Understanding and Enhancing the Scalability of IMS-based Infrastructures and Services

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Luca Foschini

Research Fellow
DEIS, University of Bologna, ITALY
luca.foschini@unibo.it

Agenda

- ***Service delivery*** in ***4G converged Internet***
- ***IP Multimedia Subsystem – IMS – scalability issues***
- ***IHMAS middleware*** for ***scalability*** of ***IMS-based infrastructure and services***
- ***IHMAS presence service scalability use case***
  - ***Infrastructure scalability***
  - ***Intra-/Inter-domain service scalability***
  - ***Implementation details*** and ***experimental evaluation***
- Concluding remarks and open research directions

4G converged world

Voice (VoIP)

Audio/Video Conference

Chat and messagging

Video on Demand (VoD)

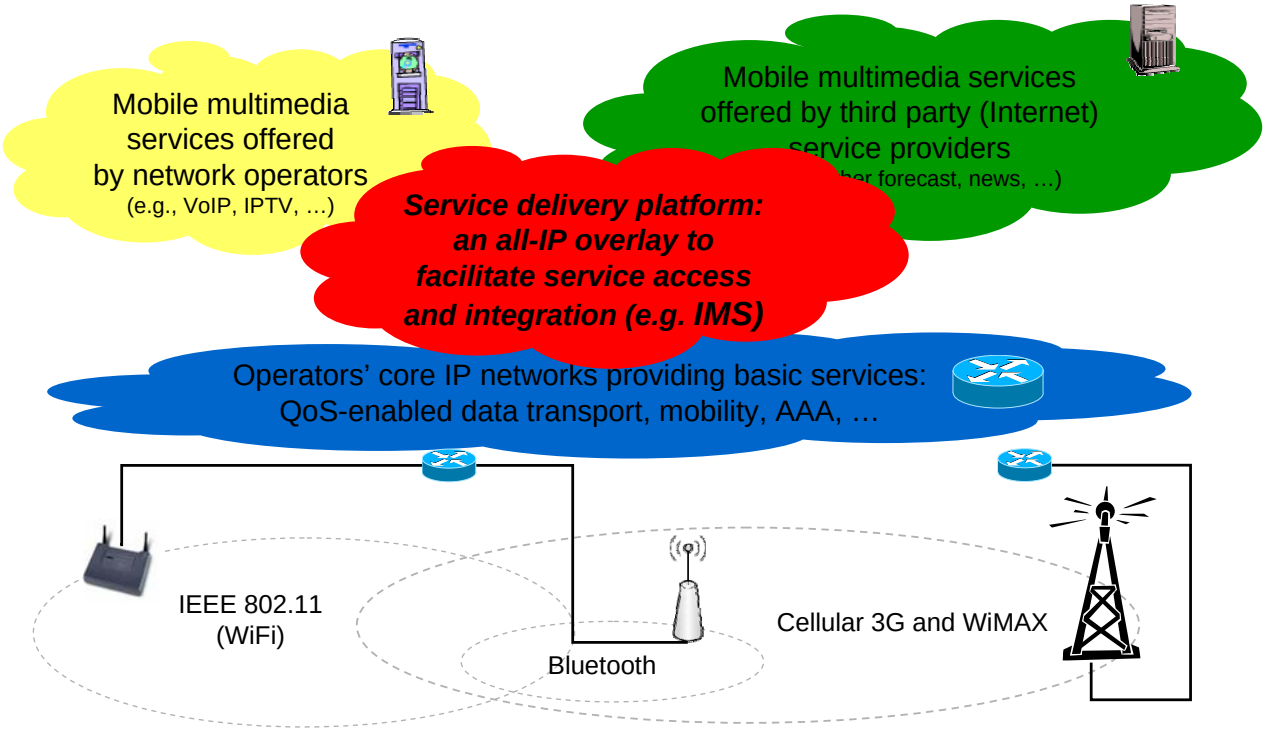
And many more…

- Push To Talk (PTT)
- PTT over Cellular (PoC)
- IPTV
- Video sharing
- ...

Ever-increasing demand and diffusion of mobile multimedia services during the last two decades, driven by:

- New powerful ***devices*** and ***wireless technologies/infrastructures***
- New (mobile) ***services***

4G converged service delivery scenario



Highly differentiated ***(wireless) access networks***

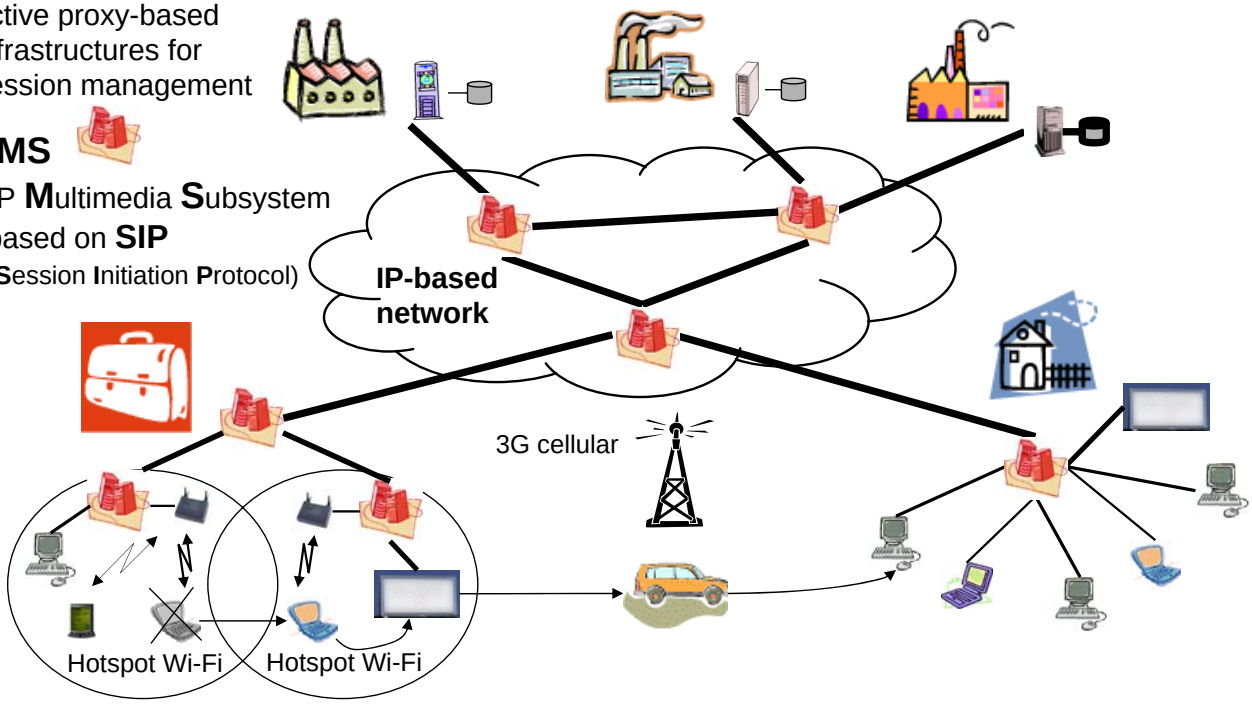
4G service & network management: a proxy-based approach

New protocols and active proxy-based infrastructures for session management

IMS

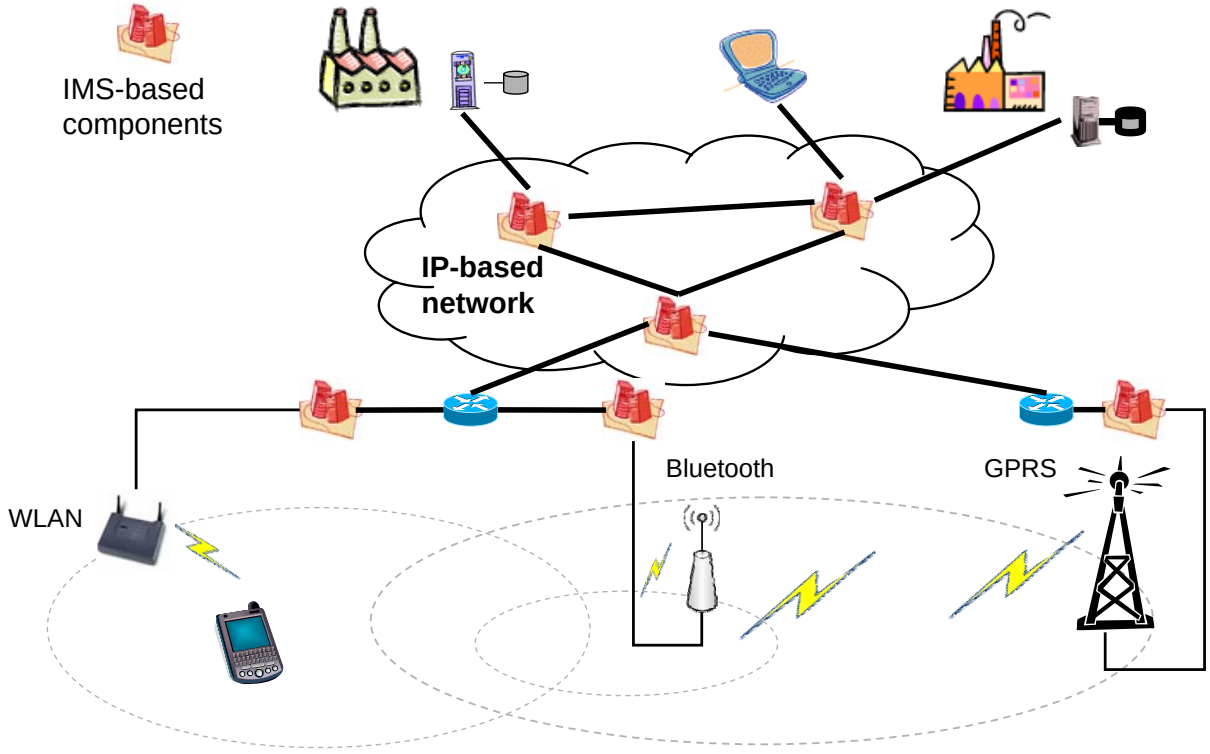
IP **M**ultimedia **S**ubsystem based on **SIP**

(**S**ession **I**nitiation **P**rotocol)



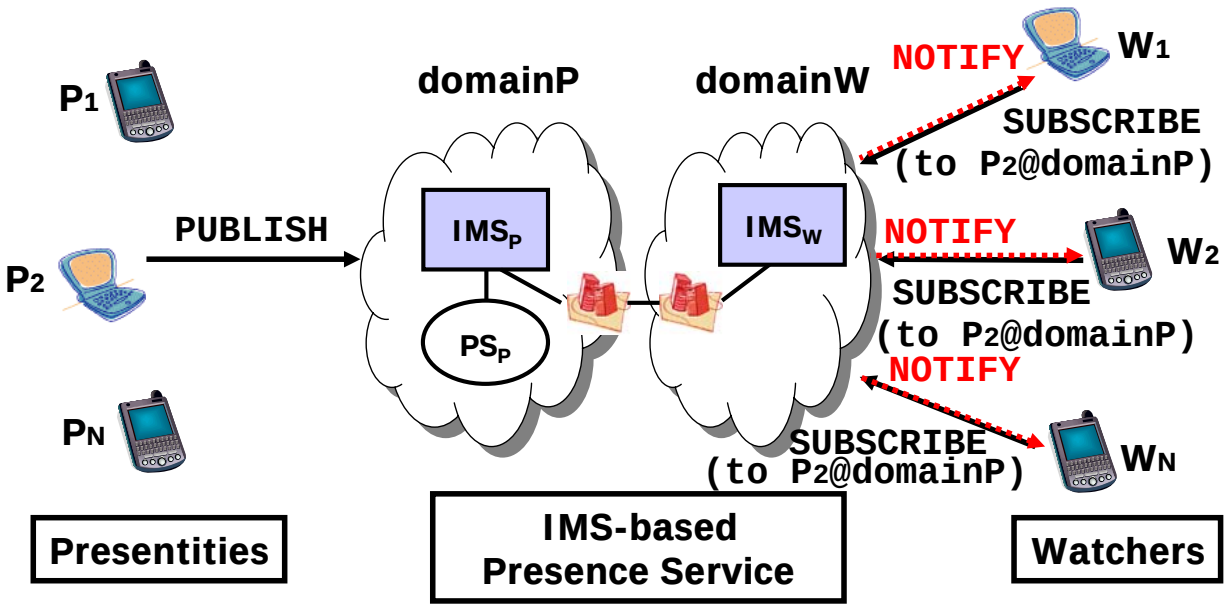
New service scenarios in 4G: handoff management of mobile multimedia

IMS-based components



New support services in 4G: presence service

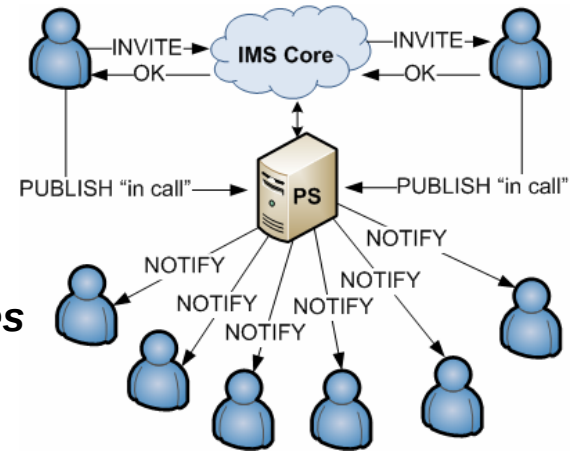
Presence service (PS) permits users and hw/sw components, called ***presentities (P_i)***, to convey their ability and willingness to communicate with subscribed ***watchers (W_j)***



Scalability issues at a glance

High mobility & context changes

New services VoIP+PS (call-status notification)



- Higher signaling traffic ***(message dimension + frequency)***
- Richer services, such as VoIP+PS (message ***multiplying effect***)
- ***Many traversed signaling entities*** (proxies-based architecture…)
- Plus, specific SIP protocol issues (***message verbosity*** and ***ACKs***)

→ Need for a better understanding of IMS ***scalability shortcomings*** and ***load-balancing support*** both at ***infrastructure*** and ***service*** levels

Some background:
SIP – Session Initiation Protocol

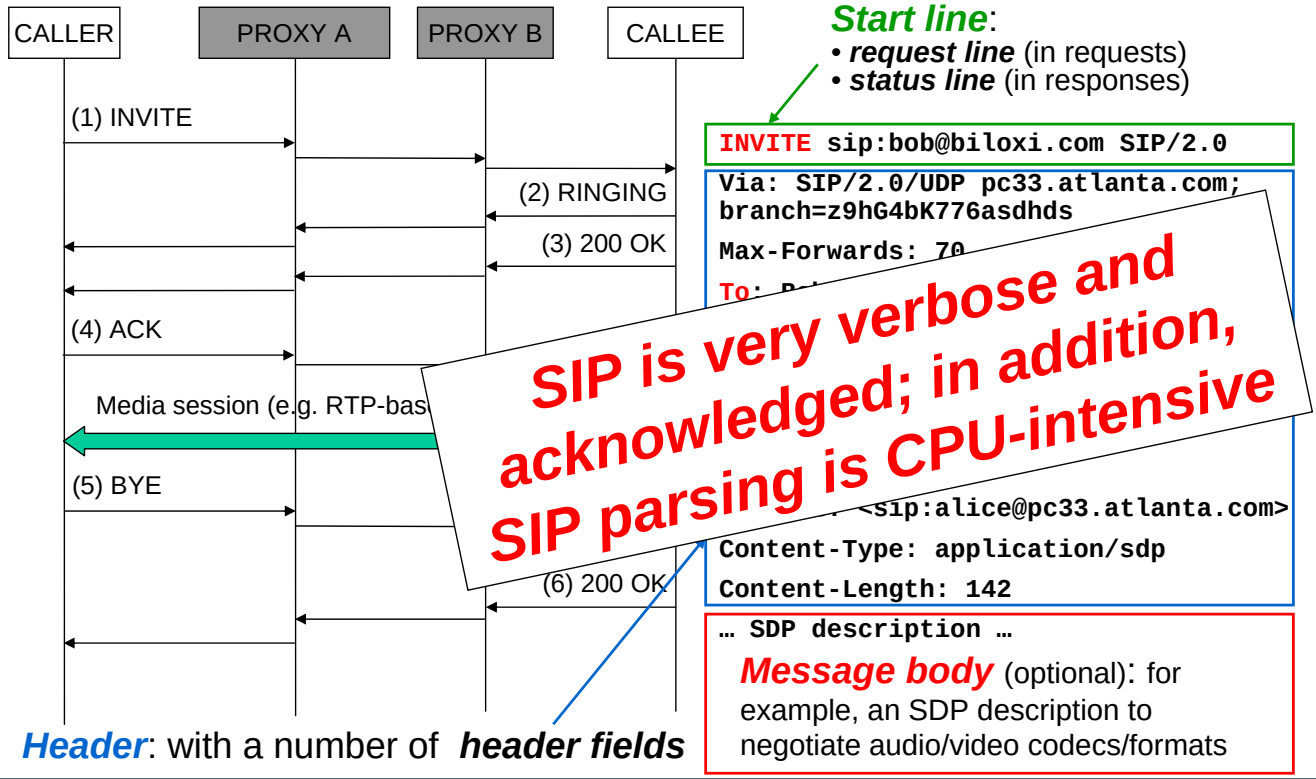
- SIP defines a ***signaling framework*** and related ***protocols and messages*** to setup ***any kind of session*** (work at the Open Systems Interconnection – OSI – ***session layer***)
  - SIP is very ***open*** and ***general purpose*** ☺
  - SIP includes several core facilities for ***mobility management***, ***session initiation***, ***termination***, and ***transfer***, …
  - SIP ***does not*** include some basic services ☹ (e.g., AAA, resource booking, …)
- SIP ***is not*** a ***data/media transmission protocol***

  Other specific protocols for that: Real-time Transport Protocol (RTP), RTP Control Protocol (RTCP), Real Time Streaming (RTSP),…
- SIP usage ***examples***
  - Setting up and tearing down VoIP voice calls
  - Instance messaging and presence service: SIP for Instant Messaging and Presence Leveraging Extensions – ***SIMPLE***
  - Session transfer and call re-direction

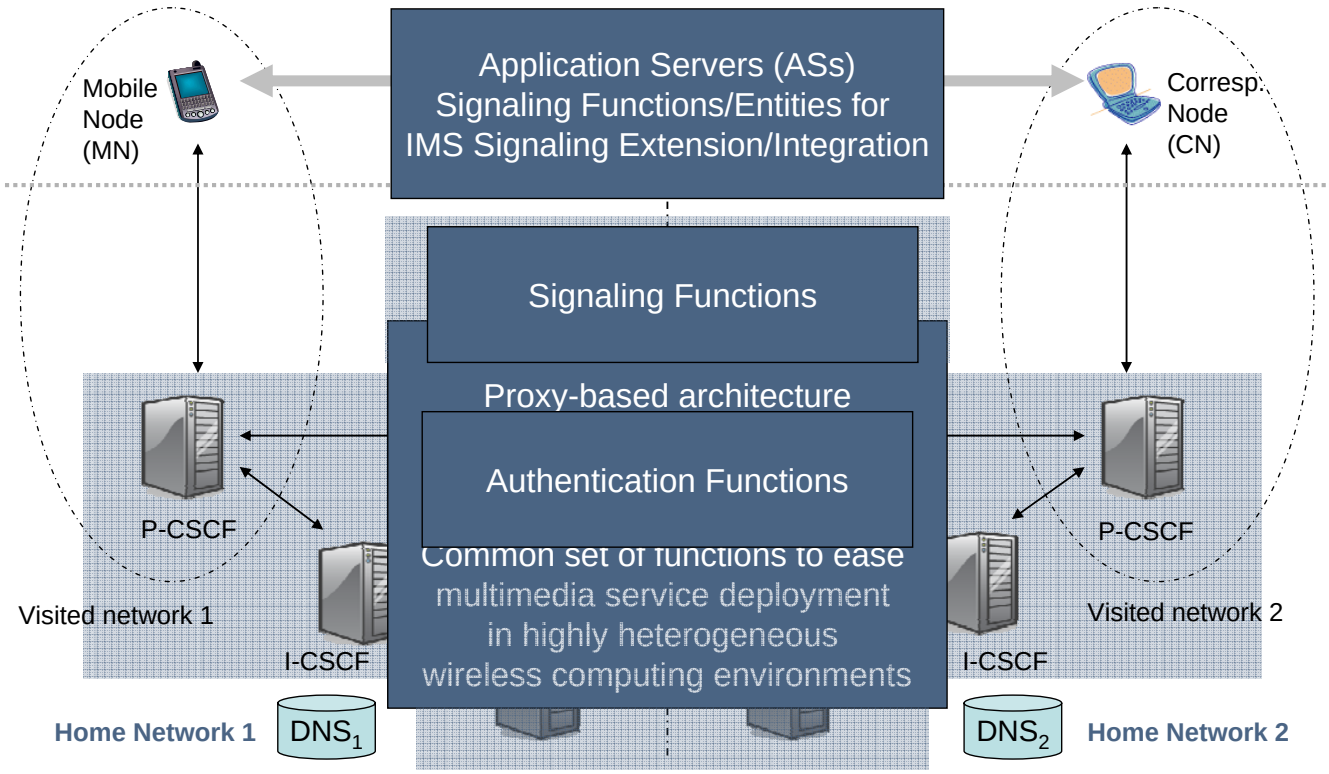
SIP in a nutshell

- SIP core signaling
  - HTTP-like text-based protocol and email-like SIP identifiers (**addresses**)
  - Client/server protocol (request/response protocol)
  - Standardized session control messages
    - INVITE, REGISTER, OK, ACK, BYE, …
- SIP proxy-based framework and ***main entities***
  - **User agents:** end points, can act as both user agent client and as user agent server
    - **User Agent Client:** create new SIP requests
    - **User Agent Server:** generate responses to SIP requests
  - **Dialog:** peer to peer relationship between two user agents, **established by specific methods**
  - **Proxy servers:** application level routers
  - **Redirect servers:** redirect clients to alternate servers
  - **Registrars:** keep tracks of users

SIP VoIP call initiation example: INVITE dialog



Some background: IMS – IP Multimedia Subsystem



IMS functional entities: DNS and HSS

Domain Name System (***DNS***):

- Standard Internet naming service
- Employed by IMS to ***resolve the IP addresses of CSCFs*** and ***ASs***

  → can be used for ***load balancing*** ☺
  (but… only with limited DNS-query frequency)

Home Subscriber Server (***HSS***):

- ***SIP requests forwarding*** in the appropriate direction (terminals or IMS network)
- Storage of all user-related subscription data, such as authentication data and profiles for clients (by using standard Data Base Management System – DBMS)
- A network may contain one or several
  - Subscriber Location Function (SLF) to map users to specific HSS

IMS functional entities: Proxy-CSCF

Proxy-Call Session Control Function (***P-CSCF***):

- First contact point in the IMS network in ***either visited domain*** or ***home domain***
- Outbound / In-bound SIP proxy (all requests from/to IMS terminals go through it)

Main P-CSCF functions

- ***SIP requests forwarding*** in the appropriate direction (terminals or IMS network)
- Several ***other functions***:
  - Security
  - Generation of charging information
  - Compression and decompression of messages

IMS functional entities: Interrogating-CSCF

Interrogating-Call Session Control Function (***I-CSCF***):

- SIP proxy at the edge of the administrative ***home domain***
  - There may be several in the same network for scalability reasons
  - Listed in the domain name server (DNS-based scalability)
- SIP redirect stateless server

Main I-CSCF functions

- ***Interaction with HSS*** to determine the S-CSCF associated with the client (***Diameter*** protocol)
- ***Redirection*** and ***routing of incoming SIP requests*** to S-CSCF

  → can be used to ***dynamically select less-loaded S-CSCFs (e.g. through DNS)*** ☺

IMS functional entities: Serving-CSCF

Serving-Call Session Control Function (***S-CSCF***):

- Always located ***in home domain***
- SIP proxy + SIP registrar with possibility of performing session control

Main S-CSCF functions

- ***Binding*** between ***IP address*** (terminal location) and ***user SIP address***
- Interaction with application servers for ***value added service purpose***
- Translation services (Telephone number / Sip URIs)
- Message routing (by using so-called ***IMS filtering criteria***)

  → can be used to ***statically divide incoming load according to user identity/profile*** ☺

IMS functional entities: AS

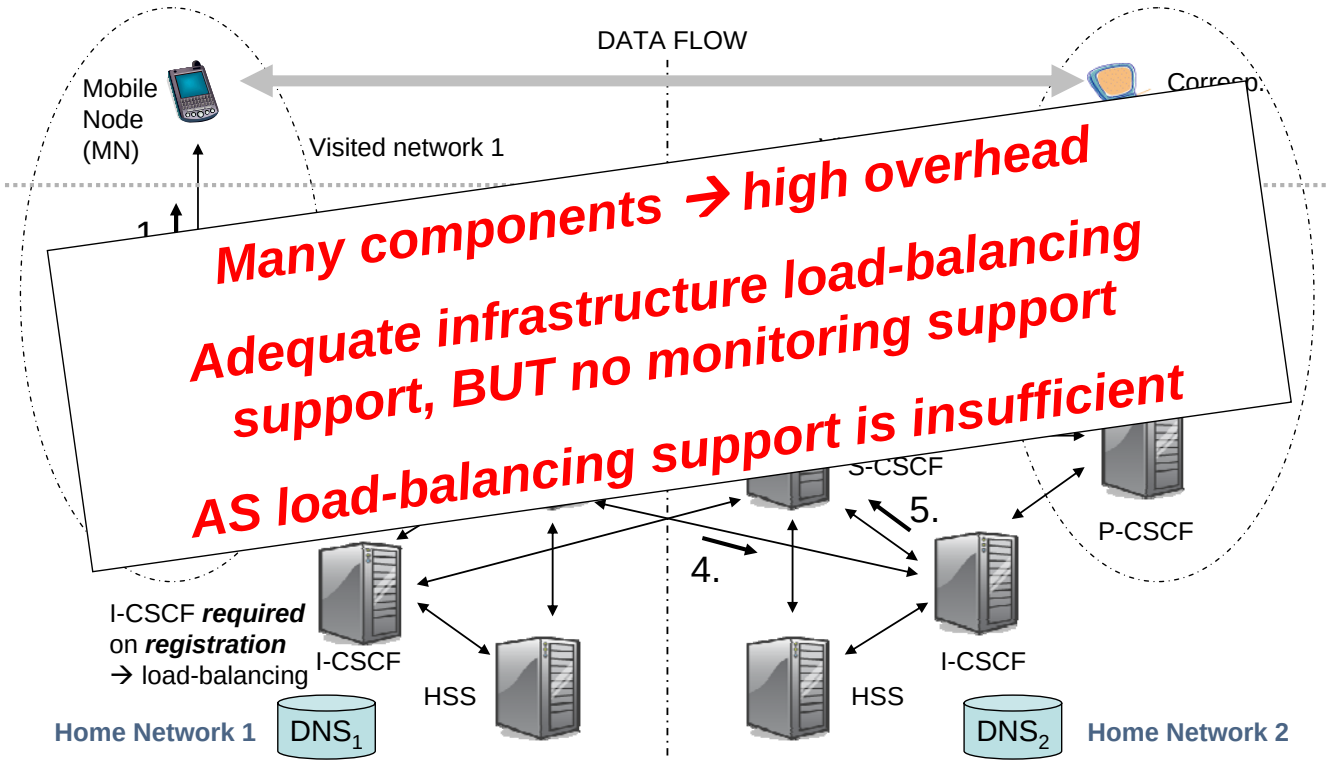
Application Server (***AS***):

- ***Host services*** and ***execute services***
- Communicates using SIP: ***very costly!!*** ☹
  - Each ***interposed AS*** generates 2 msgs (processed+ACK)
  - Complex coordination for ***stateful*** and ***distributed ASs***

Several AS types with different functions

- ***SIP AS***: ***signaling specific*** architecture (services can work only in SIP environment)
- Other types: Open Service Architecture – Service Capability Server (OSA/SCS), IP Multimedia Service Switching Function (IM-SSF), …

IMS Revisited

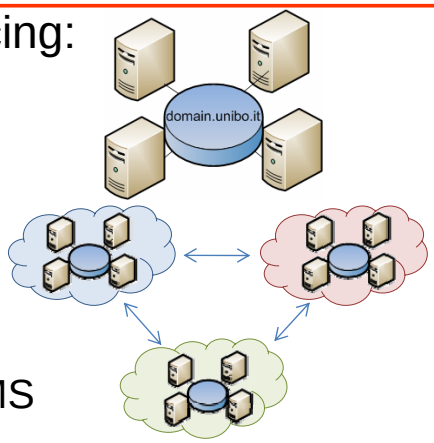


IMS scalability: (partial) solutions

- **Single host** (local) optimizations w/out (or with minimal) coordination:
  - Selective ***message dropping***
  - SIP message ***compression*** and ***incremental parsing*** techniques
  - Stateful vs Stateless SIP proxies

Widely diffused and standardized

- **Intra-domain** (distributed) load-balancing:
  - ***Infrastructure-level monitoring*** and ***dynamic load-balancing*** operations
  - ***Service-level*** AS coordination protocols ***(also ad-hoc and NON-IMS-compliant optimized protocols!!)***
- **Inter-domain** protocol optimizations:
  - Limit traffic among different domains
  - ***Service-level*** message processing at IMS domain borders ***(BUT, IMS compliant)***



IMS scalability: open issues

- One ***unique framework*** able to provide an effective solution to all the different IMS load-balancing issues ***is still lacking***
- One ***solution*** that integrates ***local***, ***intra-domain***, and ***inter-domain*** load balancing is still missing
- One ***significantly tested solution***: ***most papers*** in the IMS literature are ***insufficiently validated*** and do not include extensive experimental results collected in ***real-world distributed testbeds***

IHMAS: emerging design guidelines for IMS scalability

IMS-compliant **H**andoff **M**anagement **A**pplication **S**erver

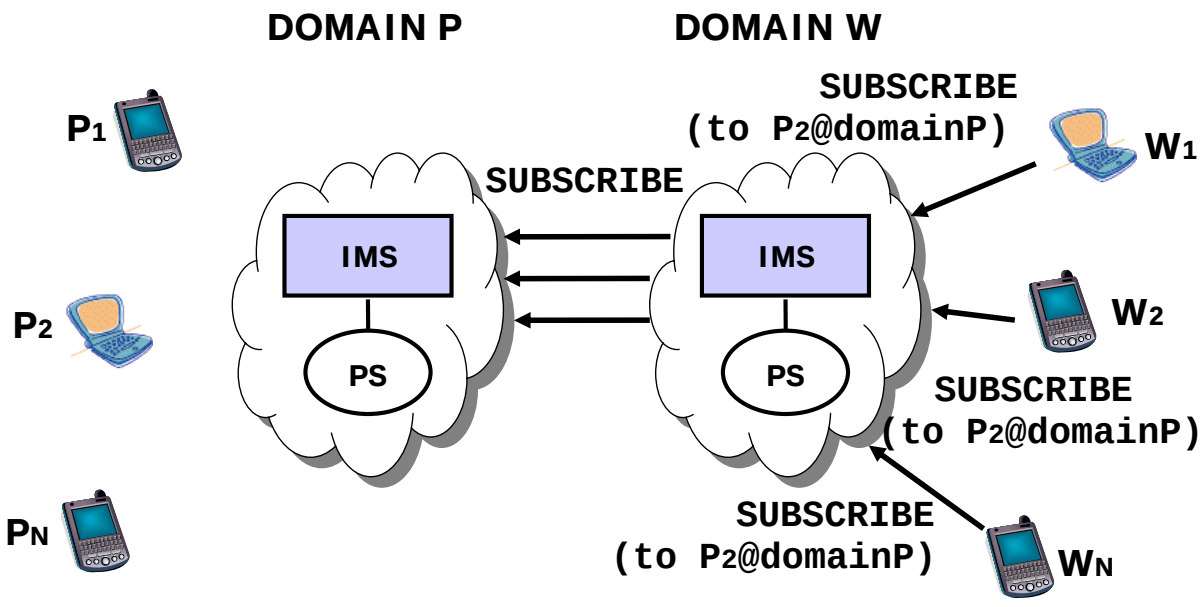
- Active session signaling ***(proxy-based approach)***
- ***Intra-domain (IMS) infrastructure load balancing***
  - ***Collects*** service-aware distributed monitor alarms
  - ***Decides*** and ***executes*** needed load-balancing actions ***(dynamic addition/removal of CSCF components)***
- ***Intra-domain service load balancing***
  - ***Adopts a data-centric*** session management approach to share service state into AS pools
  - ***Exploits*** specific service knowledge ***(service awarereness)*** to divide intra-domain load into partitions
- ***Inter-domain*** transmission optimizations
  - ***Controls*** and ***reduces*** inter-domain traffic
  - ***Realizes*** ***service-aware message aggregation*** and ***batching*** techniques based on distributed AS federation models

IHMAS PS scalability use case

P: Presentity **PS**: Presence Server

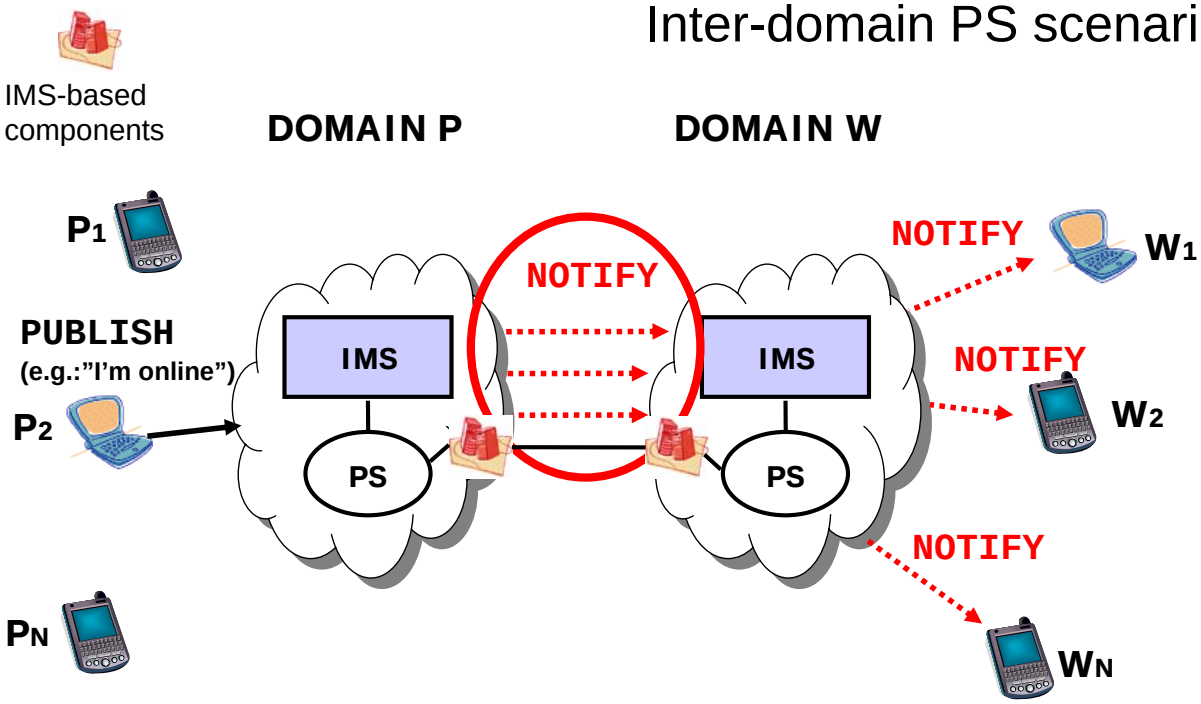
W: Watcher

Inter-domain PS scenario



IHMAS PS scalability use case

Inter-domain PS scenario



PS is very prone to load-balancing issues!!

IHMAS intra-domain PS scalability: infrastructure load-balancing

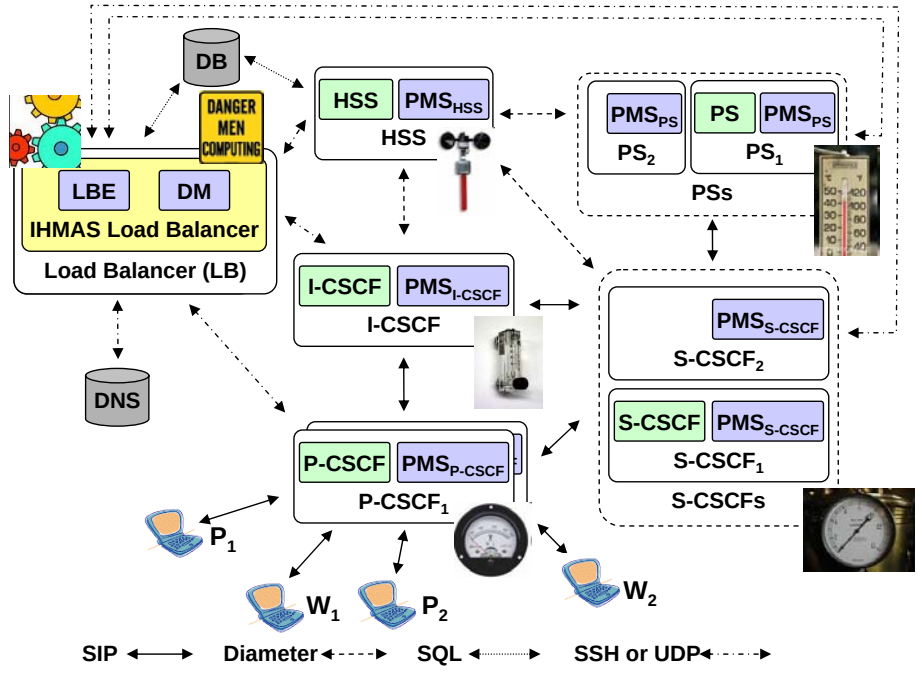
IHMAS intra-domain ***infrastructure*** load-balancing

- **monitors** distributed infrastructure and service components (I-/P-/S-CSCFs, HSS, PS, any AS, …)
  → ***load monitoring actions tailored for the specific service (service-aware approach)***
- **executes** application-level specific **component load-balancing actions**
  → ***dynamic de-/activation of distributed components and DNS (de-)registration actions***
- **integrates** seamlessly with existing infrastructures
  → ***full compliancy with IMS standard***

P. Bellavista, A. Corradi, L. Foschini, "**Enhancing the Scalability of IMS-based Presence Service for LBS Applications**", IEEE COMPSAC, 2009

P. Bellavista, A. Corradi, L. Foschini, "**IMS-compliant Management of Vertical Handoffs for Mobile Multimedia Session Continuity**", accepted for IEEE Communications Magazine

IHMAS intra-domain PS scalability: infrastructure load-balancing

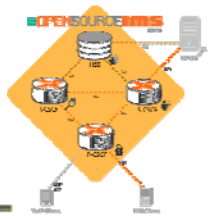


PMS: Proactive Monitoring Stub **DM:** Decision Maker **LBE:** Load-Balancing Executor

- Decision Maker – ***DM***: takes load balancing and partitioning decisions
- Load-Balancing Executor – ***LBE***: enforces them
- Proactive Monitoring Stub – ***PMS$_x$***: monitor system/ component behavior and generate overload alerts towards DM
- ***IMS components***: I-/P-/S-CSCF, HSS, PS, DNS

Implementation hints

- IMS infrastructure → **Open IMS Core**

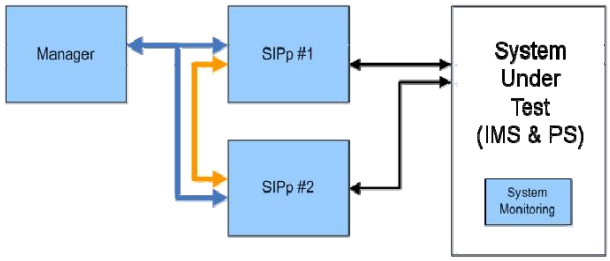


- Presence Server → **OpenSER (now OpenSIPS and Kamailio)**

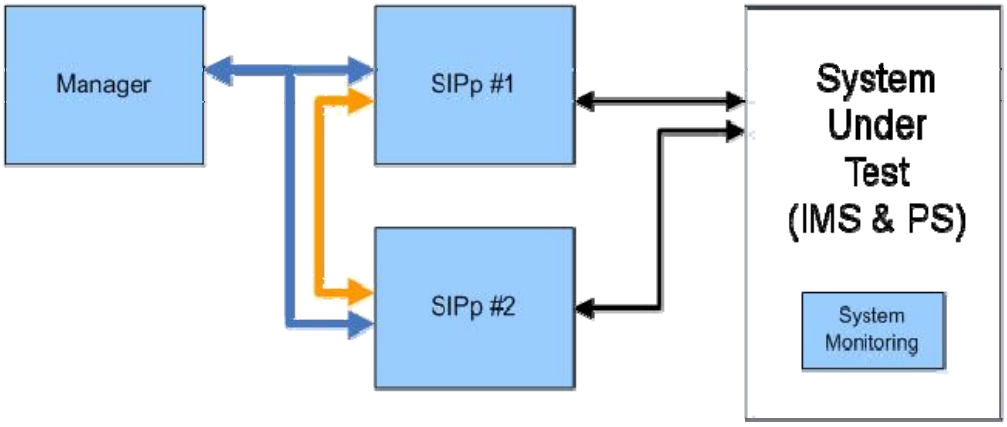
- Deployment re-configuration → **Diskless Remote Boot Linux (DRBL)**

- SIP traffic generation

  → **IMS Bench SIPp**



IMS (PS) traffic emulation



IMS Bench SIPp

- IMS traffic generator that conforms to ETSI TS 186 008 IMS/NGN Performance Benchmark specification
- IMS Bench SIPp permits to define benchmark configuration scenarios by composing different IMS session phases (e.g., registration, subscription, …)

PS traffic benchmark

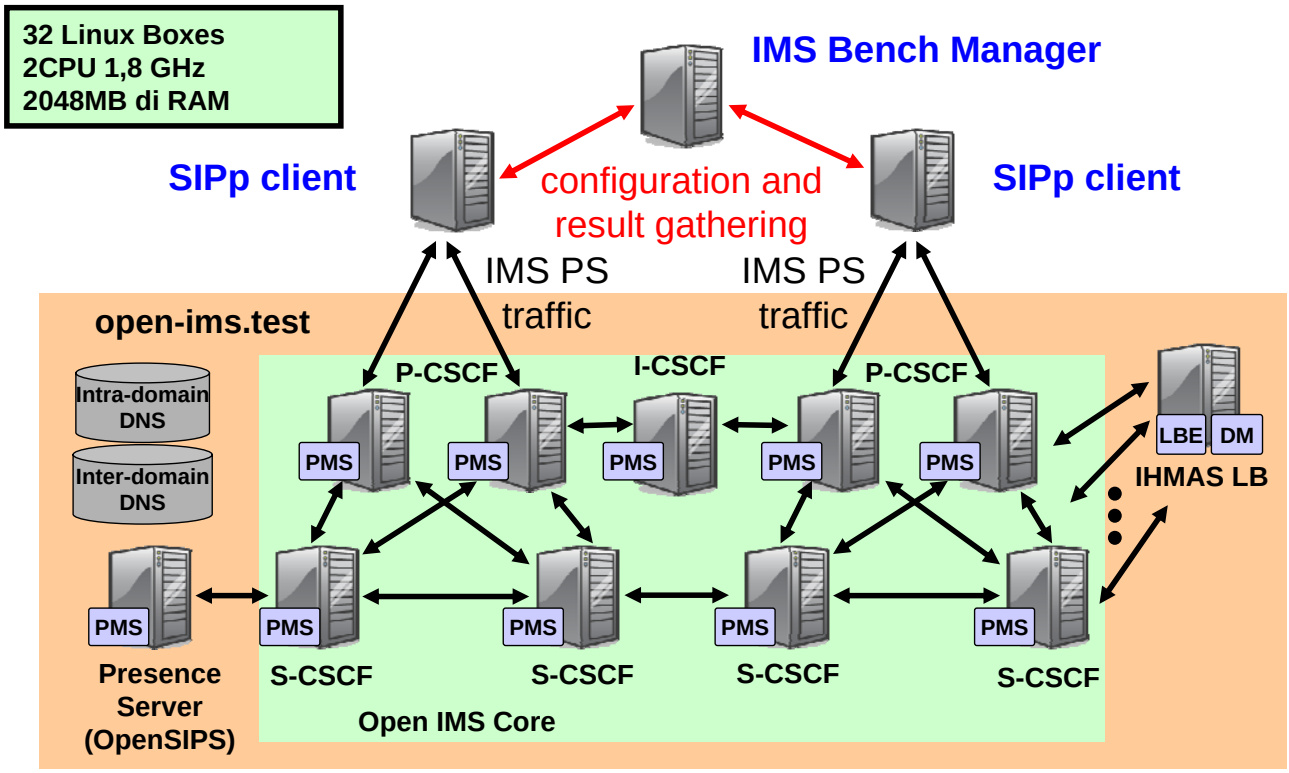
Three main phases *(in each experiment)*

1. IMS clients registration
2. Watcher subscriptions
   → ***to obtain different watcher-per-presentity (w/p) ratios***
3. ***IMS infrastructure and system stress***
   This phase is a mix of:

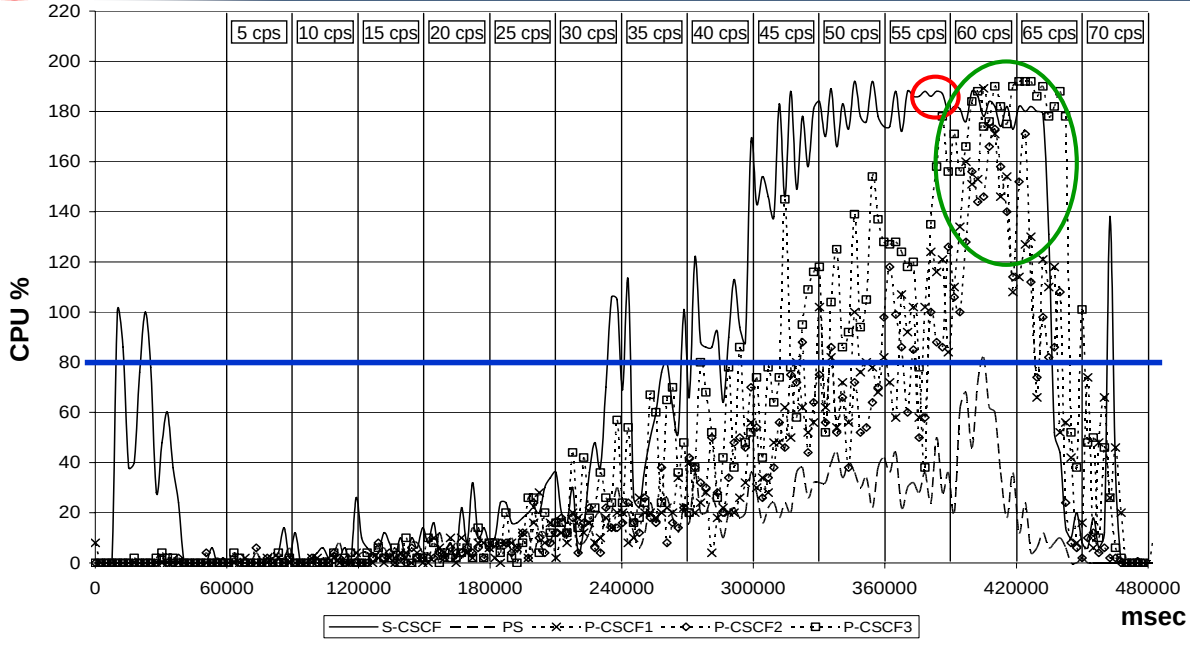
   10% subscriptions, 5% registrations,
   5% de-registrations, ***80% publications (Presentities)***

   configured with various incremental steps

Experimental testbed

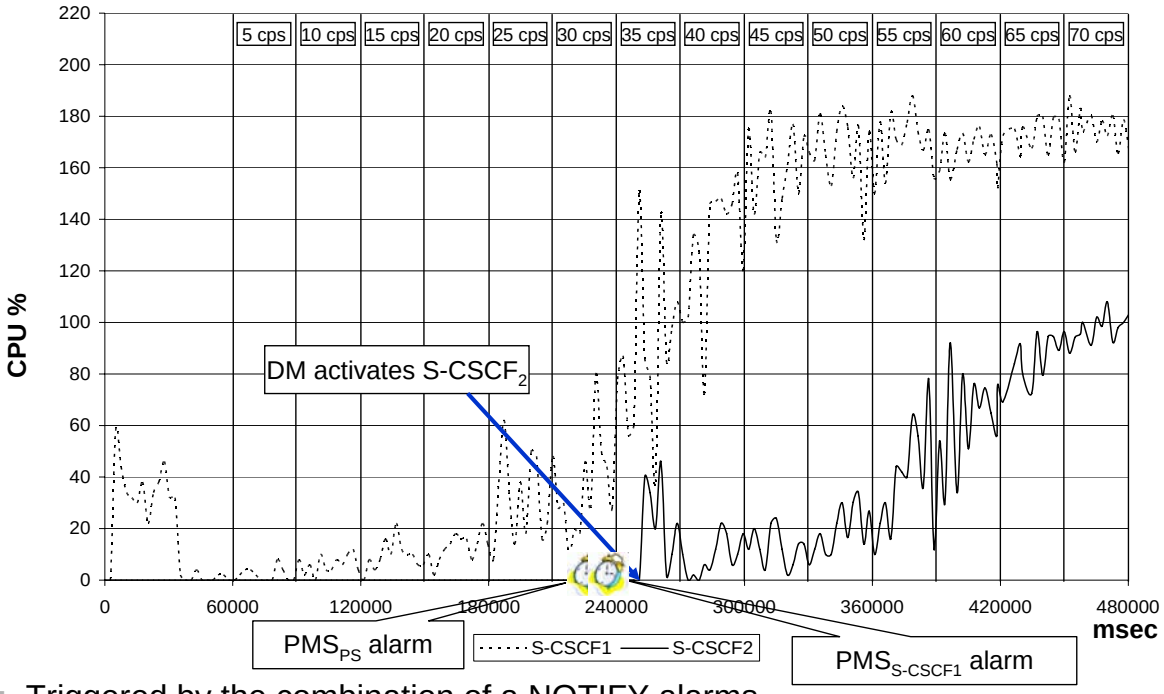


Experimental results: S-CSCF scalability



Scalability threshold of one S-CSCF component, obtained with: 1 PS, 1 I-CSCF, 1 HSS (not shown), and 3 P-CSCFs

Experimental results: dynamic S-CSCFs load-balancing



- Triggered by the combination of a NOTIFY alarms
- Filtering and prediction techniques permits to effectively smooth sporadic peaks

IHMAS intra-domain PS scalability: service load balancing

IHMAS intra-domain ***service*** load-balancing

- **extends IMS PS** to support multiple AS service state storages and fast exchange of (and access to) shared session state among ASs

  → ***novel PS intra-domain module to enable data distribution overlays and caching techniques within AS partition***

- **exploits** existing standards for data distribution

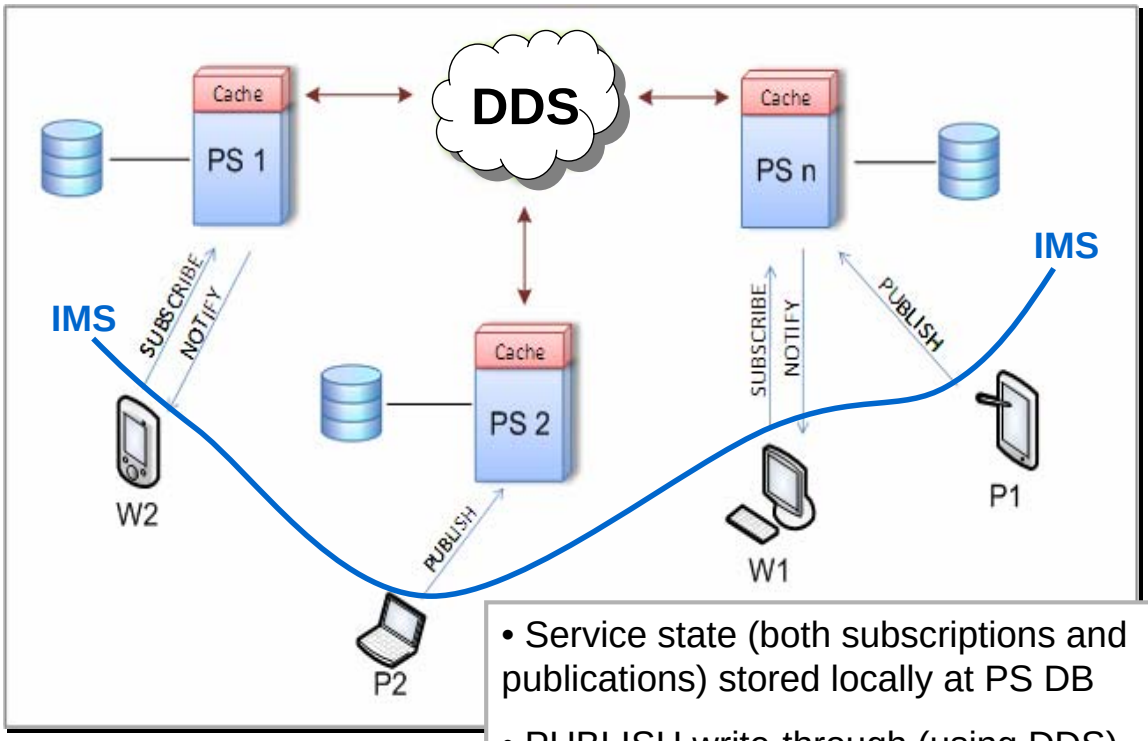
  → ***data distribution is fully compliant with Data Distribution Service (DDS), an Object Management Group (OMG) standard***

- ***divides intra-domain service workload*** by applying a divide-and-conquer principle (for big domains)

  → ***IMS routing based on HSS and IMS filter criteria***

P. Bellavista, A. Corradi, L. Foschini, "**Understanding and Enhancing the Scalability of IMS-based Services for Wireless Local Networks**", IEEE WLN, 2009

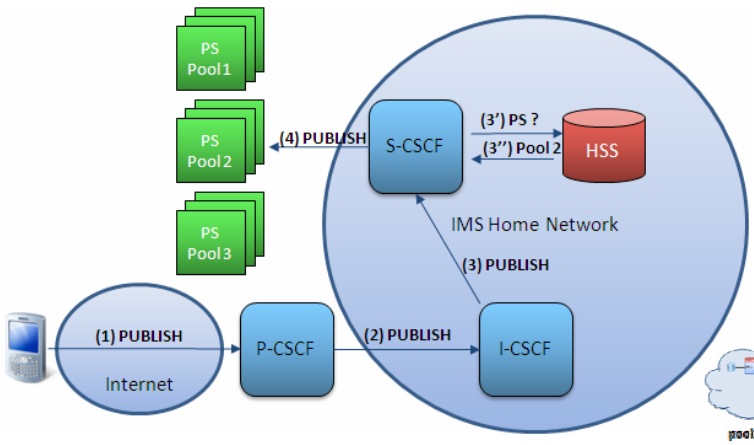
IHMAS intra-domain PS scalability: session data-centric management

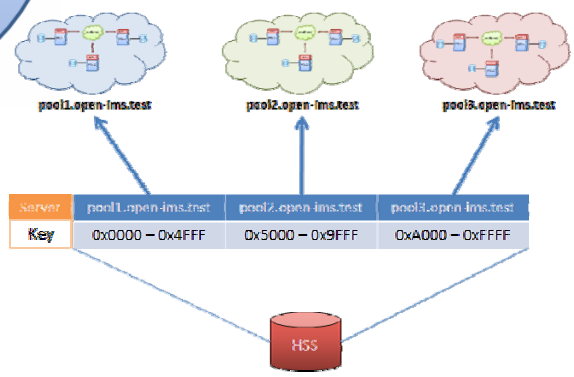


- Service state (both subscriptions and publications) stored locally at PS DB
- PUBLISH write-through (using DDS)

IHMAS intra-domain PS scalability: static balancing among PS pools

Message routing





Statistical load partition based on a hash function evaluated on presentity identifiers → ***exploits HSS + IMS filtering criteria***

IHMAS inter-domain PS scalability: transmission optimizations

IHMAS inter-domain ***service*** optimizations

- **extends IMS PS** to support message aggregation/batching (diminishes the number of inter-domain NOTIFY transmissions)

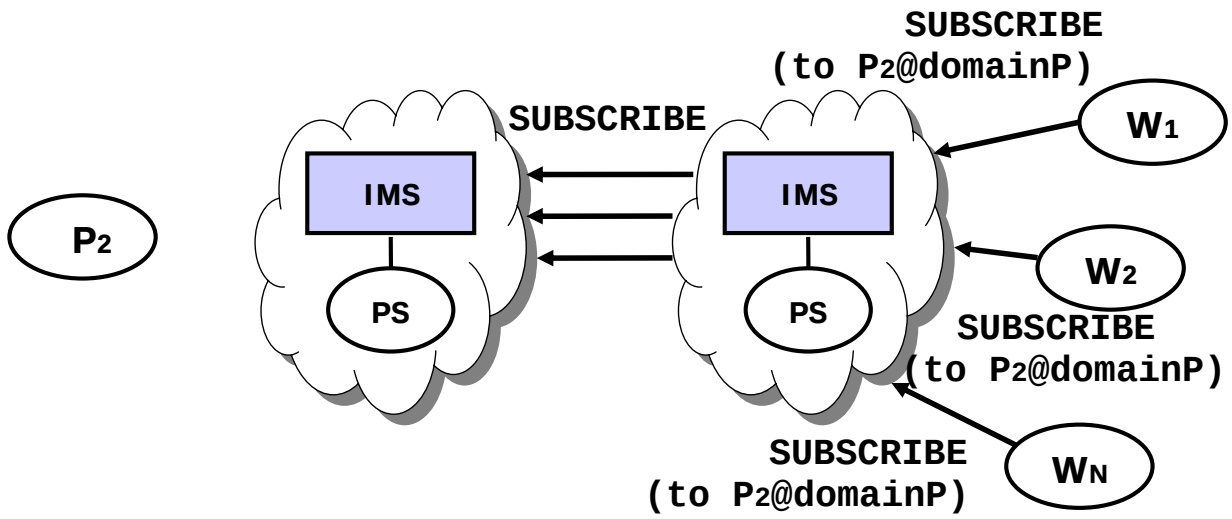
  → ***novel PS inter-domain optimization module for NOTIFY message parsing and inter-domain routing***
- **supports** mobile clients and **service differentiation** (gold, silver, copper, …)
  - **Gold:** ***instant*** presence info delivery → ***high cost***
  - **Silver:** ***slightly delayed*** presence info delivery → ***medium cost***
  - **Copper:** ***very delayed*** presence info delivery → ***low cost***
- **integrates** seamlessly with existing infrastructures

  → ***full compliance with IMS standard***

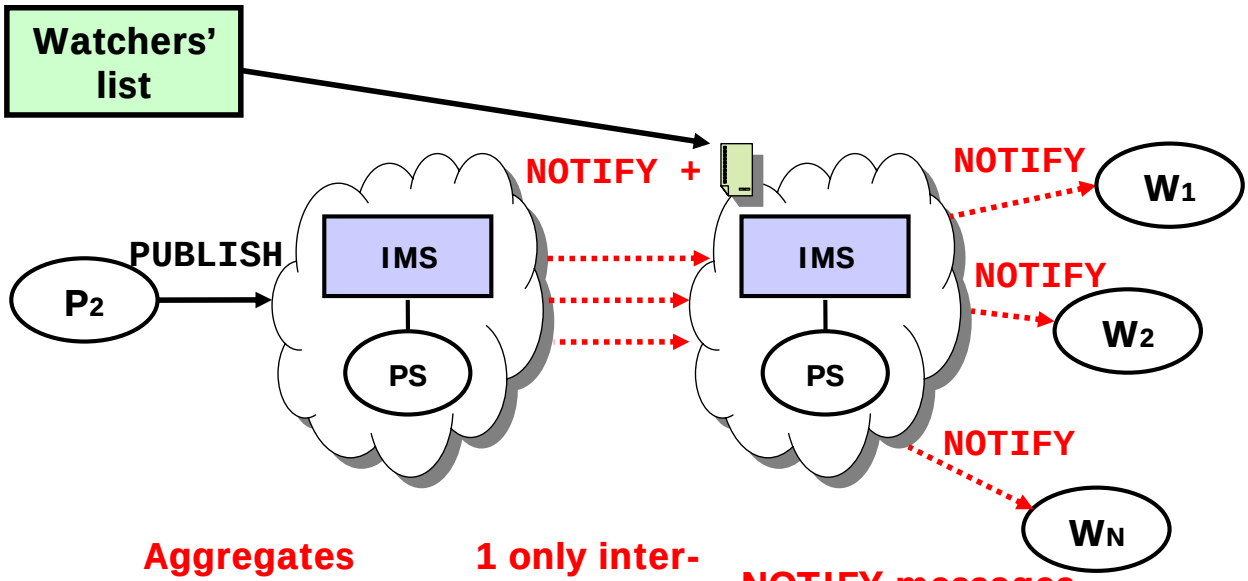
P. Bellavista, A. Corradi, L. Foschini, "**IMS-based Presence Service with Enhanced Scalability and Guaranteed QoS for Inter-Domain Enterprise Mobility**", IEEE Wireless Communications Magazine, vol. 16, no.3, Jun. 2009

Common NOTIFY

"***Several watchers*** subscribed to ***one presentity***"

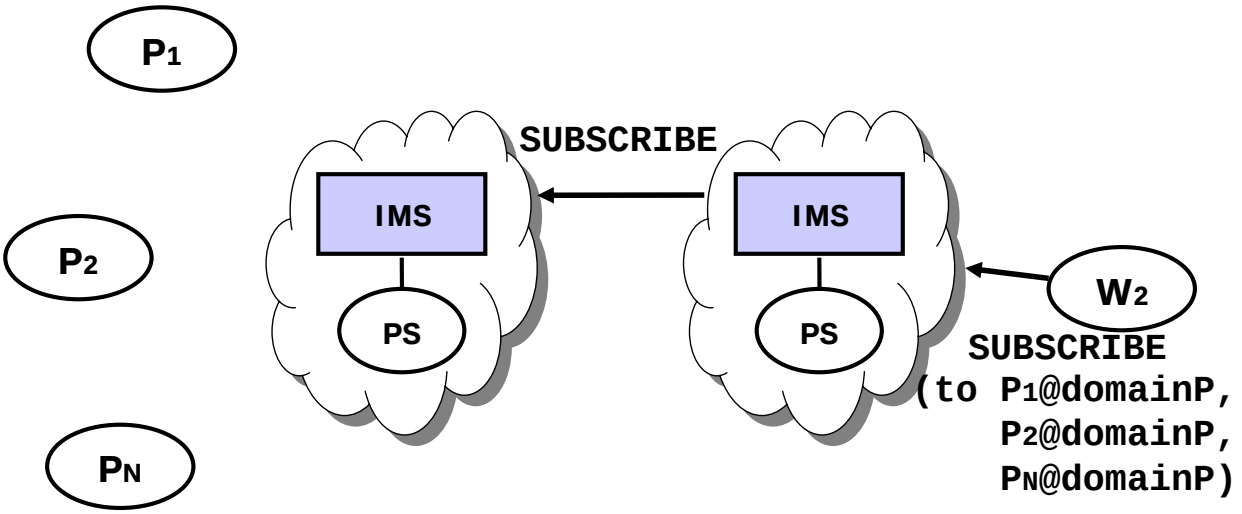


Common NOTIFY

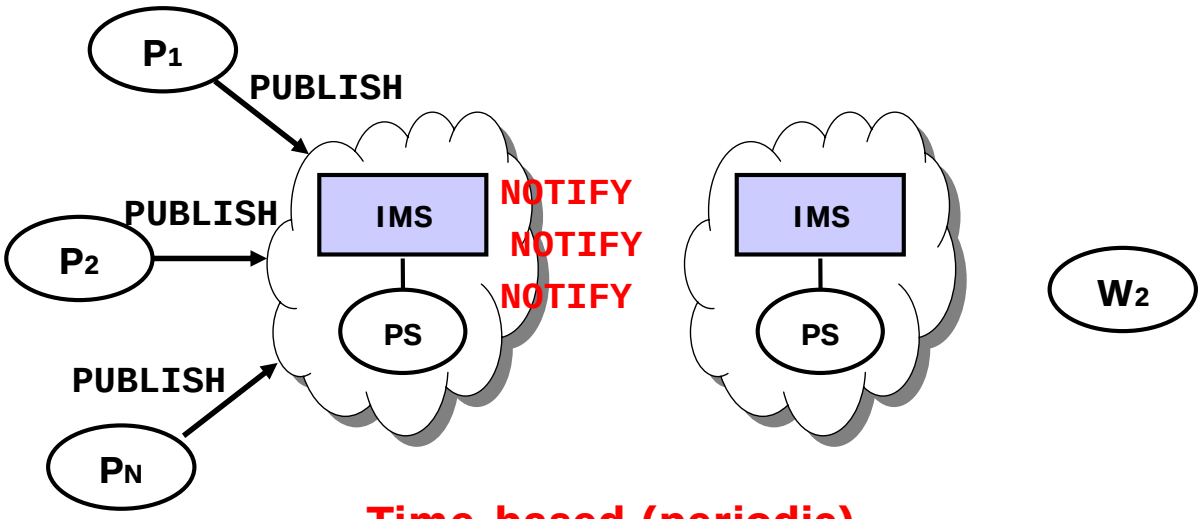


Batched NOTIFY

"One ***single watcher*** subscribed for ***multiple presentities***"

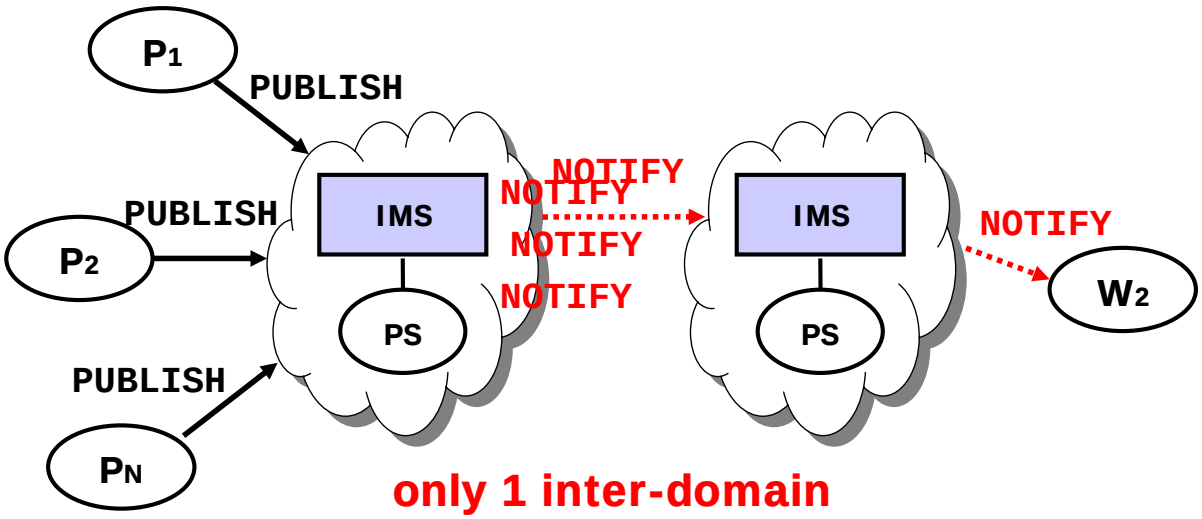


Batched NOTIFY



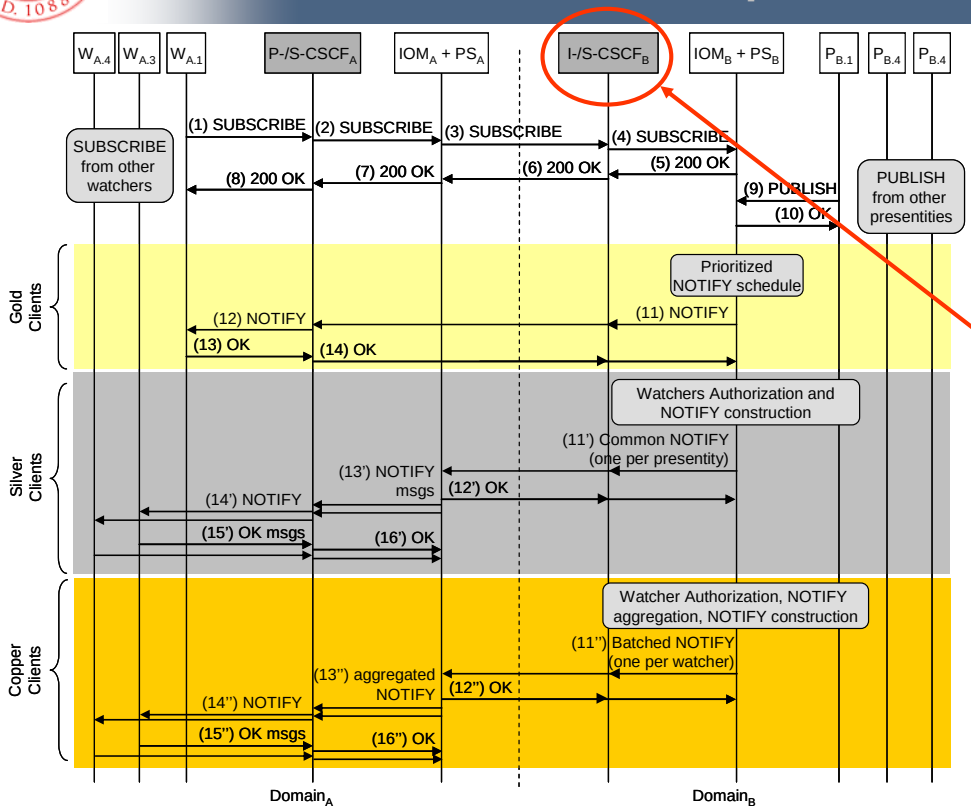
Time-based (periodic)
NOTIFY message batching

Batched NOTIFY



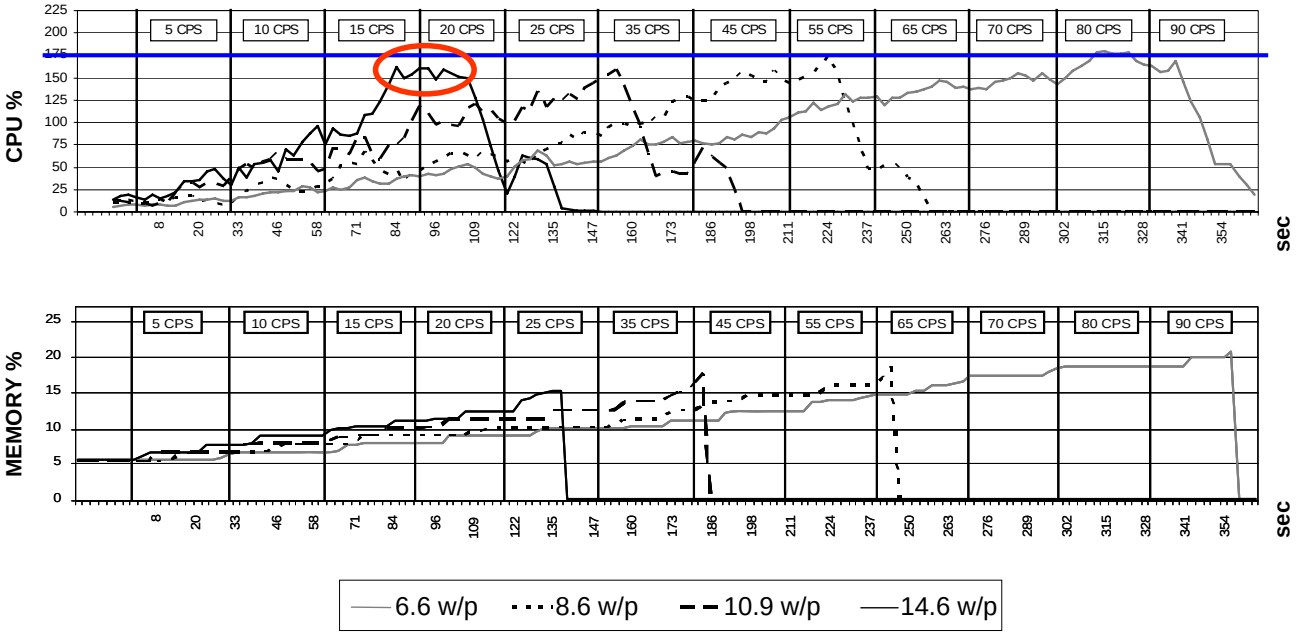
only 1 inter-domain
NOTIFY message

IHMAS inter-domain PS scalability:
PS protocol enhancements



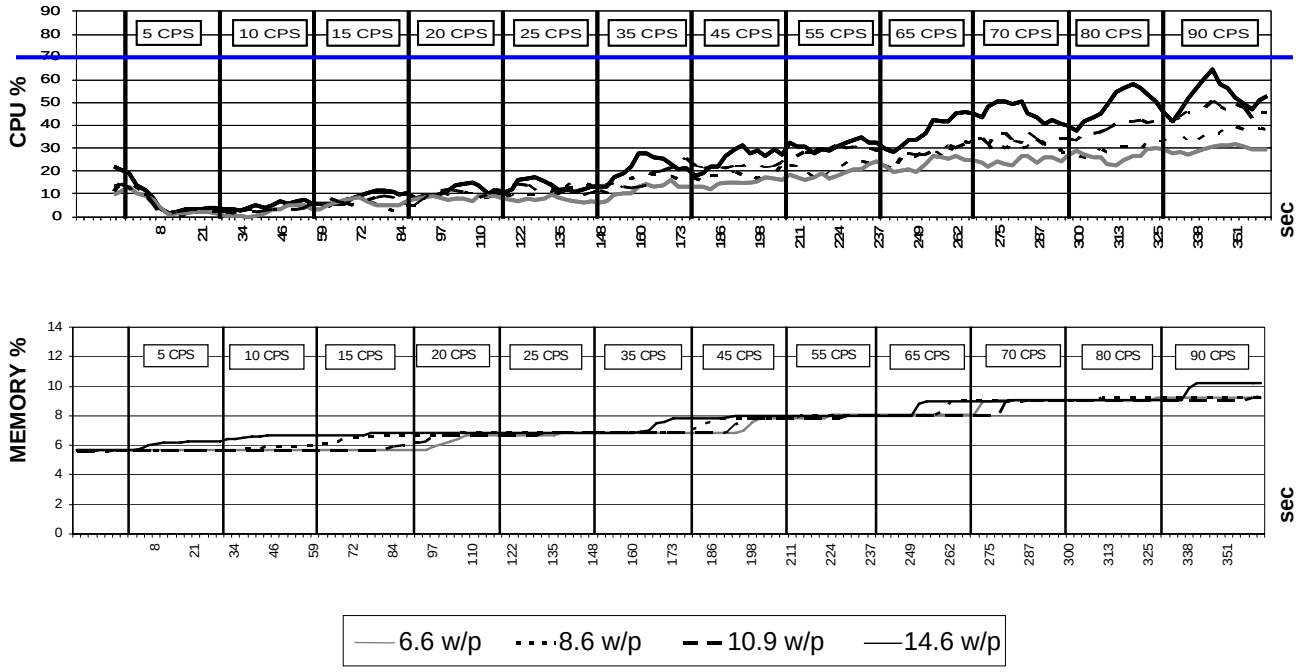
Experimental results: ***CPU load at border CSCF components***

Experimental results:
w/out IHMAS optimizations



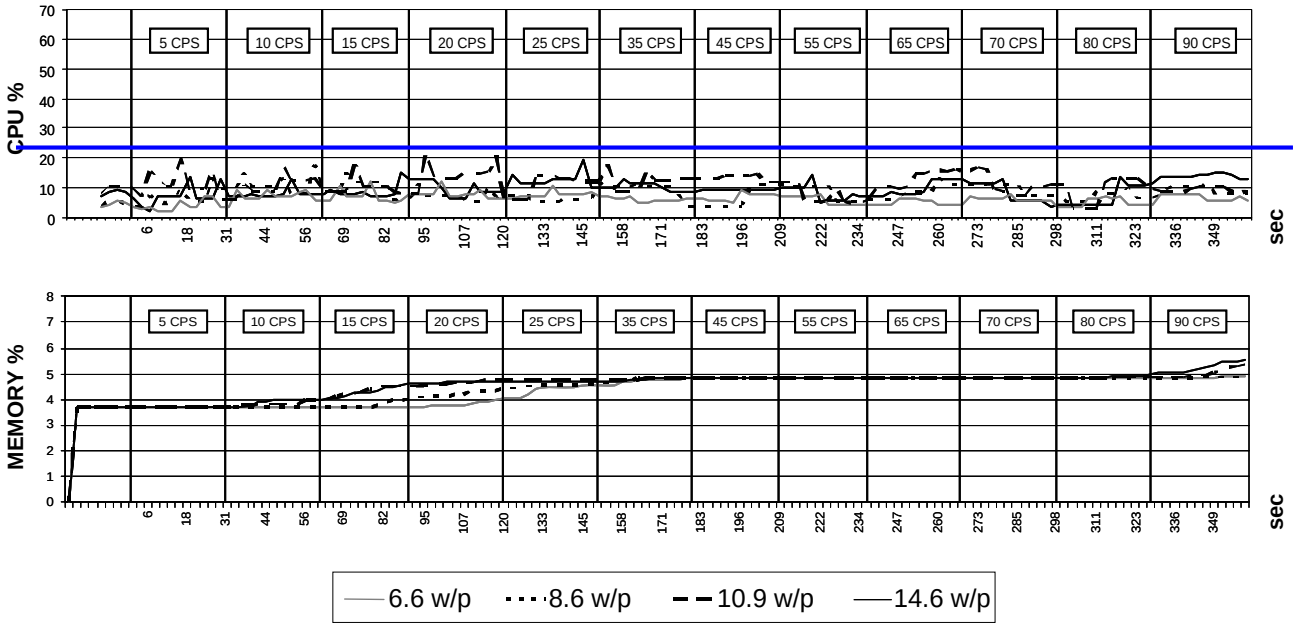
CPS: Calls Per Second
w/p: mean number watcher subscriptions for each presentity

Experimental results: with IHMAS common NOTIFY



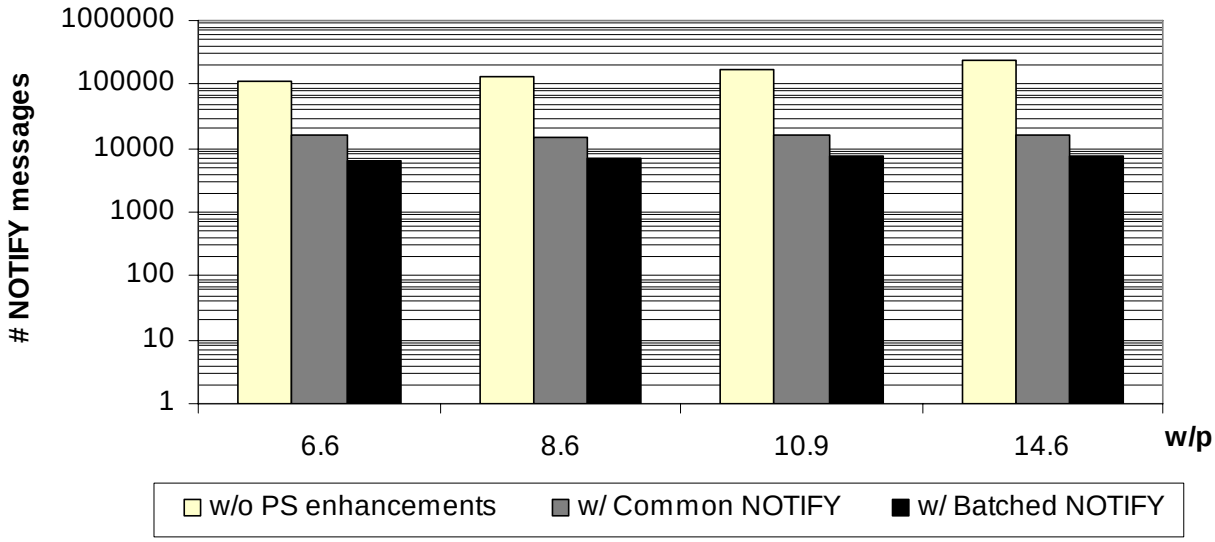
CPS: Calls Per Second
w/p: mean number watcher subscriptions for each presentity

Experimental results: with IHMAS batched NOTIFY

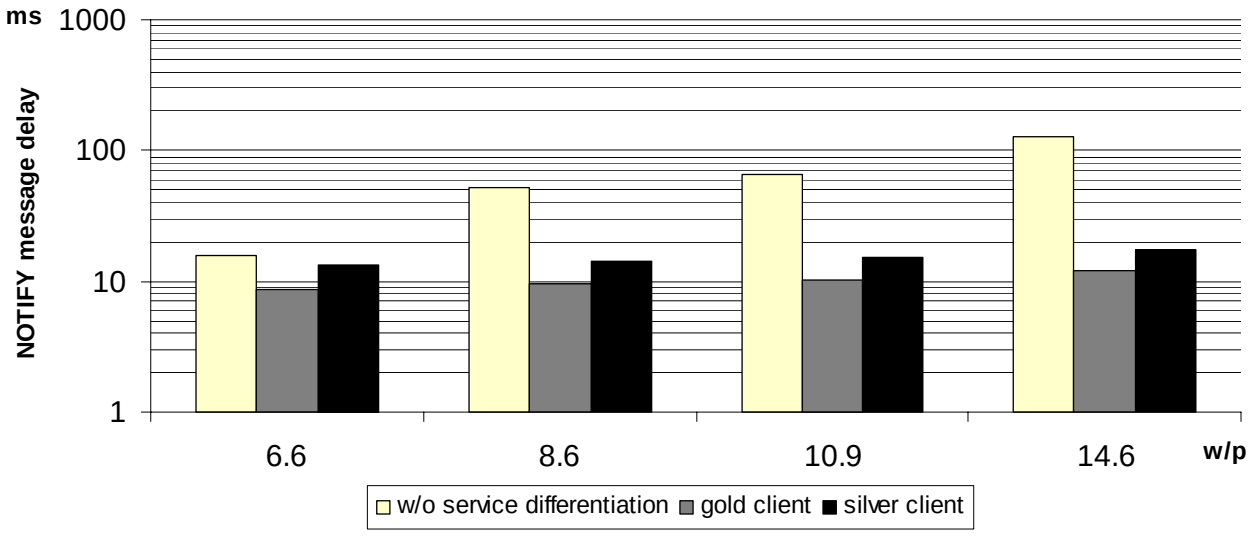


CPS: Calls Per Second
w/p: mean number watcher subscriptions for each presentity

Experimental results: number of inter-domain NOTIFYs



Experimental results: inter-domain NOTIFY delay



Conclusions

- Strong need for IMS scalable solutions
  - Both at the ***infrastructure*** and ***service*** level
  - Context- and service-aware approaches seem to be promising and should not be neglected
- Interoperability and standard compliancy
  - ***Full IMS standard compliance*** for inter-domain optimization techniques
  - ***Ad-hoc solutions*** and ***integration with other emerging standards*** at intra-domain level
- ***Real-world testbeds*** should be employed whenever possible

Research directions

- ***Context-aware*** and ***self-* middleware solutions*** for service state management
  - Scalability is a complex and still open task
    → ***Session state grain/footprint/dissemination***
  - ***Standard (r)evolution?*** (SIP, IMS, …)
- ***Session control !!!!***
  - ***Scalability first*** (millions/billions of nodes, systems of systems,…)
  - Use and interaction with different standards
    → Example: OMG Data Distribution Service (DDS) to ease and boost context and presence data dissemination
- And several others…

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IHMAS project web site and contacts

- Prototype code: **http://lia.deis.unibo.it/Research/IHMAS**

- Contacts: Luca Foschini (luca.foschini@unibo.it)

Thanks for your attention!

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