Strength and weakness of the Internet
Retrospective and Outlook

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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

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!!!

❖ 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 planned 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**
- Reachability mechanisms
- Topology discovery, reachability
- Traffic engineering
- Routing policy economic drivers
- Resource control
- Congestion control
- Re-feedback
- Load-dependent, multi-path
- TRILOGY
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