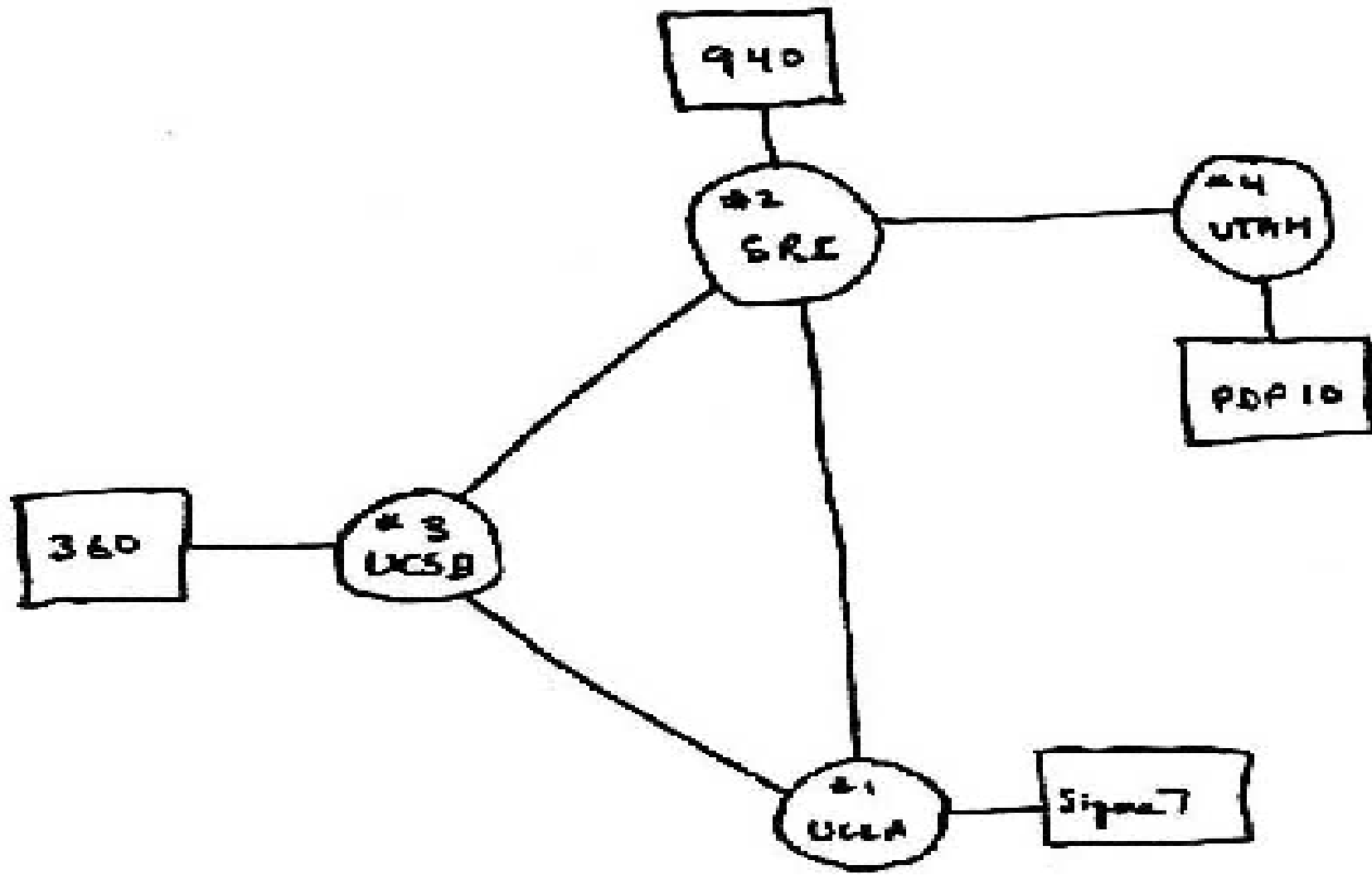


Strength and weakness
of the Internet
Retrospective and Outlook

Prof. Anja Feldmann, Ph.D.

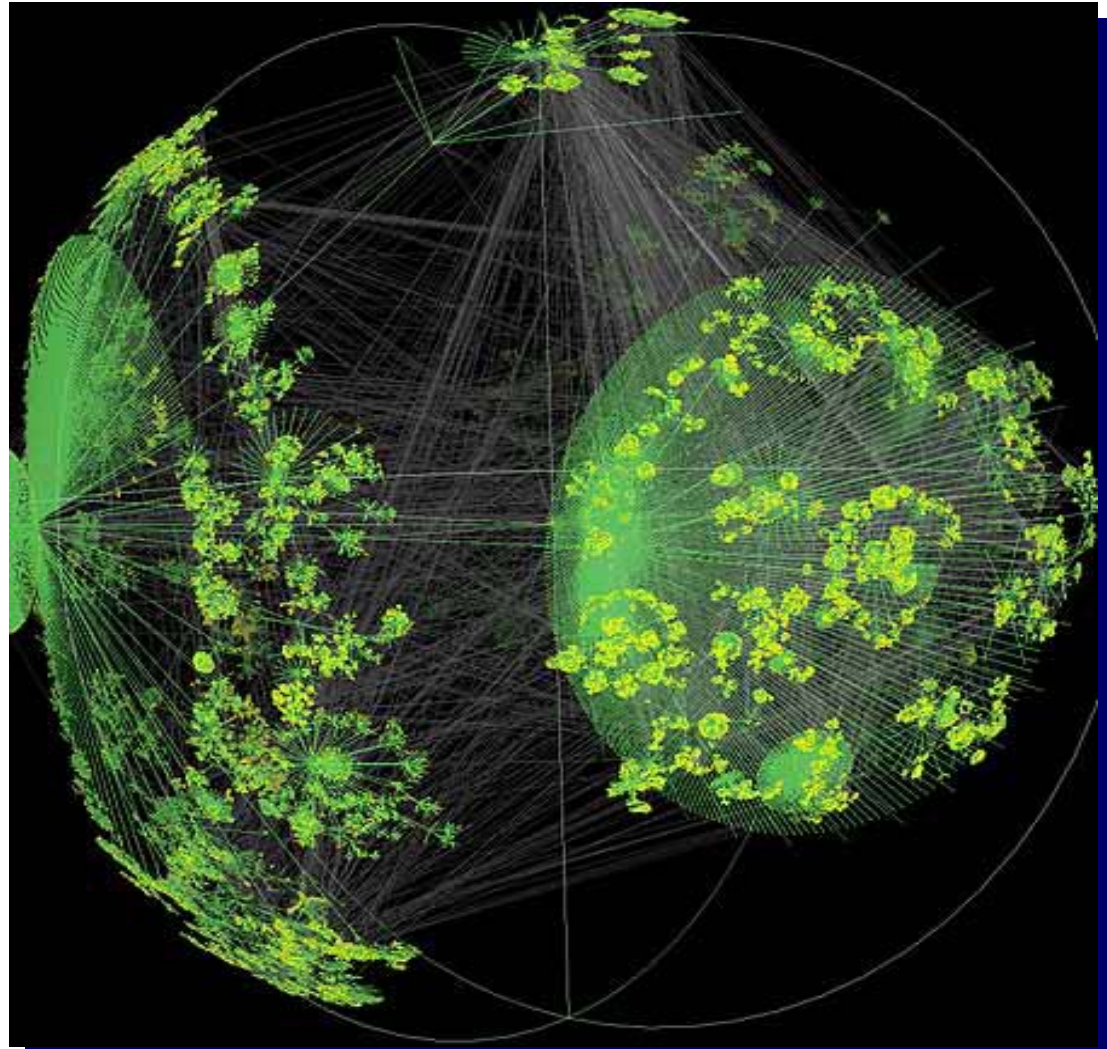
Deutsche Telekom Laboratories
TU-Berlin

Map of the „original Internet“



Map of the "Internet"

- ❑ Data:
CAIDA's
skitter
monitor
(London,
2004)
- ❑ $\sim 535,000$
Nodes
- ❑ $> 600,000$
Links



Today's Internet

- ❑ A physical entity
 - Routers, switches, ...
- ❑ An crucial infrastructure
- ❑ A communication medium
- ❑ A Service
 - Web, email, news, SMS, telephony, P2P, ...
- ❑ The foundation of someone's business
- ❑ **Social phenomena**
 - Cyberspace: redefined communication
 - Human to human, human to computer,

Internet design principles

- ❑ Packet switching
- ❑ Layered system
 - Small waist (IP!)
- ❑ End-to-end argument

Internet End-to-End Argument

- ❑ “... functions placed at the lower levels may be *redundant* or of *little value* when compared to the cost of providing them at the lower level ...”
- ❑ “... sometimes an *incomplete* version of the function provided by the communication system (lower levels) may be useful as a *performance enhancement* ...”
- ❑ This leads to a philosophy diametrically opposite to the telephone world of dumb end-systems (the telephone) and intelligent networks.

Internet End-to-End Argument (2.)

- ❑ Network layer provides one simple service: best effort datagram (packet) delivery
- ❑ Transport layer at network edge (TCP) provides end-end error control
 - Performance enhancement used by many applications (which could provide their own error control)
- ❑ All other functionality ...
 - All application layer functionality
 - Network services: DNS
 - implemented at application level

Internet End-to-End Argument (3.)

- ❑ Emphasis on correctness & completeness
- ❑ Pro?
 - **Complexity**
 - At edges result in a “simpler” architecture?
 - **Evolvability**
 - Easier/cheaper to introduce of new functionality
 - Add new edge applications rather than change routers?
 - **Technology penetration**
 - Simple network layer ⇒ “easy” for IP to spread everywhere

Internet design principles

- ❑ Packet switching
- ❑ Layered system
 - Small waist (IP!)
- ❑ End-to-end argument
 - Determines function placement
 - Allows cost-performance tradeoff
- ❑ Edge vs. core
 - Dumb network
 - Intelligent end-systems
- ❑ Network of collaborating networks

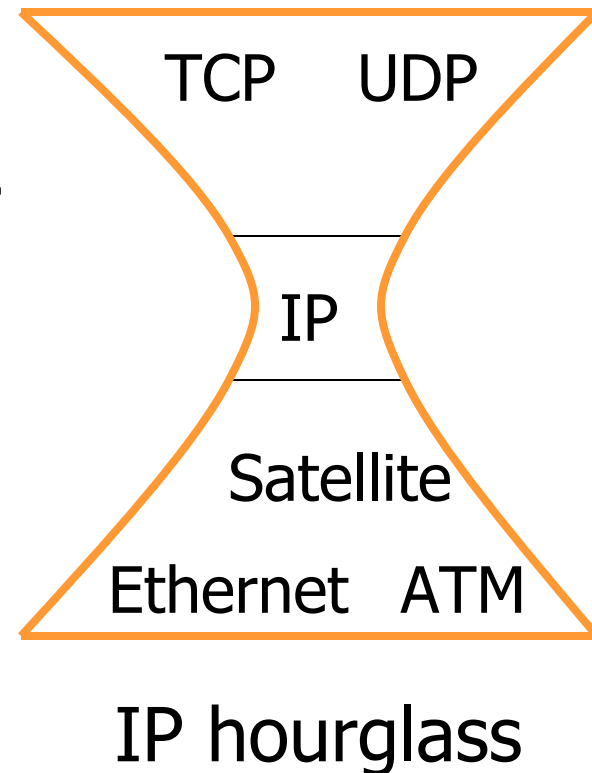
Internet design goals (Clark'88)

(in decreasing order of importance)

- **Connect existing networks**
 - Initially ARPANET and ARPA packet radio network
- **Survivability**
 - Ensure com. service even with network and router failures
- **Support multiple types of services**
 - Easy to invent/deploy of new applications
- **Must accommodate a variety of networks**
 - Minimalist service
- **Allow distributed management**
- Allow host attachment with a low level of effort
- Be cost effective
- Allow resource accountability

Internet architecture

- ❑ Packet-switched datagram network
- ❑ IP is the glue (network layer overlay)
- ❑ IP hourglass architecture
 - All hosts and routers run IP
- ❑ Stateless architecture
 - No per flow state inside network



Today's Internet: Challenges

- ❑ Heterogeneity any which way you look
 - Users, applications, hardware, traffic
- ❑ An immense moving target
- ❑ **Highly interacting systems**
 - **Temporal:** between users, hosts and networks
 - **Spatial:** among different components
 - **Vertical:** across different networking layers
- ❑ **Designed to be a open, cooperating system**

Today's Internet: Complex SWS

- ❑ Physical connectivity: Links
- ❑ Point-to-point connectivity: NIC, switches
 - Distributed hardware, protocols – local management
- ❑ End-to-end connectivity: Routers
 - Forwarding, addressing, routing
 - Distributed hardware, protocols, software, management by Internet Service Providers (ISPs)
- ❑ Process-to-process connectivity: TCP, UDP
 - De-/multiplexing, reliability, congestion control, ...
- ❑ Applications: Web, P2P, ...
 - Users
 - Distributed, independent, autonomous, ...

Internet: usage scenarios

□ Example 1:

- **Situation:** network connectivity fails
- **Presumed action:** call system administrator
- **Effect:** no phone call possible
- **Why:** telephone service via VoIP

□ Example 2:

- **Situation:** network link overloaded
- **Presumed action:** redirect traffic
- **Effect:** another link is overloaded
- **Why:** routing hard to control/predict

Architectural limits

- ❑ Trust assumptions
 - Internet assumes cooperation
- ❑ Competition
 - Original Internet assumed no commercial considerations
- ❑ Edge diversity
 - Original Internet is host-centric
 - Ignores mobility, sensors, ...
- ❑ Network services
 - Original Internet exposes limited information
 - Limits new services
 - Limits network management

Why rethink the Internet architecture

□ Reliability and availability

- E-Commerce increasingly depends on fragile Internet
 - Much less reliable than the phone network
 - Barrier to ubiquitous VoIP
- Debuggability

□ Security

- Known vulnerabilities lurking in the Internet
 - DDoS, worms, malware
- Addressing security has a significant cost
 - US federal government spent \$ 5.4 B in 2004
 - Estimated \$ 50–100 B spent worldwide on security in 2004

Why rethink the Internet architecture

❑ Scale & Diversity

- Cyberspace (everything is networked)

❑ Support for new applications/services

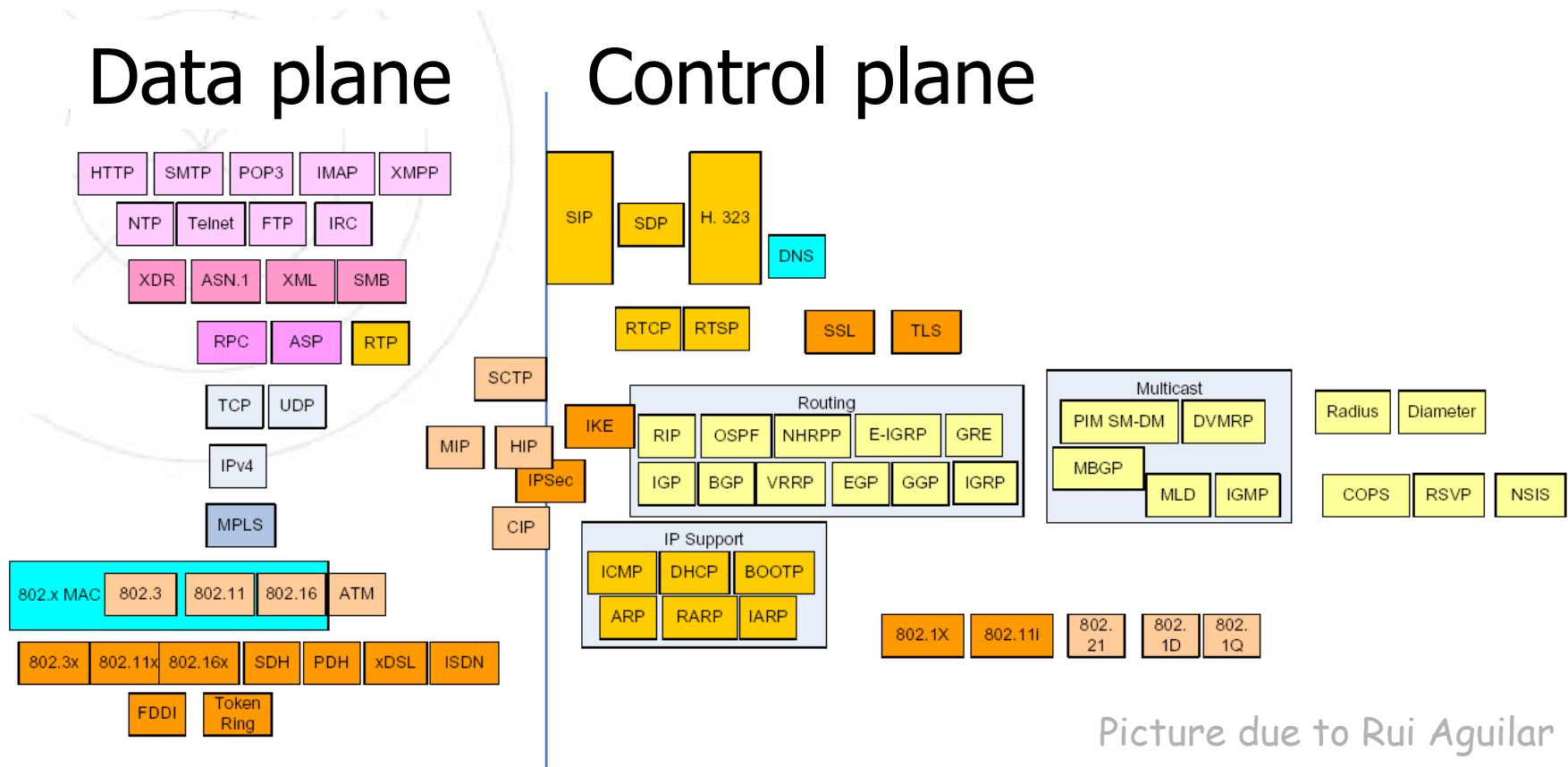
- Mobility?
- Quality of service
- High speed connections to the home

❑ Economics

- Cost-effectively
- Business models

☞ All of the above are **control plane** issues!

Today's Internet – out of shape!!!



Picture due to Rui Aguilar

Redesign needed?

Rethinking the Internet architecture

- ❑ Explore alternative architectures
- ❑ Approach
 - Incremental
 - Apply point-solutions to the current architecture
 - Clean slate design (CSD)
 - Start from scratch
- ❑ Advantage CSD
 - Architecture not intrinsic
 - Experiments and failures are possible
 - No limitations: enables rethinking of the network and service architecture

How to get there?

- ❑ How to determine that one has a good new architecture?
 - Paperware? No
 - Built, evaluated, used? Yes
 - ❑ Approach:
 - Experimental facility
 - Research into new architectures
 - ❑ Benefit:
 - Intellectual challenge:
uncover otherwise ignored system aspects
 - Research how to build/operate an experimental facility
- ☞ **Go beyond point solutions**

Clean slate design: Drivers

□ Technical

- Virtualization techniques
- Fast packet forwarding hardware
- Significant computational resources in the network
- Advances in wireless and optical networks

□ Starting points

- PlanetLab / OneLab
- Geant2/Internet2
- Emulab
- Vini
- ...

Clean slate design: Thoughts

- Phone networks were about wires, Internet about communication and networking of users, the Future Internet is more and more about sharing of **user-generated content**
 - The **network** itself is becoming more and more a **large distributed database**
 - The **push and pull paradigm** is changing due to the increase of storage in the network, which mediates the communication between users

Clean slate design: Thoughts (2.)

- ❑ Internet has **no built-in** security mechanisms, because it relies on cooperation and trust – **can** or **should** this be maintained?
- ❑ Maybe multiple architectures are needed to consider **different** requirements at the **same** time (**design for tussles**):
 - **Anonymity** and **accountability** and **security**
 - **Bulk data** transfer and **real-time** communication
 - **Performance** and **functionalities**

Clean slate design: Thoughts (3.)

- The Internet itself has always been a large experimental infrastructure in itself, so could an experimental infrastructure be a good model or starting point for a future internet?
 - Is Internet becoming more about programmable hosts rather than the network?
- Internet is more and more about wireless access
 - Spectrum allocated to Internet access is only a tiny fraction – most spectrum is unused
 - Mobile networking – research is needed

Test bed vs. experimental facility

□ Test bed:

- Real not simulated
- Specific purpose
- Focused goal
- Known success criteria
- Limited scale

Not sufficient for clean slate design

□ Experimental facility:

- Purpose:
 - explore yet unknown architectures**
 - expose researchers to real thing**
 - breakable infrastructure**
- Larger scale (global?)
- Success criteria: unknown

Success scenarios

- ❑ **Create a new network architecture**
 - Convergence of multiple architectural visions
 - Ready for commercialization
- ❑ **Meta testbed becomes the new architecture**
 - Multiple architectures co-exist
 - Create a climate of continual re-invention
- ❑ **Gain new insights and architectural clarity**
 - Ideas retro-fitted into today's architecture
 - Second path improves first path

Approaches in the US

□ NSF Nets research program: **FIND** (Future Internet Network Design)

„What are the requirements for the global network of 15 years from now – what should that network look like and do?“

„How would we re-conceive tomorrow’s global network today, if we could design it from scratch?“

□ NSF planed Initiative: **GENI** (Global Environment for Networking Innovations).

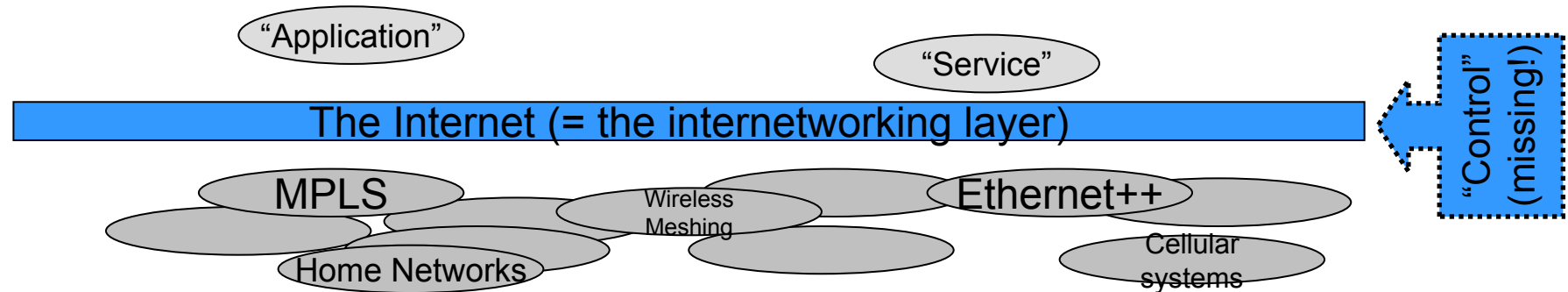
„Build an open, large-scale, realistic experimental facility for evaluating new network architectures.“

Approaches in the EU

- The Network of the Future
 - Trilogy
 - 4Ward
 - Euro-NG
 - ...

- New Infrastructure Paradigms & Experimental Facilities
 - FIRE working group
 - Call 3 ongoing

Trilogy: Technical scope



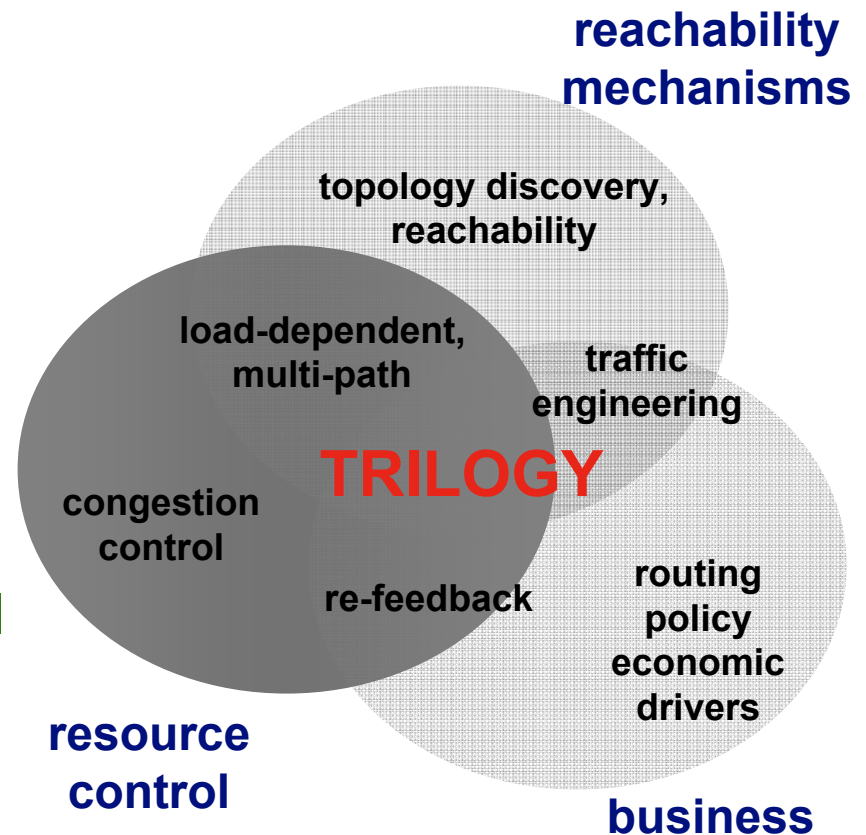
- Crudely: "Control" for "The Internet"
 - "The Internet" == the bit which has to be universal
 - Operate efficiently across arbitrary technologies
 - Operate across arbitrary organisational/economic boundaries
- Isn't this a done deal already?
 - No! **"The Internet Only Just Works"**
 - Lowest-common-denominator set of capabilities
- Vision of Convergence of mobile, fixed, public, private, home, ...
 - Control architecture allows assumptions on 'who controls what' to shift

Trilogy: An architecture for change

Main Objectives

- Develop a **unified control architecture for the Future Internet** that can adapt in a scalable, dynamic and robust manner to local operational and business requirements
- Develop and evaluate **new technical solutions for key Internet control elements**: reachability & resource control
- Assess **commercial and social control aspects** of our architecture & technical solutions, including internal & external strategic evaluation

Trilogy Concept



CSD: Reshaping the Internet

- ❑ Impact on **users**:
 - Ease of access to relevant information
 - New control plane with new capabilities
 - Easy to introduce new applications with new features
 - Security, mobility, quality of service
- ❑ Impact of new **economic models**:
 - New interfaces between providers (network/service)
 - New value-chain and new roles for providers
 - Open interfaces may enable new ecosystems of business alliances
- ❑ Impact on **society**:
 - Information society
- ❑ Impact on **operators**

CSD: Impact on operators

□ Technical impact

- Novel
 - Architecture
 - Network structure
 - Control plane (scalable, controllable, debuggable, ...)
- Ease of management
- Ease of introducing new services

□ New value chains

- New interface between operators and service providers
- Adopt appropriate solutions with technical impact
- New services and applications
 - Early deployment
 - Ease of deployment
- New business models