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LETTER

Trends in network and service operation for the emerging future Internet

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Abstract

Recent advances in disruptive technologies, such as P2P content distribution, and research in high-speed optical and wireless transmission and in the virtualization of systems have sparked fundamental discussions about how to design the *future Internet*: Is a clean-slate approach mandatory? Would an evolutionary process be more appropriate? What kind of network and application features will drive the design of the future Internet? The aims of this position paper are to outline the technological trends and challenges for the emerging future Internet and to discuss the requirements and implications.

Keywords: Future Internet; Architecture; Overlays; Design objectives

1. Introduction

The Internet is evolving from the interconnection of physical networks by a collection of protocols towards what is considered the *future Internet*: a network of applications,[1] information and content. Some characteristics of the future Internet:

- The future Internet can be seen as a network of applications.
- It will enable "peer productivity" and becomes an "architecture for participation" [1].
- In particular, the future Internet will be based on interactive, edge-based applications and overlays, such as peer-to-peer (P2P) content distribution, Skype, MySpace, or YouTube.
- However, it is not yet sure what the next major application in the future Internet is.

Recent advances in disruptive technologies, such as P2P content distribution (cf. Fig. 1), and systematic research in high-speed optical and wireless transmission and in the virtualization of links and routers have sparked fundamental discussions about how to design the architecture of the future Internet:

- Is a clean-slate approach mandatory to facilitate new network and application architectures for the future Internet?
- Would an evolutionary process for designing the future Internet be more appropriate?
- What kind of network and application features will drive the design of the future Internet?

Giving a definite answer to these questions is audacious and impossible. However, technological challenges in networking and network applications can be identified and

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[1] In this contribution, the terms "application" and "service" are used interchangeably for the application of the network in the future Internet.

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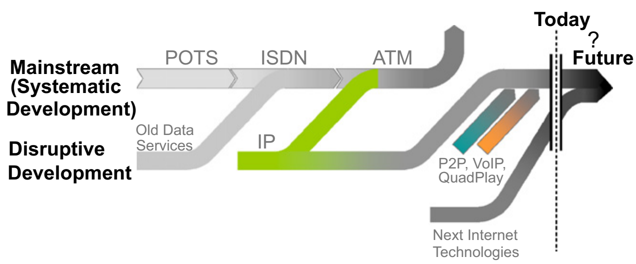

Fig. 1. Disruptive development in network design.

their implications considered for the future design. The aims of this position paper are to outline the technological trends and challenges for the emerging future Internet and to discuss the requirements and implications. The paper is organized as follows. Section 2 outlines trends in today's networking and networked applications. Section 3 discusses the challenges imposed by the trends for the design of the future Internet. Section 4 describes and evaluates briefly major national and international initiatives and technological platforms which are expected to make the future Internet happen. Section 5 summarizes the paper.

2. Trends

Today's Internet does not really show a general overload situation which would ask for a new network architecture. Actually, it performs quite well, as examples such as P2P file-sharing show.

Still, some recent remarkable developments and ideas for using the system call for new network and application architectures and for new ways of operating the system.

2.1. Edge-based services and applications

The services in classical communication networks, such as ISDN or GSM, are rather platform-dependant. The increased application of abstraction layers, like the Internet protocol (IP) or overlay techniques, permits services to be consumed now in a variety of wireless and wireline networks such as ADSL, WLAN, or UMTS. Hence, the transition from single network-centric services to application-centric *multi-network services* has occurred, cf. Fig. 2.

Classical services were designed and provisioned by network operators. However, the success of P2P file-sharing, such as BitTorrent [2,3], has blurred the boundary between content providers and consumers. In addition, they showed that edge-based communities can easily design, deploy and offer services. The new services reveal *edge-based intelligence* and form *overlays* with application-specific naming and routing concepts.

Furthermore, users transfer their social behavior increasingly to networks and networked applications. *Social networking web sites* like YouTube [4] or MySpace [5] with *user-generated content* became tremendously popular. They permit the users to structure the use of the information according to their specific social relationships.

The ubiquity and availability of networked application in today's wired and wireless networks combined with an increasing commercial significance has led to a demand for highly *dependable networks and services*. Automatic resilience, fault management and overload mechanisms have been proposed at different layers: fast reroute mechanisms at the network layer [6] or dependable overlay services for supporting vertical handovers in mobile networks [7,8] at the application layer.

The successes of virtual mobile operators [9] or the P2P VoIP service Skype [10] have shown that *virtualization of telecommunication services or applications* is no longer an academic concept. For example, it virtualized central indices for user locations by a distributed software running on the end user's client. Open programming interfaces permit third parties to rapidly develop numerous commercial services on top of Skype [11].

2.2. High-speed data transport

Advanced optical core networks using dense wavelength division multiplexing (DWDM) or hybrid optical network architectures have brought tremendous amounts of flexible point-to-point transmission capacity into core networks [12,13]. *Fibre-based access technologies*, such as ethernet passive optical networks (EPON), permit to deliver this capacity to end users at very low cost [14].

Furthermore, infrastructure-based wireless communication has experienced a huge *diversification of radio access technologies* while experiencing a steady increase of capacity. Beyond third generation (B3G) wireless networks [15] will comprise highly ubiquitous and very different mobile broadband access technologies such WLAN, HSPA [16], or Mobile WiMax [17].

2.3. Network and service control and management

The need for fast responses on failures and the reduction of operational costs (OPEX) led to the development of *autonomous procedures* for network and service operation. Thus, *self-organizing mechanisms* and self-* procedures have been suggested [18]. The algorithms automate, for example, the quick pinpointing of system faults [19] or specific configuration tasks in mobile access networks [20].

The end-to-end control paradigm of TCP/IP networks has decoupled the user and the operator from direct quality feedback. User and network operator are typically not informed about the performance of an application. As a result, *integrated quality feedback mechanisms* have been investigated lately which notify users and operators independently from

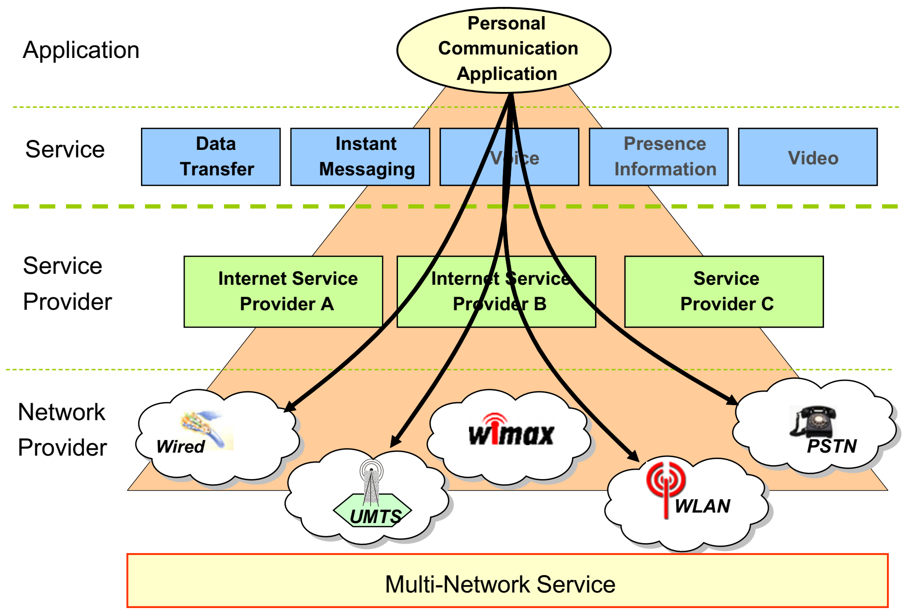

Fig. 2. Emerging to multi-network service.

the application when end-to-end quality degradations occur [21,22].

Users judge the quality of networks, services, and networked applications more and more by the subjective perception of the performance. Hence, the concept of *quality-of-experience* (*QoE*) has been developed lately [23,24]. It describes the user's view how usable a service or a networked application is.

3. Technical challenges

Considering the above-mentioned trends, significant challenges arise for the design of the future Internet which will be discussed next.

3.1. Overlays for participation

Similar to the current trend of user-generated content, future networks will increasingly derive their applications, services and infrastructures from user-generated contributions. This paradigm refers mainly to content but also to hardware, as the FON project [25] has recently shown for WLAN access points.

An easy tool for integrating widely distributed contributions are virtual networks, so-called *overlays*. Thus, a major challenge for the architecture of the future Internet is the support of *overlays for participation*. Edge nodes should be enabled to form overlays of coordinated communities. They require mechanisms to define overlays with *application-specific name spaces, routing and self-organizing procedures for topology and resource management*, cf. Fig. 3.

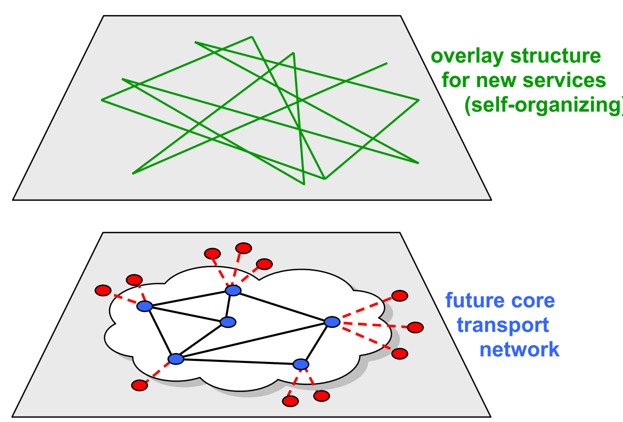

Fig. 3. Overlay networks.

Furthermore, services provided to or by the overlay node have to be supplied on small time scales while their quality is ensured.

The *network independence* of future Internet applications requires the system to consider *mobility as the norm*. To support high mobility but also for dedicated QoS and security, new addressing scheme which *separate between location and identity* are needed. In addition, future applications should be able to apply their own mechanisms to maintain their QoE, e.g. by adapting the bandwidth of the codecs. However, the execution of such mechanisms might not be fair as it has been identified for recent voice codecs [26]. Hence, future Internet applications need *fairness mechanisms* to control the behavior of egoistic users and applications [27].

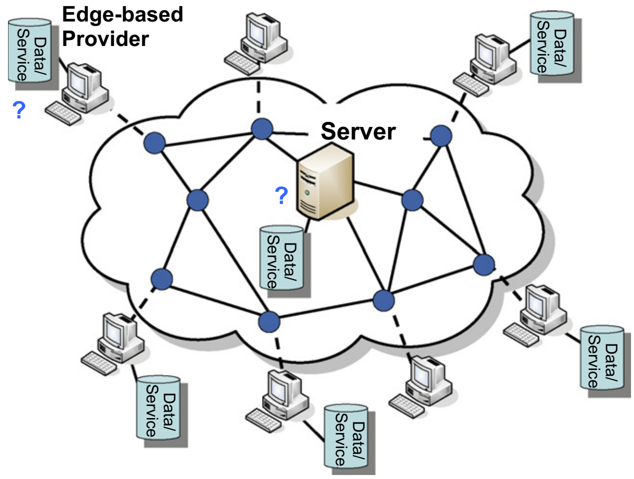

Fig. 4. Intelligent content and service placement.

A further challenge for a participation architecture is the efficient locating and exchanging of *user-supplied resources*, such as phonebooks, pod-/videocasts, or WLAN access points. Fast and scalable self-organizing mediation overlays are needed in wireline [28] and wireless environments [29].

The question where to store content or to place services might particularly influence the future network structure, cf. Fig. 4. Centralized storage and service concepts are easily controllable by operators, e.g. for protecting copyright, and are highly efficient. However, they are vulnerable to overload and system faults. Distributed concepts may suffer from synchronization and additional network traffic, but might be more reliable. Hence, intelligent, controllable, and scalable edge-based content and service provisioning mechanisms are needed for the future Internet.

3.2. High-speed data transport: future access systems, core network and routing architecture

A major challenge for the future Internet is the *heterogeneity* of access technologies. For example, future mobile devices will move through a landscape of different wireline and wireless access systems and operators. Moreover, the number of access points and their inter-connectivity may fluctuate permanently since the node may fail or the operators interconnect them on demand when additional coverage is needed. Self-organizing vertical handover mechanisms are needed for bridging the heterogeneity between the access technologies and have to be executed in very few time. Hence, the architecture of the future Internet requires *scalable mobility management mechanisms*.

A further major challenge is achieving fast and reliable *resilience* in core networks. In particular, fast reroute technologies should be pursued and protection mechanism are need which avoid unnecessary backup capacity [6].

The capability to arbitrarily structure the future Internet needs *mechanisms for virtual and flexible network configurations*, *routing architectures and overlays*. Future core network nodes need the capability to support in parallel multiple overlays which form arbitrary and flexible topologies. Each node should be able to configure every of its overlays with a random number of virtual interfaces and virtual edges to other distant core nodes [30]. The virtual edges should expose their performance and any lower layer faults to nodes. In addition, the future core nodes require mechanisms for forwarding and routing traffic along a virtual edge and for distributing the routing information. These mechanisms should also be available and controllable by edge nodes since the future Internet will not distinguish between the edge and the core of the network.

3.3. Future service control and management

Current *self-organization mechanisms for applications and services* are typically designed for end-user constraints where the consumption of network resources is of minor interest and for the optimization of a single objective. In the future Internet, however, these algorithms need to consider network resources, multiple stakeholders, and objectives.

Future reliable edge-based services require the provisioning of checkabel resources. Hence, *flexibl*e service-level agreements (SLAs) are needed for negotiating and validation of the resource quality. The new SLAs should address the combination and encapsulation of the provided services, their provisioning on small time scales, and meaningful quality concepts, e.g. QoE [31].

Offering a universe of diverse services to a large number of users requires the future Internet to be orchestrated with a *scalable monitoring architecture* that surveys independently the provisioning of the services. Hereby, end-to-end network monitoring has to be achieved while being able to pin-point bottlenecks.

3.4. Future layering and abstraction architecture

Today's Internet architecture is largely based on the hourglass concept of the IP where every data is transported over the IP protocol and any IP packet could be transported over every network. The so-called "IP waist" increasingly constitutes a bottleneck in today's Internet architecture [32,33].

Internal pressure to IP waist comes from the increasing complexity and the deficiencies of the IP protocol such as the lack for scalable support for end-to-end quality of service across domains, limited resilience and mobility support for on-going data flows, and the very simple network management protocols. External pressure for the IP waist results, amongst others, from the efficiency and flexibility of application-specific overlays.

Hence, instead of having insufficient layers, such as the IP layers,[2] and by-passing them by using overlays, a *thinning*

[2] Similar considerations can be applied to the OSI layering model since it partly shares the structure and interfaces with the IP layering concept.

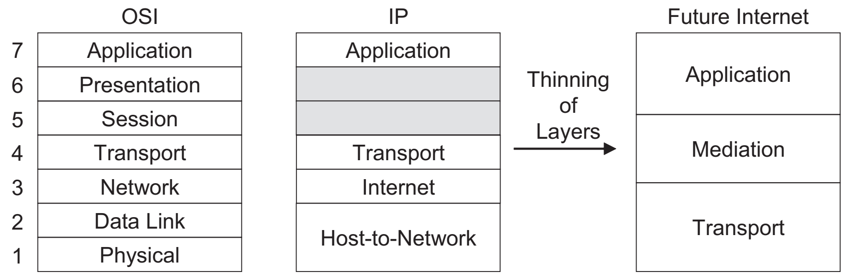

Fig. 5. Thinning of protocol layers.

of the layers and a *more basic separation* of them is needed. This separation should focus on (a) the application layer (for addressing application needs), (b) the mediation layer (for network structuring, naming, and routing), and (c) the transport layer (for reliable and cost-efficient transport), cf. Fig. 5.

Within these layers, concepts from application-specific overlays can be applied. For example, for forming *virtual networks* for different applications which are operated in parallel. The overlays can structure their topology more directly to the needs of the application, e.g. for reflecting the relationships of communities, can apply routing strategies which are better suited for an application, and can make efficiently use of cross-layer information.

All in all, future layering concepts should provide advanced programming interfaces for applications in order to let them influence (a) the (virtual) network structure, (b) the routing mechanisms, and (c) the resource management.

As a result, a new *overlay and virtualization concepts* are currently under development, like PlanetLab's slices notation, cf. Section 4.2, cross-layer visibility as a services [34], or specific middle layers [35,36]. The future concepts should provide advanced programming interfaces for applications in order to let them influence on the network structure, the routing mechanisms, and the resource management.

3.5. Scientific challenges

The above described technical requirements reveal two areas of scientific challenges in the design of the future Internet. The first category of challenges aims at *reorganizing the layering structure of today's Internet* and at developing new algorithms and architectures which permit *edge nodes to control the communication and routing*. The algorithms should support the set-up, operation and resource management for and between overlays. The new interfaces of the layers should permit the applications and edge nodes to structure the network, define their own routing schemes and manage the required resources autonomously. The new algorithms have to be flexible, fast, and reliable in order to support high transmission capacity, controllability, and cost-efficient system operation. Furthermore, the new architectures should support multiple providers, the separation of location and identity, and permit new routing schemes for increased reliability, QoS and security.

The second class of scientific challenges is the *development of new methodologies for operating and analyzing networks and networked applications*. In particular, new self-organization concepts are required which incorporate cooperation strategies, such as incentives and game theory, in a fair and controllable way. In addition, they should support multiple objectives and level performance trade-offs, e.g. between efficiency and robustness. Furthermore, advanced performance metrics and analysis methods are needed to evaluate the new features of the future Internet. For example, new concepts are required to quantify the quality of self-organization, scalability, dependability, or security. In addition, new evaluation methods have to be developed for enabling SLAs across service and provider domains and for distributed resource management.

Meeting these challenges will permit answering questions such as "Which overlay or control mechanism is suited best for a particular edge-based application?" or "What performance can be expected from the mechanisms?".

4. Paths towards the future Internet

Today's Internet was in its infancy a very small networking research project with only a few researchers and institutions participating. In contrast to that, the future Internet will have a large number of stakeholders and researchers from the very first beginnings of its design. Hence, the path of implementing the future Internet will not be a single trail that everybody follows. Multiple paths are expected, addressing the different needs of the stakeholders or the opinions of researchers, resulting in a growing number of initiatives and projects.

Larger and more focussed research funding programs and instruments have been initiated at the political and national level, while more detailed, smaller and targeted projects such as implementation platforms are already running. Our overview will include both levels.

4.1. National and international implementation plans

it839/u-it839. Korea's "it839"[3] project of 2004 has been one of the first national future Internet initiatives.

It aims at funding research in eight different communication services (WiBro, DMB, home networks, Telematics, RFID-based, WCDMA, terrestrial DTV, and Internet telephony), three future network infrastructures (Broadband converged networks (BcN), soft infraware, the IPv6 architecture) and nine hardware-related businesses [37]. After achieving the first technical goals in 2006, such as the definition of standards for Wireless Broadband (WiBro) systems and Digital Multimedia Broadcasting (DMB), the project has been renamed to "u-it839" and reshaped to focus on ubiquitous environments such as sensor networks. The anticipated new three future network infrastructures are BcN (combined with IPv6), sensor networks and soft infrastructure.

The strength of the u-it839 project and its potential impact on standardization is its direct support of hardware-related businesses for wireless and ubiquitous environments.

4.1.1. Evolved Internet future for European leadership – EIFFEL

The European Commission has started the EIFFEL initiative in July 2006 as a part of the larger Information and Communication Technology (ICT) research activities in 7th EU Framework Program. The aim is to foster fundamental and risky, clean slate research projects for overcoming the limitations of today's Internet. In particular, it addresses new forms of routing and addressing, handling of mobility and connectivity in a generalized wireless environment [33]. The obtained research findings will later be transferred for validation into a large-scale test facility. EIFFEL's mode of operation and funding has not yet been decided. Various proposals have been made by the research community to clarify EIFFEL's concept. The proposals range from a "school of network architects" to the support of a small set of specific research projects. So far, the EIFFEL initiative is too young to provide detailed technical guidelines for the future Internet. However, there is strong resemblance with the North-American FIND project.

Besides EIFFEL, the new European initiative Future Internet Research and Experimentation (FIRE) was started lately [38].

4.1.2. Information and communication technology 2020 – IKT 2020

In early 2007, the German Federal Ministry of Education and Research (BMBF) has initiated a research project for future network services and network architectures under the label of "IKT 2020". It covers a period of 10 years, supporting long-term theoretical investigations of future Internet requirements. Technically, it aims at new services in conventional networks as well as at new services in new networks, to be implemented in test facilities. The BMBF has acknowledged the commercial significance of the future Internet and provides substantial and rapid funding for research projects.

4.1.3. Future Internet network design – FIND

The need for new fundamental networking research was identified early by North-American universities and research institutions in a number of projects [39–42]. As a result the future Internet network fesign (FIND) initiative was started as part of the Networking Technology and Systems (NeTS) project of the National Science Foundation (NSF) [43]. The FIND initiative can be characterized by two fundamental questions: "What are the requirements for the global network of 15 years from now – what should that network look like and do?" and "How would we re-conceive tomorrow's global network today, if we could design it from scratch?". By its radical approach, FIND coined the term of "clean slate" approach for design of the architectures and principles of the future Internet, adopted by many others. The focus areas of the FIND initiative are the evolution of the network edge, the integration of sensor networks, future services, location and identity management, and future core networks. FIND is currently funding at least twelve projects which cover a broad range of research issues [44].

4.2. Emerging new network platforms

4.2.1. PlanetLab

PlanetLab can be viewed as one of the origins of the current race of future Internet research [45]. It is the ancestor of the GENI and VINI projects (see below). It originated from the insight that real world and large scale experiments of new mechanisms and architectures have become almost impossible in today's Internet. For example, even slight experimental changes in today's BGP routing protocol might be too delicate and being blocked by Internet Service Providers. The aim of the project has therefore been to develop a global platform for researchers to develop, deploy and evaluate widely-distributed applications such as large-scale P2P systems. PlanetLab follows three principles: *application-centric interfaces*, *distributed virtualization*, and *unbundled management*. The *execution environment* of a PlanetLab node (currently more then 700 nodes in 350 sites world wide) provides the experimenter with a virtualized Linux machine. It is accompanied by the concept of *slices*: distributed collections of virtual machines in which an application or a service runs. A slice can be viewed as an *overlay* and can be set up in an arbitrary way, enabling PlanetLab to support multiple

[3] The three numbers are certain lucky numbers in the Asian region.

competing services contributed by its users. PlanetLab is the most used (though suffering from high load) public test bed for the future Internet.

4.2.2. Global environment for network innovations – GENI

While the FIND initiative addresses the fundamental research issues of the future Internet, the NSF's GENI project [46] is aiming at building an open, large-scale, realistic experimental facility for the evaluation of future network architectures. In contrast to conventional test beds, the GENI facility attempts a "clean slate approach" in order to (a) support multiple experiments running in parallel, (b) carry real traffic on behalf of end users, and (c) connect to the existing Internet to external sites, permitting thorough experimental validation of research concepts. GENI extends PlanetLab specifically by providing dedicated networking hardware such as compute nodes, backbone links, customizable routers and wireless subnets [47]. Customizable high-speed routing hardware and optical switching are candidate hardware platforms for GENI concepts. Edge sites in the GENI network have significant computing and storage resources and can host wireless subnets including 802.11-based ad hoc meshes, 3G, WiMax, and sensor networks. The GENI backbone will be connected to the legacy Internet to Internet exchanges (IX) for connectivity to commercial ISPs. Each experiment using GENI will also run in a *slice* (cf. PlanetLab) and includes management software for resource allocation, embedding of slices in the resources and interference avoidance. It is planned that the physical GENI backbone network will comprise approximately one dozen points-of-presences (PoPs) in North-America which are interconnected by links of at least 10 Gbps capacity [48]. GENI is currently the most ambitious project and conceptually well specified on paper, but so far only initial implementations are available (see below).

4.2.3. Virtual network infrastructure – VINI

VINI [30,49] is an incremental step from the Planet system towards the GENI facility. Physically, it is a distributed collection of network equipment and circuits, coupled with software. VINI software runs in the PlanetLab environment and uses high-end PCs as *programmable nodes*. The VINI core project investigates the development of software for running the programmable node. In particular, it investigates (a) the improved virtualization of the protocol stack, (b) the management mechanisms for instantiating experiments in the VINI substrate, (c) a monitoring infrastructure to survey the system and to collect data of experiments, and (d) the reference implementation of experimental software for IP and related protocols. The VINI project focuses mainly on novel principles for *transport overlays*. VINI is currently the project with the most advanced mechanisms for testing the future Internet, implementing the most innovative future transport network features.

4.2.4. Internet research task force – Routing Research Group

The Routing Research Group (RRG) of the Internet Research Task Force (IRTF) has been re-vitalized in 2007 [50,51]. The group is now aiming at new routing and Internet addressing architectures which provide scalable support for core network routing tables, traffic engineering, multihoming, and mobility. Currently, the RRG is discussing the decoupling of location and identification for simplified routing and renumbering of networks [52]. Various proposals to achieve this aim have been by the members. The *hybrid link-state path-vector* (*HLP*) protocol [53] claims to provide vastly better scalability, isolation and convergence properties. The author of [54] argues that two different name spaces should be applied for identification and location. The *identifier* is not used inside headers of packets nor for routing through the core Internet, but for referring to devices that terminate transport-level connections, e.g. hosts. Whereas, the *locators* are used inside packet headers and should have topological meaning to aid aggregation. The eFIT approach [55] suggests to add location information, in addition to topology information, into the IP address structure. The *locator/ID separation protocol* (*LISP*) [56] suggests to split Internet addresses into endpoint identifiers (EIDs) and routing locators (RLOCs). Thus, it permits better routing scalability. Since the IRTF and IETF are aiming at medium and short term solutions, a rapid and deep impact on routing architectures, and particular on numbering schemes for the future Internet, can be assumed.

5. Conclusion

The future Internet is no longer a collection of links, routers, and protocols. It will be viewed as a network of applications, information, and contents. The future Internet will become an architecture for participation by the users and eventually, for contribution of hardware resources. Hence, *intelligent edge-based applications* and services will dominate the future Internet. These applications and services will be typically implemented in an abstract way as *overlays*.

Recent advances in networking technology such as high speed optical networking, wireless transmission, or virtualization of links and routers will challenge the design of the future Internet. In order to address these challenges new *methodologies for implementing and operating overlays* are needed. In particular new mechanisms are required which permits edge-based overlays to structure their topology, to define their routing scheme, and to manage their resources independently.

Moreover, the pressures from the efficiencies of overlays on the conventional layering model of IP and OSI initiate currently a re-thinking of these models. A *thinning* of protocol layers and a *more basic separation of the layers* appear essential. This separation should focus on a split into three layers: (a) the application layer (for addressing the application needs), (b) the mediation layer (for network structuring, naming, and routing), and (c) the transport layer (for reliable and cost-efficient transport).

Different national and international initiatives and projects for evolving today's system into the future Internet have been started lately. One of the most praised initiative is the GENI project. Although only initial funding is yet available, it has currently the most significant impact on the design of the future Internet. Other and more focused initiatives like the "u-it839" project or the ideas of the IRTF RRG might also have significant impact on specific parts of the architecture of the future Internet, such as the wireless subsystem or the routing subsystem.

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References

[1] Anderson, C. People power. Wired, July 2006, p. 132.
[2] Anonymous. Protocol specifications v1.0. 2006. Information available at ⟨http://www.bittorrent.org⟩.
[3] BitTorrent Inc. What is bittorrent? 2007. Information available at ⟨http://www.bittorrent.com/what-is-bittorrent/⟩.
[4] YouTube Inc. YouTube Fact Sheet. 2006. Available at ⟨http://www.youtube.com/t/fact_sheet⟩.
[5] MySpace Inc. MySpace.com. 2006. Information available at ⟨http://www.myspace.com/⟩.
[6] Martin R, Menth M. Backup capacity requirements for MPLS fast reroute. 7. ITG Fachtagung Photonische Netze (VDE), Leipzig, Germany, April 2006.
[7] Hoßfeld T, Oechsner S, Tutschku K, Andersen F-U, Caviglione L. Supporting vertical handover by using a pastry peer-to-peer overlay network. In: Proceedings of the 3rd IEEE international workshop on mobile peer-to-peer computing (MP2P'06), Pisa, Italy, March 2006.
[8] Hoßfeld T, Oechsner S, Tutschku K, Andersen F-U. Evaluation of a pastry-based P2P overlay for supporting vertical handover. In: Proceedings of the 2006 IEEE wireless communications and networking conference (WCNC 2006), Las Vegas, USA, April 2006.
[9] Varoutas D, Katsianis D, Sphicopoulos T, Cerboni A, Canu S, Kalhagen K, et al. Economic viability of 3g mobile virtual network operators. In: Proceedings of 3G wireless 2002, San Francisco, USA, May 2002.
[10] Skype Technologies SA. Skype Homepage. 2006. Information available at ⟨http://www.skype.com/⟩.
[11] Skype Limited. Skype Extras. 2006. Information available at ⟨http://extra.skype.com/⟩.
[12] O'Mahony M, Simeonidou D, Hunter D, Tzanakaki A. The application of optical packet switching in future communications networks. IEEE Commun Mag 2001; 39.
[13] Gauger C, Kuhn P, Breusegem E, Pickavet M, Demeester P. Hybrid optical network architectures: bringing packets and circuits together. IEEE Commun Mag 2006; 44.
[14] Chanclou P, Gosselin S, Palacios J, Alvarez V, Zouganeli E. Overview of the optical broadband access evolution: a joint article by operators in the IST network of excellence e-Photon/One. IEEE Commun Mag 2006; 44.
[15] Dahlmann E, Ekström H, Furuskär A, Jading Y, Karlsson J, Lundevall M, et al. The 3G long-term evolution – radio interface concepts and performance evaluation. In: Proceedings of the 63rd IEEE vehicular technology conference (VTC '06 - Spring), Melbourne, Australia, May 2006.
[16] UMTS Forum. HSPA: High speed wireless broadband – from HSDPA to HSUPA and beyond. 2006. White Paper; Information available at ⟨http://www.umts-forum.org⟩.
[17] WiMAX Forum: Mobile WiMAX Part I: a technical overview and performance evaluation. 2006. White Paper; Information available at ⟨http://www.wimaxforum.org/news/downloads/⟩.
[18] IBM Research: Autonomic computing. 2006. Information available at ⟨http://www.research.ibm.com/autonomic/⟩.
[19] Patterson D, Brown A, Broadwell P, Candea G, Chen M, Cutler J, et al. Recovery-oriented computing (ROC): motivation, definition, techniques, and case studies. UC Berkeley computer science technical report UCB//CSD-02-1175. March 2002.
[20] Oechsner S, Hoßfeld T, Tutschku K, Andersen F-U, Caviglione L. Using Kademlia for the configuration of B3G radio access nodes. In: Proceedings of the 3rd IEEE international workshop on mobile peer-to-peer computing (MP2P'06), Pisa, Italy, March 2006.
[21] Elster C, Raz D, Wolff R. Autonomous end-to-end QoS monitoring. In: Proceeding of the IEEE/IFIP workshop on end-to-end monitoring techniques and services (E2EMON), Nice, France, May 2005.
[22] Binzenhöfer A, Tutschku K, auf dem Graben B, Fiedler M, Arlos P. A P2P-based framework for distributed network management. In: Proceedings of the second international workshop of the EURO-NGI network of excellence on wireless systems and network architectures in next generation Internet, LNCS 3883, Loveno di Menaggio, Como, Italy, January 2006.
[23] Nokia Corporation. Quality of experience (QoE) of mobile services: can it be measured and improved? 2004. White Paper.
[24] Soldani D, Li M, Cuny R, editors. QoS and QoE management in UMTS cellular systems. Chichester: Wiley; 2006.
[25] The FON Project. 2006. Information available at ⟨http://www.fon.com/en/info/fonFriends⟩.
[26] Hoßfeld T, Binzenhöfer A, Fiedler M, Tutschku K. Measurement and analysis of skype VoIP Traffic in 3G UMTS systems. In: Proceedings of the 4th international workshop on Internet performance, simulation, monitoring and measurement (IPS-MoMe 2006), Salzburg, Austria, February 2006.
[27] Schlosser D, Hoßfeld T, Tutschku K. Comparison of robust cooperation strategies for P2P content distribution networks

with multiple source download. In: Proceedings of the sixth IEEE international conference on peer-to-peer computing (P2P2006), Cambridge, UK, September 2006.

[28] Tran-Gia P, Binzenhöfer A. On the stochastic scalability of information sharing platforms. 2005 Tyrrhenian international workshop on digital communications, Sorrento, Italy, July 2005.

[29] Kellerer W, Kunzmann G, Schollmeier R, Zöls, Z. Structured peer-to-peer systems for telecommunication and mobile environments. Int J Electron Commun (AEÜ) 2006; 60(1).

[30] Bavier A, Feamster N, Huang M, Peterson L, Rexford J. In VINI Veritas: realistic and controlled network experimentation. In: Proceedings of the ACM Sigcomm 2006 conference, Pisa, Italy, September 2006.

[31] Hoßfeld T, Tran-Gia P, Fiedler M. Quantification of quality of experience for edge-based applications. In: 20th international teletraffic congress (ITC20), Ottawa, Canada, June 2007.

[32] Roscoe T. The end of Internet architecture. In: Proceedings of the fifth workshop on hot topics in networks (HotNets-V), Irvine, USA, November 2006.

[33] Mähönen P, Trossen D, Papadimitriou D, Polyzos G, editors. The future networked society. A White paper from the EIFFEL (Evolved Internet Future for European Leadership) Think-Tank; published by the European Commission, December 2006.

[34] Kompella R, Greenberg A, Rexford J, Snoeren A, Yates J. Cross-layer visibility as a service. In: Proceedings of the fourth workshop on hot topics in networks (HotNets-IV), College Park, Maryland, November 2005.

[35] Nakao A, Peterson L, Bavier A. A routing underlay for overlay networks. In: Proceedings of the ACM Sigcomm 2003 conference, Karlsruhe, Germany, August 2003.

[36] Koulouris T, Henjes R, Tutschku K, de Meer H. Implementation of adaptive control for p2p overlays. In: Proceedings fifth annual international working conference on active networks (IWAN 2003), Kyoto, Japan, December 2003.

[37] KOREA IT TIMES: New "u-it839" strategy looks to the future. April 2006. Information available at: ⟨http://www.ittimes.co.kr/en/node.asp?em = M&mcode = 200604&idx = 1195⟩.

[38] European Commission. Fire: future internet research and experimentation. 2007. Information available at: ⟨http://cordis.europa.eu/ist/fet/comms-fire.htm⟩.

[39] MIT Laboratory for Computer Science. Newarch project: Future-generation internet architecture. 2003. Information available at: ⟨http://www.isi.edu/newarch/⟩.

[40] 100x100network. 100 × 100 clean slate project. 2003. Information available at: ⟨http://100x100network.org/⟩.

[41] McKeown N, Girod B. Clean slate design for the Internet. April 2006. Whitepaper; Information available at: ⟨http://cleanslate.stanford.edu/⟩.

[42] Defense Advanced Research Projects Agency. Assurable global networking. 2006. Information available at: ⟨http://www.darpa.mil/sto/solicitations/AGN/index.html⟩.

[43] National Science Foundation. Networking Technology and Systems (NeTS). 2006. Information available at ⟨http://www.nsf.gov/pubs/2007/nsf07507/nsf07507.htm⟩.

[44] Tafazolli R. Post-ip working group. Presentation at the second general assembly of the eMobility European technology platform, November 2006. Information available at ⟨http://www.emobility.eu.org/GA2/GA2-intro.html⟩.

[45] Steinmetz R, Wehrle K, editors. Peer-to-peer systems and applications. Berlin: Springer; 2005.

[46] GENI Consortium. GENI – Global environment for network innovations. 2006. Information available at ⟨http://www.geni.net/⟩.

[47] GENI Planning Group. GENI design principles. IEEE Comput (2006); 39(9).

[48] GENI Planning Group. GENI: Conceptual design, project execution plan. GENI design document 06–07, January 2006. Information available at ⟨http://www.geni.net/⟩.

[49] VINI Consortium. VINI Homepage. 2006. Information available at ⟨http://www.vini-veritas.net/⟩.

[50] Meyer D, Zhang L, Fall K. Report from the IAB workshop on routing and addressing. IRTF draft "draft-iab-raws-report-02.txt", April 2006. Available at ⟨http://www.ietf.org⟩.

[51] IRTF. Routing Research Group – Charter. 2007. Information available at ⟨http://www.irtf.org/charter?gtype = rg&group = rrg⟩.

[52] Li T. Design goals for scalable internet routing. IRFT draft document: "draft-irtf-rrg-design-goals-00.txt"; April 2007. Available at ⟨www.ietf.org⟩.

[53] Subramanian L, Caesar M, Ee C, Handley M, Mao M, Shenker S, et al. HLP: A next-generation interdomain routing protocol. In: Proceedings of the ACM Sigcomm 2005 conference, Philadelphia, PA, USA, August 2005.

[54] Bonaventure O. Reconsidering the Internet routing architecture. IRTF draft "draft-bonaventure-irtf-rrg-rira-00.txt". March 2007. Available at ⟨http://www.ietf.org⟩.

[55] Massey D, Wang L, Zhang B, Zhang L. A Proposal for Scalable Internet Routing & Addressinge. IRTF draft "draft-wang-ietf-efit-00.txt". March 2007. Available at ⟨http://www.ietf.org⟩.

[56] Farinacci D, Fuller V, Oran D, Locator/ID Separation Protocol (LISP). IRTF draft "draft-farinacci-lisp-00.txt". January 2007. Available at ⟨http://www.ietf.org⟩.

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