Future Internet Research Challenges

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Webinar Agenda

- Internet & Future Internet (FI)
- Future Internet User’s Perspective & Evolution
- Future Internet Research Challenges (technical)
Future Internet Research Challenges
How to get there?

Future Internet:
- User’s View/ perception:
  - Numbers, application scenarios and impacts users perceive
- Technical View:
  - Research challenges involved towards the Future Internet scenario
Internet (Re)Evolution

- Internet evolved from an **academic network** to a **global commercial network**
- Very successful **design paradigm** and network implementation:
  - Architectural principles: simple, multi-layer and end-to-end design
- **What changed?**
  - Number of users increased dramatically
  - Many new application scenarios
  - New challenges → **Future Internet research**
Ways to perceive and/or understand the INTERNET?

- A **network of networks** (technical view)
- The **world-wide-web** (web) (site references) (the user scenario)

What is behind the Internet (re)evolution?
A huge number of new and highly interesting applications, demanded by billions of users with variable requirements in relation to the network supporting them (the INTERNET)
Internet (Re)Evolution

Global Users

- Big number for “Internet users”

Future Internet “users”:
- Global usage and coverage
- “Users”: computers, tablets, mobile/ smartphones, cars, home appliances, “things”, sensors and “people”
## Internet Users by Country & Penetration

### Global (re)evolution

<table>
<thead>
<tr>
<th>Country</th>
<th>Internet Users 2012 (MMs)</th>
<th>Penetration</th>
<th>2008 – 2012 (+MMs)</th>
<th>Growth by Year</th>
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<tbody>
<tr>
<td>China</td>
<td>564</td>
<td>42%</td>
<td>264</td>
<td>10%</td>
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<tr>
<td>USA</td>
<td>244</td>
<td>78%</td>
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<tr>
<td>India</td>
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<td>11%</td>
<td>88</td>
<td>26%</td>
</tr>
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<td>45%</td>
<td>27</td>
<td>6%</td>
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<tr>
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<td>49%</td>
<td>33</td>
<td>6%</td>
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<tr>
<td>Indonesia</td>
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<td>23%</td>
<td>39</td>
<td>58%</td>
</tr>
<tr>
<td>Nigeria</td>
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<td>30%</td>
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<td>15%</td>
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<tr>
<td>Iran</td>
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<tr>
<td>Turkey</td>
<td>35</td>
<td>47%</td>
<td>13</td>
<td>17%</td>
</tr>
</tbody>
</table>

*Source: United Nations/ International Telecommunications Unit*
Future Internet Devices/ Users
Actual Technological Cycle and “Content”

- Internet is following the computing evolutionary cycles: mainframe, mini-computers, personal computing, desktop internet and now: mobile internet + wearable + IoT (Internet of Things), ...

- **Multimedia content** is an important trend towards Future Internet (FI):
  - More photos, videos, music, audio, ..., with increasing volume, easy access and quality

- Equipment and appliances involved:
  - **Smartphones**, tablets, MP3 players, cameras, e-readers, car electronics, home entertainment, TV, appliances and “sensors” are integral part of current FI cycle
  - Equipment has high processing capacity with increasing low cost and high portability (small, low cost and powerful)
Future Internet Trends

- Global phenomena (business) with continuous growth (application & business)
- Multimedia “content”
- Research: need of new protocol(s), service(s), architecture(s) and eventually, need to redesign the entire platform (TCP/IP) (research)
Internet & People (users)
“Content” is a trend

Digital “content” (documents, pictures, tweets, messages, ...):

- Digital information by 2011: ± 2 Zettabytes (findable, sharable, ...)*
- Up 09 times in 05 years
- Still going up → continuous trend

01 zettabyte = 01 Trillion Gigabytes - 10^{21}

* Source: IDC Report “Extracting Value from Chaos”
FI Content
“Content” is a trend

Future Internet Challenge:
- How to support a continuous exponential growth in multimedia content?

Example: Privacy & Security
- Nearly no privacy (actual scenario)
- Challenge: How to share, tag and have large volume of “content” available still preserving security aspects

Other research topics:
- Storage, cloud computing, grid computing, content identification, content access, routing, quality of service, management
**FI Content**

“Content” is a trend

- Photo, video, messages, voice, social content, other mix of contents (including context, extracted knowledge, sensor data, ...)

“Content” numbers & trends
Photos
Internet & Future Internet

Smartphone, “selfie” phenomena, ...

Future Internet scenario:

- High quality photos taken with increasingly lower cost cameras (+smartphone) and possibly stored and/or shared in low cost memory system (cloud, social networks, ...)
Selfie: "a photograph that one has taken of oneself, typically one taken with a smartphone or webcam and uploaded to a social media website" (The Guardian – 2013)
500 millions photos uploaded by day – 2013
Fostered by increasingly low cost cameras and smartphones
Trend to go up 2x by year
Half of YouTube views are on mobile devices

300 hours of video are uploaded to YouTube every minute - 2015
Video Content
Numbers & Trends

TV and movies over the Internet
- NetFlix, Internet TV, ...

Short-Form videos and surveillance:
- WhatsApp, Twitter Video, Vine, Dropcam, other
- “Big Brother” effect (surveillance), twitter, other

Video is a trend to grow fast:
- Longer videos with more quality and stored volume (content creation)
- High quality videos (HDTV, 2K, 4K) to be distributed (content access and distribution)

Future Internet challenge:
- Volume stored, content indexing, context identification and finding, caching, quality of video distribution – QoS – QoE, other
Voice & Message Trends

- **Voice** market – VoIP with various consolidated players:
  - Telecommunications market adopted TCP/IP (network support)

- **Message** is a new phenomena:
  - Instant message now including audio and video
  - WhatsApp, Gtalk, Twitter, Hangout, ...

- **Smartphones** and **mobility** fostering the up trend

- **Research** on new telecommunications approaches to support internet access with multimedia support: 5G, LTE, ...
  - Where telecom and networks “meet”
Mobile traffic is going up in relation to global Internet traffic

- Research on mobility includes both “networking” and “telecommunications” aspects (operators): 5G, LTE, ...
Other Applications
Trends

✧ Social Networks:
  - Facebook, Google+, LinkedIn, MySpace, Foursquare, Twitter, ...

✧ Geo-referencing & Applications:
  - Waze, Google Maps, ...

✧ Research: content “context”, correlation and “knowledge extraction” are actual possible focus
Wearable, Appliances, “Things”, Sensors, Flyable, ... Trends

“Wearable” are present in domains such as entertainment, e-health, ...

“Appliances” (TV, sound, refrigerator, mobile, ...) are present in domains such as home entertainment and smart-home

“Internet if Things - IoT” with “sensors”:
  - 100 billion of sensors by 2020
  - “Cloud” support is a trend

Research: typically multidisciplinary in broad domains like smart-cities, smart-grid, e-agriculture, smart-water, environment management, green computing, intelligent transportation systems, ...
Internet Evolution (so far)

- Wide scale proliferation and service diversification has lead to:
  - “Plumbing” of IP external artifacts:
    - IPv6, NAT, CIDR, DiffServ, MPLS, Mobile IP, ...
  - Overall result:
    - Conflict with Internet (IP) basic principles and assumptions
    - Current network becomes inefficient, difficult to manage and with various “side effects”
    - The hourglass issue
    - IP architecture “ossification”
Source: Peter Stuckmann and Rainer Zimmermann, “European Research on Future Internet Design”, IEEE Wireless Communications Magazine, October 2009
Incremental Network Evolution

IP Developments (examples)

- Subnets, Autonomous Systems (AS) and DNS (Domain Name System)
- CIDR – *Classless InterDomain Routing*
- TCP Congestion Control
- IP Multicast
- IPv6
- NAT – *Network Address Translation*
- IPSec – *IP Security*
- Mobile IP
- Quality of Service (QoS) and Diffserv (Differentiated Services)
- Caches
- Firewalls
- Other ...

Too many patches!!!
In Brief: **What we Need** for Future Internet

- **Visions and proposals** for the Future Internet:
  - (Re)Think fundamentals: routing, access, identity, other issues

- We need **experimentally-driven research**:
  - Fast and scalable realistic scenarios

- We need **new business models and business incentives** for adoption
Future Internet
How to Evolve?

How to evolve from current Internet to Future Internet (FI)?

- **Incremental approach:**
  - The basic architecture is kept; small solutions are adopted incrementally

- **Clean-Slate Design:**
  - The principle is to innovate from the scratch, eventually, adopting radical changes on the network architecture (Stanford approach) → Openflow/ SDN – Software-Defined Networking

- **Hybrid Approach**

New protocols and new architectures have been proposed but there is a problem:

- Internet is so big that any modification is not easily adopted by stakeholders
- Innovation process on current Internet may take years (from protocol/service development to overall adoption)
Future Internet
Networks for Experimentation (NfExp)

- Network innovation and experimentation is difficult:
  - Routers and switches are “closed”
  - Software-only experiments have both performance and scalability issues
  - New protocols development make take years
- Need a validation process for new design
- New infrastructures (testbeds) for developing and testing new or futuristic networking ideas:
  - TESTBED architectures
Future Internet Networks for Experimentation (NfExp)

- GENI (US) - Global Environment for Network Innovations
- FIRE (EU) - Future Internet Research and Experimentation
- FIBRE (BR-EU) - Future Internet testbeds / experimentation between Brazil and Europe
- FED4FIRE
- AKARI (JP)
- OFELIA
- ...

[Map of network infrastructure with various network labels and logos including GENI, FIRE, FIBRE, FED4FIRE, AKARI, OFELIA, and OMF.]
Future Internet
Some Solutions

There are several evolutionary paths for the “Future Internet – FI”
Technical Solutions and Terminology

- Smart Ubiquitous and Pervasive Networks:
  - Smart Grid, Smart-Cities, Smart Water, Smart Home, Smart-*, ...
- Internet-of-Things (IoT)
- Cloud Computing & Network as a Service (NaaS)
- SDN – Software-Defined Networking & OpenFlow

- Networks for Experimentation and Experiment as a Service (EaaS)
- Autonomic Networks & Self Organizing Networks
- Information-Centric Networks & Service-Centric Networks
- Other
Future Internet
Some Possible Technical Approaches
(new ideas) (resume)

- New network architectures and mechanisms:
  - Content Distribution Networks (CDN), Mechanisms for Heterogeneous Access Networks, other
- Management
- Scalability
- Security
- Mobility
- Federation & Access
- Ubiquitous and pervasive
- Business Model
Future Internet
New Internet Architectures, Paradigms and Mechanisms

Actual “content” distribution paradigms:
- Client/Server (server based), Content Distribution Networks (CDN) and Peer-to-Peer (P2P)

Next generation CDN with high definition and volume multimedia content:
- The middle-mile problem actually found on CDN networks:
  - How to move terabytes among users

Next generation Peer-to-Peer:
- Focused on the self-organizing and self-healing mechanism for FI:
  - Bandwidth provisioning, dynamics of sharing, P2P overlay traffic engineering problems

Reference: “Architectures for the Future Networks and Next Generation Internet: a Survey”
Subharti Paul, Jianli Pan and Raj Jain, Computer Communications, 2011
Future Internet
New Internet Architectures, Paradigms and Mechanisms

Swarming architecture:
- Swarming architecture as the basis of FI content distribution
- “Swarm” (P2P context): a set of loosely connected hosts that act in a selfish and highly decentralized manner to provide local and system level robustness through active adaptation

Content Centric Networks:
- Paradigm shift from host-centric actual Internet design
  - Actual Internet design: oriented to share distributed resources (printers, servers, ...)
  - FI Internet design: more focused on content delivery
- Clean-slate approaches:
  - Networking Named Content:
    - A network-wide caching mechanism
  - Data Oriented Network Architecture:
    - New naming approach focusing on services and data access

Future Internet Approaches
Architectures and Management

- FI scenario: control and management of a massively distributed and multi-ownership
  - Need to scale-up in size and complexity
  - Some clean-slate architectural approaches

- 4D Architecture:
  - Re-design of the actual Internet control and management planes
  - Discovery, Dissemination, Decision and Data planes (4D)
  - Centralized control architecture based on “network-wide views”

Reference: “Architectures for the Future Networks and Next Generation Internet: a Survey”
Subharti Paul, Jianli Pan and Raj Jain, Computer Communications, 2011
Future Internet Approaches
Architectures and Management

Autonomic Network Management and Autonomic Computing:

- IBM proposal (2001)
- New paradigm for FI:
  - Self-* properties: self-configuration, self-healing, ...
- ANA Architecture
- In-Network Management Architecture

Routing scalability issues:

- Huge routing tables with increasing number of Internet users:
  - Site multi-homing
  - Host multi-homing
- Ad Hoc routing:
  - Vehicular networks, mesh networks, other
  - Large number of users
FI Requirements and Approaches

Security

Actual Internet architecture adopts a trust-all environment (universities, research labs, other institutions)

Commercial Internet:

- New and strong security requirements
- Many different users and many applications

FI security approaches:

- Trend to be part of the FI architecture (not a overlaid approach)
- Relationship-oriented networking:
  - Network architecture that makes use of secure identities to establish relationships among people
- Enhanced architecture for security (clean-slate security):
  - SANE (Security Architecture for Networked Enterprises) architecture
- Trustworthy network and service infrastructure
- Other

Reference: “Architectures for the Future Networks and Next Generation Internet: a Survey”
Subharti Paul, Jianli Pan and Raj Jain, Computer Communications, 2011
Future Internet Mobility

- Increasing number of wireless appliances (phones, tablets, “things” – IoT, sensors, ...) with mobile users

- Mobility issues:
  - Handover:
    - Mobility among Access Points (APs) keeping identity (IP address or another clean-slate approach to “identity”)
  - High variability of wireless links
  - DTN (Delay Tolerant Network) mobility
  - Other
“Federation” of diversified networking environments is present in FI scenario:

- A “network of networks” in the application domain

**End-to-end access and connectivity** in heterogeneous network environments:

- Wireless sensor networks (WSN), wireless ad hoc networks, post-disaster networks, interplanetary networks, underwater networks, other
- Delay Tolerant Networks (DTN):
  - An end-to-end message oriented overlay (“bundle layer”)
  - End-to-end principle is re-defined and routing is revisited
- Delay/fault Tolerant Mobile Sensor Networks:
  - Actual focus: to achieve high throughput while minimizing power consumption
  - FI: will benefit from energy efficient systems intermixed with DTN approaches
- Disaster After Day Networks (DAN):
  - Architectural approaches for survivable networks in disaster scenarios

FI Requirements and Approaches
Business Model (new)

- How to allow service and network providers to be “adequately” remunerated in order to sustain investments
  - Actual Internet is a set of autonomous systems (ASs)
  - Essentially “basic services” are offered (commodities):
    - Email, bandwidth, other
- Service-based architectures are basic constructs for new business models:
  - +adaptable architectures
- Interest conflict mediation:
  - Users (data exchange and interaction), providers (profit) and government (regulation)
Future Internet
Global Business

- Global access with global users and global impact
- Business mostly located in US:
  - China, East Asia and Europe are coming (new players)

Source: KPCB Internet Internet D11 Conference, 2013
Future Internet
Multiple Aspects

Internet of Services, Service Web

- Collective End-user Intelligence
- Multi-Channel Access
- Discovery
  - Mashup
  - Tagging
- Resources

Professional Business Applications
Value-Added Services
Interoperability Service

3D Internet

Security

Networks of the Future - Telecommunications

Internet of Things
Future Internet & Future Networks

What we Expect?

Facilities & Opportunities with “Future Internet”:

- Ability to deliver “on demand” network resources
- Ability to deliver “on demand” network services
- Hide network complexity through “abstraction layers”
- Network management improvement: dynamic, programmable, ...
- New facilities: bandwidth on demand, network virtualization, cloud networks, other
Thanks

Discussion and Questions

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