Stärken und Schwächen des Internet
Rückblick and Ausblick

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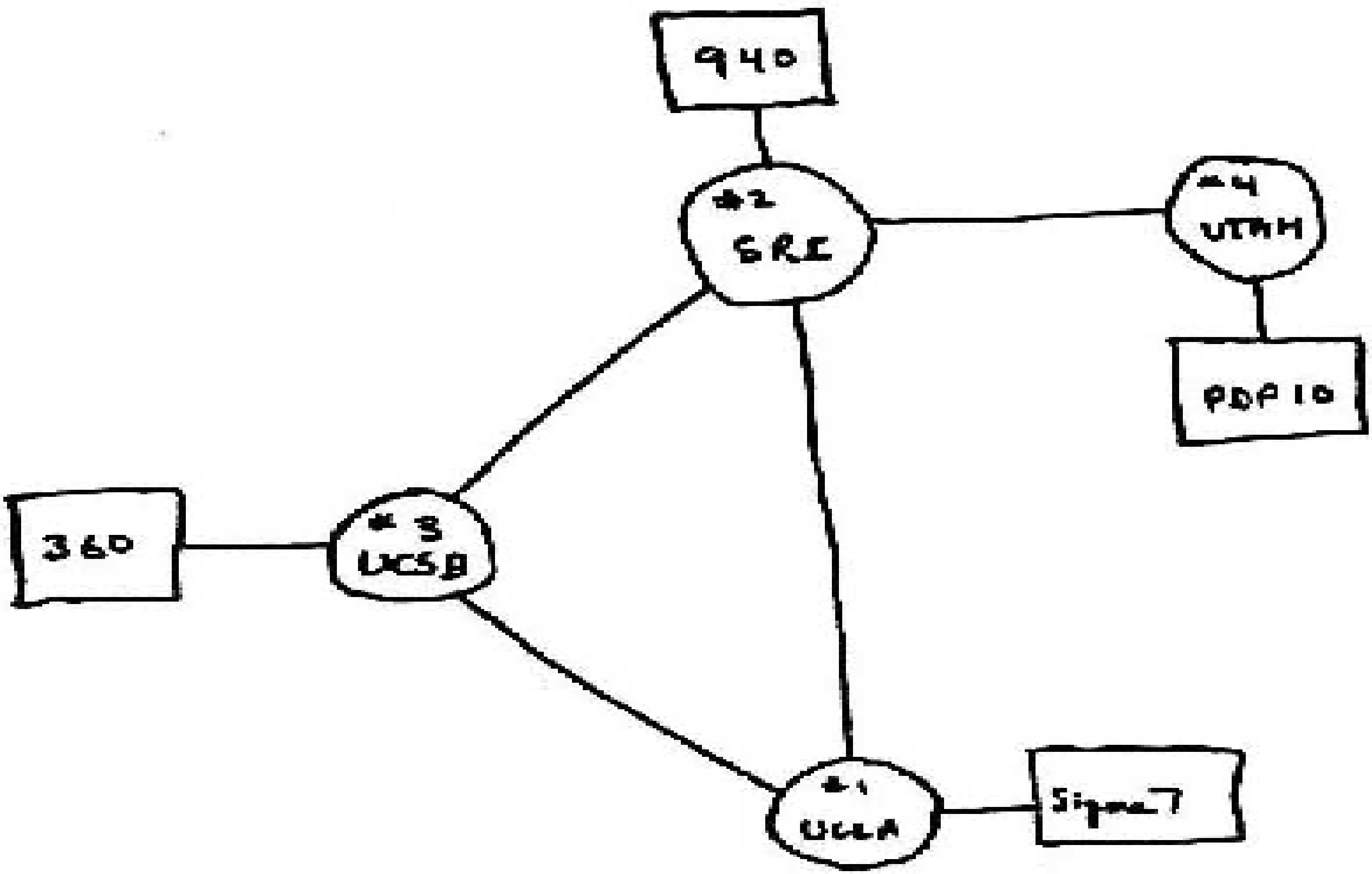
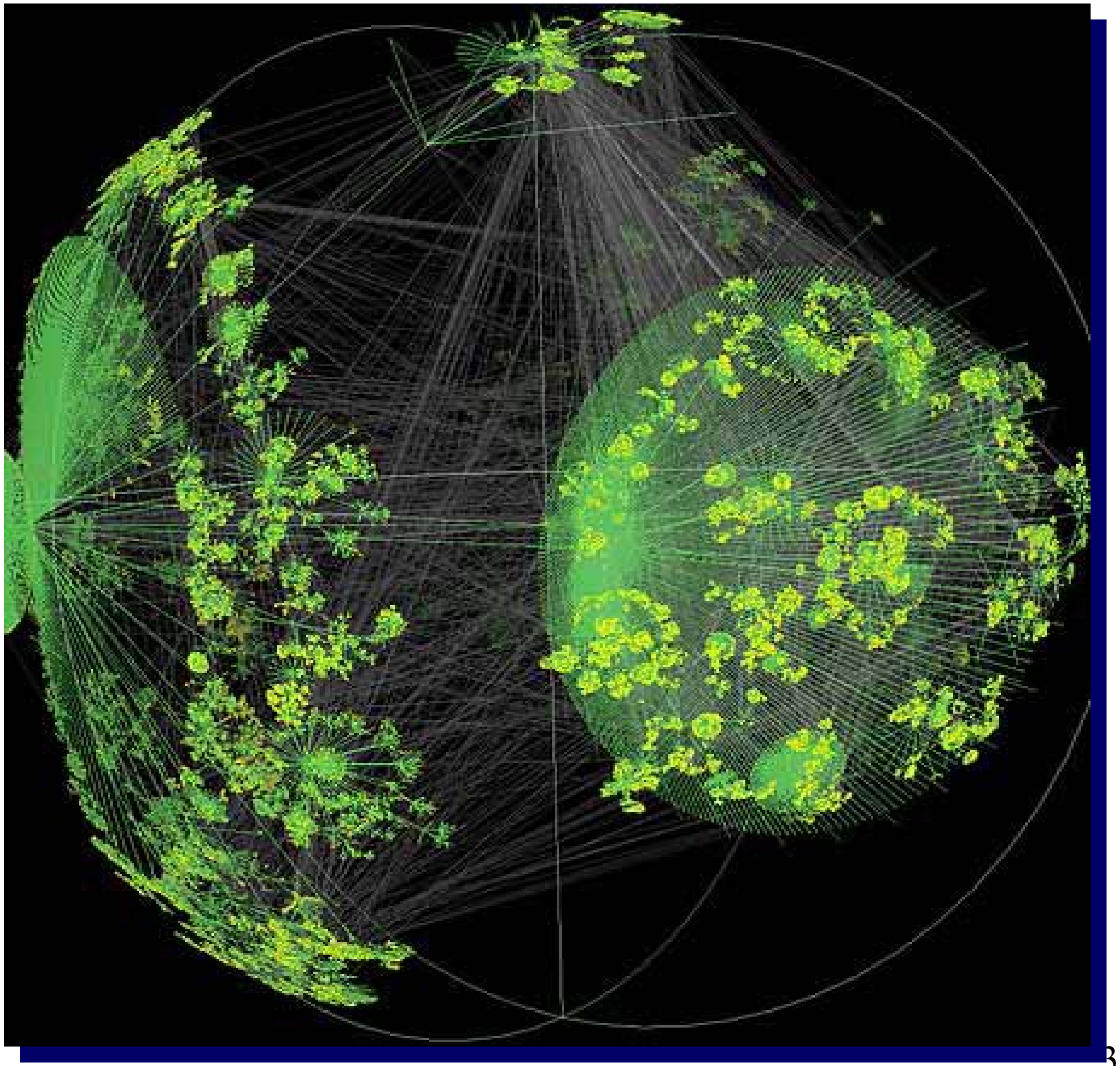
Map of the „original Internet"



Map of the "Internet"

- Data: CAIDA's skitter monitor (London, 2004)
- ~ 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
  - Cyperspace: 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

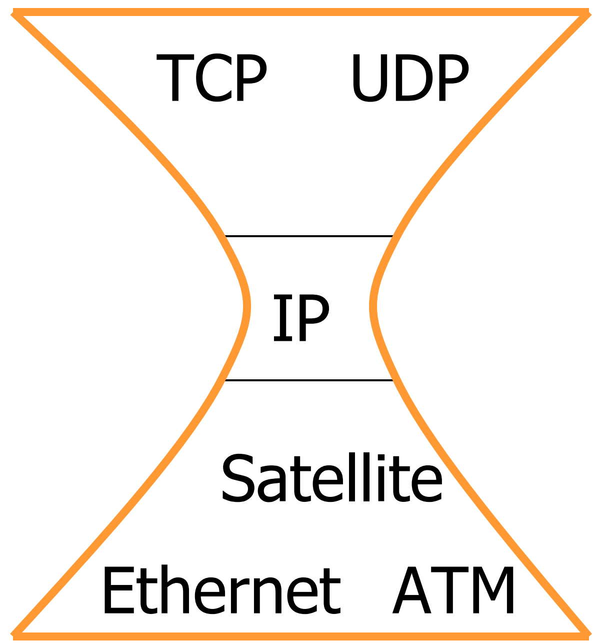
Internet design goals (Clark'88)

(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



IP hourglass

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

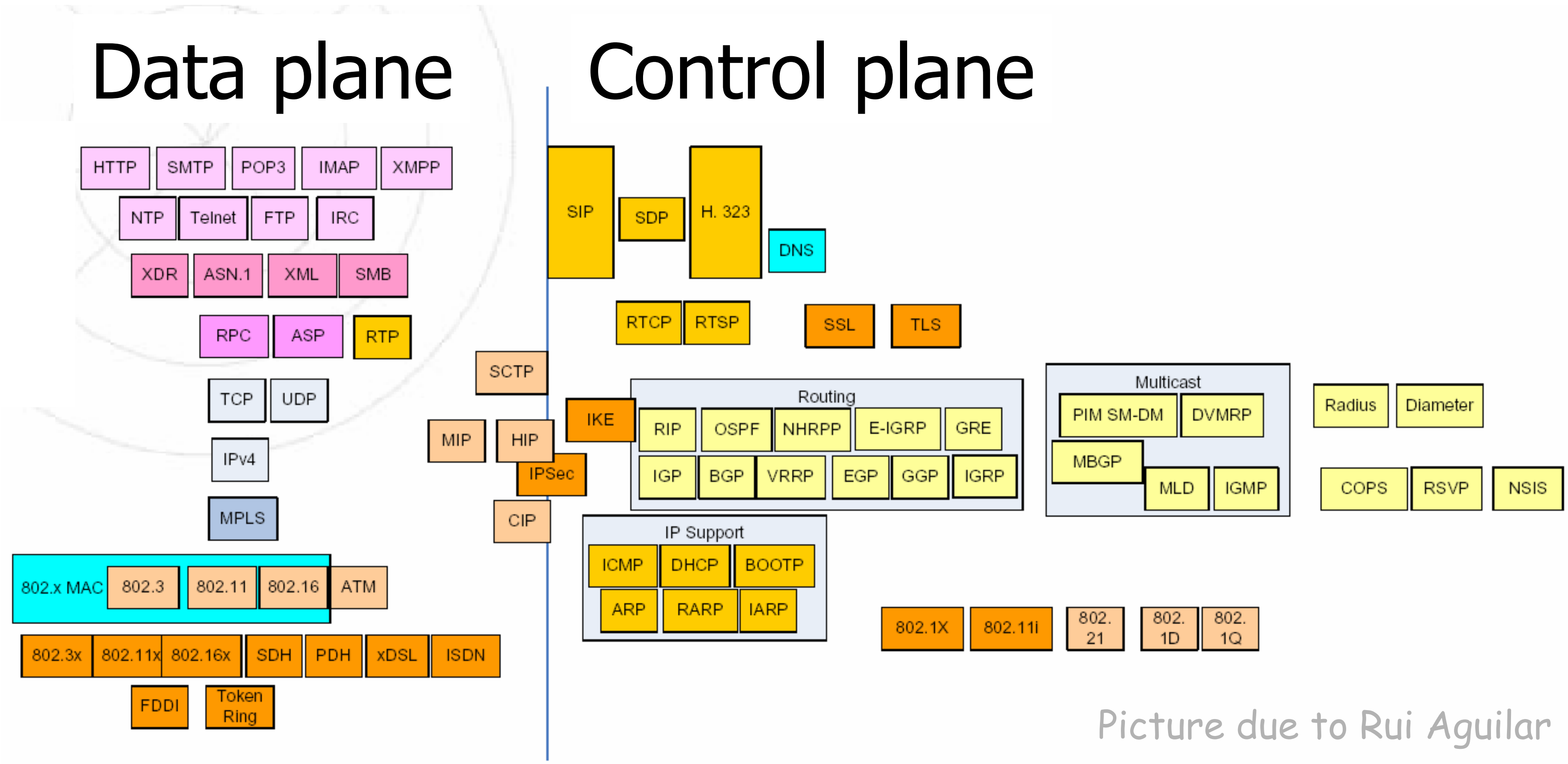
- Reliability and availability
  - E-Commerce increasingly depends on fragile Internet
    - Much less reliable than the phone network
    - Barrier to ubiquitous VoIP
  - Debuggability
- Security
  - Known vulnerabilities lurking in the Internet
    - DDoS, worms, malware
  - Addressing security has a significant cost
    - US federal government spent $5.4 B in 2004
    - Estimated $50-100B 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!!!



- 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).

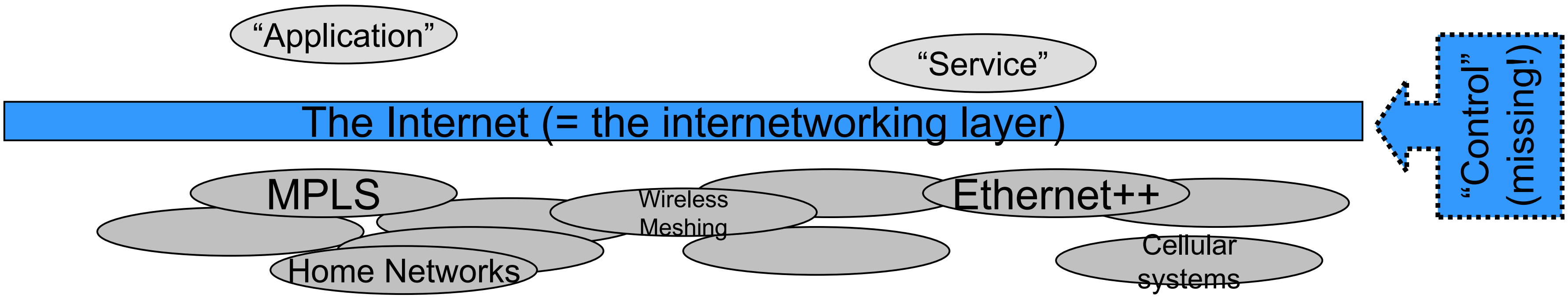
  „Build an open, large-scale, realistic experimental facility for evaluating new network architectures."

Approaches in the EU

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

- New Infrastructure Paradigms & Experimental Facilities
  - FIRE working group
  - Call 2 evaluations ongoing

Trilogy: Technical scope



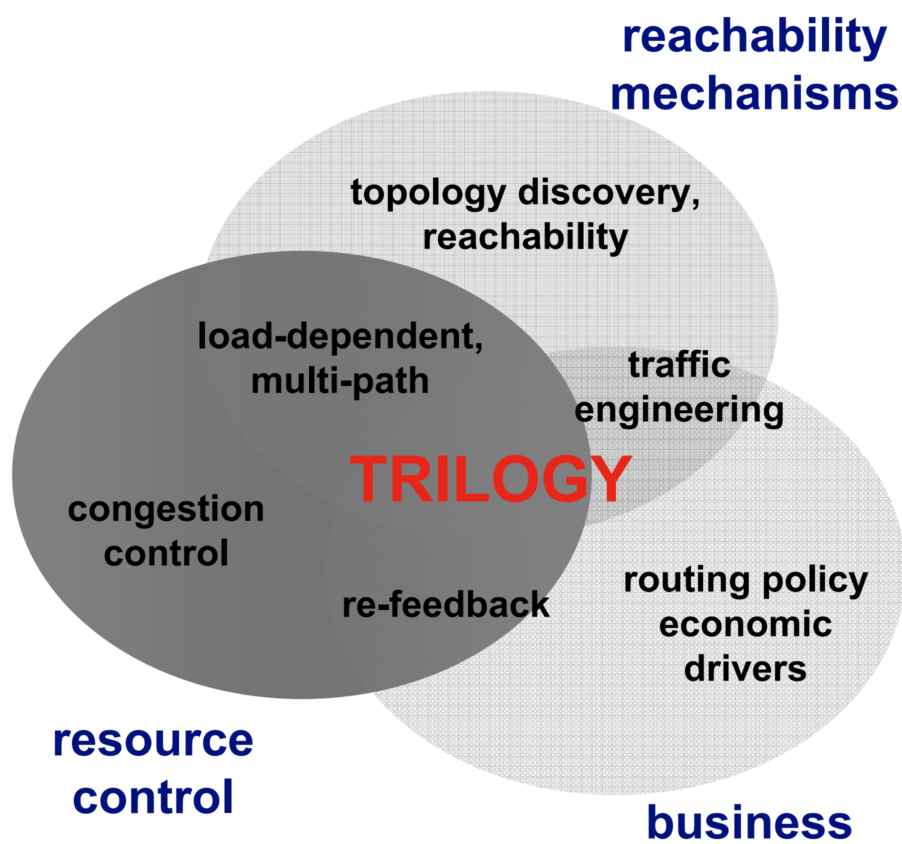
- Crudely: "Control" for "The Internet"
  - "The Internet" == the bit which has to be universal
    - Operate efficiently across arbitrary technologies
    - Operate across arbitrary organisational/economic boundaries
- Isn't this a done deal already?
  - No! "The Internet Only Just Works"
  - Lowest-common-denominator set of capabilities
- Vision of Convergence of mobile, fixed, public, private, home, …
  - Control architecture allows assumptions on 'who controls what' to shift
- … but the technical scope is deliberately tightly focussed
  - Don't look 'downwards' at particular link classes
  - Don't look 'upwards' at middleware, service support infrastructures, virtualisation …

Trilogy: An architecture for change

Main Objectives

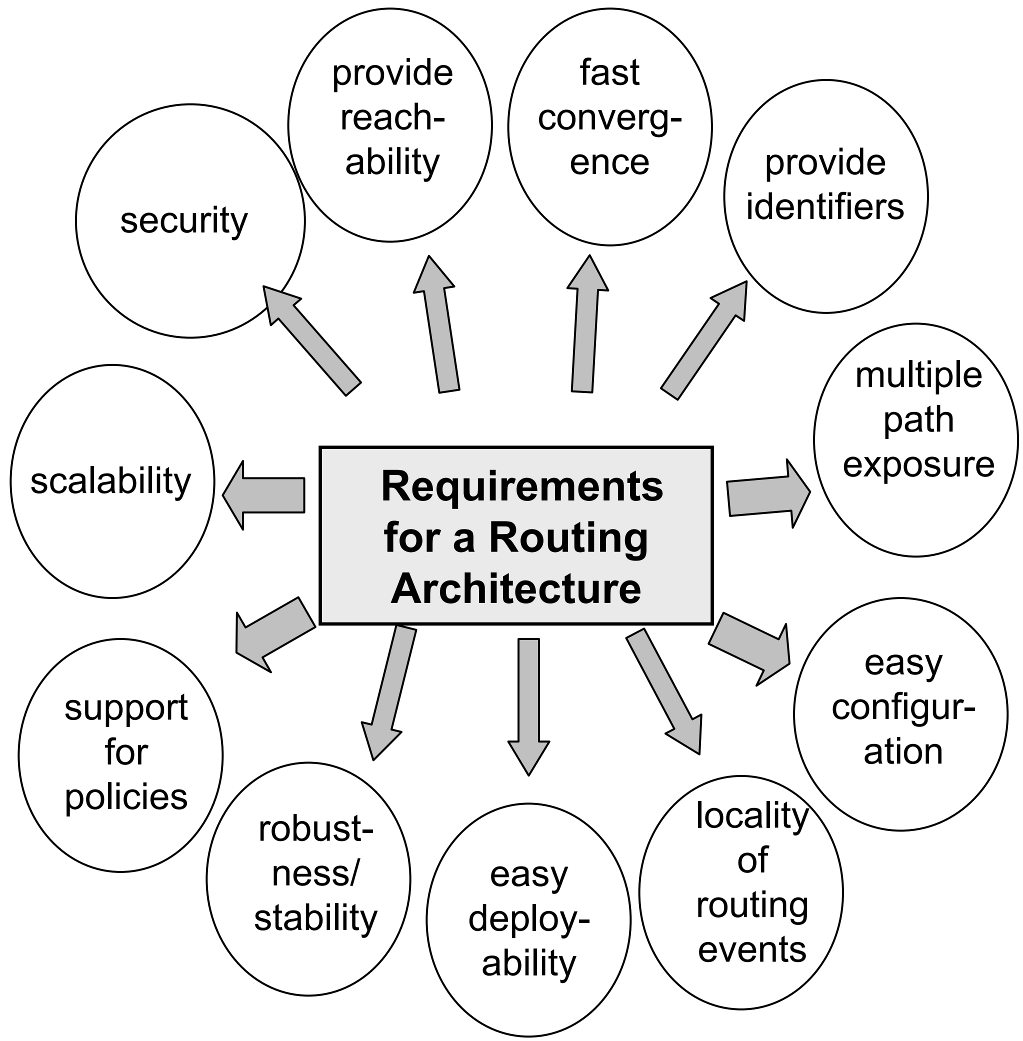
- Develop a **unified control architecture for the Future Internet** that can adapt in a scalable, dynamic and robust manner to local operational and business requirements
- Develop and evaluate **new technical solutions for key Internet control elements**: reachability & resource control
- Assess **commercial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

Trilogy Concept



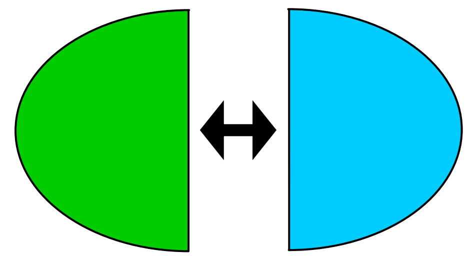
Trilogy: Reachability

- Establish & control transparent reachability in a scalable, dynamic & resilient manner
  - Routing fragility
  - Growing organisational complexity
  - Need extra capabilities
- Topics include:
  - Routing
  - Multi-homing
  - Remote traffic filtering



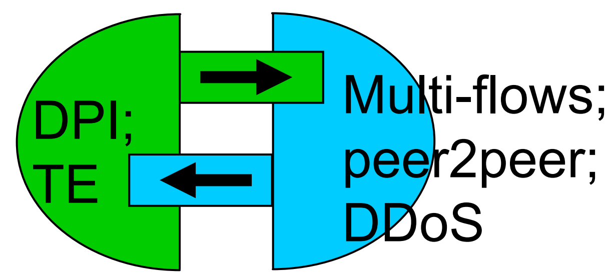
Trilogy: Resource control

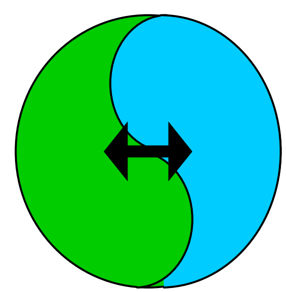
- Develop & evaluate a unified approach to resource control that is efficient, fair and incentive-compatible
  - Utilisation
  - Different fairnesses
  - Cheat-proof
- What is a resource?
  - Congestion
  - Storage, battery life, spectrum…
- Allow a diverse set of parties to use & share the internetwork
  - Allow parties to make autonomous cost-benefit tradeoffs without opening up a global free-for-all
  - Congestion control
  - Path selection / balancing…



Resource user

Resource provider

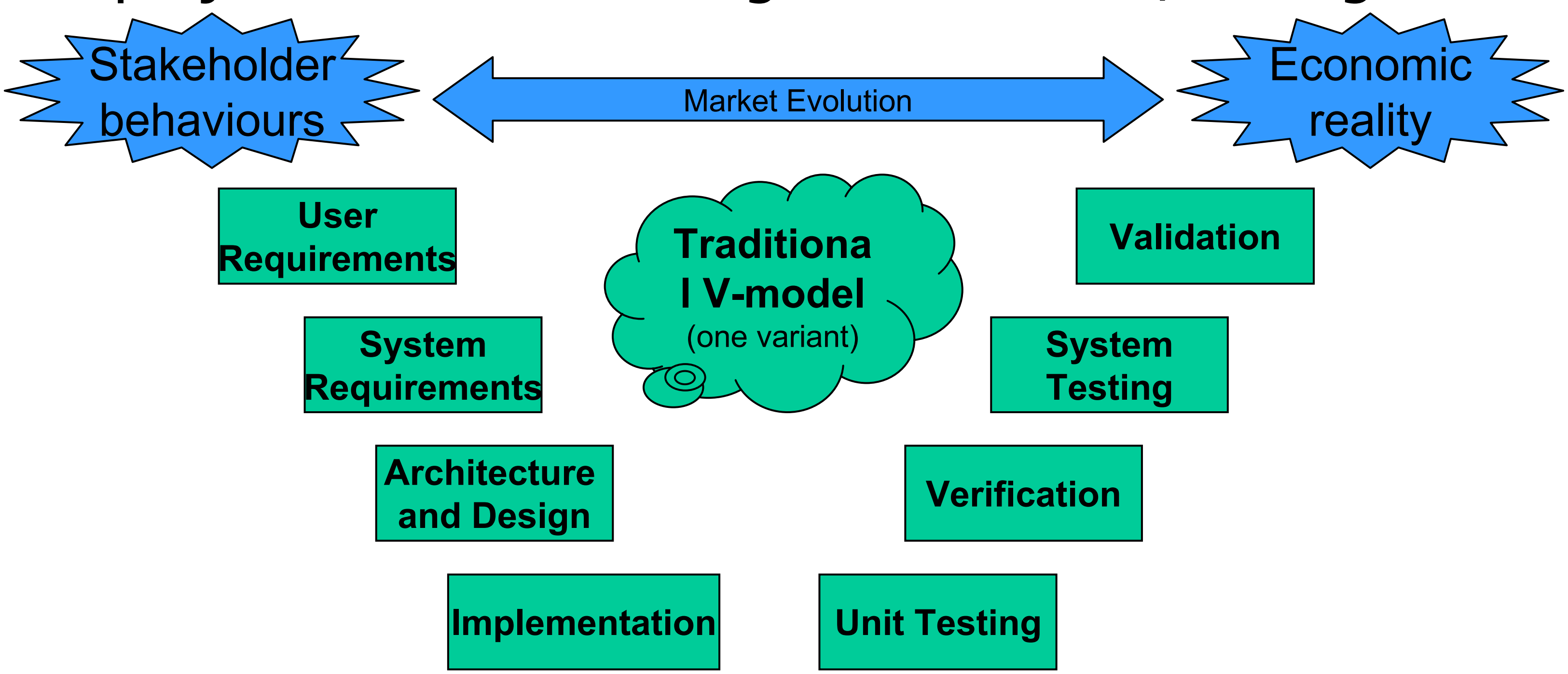




Trilogy: Design for Tussle

Trilogy: Social & commercial control

- Understand what architectural features allow controlled behavioural flexibility different technical, social and economic outcomes
- Assess whether we have indeed achieved such a design
- Interact with business stakeholders from beyond direct project involvement to get commercial/strategic steer



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

Upcoming challenges

The total is more than the sum of its pieces

- Specify and manage **services** rather than **components**
- Address the gap in understanding between **individual pieces** and the **overall**
- Clean slate Internet design: **What principles to keep**?