# Interoperability Evolvability

Protocol Design

## Interoperability

- Between implementations from different sources
  - specification quality
  - complexity
  - testability, debuggability
- Between less and more complete implementations
  - negotiation
  - optional functions
- Between early (buggy) and later implementations
  - robustness
- Between V1 and V2 implementations ➔ **evolvability**

## Aiding extensibility

To enable V2, extensibility must already be built into V1

- Standard approaches: extension points
  - Managing protocol numbers (IANA!)
  - Negotiation (latency!)
  - Identifying optional information, reacting to it if understood
    - E.g., reserved fields (in V1: sent as 0, ignored on reception)
- Alternative:
  meta-information allows selection of appropriate version
  - Configuration (e.g., POP3 vs. IMAP)
  - Referencing data (e.g., URI schema)
  - Directory information (e.g., DNS SRV record)
  - Pre-negotiation

Never use up
all extension points

## Drivers for evolution

- Deployment experience
  - (handling old problems better, correctly at all)
- Environment changes, brings new requirements
  - At best, market driven evolution
- Protocol is applied to new problems
  - (but do they fit?)
  - Sometimes academic/vendor/architect driven evolution
- Box vendors want to sell new boxes
- Architects want to make new/better architecture
  - Often in the name of evolvability!

## What is Evolvability?

- The ability to evolve easily
- Technology and human organization
  - What is the process that guides the evolution?
  - Is there an architecture, guidelines for future development? Does anyone guard against mission creep?
- Do you believe in “futureproof” technologies?
  - The junkyards are full of these
- Designing to be part of something else
  - Interfacing with the evolving environment
  - Accommodate **unforeseeable** requirements

[based on Tim Berners-Lee]

## The “Test of Independent Invention”

- Design:
  - Important architectural decisions
  - Arbitrary decisions (“byte order”)
- Thought experiment: Somebody else invents the same
  - At some point, both designs will meet in the marketplace
- Now what?
  - A huge battle, involving the abandonment of projects, conversion, loss of data?
    - Sweden switches to driving on the right side of the road
  - Division of the world into two separate communities?
    - 110 V, 60 Hz, 525 lines, NTSC ↔ 230 V, 50 Hz, 625 lines, PAL
  - Smooth integration with only incremental effort?
- Can they be made to interoperate?
  - (Alternative: Wait until one has beaten the other)

## How to obtain Evolvability?

- There are no hard and fast answers
  - Too many forces pull on a protocol design
- Rule 1: It is almost always wrong to optimize for the moment
  - Protocols need two, three years before they actually arrive on the market
  - Deployed life may then be 5, 10, 30 years!
- However, it is also wrong to optimize for an unknown future
  - Even if Moore's law can be taken into account:
    - Adaptive range needs to go into values that may seem preposterous now
  - Future requirements, future solutions can't
- The only constant is **change**!

- Let's look at specific protocols…

## Case study: IP (1)

How did IP evolve? Not really much!

Addressing architecture: Two-dimensional (net/interface) in 32 bit

- Original: 8+24
- Class-based: 7+24, 14+16, 21+8
  - Augmented by subnetworking
- CIDR (class-less inter-domain routing): N+M
  - Killed RIPv1 (replaced by RIPv2 or OSPF)
  - Required host changes in ICMP, DHCP, forwarding
- End-of-life in full view ➔ IPv6 (complete redesign)

## Case study: IP (2)

Other field sizes:

- 16-bit fragment ID (out of 32 bits): disaster in the making
  - **RFC 4963**: MTU 1500 bytes, MSL 30 s ➔ 26 Mbit/s max!
    - Hosts generally ignore this ➔ large number of mis-associated fragments can result
  - Fragmentation creates large number of other problems
    - DoS attacks on fragment buffers, making life harder for middleboxes
  - Implementations generally try to avoid fragmentation
    - Hard to do for certain UDP-based applications
  - Oh, and there is one free bit of extensibility left!
- 4-bit IP header length
  - Uses only 5-15 range: 40 bytes of options max
  - Seriously limits usefulness of IP options

## Case study: IP (3)

Other field sizes (continued):

- 8-bit Precedence/TOS field
  - Now split into 6-bit TOS and 2-bit ECN
- 16-bit header checksum: useless, but impossible to reuse
- 8-bit protocol ID: serious limitation for protocol number assignment
- 8-bit TTL: apparently fine!
  - After de-facto redefinition from “time” to hop count

## An IP innovation: IP multicast

- Previously unused address space: Class D
- New host-to-router (host-to-subnet) protocol: IGMP
- Requires pervasive host/router changes
  - Pretty much deployed, but not turned on on the router side
- Huge impact on routing infrastructure
  - Started out as overlay network (successful), DVMRP
  - Tried to “go native” (and died), PIM + BGMP
    - Never finished
    - A limited version survived as MSDP
- Essentially failed for global deployment
  - Works well in a corporate network or in special environments (academic)

## An IP innovation: Integrated Services

- A new signalling protocol: RSVP
- QoS specs: Controlled Load (C-L), Guaranteed Service (G-S)
  - C-L is compatible with Ethernet style network
  - G-S requires more (ATM-style) control
- Requires pervasive host/router changes
  - Pretty much deployed, but not turned on
  - Applications don’t know how to make use of this
- Essentially failed
  - Almost nobody wants to pay for resource reservation
- Spawned successor (“ng” effort): NSIS

## An IP innovation: ECN

- Original congestion management idea: ICMP source quench
  - Misguided (sending additional packets to signal congestion)
  - Never clearly defined (send them when, what do they do in hosts, see RFC896)
- TCP congestion control works with one signal: packet drop
- ECN: one more bit of router→host information (+ 1 host→router)
  - It was hard enough to free two bits
- Slow Deployment
  - Problems with middleboxes choking on these bits
    - Based on earlier experience with attackers playing tricks on rarely used bits
  - Situation only slowly improving (TBIT initiative)
  - 2006: ECN generally not turned on in client hosts (desktops)
  - RED is hard to tune (hard to configure routers to signal ECN)
  - But it is still too early to declare outright failure

## IP: The verdict

- Apart from TTL, all field sizes were wrong
  - But then,
    the requirements of 2000’s Internet really were impossible to foresee in 1978
- Almost all innovations at the IP layer since 1990 failed
  - Often, hosts **and** routers would have had to upgrade — chicken and egg
- IPv6 is a better protocol
  - Unfortunately, incentive to deploy not clear in all markets

## Case study: TCP (1)

How did TCP evolve? Extremely well!

- RFC 4614 (TCP roadmap)

- Some parts became obsolete
  - PSH flag is useless
  - Handling of IP precedence and security compartments
  - Urgent-pointer (out-of-band data) is near-obsolete
- **Algorithms** were replaced a lot!
  - General operation: e.g., silly window avoidance (RFC813)
  - RTO estimation (RFC1122, RFC2988)
  - Most prominently: congestion control
    - RFC 896 (January 1984!) diagnosed congestion collapse
    - VJ's 1988 paper showed the solution
    - RFC 2581 = Reno TCP documents it in detail:
      slow start, congestion avoidance, fast retransmit, and fast recovery.
    - Many more congestion control and retransmission tweaks were made or proposed

## Case study: TCP (2)

- RFC 1323 fixed the more important field size problems
  - Optional window size scaling fixes 16-bit windows
  - Optional timestamps can be used to overcome 32-bit sequence number limit

- TCP was adapted to IPv6
- TCP supports jumbograms
  - Minimal changes in MSS option and Urgent pointer

- TCP now supports selective acknowledgements (SACK)

- TCP now supports ECN

## TCP innovations that didn’t work

- RFC1263: replace options by an elaborate versioning scheme
  - Would have added roundtrips at the start of each session
  - Would have reduced, not added to, interoperability
- T/TCP (transactional TCP)
  - Save 1/2 of a roundtrip
  - Too easy to attack
- RFC1693: Partial Order Service
  - Lack of interest
  - Was suppressed by ALF craze
  - Ideas later resurfaced in SCTP

## Why did TCP evolution work so well?

- Simple service, simple + orthogonal mechanisms, little policy
  - could be made to work with later requirements
- Field sizes were somewhat preposterous at the outset (32-bit sequence numbers!) so they have aged well

- Algorithm enhancements could be introduced unilaterally
- Some enhancements require both hosts to play (e.g., SACK)
- Only a few need cooperation from both hosts **and** the routers

- Problems remain with SYN flooding and RST attacks
  - Mitigations exist, outright solutions are hard to find

## Case study: Mail

- Mail = RFC821 (SMTP) + RFC822 (header format)
  - These evolved out of earlier specifications that sent mail in FTP
- Both are text-based protocols
  - Require TCP, DNS (retrofit)
- SMTP: Interactive
  - Can try out new commands without losing state
  - Extension mechanism retrofit to announce capabilities (1995, RFC1869)
- RFC822: “Batch”
  - Rule: Ignore what you don’t understand
  - Pioneered “free extension” situation
- RFC2821/2: Consolidate 19 years of operational experience
- MIME (1992): retrofit content types and encodings
- Secure Mail (S/MIME and OpenPGP): not so successful

## Case study: HTML

- HTML was officially an SGML application
  - Only validated pages should have been used
- Reality: “free extension” to the max
  - Principle: unknown markup is ignored
- Development between 1994 and 1998 was influenced by the “browser wars”
  - Microsoft and Netscape tried to one-up each other on browser features
  - HTML extensions played a major role here (“embrace and extend”)
- Cycle-based development bursts, fuelled by tension between:
  - the competitive urge of companies to outdo each other and
  - the common need for standards for moving forward

## The HTML cycle (1)

[based on Tim Berners-Lee]

Experimentation phase:

- HTML standard is open and usable by anyone
  - any engineer, in any company or waiting for a bus can think of new ways to extend HTML, and try them out

Growth phase:

- some of these many ideas are tried out in prototypes or products
  - free extension rule: any unrecognized extensions will be ignored by everything which does not understand them
  - result: dramatic growth in features
- Some of these become product differentiators
  - Now, originators are loath to discuss the technology with the competition (hard to do because of "view source", though).
- Some features die in the market and disappear from the products
- Successful features don’t stay product differentiators:
  - soon emulated in some equivalent (though different) feature in competing products

## The HTML cycle (2)

Consolidation ("firefighting"?) phase:

- there are now three or four ways of doing the same thing
  - engineers in each company are forced to spend their time writing three of four different versions of the same thing,
  - coping with the software architectural problems which arise from the mix of different models.
- This wastes program size, and confuses users.
- Example: TABLE element
  - multiple extensions were all using the same element name
  - browser had to guess which semantics to render
  - server could never be sure what to send
- Result: Fragmentation, brittleness.

- Fix: develop common specification from the best features
  - And let the cycle begin again…

## The end of the HTML cycle

- 1998: W3C was starting to lead the development
- Spec was big enough to **require** some modularity
- CSS, DOM/JavaScript were split off
- New developments (MathML, SVG) could use XML namespaces
  - identify extensions -- no ambiguity
  - Modularity
  - language mixing
- “partial understanding”!

- “When expressing something, use the least powerful language you can.”
  - (cf. "be conservative in what you do"...)

## Case study: HTTP

- HTTP 0.9: hack
- HTTP 1.0: uses MIME, RFC822 style text-based
  - Formalized only 1996 (RFC1945) — based on considerable experience
  - Deployed 1.0 then significantly extended by pre-1.1 functions
- HTTP 1.1: addresses connection reuse, caching, “virtual hosts”
  - Formalized 1999 (RFC 2616)
  - Fully compatible to HTTP 1.0 and various deployed pre-1.1 versions
  - Stable! Ubiquitous! Used beyond the traditional Web.

- HTTPng: attempt to redo HTTP in a more well-layered way
  - Much uncertainty, little demonstrable gain
  - Abandoned

## Case Study: SIP

**355**

**+30**

**+50**

**+...**

## Timeline: 1996

**Initial Internet Drafts:**
**Session Invitation Protocol (SIP) – M. Handley, E. Schooler**
**Simple Conference Invitation Protocol (SCIP) – H. Schulzrinne**

**SIP: Setup +**
**Caps Negotiation**

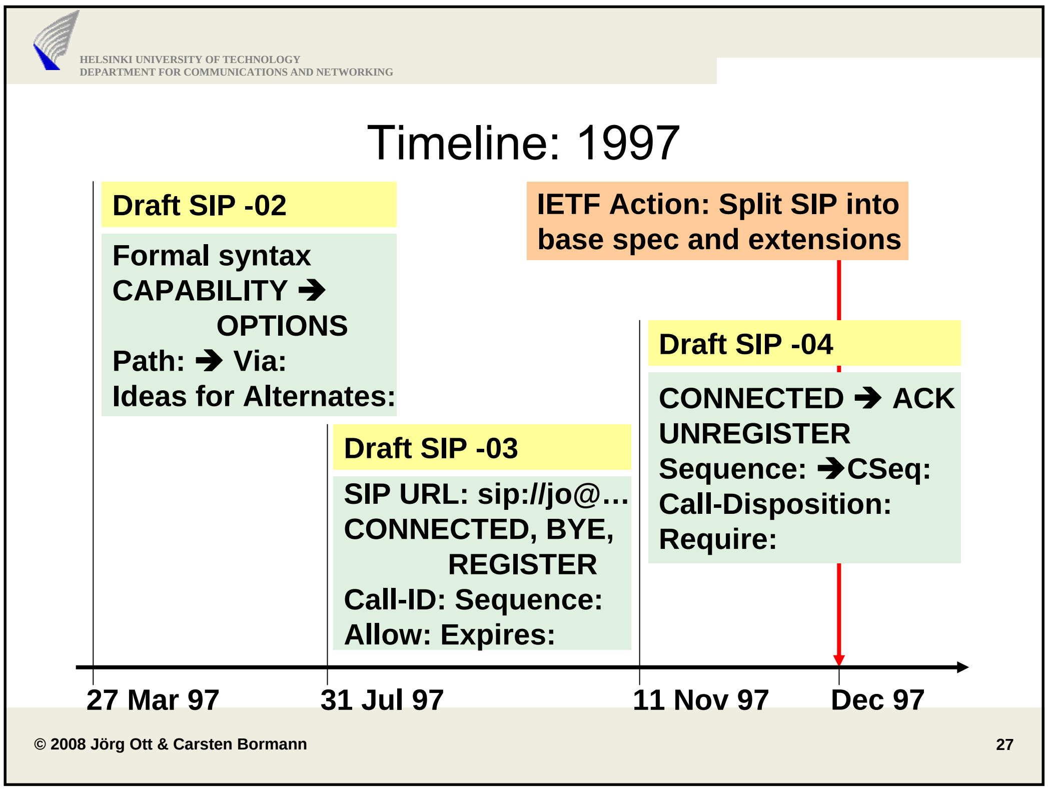
**SCIP: Setup + Caps**
**Modify + Terminate**

**Presentations**
**at 35th IETF,**
**Los Angeles**

**Merged Draft:**
**SIP -01**

**Main Features set:**
**TCP/UDP, Forking,**
**Redirection, addrs**
**INVITE,CAPABILITY**
**From: To: Path:**

**22 Feb 1996** **4-8 Mar 1996** **2 Dec 1996**



## Timeline: 1997

**Draft SIP -02**

Formal syntax
CAPABILITY ➔ OPTIONS
Path: ➔ Via:
Ideas for Alternates:

**Draft SIP -03**

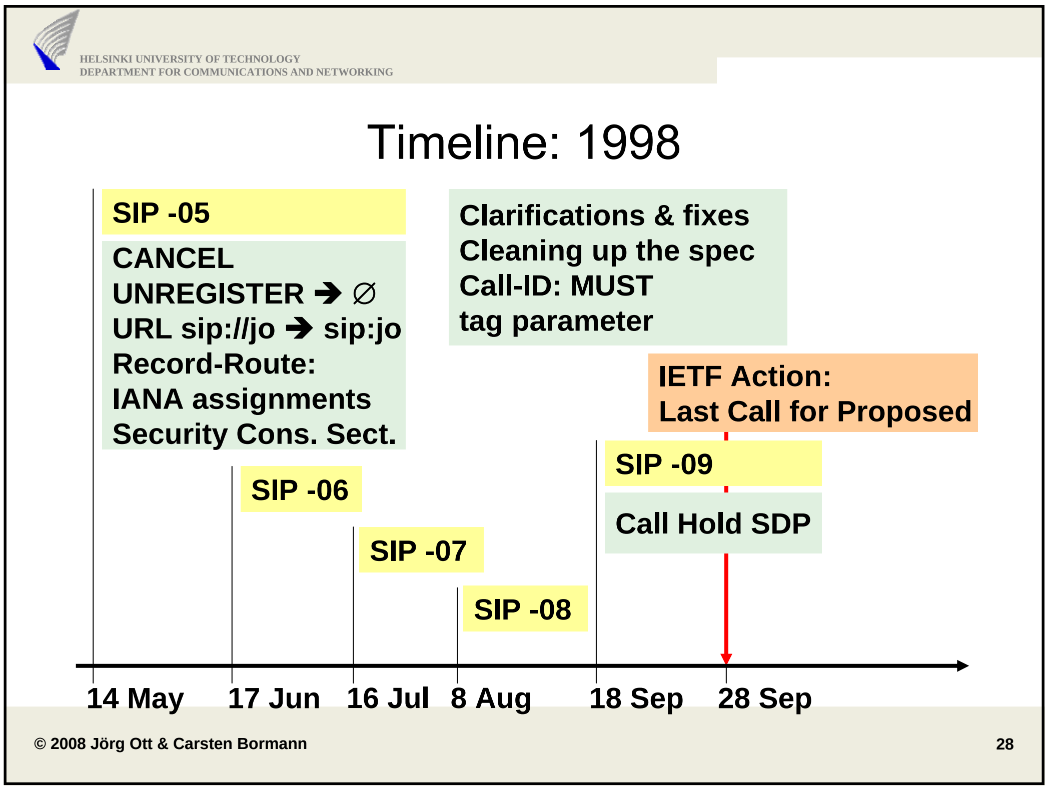
SIP URL: sip://jo@…
CONNECTED, BYE, REGISTER
Call-ID: Sequence:
Allow: Expires:

**IETF Action: Split SIP into base spec and extensions**

**Draft SIP -04**

CONNECTED ➔ ACK
UNREGISTER
Sequence: ➔CSeq:
Call-Disposition:
Require:

27 Mar 97 — 31 Jul 97 — 11 Nov 97 — Dec 97



## Timeline: 1998

**SIP -05**

CANCEL
UNREGISTER ➔ ∅
URL sip://jo ➔ sip:jo
Record-Route:
IANA assignments
Security Cons. Sect.

Clarifications & fixes
Cleaning up the spec
Call-ID: MUST
tag parameter

**SIP -06**

**SIP -07**

**SIP -08**

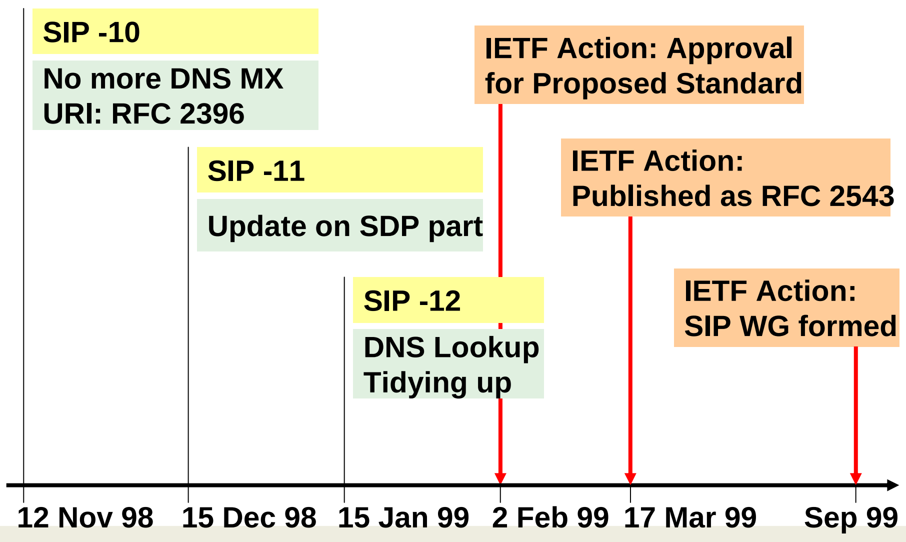
**IETF Action: Last Call for Proposed**

**SIP -09**

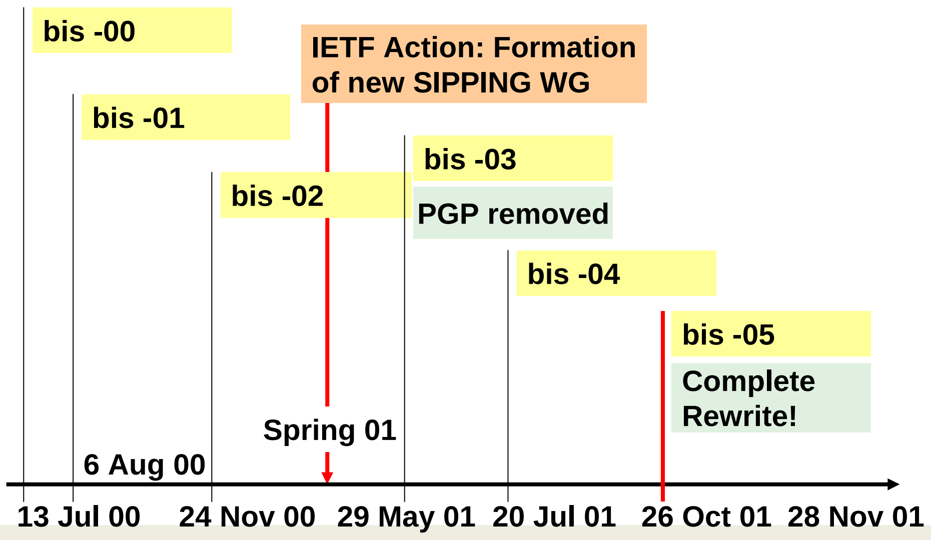
Call Hold SDP

14 May — 17 Jun — 16 Jul — 8 Aug — 18 Sep — 28 Sep

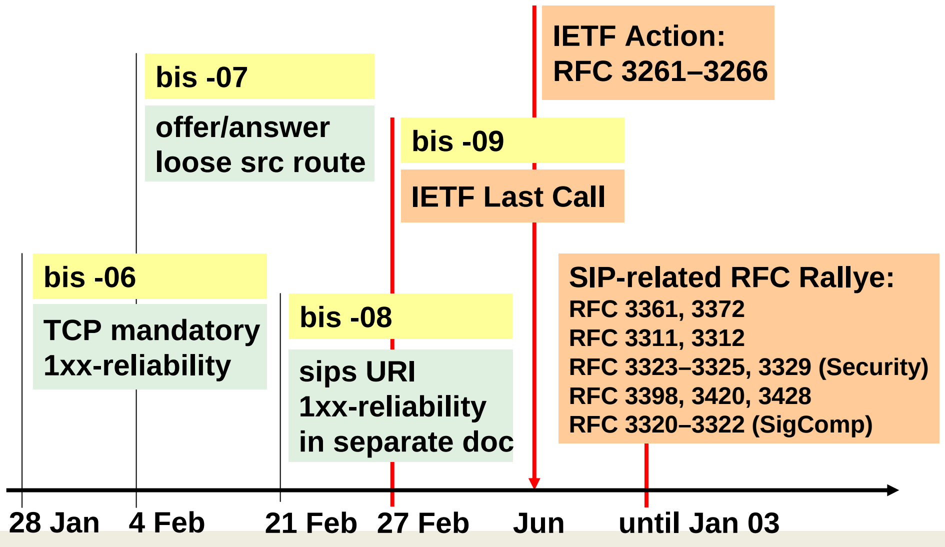
## Timeline: 1998/99


SIP -10
No more DNS MX URI: RFC 2396
SIP -11
Update on SDP part
SIP -12
DNS Lookup Tidying up
IETF Action: Approval for Proposed Standard
IETF Action: Published as RFC 2543
IETF Action: SIP WG formed
12 Nov 98
15 Dec 98
15 Jan 99
2 Feb 99
17 Mar 99
Sep 99

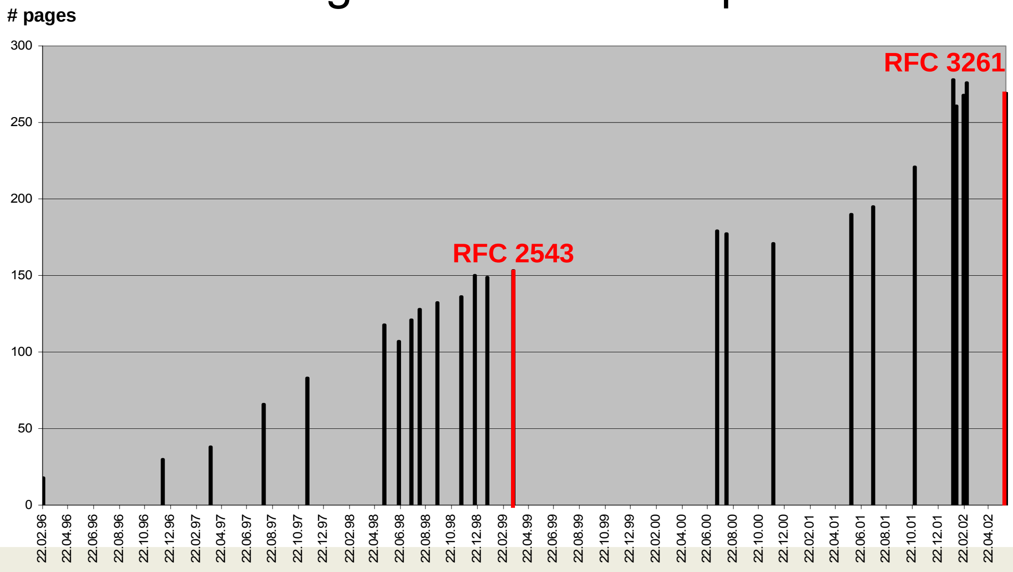
## Timeline: RFC2543bis (2000/2001)



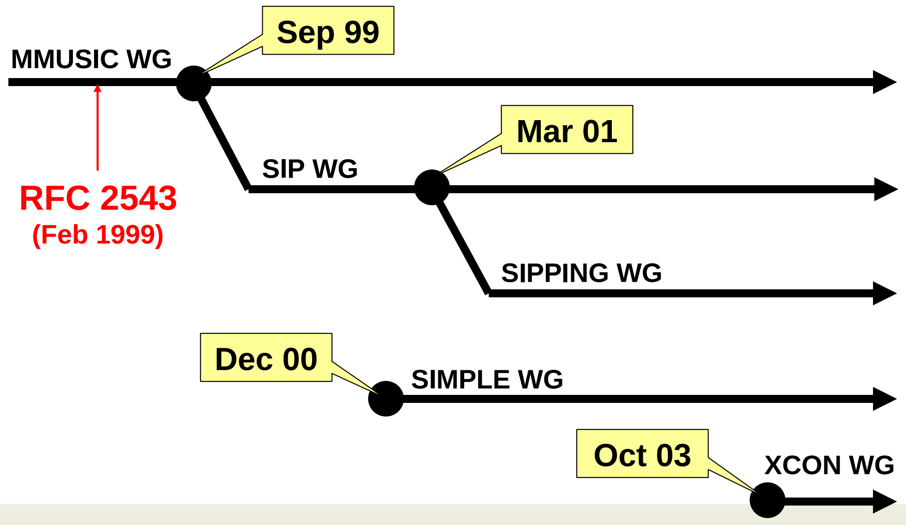
## Timeline: RFC2543bis, RFC3261 (2002)



## “Weight” of SIP Base Spec



## IETF SIP-related Working Groups (1)



## IETF SIP-related Working Groups (2)

**MMUSIC WG**
- SDP extensions
- SDPng

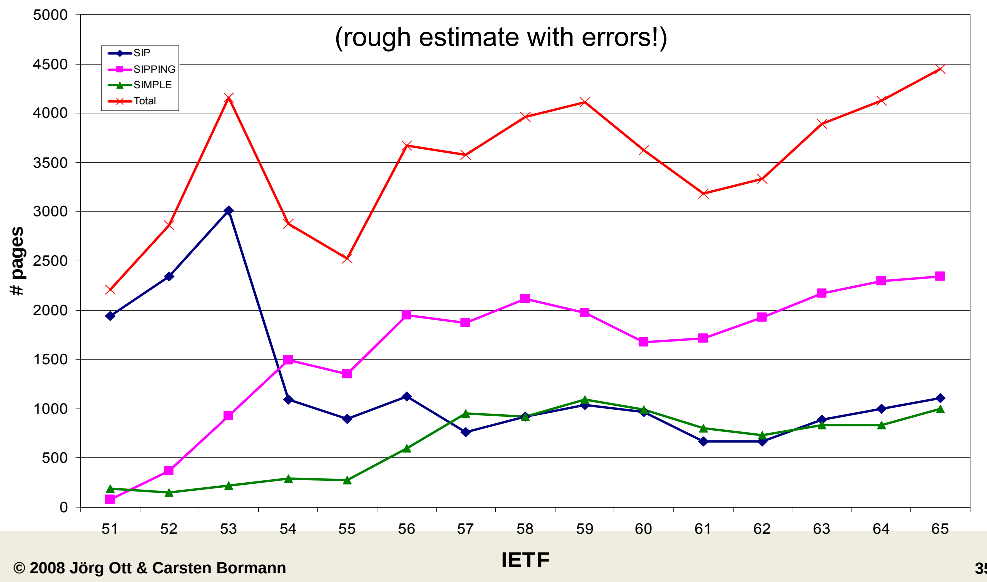
**SIP WG**
- SIP core spec maintenance
- SIP protocol extensions

**SIPPING WG**
- Requirements for SIP
- Specific SIP application services

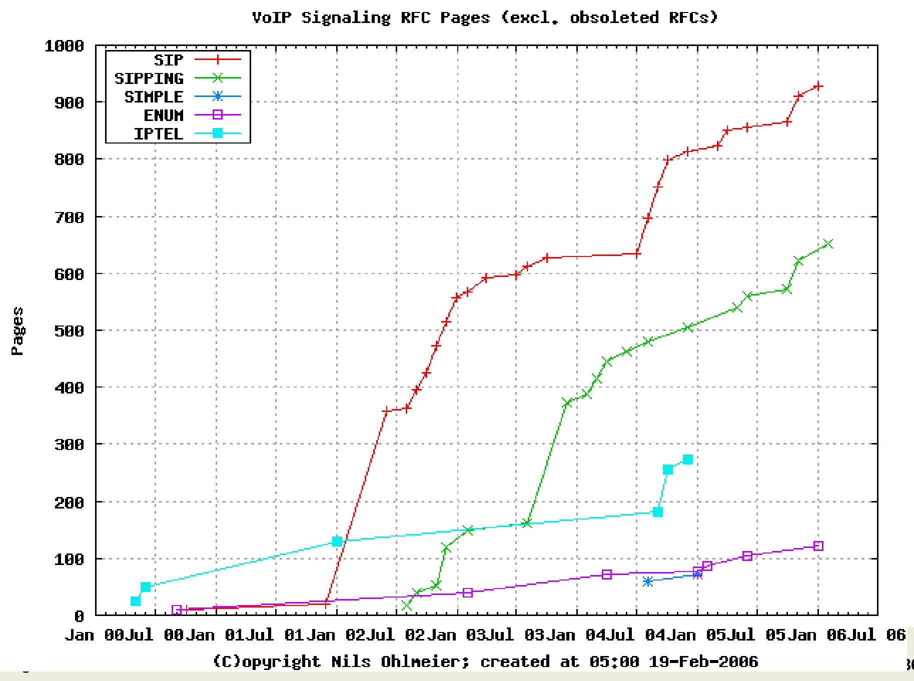
**SIMPLE WG**
- SIP for Presence and Instant Messaging

**XCON WG**
- Centralized Conferencing

## “Productivity” (1): Internet Draft Pages



## “Productivity” (2): RFC Pages



## RFCs related to SIP (1)

- Base spec
  - **RFC 3261: SIP: Session Initiation Protocol**
  - **RFC 3263: Locating SIP Servers**
  - **RFC 3264: An Offer/Answer Model with SDP**
- Extended Features
  - RFC 2976: The SIP INFO Method
  - RFC 3262: Reliability of Provisional Responses in SIP
  - RFC 3265: SIP-specific Event Notification
  - RFC 3311: SIP UPDATE Method
  - RFC 3312, RFC 4032: Integration of Resource Management and SIP
  - RFC 3326: Reason Header
  - RFC 3327: Registering Non-Adjacent Contacts
  - RFC 3428: Instant Messaging
  - RFC 3487: Requirements for Resource Priority
  - RFC 3515: SIP REFER Method
  - RFC 3581: Symmetric Message Routing
  - RFC 3680: SIP event package for registrations
  - RFC 3725: Third-party Call Control (3PCC)
  - RFC 3840, 3841: Callee capabilities and caller preferences
  - RFC 3842: Message waiting indication / message summary
  - RFC 3857, 3958: Watcher Information event package + XML format
  - RFC 3891: Replaces: header
  - RFC 3892: Referred-By: header
  - RFC 3903: Event state publication (SIP PUBLISH method)
  - RFC 3911: Join: header
  - RFC 4028: Session timers
  - RFC 4168: SCTP as transport protocol

## RFCs related to SIP (2)

- Security
  - RFC 3323: A Privacy Mechanism for SIP
  - RFC 3325: Private Extension for Asserted Identity in Trusted Networks
  - RFC 3329: Security-Mechanism Agreement for SIP
  - RFC 3603: Proxy-to-Proxy Extensions
  - RFC 3702: AAA requirements for SIP
  - RFC 3853: S/MIME AES
  - RFC 3893: Authenticated Identity Body
- Others
  - RFC 3665, 3666: SIP Call Flows
  - RFC 3361: DHCP Option for SIP Servers
  - RFC 3608: Service Route Discovery
  - RFC 3398, 3578: ISUP and SIP Mapping
  - RFC 3420: Internet Media Type message/sipfrag
  - RFC 3427: SIP Change Process
  - RFC 3455: Header Extensions for 3GPP
  - RFC 3485, 3486: SIP header compression
  - RFC 3764, 3824: Using ENUM with SIP
  - RFC 3959: Early Session disposition type (early-session, session)
  - RFC 3960: Early Media and Ringing Tone Generation
  - RFC 3968, 3969: IANA SIP header field and URI registry
  - RFC 3976: SIP – IN Interworking
  - RFC 4117: 3rd party call control invocation of transcoding services
  - RFC 4123: SIP – H.323 Interworking requirements
- Related: RTP, SDP, Security basics, 3GPP requirements and extensions

**Plus some 100+ Internet Drafts**

## SIP: The verdict

- Set out with the promise of Simplicity ("Simple Conference Invitation Protocol")
  - Was meant for conferencing
  - Retargeted for embracing telephony
- Tried to leverage (and extend) an unrelated protocol (HTTP) and a vaguely related protocol (RFC822)
- Protocol Issue: Confusing transport layer and application layer
  - The curse of UDP, fragmentation, forking/multicast, …
- Marred by SDP
  - Another retargeted protocol extended to death ("offer-answer")
- Interesting case study:
  building-block based extensibility vs. well-defined services

## "ng" efforts

- IP: IPv4 ➔ IPv6
  - Motivated by field size issues
  - Convenient time to change not only syntax, but also semantics
  - No interoperability (ships in the night) because of fear of NATs
- HTTP: HTTP 1.1 ➔ HTTPng
  - Grandiose ideas of a "new session layer"
  - Just wasn't worth it
- SDP: SDP ➔ SDPng
  - XML substrate came too early
- RADIUS: RADIUS ➔ DIAMETER
  - Field size issues again
  - "Fixing" broken protocol semantics

## Why “ng” efforts usually don't work

- Market is supplied by market players
- Incumbents are heavily invested (and have debugged) “pg”
- “ng” might exhibit unknown technical (as well as patent!) issues
- Incumbents consider complexity of working with old, overstretched protocol to be a convenient barrier to market entry
- “ng” development is likely to fall victim to:
  - second system syndrome
  - random non-market oriented forces (academics, patent players, architects, …)
- All the while more market-driven features continue to be put into “pg” — even when it hurts

## Wholesale replacements do work, if…

- Disruptive technology
  - Market values new economy over features that are oversupplied by “pg”
- Carried forward not by incumbents, but by strong new players
- Concurrence with investment/technology replacement cycle

- GGP ➔ EGP ➔ BGP
  - The underlying structure of the Internet changed
  - There just **had** to be a change at the protocol level
- (PSTN, H.323) ➔ SIP
  - H.323 eclipse was helped tremendously by PER disaster
    - H.323 had no “Henry”, either
  - Bubble helped, too