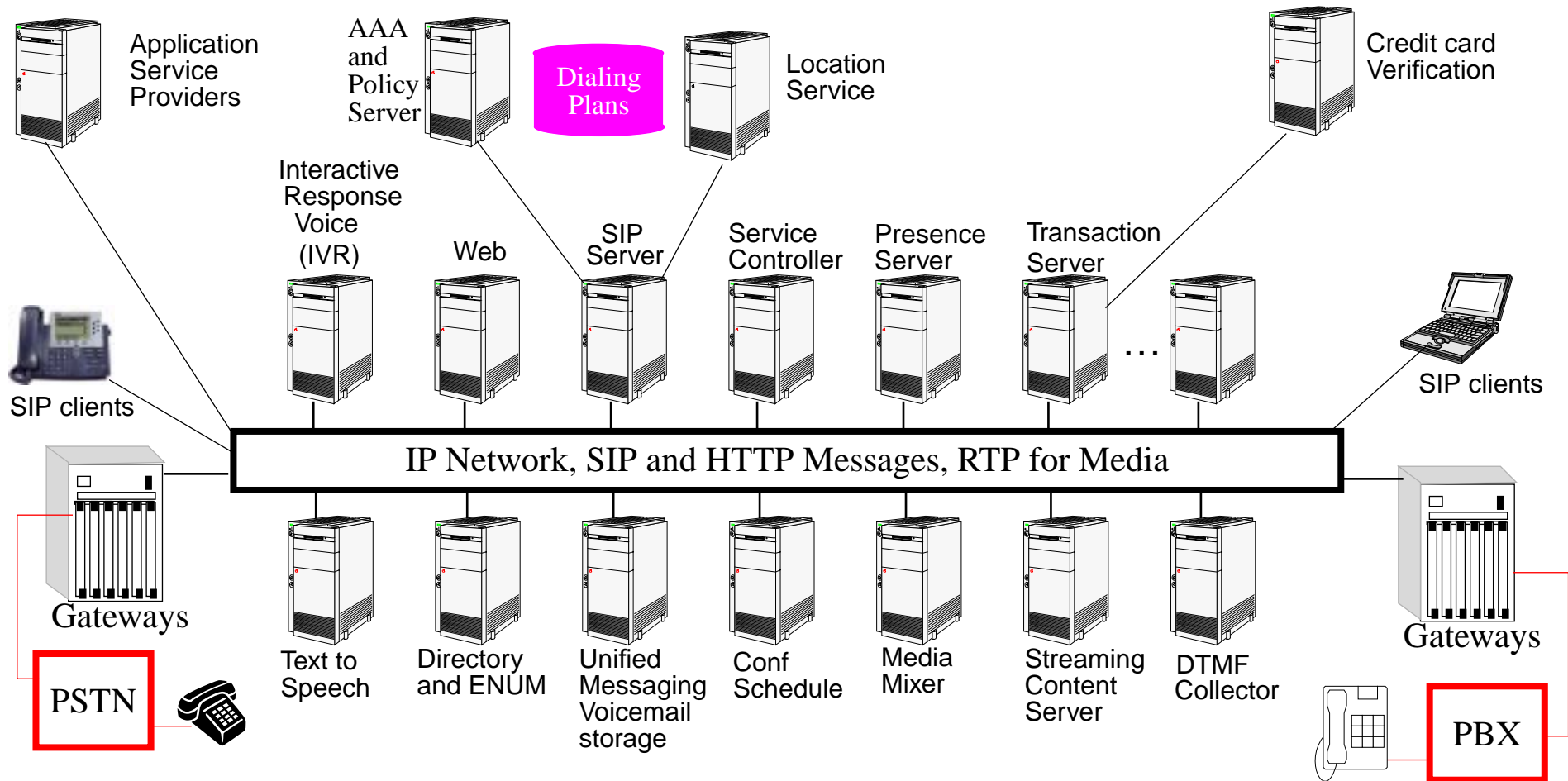
Advantages

- ## Decomposition
  - No complex APIs, just HTTP and SIP $\Rightarrow$ rapid development
  - User can provide input to the service controller via Web servers, DTMF digit collector, voice portal (via VoiceXML), DTMF input, ... $\Rightarrow$ just about any internet attached device can be used to provide input.
  - Easy to scale
  - New services can combine the "best of the best" (thus allowing developers to specialize)
  - Servers and services can be located anywhere on the internet and operated by anyone
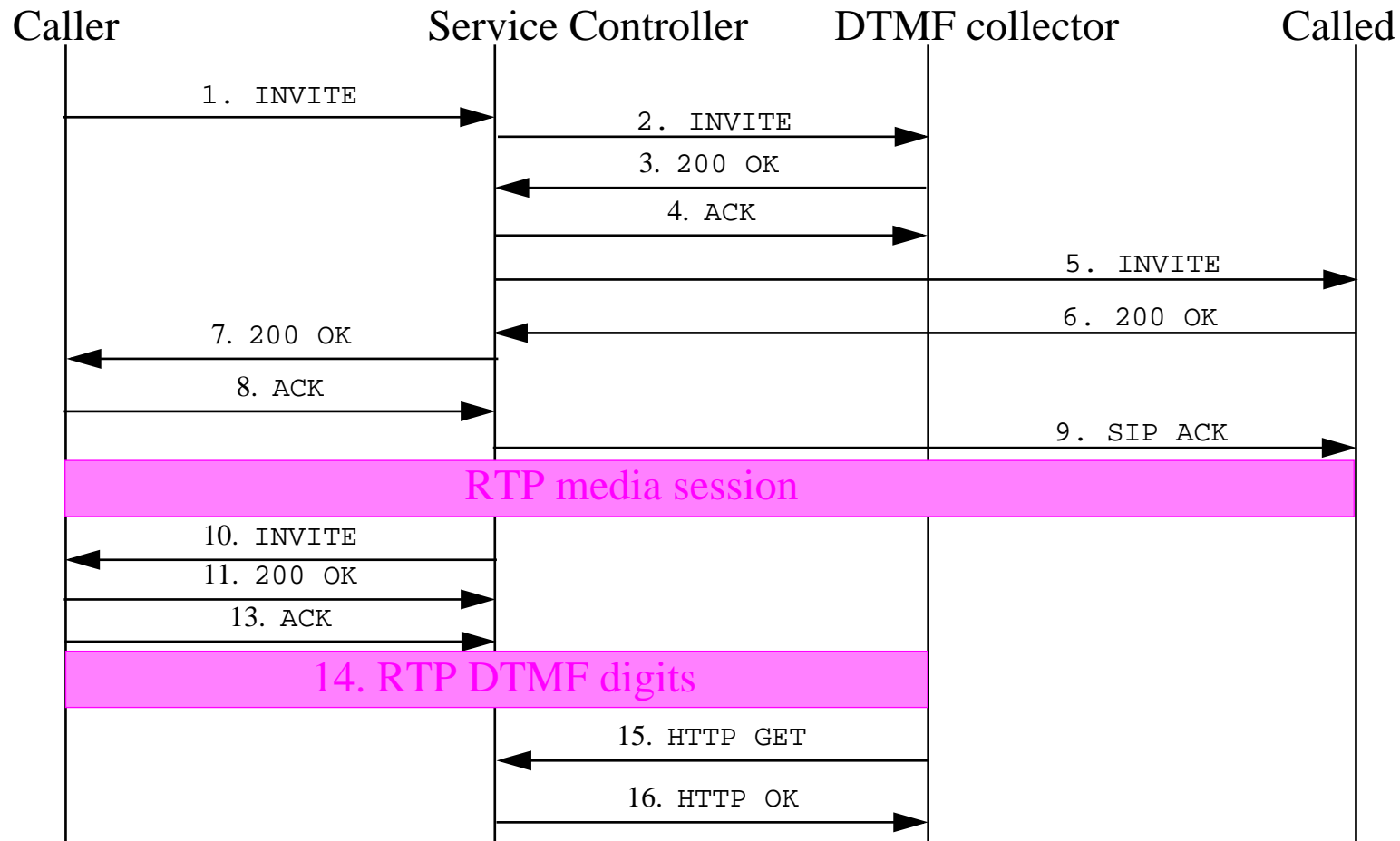
- ## Decoupling
  - Loosely coupled and distributed
    - Flexible location of servers
    - if properly designed, implemented, and operated $\Rightarrow$ higher reliability and resilience
  - Separation of businesses (leads to a rich variety of outsourcing, reseller, … models)
  - Since the functions are highly independent $\Rightarrow$ rapid development

- ## Anyone can introduce a new service

However, if you want to use service components of others, then you may need to work out a suitable agreement (which will probably include an agreement about authorization) $\Rightarrow$ security can be more complex.

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maguire@it.kth.se

Advantages
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Practical Voice Over IP (VoIP): SIP and related protocols

Collecting DTMF digits for use within a service

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maguire@it.kth.se
Collecting DTMF digits for use within a service
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Practical Voice Over IP (VoIP): SIP and related protocols

Reponse "3. 200 OK" looks like:

```
SIP/2.0 200 OK
Via: SIP/2.0/UDP 100.101.102.103
To: User A <sip:UserA@here.com>
From: UserB <sip:UserB@there.com>
Call-ID: a84b4c76e66710100.101.102.103
CSeq: 1 INVITE
Contact: <sip:UserB@there.com>
Content-Type: application/sdp
Content-Length: …

v=0
o=UserA 289375749 289375749 IN IP5 110.111.112.113
S=-
c=IN IP4 110.111.112.113
t=0 0
m=audio 5004 RTP/AVP 0
```

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maguire@it.kth.se

Collecting DTMF digits for use within a service
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Practical Voice Over IP (VoIP): SIP and related protocols

Controller issues a "re-Invite" at 11 which looks like:

```
INVITE sip:UserB@there.com SIP/2.0
Via: SIP/2.0/UDP 100.101.102.103
To: UserB <sip:UserB@there.com
From: User A <sip:UserA@here.com>
Call-ID: a84b4c76e66710100.101.102.103
CSeq: 1 INVITE
Contact: <sip:UserB@there.com>
Content-Type: application/sdp
Content-Length: …

v=0
o=UserA 289375749 289375749 IN IP5 100.101.102.103
S=-
c=IN IP4 100.101.102.103
t=0 0
m=audio 5004 RTP/AVP 0
m=audio 53000 RTP/AVP 0
c=IN IP4 200.201.202.203
a=rtpmap:96 telephone-event
```

Note the 2nd "m=audio" line in the SDP (see Sinnreich Johnston page 257), this second connection is the RTP connection to the DTMF digit collector.

Maguire
maguire@it.kth.se

Collecting DTMF digits for use within a service
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Practical Voice Over IP (VoIP): SIP and related protocols

Voice Portal Service using Interactive Voice Response (IVR)
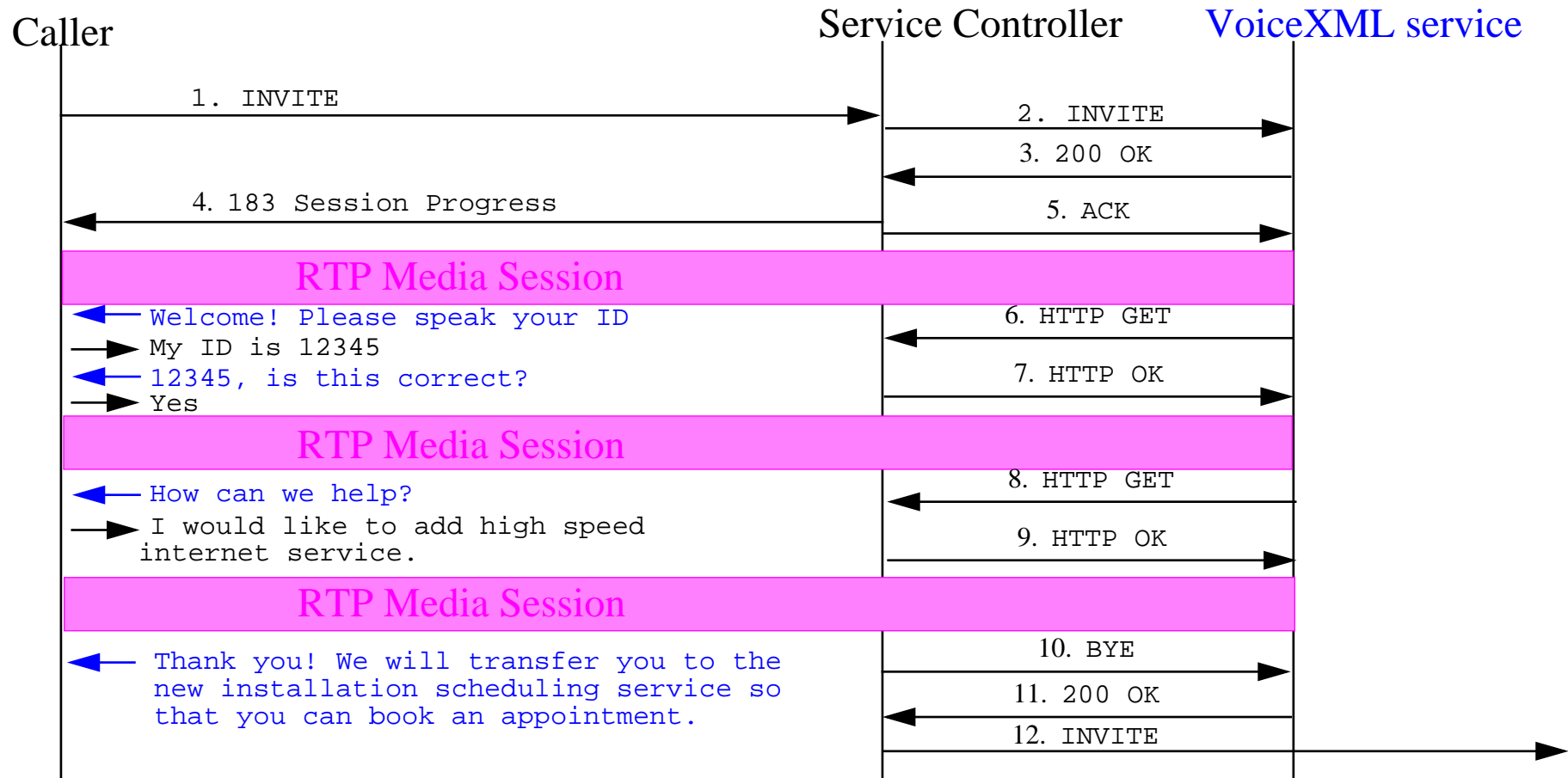
The service controller proxies the caller to the IVR system.

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maguire@it.kth.se

Voice Portal Service using Interactive Voice Response (IVR)
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Lots more services

<< more to be added here - as time permits >>

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maguire@it.kth.se

Lots more services
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Practical Voice Over IP (VoIP): SIP and related protocols

References and Further Reading

SIPPING

[100]<u>http://www.greycouncil.com/sippingwg</u>

[101]J. Rosenberg and H. Schulzrinne, "Session Initiation Protocol (SIP): Locating SIP Servers", IETF RFC 3263, June 2002.

Maguire
maguire@it.kth.se

References and Further Reading
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Practical Voice Over IP (VoIP): SIP and related protocols

2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Module 16: More than Voice

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 *and* Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

Non-voice Services and IP Phones

Phone Services: built using scripts which the IP phone executes to acquire information and display it

For example, some of the Cisco IP telephones (7940 and 7960) have a web browser which understands XML and a 133x65 pixel-based LCD display to display output.

Sample services:

- Conference room scheduler
- E-mail and voice-mail messages list
- Daily and weekly schedule and appointments
- Personal address book entries ($\Rightarrow$ any phone can become "your" phone)
- Weather reports, Stock information, Company news, Flight status, Transit schedules, …
- Viewing images from remote camera (for security, for a remote receptionist, …)

Maguire
maguire@it.kth.se

Non-voice Services and IP Phones
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Practical Voice Over IP (VoIP): SIP and related protocols

XML

XML objects include: CiscoIPPhoneMenu, CiscoIPPhoneText, CiscoIPPhoneInput, CiscoIPPhoneDirectory, CiscoIPPhoneImage, CiscoIPPhoneGraphicMenu, CiscoIPPhoneIconMenu, CiscoIPPhoneExecute, CiscoIPPhoneError and CiscoIPPhoneResponse.

Cisco IP Phone Services Software Developer's Kit:

`http://cisco.com/warp/public/570/avvid/voice_ip/cm_xml/index.html`

Maguire
maguire@it.kth.se

XML
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Practical Voice Over IP (VoIP): SIP and related protocols

Invoking RTP streams

On the Cisco phones it is possible to invoke RTP streaming (transmit or receive) via URIs in above services. RTP information for the stream types must be of the form:

CODEC	G.711 mu-Law
Packet size	20 ms

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maguire@it.kth.se

Invoking RTP streams
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Practical Voice Over IP (VoIP): SIP and related protocols

More details

see 'Thinking Outside the "Talk" Box: Building Productivity-Boosting Applications for Your Cisco IP Phones' by Anne Smith, Cisco Packet, Third Quarter, 2002, pp. 21-23

The book includes a CD which has a CallManager Simulator - so you can write applications with just a web server and a Cisco IP phone.

You can download the SDK, etc. from:

http://cisco.com/warp/public/570/avvid/voice ip/cm xml/cm xmldown.shtml

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maguire@it.kth.se

More details
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Practical Voice Over IP (VoIP): SIP and related protocols

Services for sale - building a market

Purchase existing services or contract for new third party XML services or support for Cisco's IP Telephony products: HotDispatch

http://www.hotdispatch.com/cisco-ip-telephony

They have 91 Existing products as of 20 October 2002

HotDispatch has partnered with Cisco to provide IP Telephony **marketplace**

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maguire@it.kth.se

Services for sale - building a market
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Practical Voice Over IP (VoIP): SIP and related protocols

Network Appliances

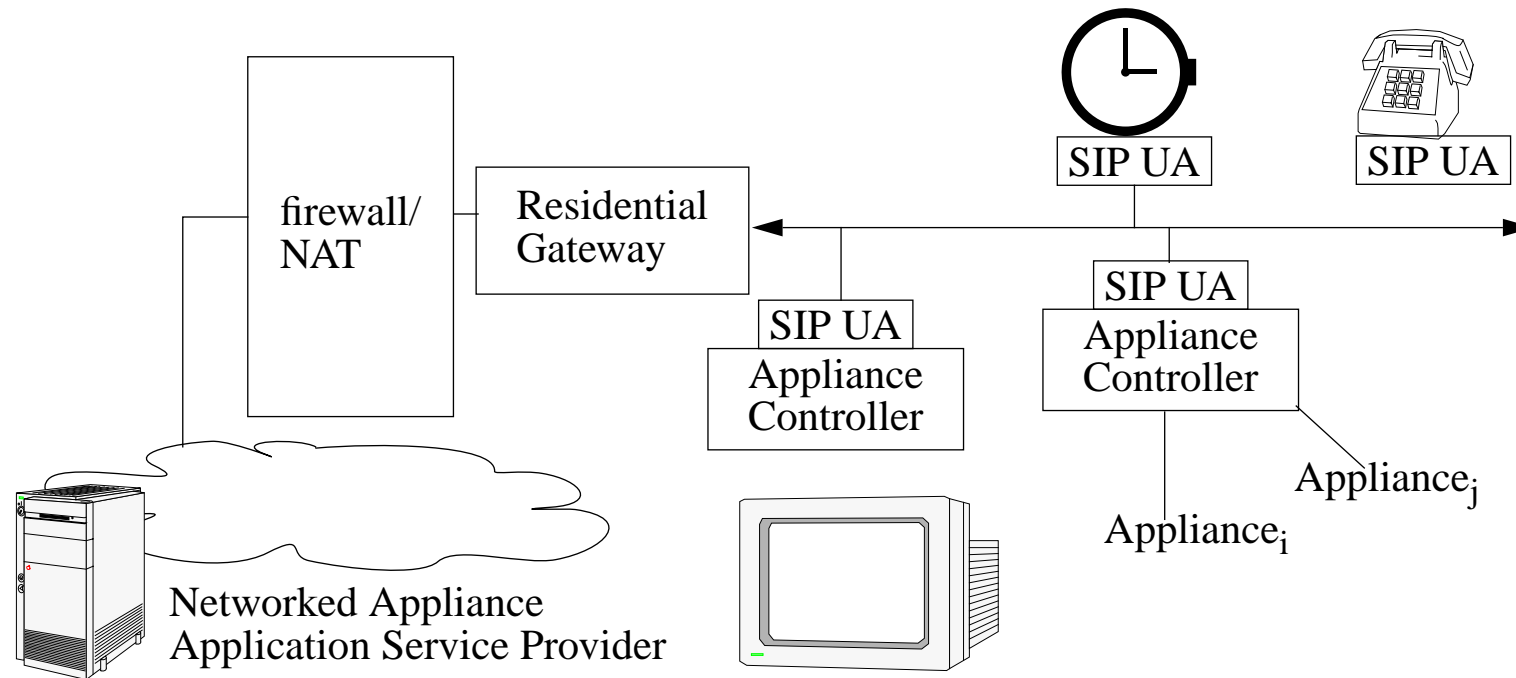Figure 15: Using SIP for Service Portability (adapted from figure 2 of Moyer, Maples, Tsang, and Ghosh)

See: Stan Moyer, Dave Maples, Simon Tsang, and Abhrajit Ghosh, "Service Portability of Networked Appliances", IEEE Communications Magazine, January 2002, pp. 116-121.

Maguire
maguire@it.kth.se

Network Appliances
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Practical Voice Over IP (VoIP): SIP and related protocols

Proposed Extension of SIP

Add **DO** message type

Build upon Event extensions (specifcally **SUBSCRIBE** and **NOTIFY**).

Add a new payload type via the new MIME type: **Device Message Protocol** (DMP) -- this payload is translated into device specific payload at the SIP User Agent.

Note that you could also send **SOAP** payload either separately or as part of DMP.

Maguire
maguire@it.kth.se

Proposed Extension of SIP
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Practical Voice Over IP (VoIP): SIP and related protocols

Service Location Protocol (SLP) URL

To: [SLP:/d=lamp, r=office, u=maguire]@it.kth.se

Note that the information inside the [ ] can be encoded in BASE-64 and encrypted, those making it opaque to entities outside the domain.

See: E. Guttman, et al., "Service Location Protocol, version 2", RFC 2608, June 1999.

Maguire
maguire@it.kth.se

Service Location Protocol (SLP) URL
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Practical Voice Over IP (VoIP): SIP and related protocols

Example service

This example is adapted from the above article, and the service is a network-based alarm clock service:

- delivers user specific information (latest news, weather, etc.)
- at a user selected time
- to the user's "alarm clock" network appliance

Specifically:

1. `REGESTER register@home.net`
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   From: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   Content-type: application/ddp
   [Device address]

2. `INVITE sip:[slp:/d=alarmclock, r=bedroom, u=maguire]@home.net SIP/2.0`
   From: sip:announcement@alarmclock.net
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   Via: `alarmclock.net`
   Content-type: application/sdp
   [SDP for uni-directional RTP stream]

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Example service
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Practical Voice Over IP (VoIP): SIP and related protocols

3. `INVITE sip:[slp:/d=alarmclock, r=bedroom, u=maguire]@home.net SIP/2.0`
   From: sip:announcement@alarmclock.net
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   Via: `home.net`
   Via: `alarmclock.net`
   Content-type: application/sdp
   [SDP for uni-directional RTP stream]

4. `INVITE sip:[slp:/d=alarmclock, r=bedroom, u=maguire]@home.net SIP/2.0`
   From: sip:announcement@alarmclock.net
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   Via: `chips.home.net`
   Via: `home.net`
   Via: `alarmclock.net`
   Content-type: application/sdp
   [SDP for uni-directional RTP stream]

5. The alarm clock responds with its RTP parameters and the RTP session plays the annoucement to the user via the "alarm clock" network appliance

Maguire
maguire@it.kth.se

Example service
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Practical Voice Over IP (VoIP): SIP and related protocols

Example of service portability

This example is adapted from the above article, Chip visits his friend Mark:

- delivers user specific information (latest news, weather, etc.)
- at a user selected time
- to the user's "alarm clock" network appliance
- But the service now has to be delivered to the correct "alarm clock"
  - Either Chip takes his alarm clock with him or
  - Utilizes Mark's guest alarm clock as his alarm clock

```
1.REGESTER register@home.net
  To: [slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net
  From: [slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net
  Contact: *; expires=0
```

The above cancels the service to Chip's home alarm clock

```
2.REGESTER register@home.net
  To: [slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net
  From: [slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net
  Contact: sip:[slp:/d=alarmclock, r=guest_bedroom, u=maguire]@ua.marks.home.net]
  Content-type: application/ddp
  [Device description (including address)]
```

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Example of service portability
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Practical Voice Over IP (VoIP): SIP and related protocols

3. `INVITE sip:[slp:/d=alarmclock, r=bedroom, u=maguire]@home.net SIP/2.0`
   From: sip:announcement@alarmclock.net
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@us.chips.home.net`
   Via: `alarmclock.net`
   Content-type: application/sdp
   [SDP for uni-directional RTP stream]

   Now the SIP Proxy at home.net looks up
   `[slp:/d=alarmclock, r=bedroom, u=maguire]@home.net` and determines that it is
   `[slp:/d=alarmclock, r=guest_bedroom, u=maguire]@ua.marks.home.net]`so it
   forwards the messages to the SIP proxy at `marks.home.net`

4. `INVITE sip:[slp:/d=alarmclock, r=guest_bedroom,`
   `u=maguire]@ua.marks.home.net] SIP/2.0`
   From: sip:announcement@alarmclock.net
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   Via: `home.net`
   Via: `alarmclock.net`
   Content-type: application/sdp
   [SDP for uni-directional RTP stream]

5. `INVITE sip:[slp:/d=alarmclock, r=guest_bedroom,`
   `u=maguire]@ua.marks.home.net] SIP/2.0`
   From: sip:announcement@alarmclock.net
   To: `[slp:/d=alarmclock, r=bedroom, u=maguire]@ua.chips.home.net`
   via: `marks.home.net`
   Via: `home.net`
   Via: `alarmclock.net`

Maguire
maguire@it.kth.se

Example of service portability
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Practical Voice Over IP (VoIP): SIP and related protocols

Content-type: application/sdp
[SDP for uni-directional RTP stream]

6. Mark's guest bedroom alarm clock responds with its RTP parameters and the RTP session plays the annoucement to the user via the "alarm clock" network appliance

Maguire

maguire@it.kth.se

Example of service portability

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Practical Voice Over IP (VoIP): SIP and related protocols

References and Further Reading

Phone Services

[102] Darrick Deel, Mark Nelson, Anne Smith, *Developing Cisco IP Phone Services: A Cisco AVVID Solution*, Cisco Press, Feb. 15, 2002, 288 pages, ISBN 1-58705-060-9

   `http://www.ciscopress.com/catalog/product.asp?product_id={C44DC455-B95D-421D-BF88-16C4A61CC6C9}`

[103] Cisco IP Phone Services Application Development Notes, Oct. 1, 2002,

   `http://www.cisco.com/application/pdf/en/us/guest/products/ps556/c1671/ccmigration_09186a00800f0d66.pdf`

Network Appliances

[104] S. Tsang, et al., "Requirements for Networked Appliances: Wide-Area Access, Control, and Internetworking", IETF Draft draft-tsang-appliances-reqs-01.txt, Sept. 2000

[105] Open Services Gateway Iniative (OSGi), `http://www.osgi.org`

Maguire
maguire@it.kth.se
References and Further Reading
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Practical Voice Over IP (VoIP): SIP and related protocols

[106]S. Moyer, et al., "Framework Draft for Networked Appliances UIsing the Session Initiation Protocol", IETF draft, July 2000, work in progress.

Maguire

maguire@it.kth.se

References and Further Reading

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Practical Voice Over IP (VoIP): SIP and related protocols

2G5564 Practical Voice Over IP (VoIP): SIP and related protocols

Module 17: VOCAL

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with Luan Dang, Cullen Jennings, and David Kelly, *Practical VoIP: Using VOCAL*, O'Reilly, 2002, ISBN 0-596-00078-2 ***and*** Henry Sinnreich and Alan B. Johnston, *Internet Communications Using SIP: Delivering VoIP and Multimedia Services with Session Initiation Protocol*, Wiley, 2001, ISBN: 0-471-41399-2.

VOCAL System Overview

Figure 16: VOCAL: Simplified overview

MGCP = Media Gateway Control Protocol

Maguire
maguire@it.kth.se

VOCAL System Overview
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Practical Voice Over IP (VoIP): SIP and related protocols
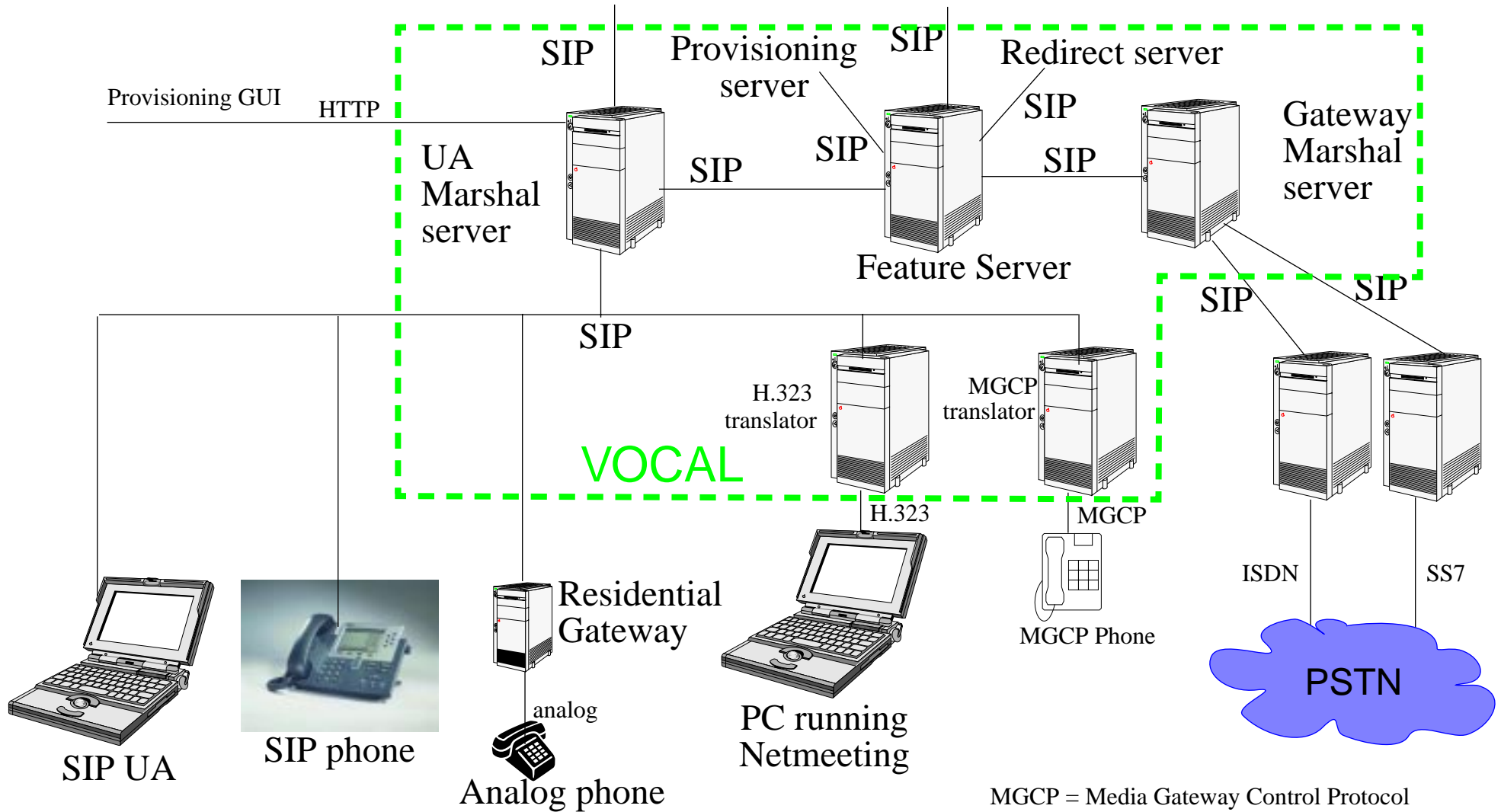
VOCAL Servers

- Marshal server (MS)
  - User Agent (UA) Marshal server
    - interface to/from IP phones connected to this network
    - can do different types of authentication on a per-user basis
  - (PSTN) Gateway Marshal servers
    - provides interworking with PSTN
  - Internet Marshal server
    - interface to/from a SIP proxy server on another IP network
    - authenticate calls via Open Settlement Protocol (OSP)
    - can request QoS via Common Open Policy Service (COPS)
  - Conference Bridge Marshal server
    - interface to/from third party conference servers

- Feature server (FS)- to provide advanced telephony services

- Redirect server (RS) - keep track of registered users and provide routing to/from them

- Provisioning server (PS) - for configuration

- Call Detail Record (CDR) server - stores start/end information about calls for billing and other purposes

Maguire
maguire@it.kth.se

VOCAL Servers
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Practical Voice Over IP (VoIP): SIP and related protocols

Scaling of a VOCAL system

From table 3-1 of *Practical VoIP: Using VOCAL*

Server types	6-host system	14-host system	26-host system
Redirect servers	1	2	5
Feature servers	1	2	5
Marshal servers	2	4	10
Call Detail Record servers	1/2	2	2
Provisioning servers	1	2	2
Policy servers	1/2	2	2
Total number of hosts	6	14	26
Capacity in calls per second	35	70	175
Capacity in busy-hour call attempts (BHCA)	125,000	250,000	630,000

Each host is a 700MHz Pentium III with 512 MB or RAM.

Note that unlike a PBX or Public Exchange, the capacity in calls per second (or BHCA) is **independent** of the call durations, since the **call traffic** is carried directly between the endpoints via RTP and **does not use** the VOCAL system!

Maguire
maguire@it.kth.se

Scaling of a VOCAL system
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Practical Voice Over IP (VoIP): SIP and related protocols

For comparison with a PBX

- NEC's latest PBX: EAX2400 IMX - Integrated Multimedia eXchange, model ICS IMGdxh uses a Pentium control process and the claimed[1] BHCA is 25,600.
- Tekelec's softswitch[2] "VXiTM Media Gateway Controller" claims[3] a capacity which scales from 250,000 to over 1 million BHCA - their is Class 5 exchanges.
- Frank D. Ohrtman Jr. says that a Class 4 Softswitch should handle 800,000 BHCA, support 100,000 DS0s (i.e., 100K 64 bps channels), with a reliability of 99.999%, and MOS of 4.0 (i.e., high quality voice)[107].
  - His pricing data shows that softswitches are about 1/4 the price per DS0 of Class 4 exchanges (e.g., Nortel DMS250 and Lucent 4ESS vs. Convergent Networks's ICS2000 and SONUS GSX9000) -- additionally the softswitches are physically much smaller.

Many claim that softswitch and VoIP reliability already **exceeds** that of central office exchanges; because with VoIP it is cheaper to implement redundancy and easier to build physically distributed systems; plus more features {sooner}, while also providing potentially better quality (i.e., better than "toll" quality)!

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1. http://www.stfi.com/STF_part3e.html

2. "A softswitch is the intelligence in a network that coordinates call control, signaling, and features that make a call across a network or multiple networks possible."[107]

3. http://www.tekelec.com/productportfolio/vximediagatewaycontroller/

Maguire
maguire@it.kth.se

For comparison with a PBX
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Marshal server (MS)

A SIP proxy server which provides:

- authentication of users

- generates call detail records (CDRs)

- provides a entry point for SIP messages into the VOCAL system
  - thus the other elements of the VOCAL system don't need to authenticate each message

- monitor heart beats - can uses this for load balancing across RSs

- SIP transaction stateful, but not call (dialog) stateful

Allows better scaling, since these servers can be replicated as needed; while allowing the redirect server to focus just on keeping registration information.

Maguire
maguire@it.kth.se

Marshal server (MS)
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Redirect Server (RS)

- receives SIP `REGISTER` messages from User Agents (UAs)
- keeps track of registered users and their locations (i.e., registrations)
- provides routing information for SIP `INVITE` messages
  - based on caller, callee, and registration information (for either or both parties)
  - based on where the `INVITE` message has already been
- Supports redundancy
  - Utilizes multicast heartbeat
    - starts by listening for 2s for another RS
    - if found, then it synchronizes with this RS and will act as a redundant backup RS (following synchronization)
    - if not found, then it starts transmitting its own heartbeat
  - a given RS must mirror `REGISTER` messages (received from the MS) to the other RSs

Maguire
maguire@it.kth.se

Redirect Server (RS)
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Feature Server (FS)

- Implements Call Forward, Call Screening, Call Blocking
  - The "Core Features" are implmented "within the network"
    - for example, you can't implement features in aphone which is not there!
    - you can't give an end system the caller's ID, but guarantee that they **don't** display it, …
- Execute arbitrary Call Processing Language (CPL) scripts written by users
  - CPL is parsed into eXtensible Markup Language (XML) document object model (DOM) trees, these are then turned into state machines (in C++), then executed.

Maguire
maguire@it.kth.se

Feature Server (FS)
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Residential Gateway (RG)

A residential gateway (RG) provides "… Internet access throughout the home and remote management of common household appliances such as lights, security systems, utility meters, air conditioners, and entertainment systems."[1]

Open Services Gateway Initiative (OSGi™) Alliance *http://www.osgi.org/* is attempting to define a standard framework and API for network delivery of managed services to local networks and devices.

An alternative to using a residential gateway to attach analog phones are devices such as the Cisco Analog Telephone Adaptor (ATA) 186

http://www.cisco.com/warp/public/cc/pd/as/180/186/ .

In VOCAL: "SIP Residential Gateway is an IP Telephony gateway based on SIP which allows a SIP user agent to make/receive SIP call to/from the Public Switched Telephone Network (PSTN)."[2]

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1. *http://www.national.com/appinfo/solutions/0,2062,974,00.html*

2. http://www.vovida.org/fom-serve/cache/761.html

Maguire
maguire@it.kth.se

Residential Gateway (RG)
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References and Further Reading

[107]Frank D. Ohrtman Jr., Softswitch: Architecture for VoIP, McGraw-Hill Professional, 2002, ISBN: 0071409777.

Maguire
maguire@it.kth.se
References and Further Reading
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