Next Generation Mobile Internet – Network and Service Platform

Die nächste Generation des mobilen Internet – Netz- und Serviceplattform

Wolfgang Kellerer, Jörg Widmer, Hendrik Berndt, DOCOMO Communications Laboratories Europe GmbH, München

Summary The Internet has become the main network technology supporting communications and Web services in all areas of our society. In order to perform this role efficiently, a fundamental redesign of the Internet architecture is being discussed. In particular, mobile devices and wireless access networks will constitute an important part of the Internet infrastructure. Based on a general discussion of requirements, this article focuses on the challenges of a next generation mobile Internet and discusses research approaches for mobility, addressing, heterogeneous access, and service platforms. ►►► **Zusammenfassung** Das Internet unterstützt Kommunikation und Web Dienste in allen Bereichen unserer Gesellschaft und hat sich damit zu der Schlüsseltechnologie der vernetzten Welt entwickelt. Damit das Internet dieser Rolle bei gesteigerten Anforderungen weiterhin gerecht werden kann, wird derzeit seine grundlegende Überarbeitung diskutiert. In Zukunft werden insbesondere mobile Endgeräte und drahtlose Zugangsnetze einen erheblichen Anteil an der Internet Infrastruktur haben. Daher geht dieser Artikel ausgehend von einer generellen Betrachtung der Anforderungen speziell auf die Herausforderungen eines Next Generation Mobile Internet ein und diskutiert Forschungsansätze für Mobilität, Adressierung, heterogene Zugangsnetze und Diensteplattformen.

KEYWORDS C.2.1 [Computer Systems Organization: Computer Communication Networks: Network Architecture and Design Future]; future Internet, mobile Internet, virtualization, overlay networks

1 Introduction

The Internet has become the communications backbone of our society in all respects. When using the term Internet, we usually do not limit ourselves to its core set of protocols such as TCP/IP but refer to its whole offer of services and applications provided by a plethora of protocols on all protocol layers. Moreover, the Internet has stretched out from the fixed line infrastructure to cellular networks. There, access to the Internet was offered as an add-on for second generation mobile networks. Today, the Internet protocols are an integral part of third generation mobile communication systems such as UMTS. With the emergence of the Next Generation Network (NGN) in fixed infrastructures and the All IP Network in mobile systems, the Internet Protocol (IP) suite is expected to play the dominant role in networking. With our theme on *mobile Internet* in this article we cover the aspects of a next generation Internet encompassing the particular requirements of mobile and wireless systems.

The importance of the Internet can also be observed in the area of service delivery platforms, where the IP Multimedia System (IMS) becomes more and more important as a service platform for packet switched services for fixed and mobile networks.

Despite its popularity, the Internet suffers from several deficiencies originating from its basic design principles. Targeted as a network for robust data transport over a fixed infrastructure, its suitability for today's variety of services including real-time traffic and mission critical applications is limited. To fix some of the problems, plenty additional protocols have been proposed, complementing IP in such areas as security, mobility, and quality of service (QoS). However, none of these proposals have seen widespread deployment in the Internet. For a number of reasons, adding functionality to the current Internet has become almost impossible, leading to an ossification of the Internet architecture. Thus, recently initiatives have started to reconsider the Internet design as such.

The most pressing problems to be solved for the future Internet are summarized in the following paragraphs [1]. They can be grouped by short term, mid term and long term problems according to their urgency [2].

The most obvious annoyance of the Internet that has to be solved on a short term basis is probably Spam, followed by security as the biggest imminent problem facing the Internet. Today's security infringements such as viruses, phishing, denial-of-service attacks, etc. largely diminish the users' trust in the network and prevent critical applications from being deployed. A further problem is the presence of middleboxes such as firewalls or NATs, some of them deployed to improve network security. They do not fit well with the original concept of end-to-end connectivity and cause enormous problems for application developers.

Medium term problems relate to QoS, management, routing, mobility and the overall layered architecture itself. Despite many research and standardization efforts the best-effort characteristic of the Internet prevails. QoS is addressed by simple overprovisioning today. However, to cope with the rise in traffic volume and the requirements of emerging applications (e. g., real-time, interactive) as well as the use of networks with different physical layer characteristics (e. g., wireless), comprehensive solutions have to be developed and deployed in order to transform the Internet from a commodity best-effort network to a commercial telco-grade one. In the same way, Internet network management is lacking some of the functionality known from traditional telecommunications. Further, the slow convergence and other deficiencies of the BGP protocol limit the scalability of inter domain routing and thus limit the business relationships between Internet service providers (ISPs).

Many of the Internet hosts are considered to be mobile in the future. Yet, this is not reflected in the Internet design where both identity and location are designated by IP addresses. This creates problems when a host moves between networks, is attached to multiple networks for multi-homing, or in case it has multiple service-specific addresses.

Another problem of the Internet to be solved in the medium term is the layered protocol reference model itself, which is one of the main reasons why the other problems remain unsolved. Due to many short sighted fixes but also due to its huge success as *the* platform for networking, the architecture has ossified and lost all necessary flexibility.

Finally, while the problem of address space depletion is addressed by IPv6, its widespread deployment is lagging behind. Enhancing the address space through IPv6 or any other suitable solution thus remains a problem to be solved in the long term.

As a very general tendency, one can observe that the solutions to those problems will move some intelligence back to the network, which is in favor of the operators to be able to handle traffic flexibly with respect to the varying application requirements. In general, the operator expectations for a future Internet target an innovation-friendly Internet that is service oriented rather than designed for host-to-host packet forwarding, to prepare for unknown upcoming applications.

For a *mobile operator*, the same problems apply for its IP core network. In particular, when changing the viewpoint from mainly fixed hosts to mobile hosts several challenges have to receive additional attention: Address management has to be able to cope with a rapidly increasing number of mobile terminals, each possibly equipped with several air interfaces of different QoS characteristics. Furthermore, the heterogeneity of device capabilities and wireless access links needs to be considered in the network design.

Among the research undertaken to reconsider the Internet design, two directions can be observed. The clean slate approach tries to come up with a new Internet architecture from scratch, whereas the evolutionary approach builds on step by step improvements, starting from the existing design. Both should not be regarded as exclusive but rather complement each other. With overlays and virtualization, we describe tools for the implementation of solutions for both approaches.

The remainder of this article is structured as follows. First, we highlight selected mobile operator related solution concepts to deal with the above requirements. In Section 3 and Section 4, we describe mechanisms such as overlays, virtualization and cross-layer design as tools to implement solutions in the core network and in the wireless access network, respectively. Service platform related aspects of a next generation Internet are discussed in Section 5.

2 Selected Future Internet Concepts

Of the general architectural problems of the Internet discussed above, some are more relevant to mobile operators than others. To use IP as a basis for future operator networks, specifically the aspects of device mobility and multi-homing (or the use of multiple radio interfaces for different wireless networks on the same device) need to be solved. Also, addressing is an important issue, in particular if the increase in the number of devices connected to an operator network continues to increase. However, as long as device mobility or the use of multiple radio interfaces are confined to the network(s) of a single mobile operator, it is possible to deploy solutions without coordinating with other operators, thus significantly simplifying deployment hurdles compared to Internet ISPs.

On the other hand, mobile operators have to deal with much higher degrees of network dynamics at the edges of the networks. Mobility solutions in the Internet, such as Mobile IP, have never been widely adopted, mainly because the most widely used applications like web browsing and e-mail do not require a static address. Better mobility support is a central element of future Internet research, but its realization in production networks will depend on the emergence of applications that require it, such as VoIP.

A major criticism of the current Internet architecture is the overloading of IP addresses to serve the function of node locator and identifier. The hierarchical address space of IP is instrumental for the scalability of the Internet since it allows aggregation of routing table information. However, it also identifies nodes as being part of a specific network, which hinders node mobility between networks and multi-homing.

Proposals such as [8; 9] break up this double role and use IP addresses only for routing purposes (if at all). Mapping between locator and identifier space requires a lookup service similar to DNS. The problems of multi-homing and mobility are thus relegated to the lookup service which has to be performant enough to support frequent changes of the identifier to address resolution entries. Some recent work takes the concept of a flat identifier space one step further by proposing a routing protocol that does not require any location information embedded in addresses, but is based only on identifiers [6]. The routing mechanism is based on ideas borrowed from structured Peer-to-Peer architectures (Section 3). This obviates the need for a separate lookup service which increases the overall robustness of the network. However, as the authors themselves state, their work can only be seen as a very first step to expand the design space for future routing protocols. The performance and scalability compared to traditional Internet routing protocols make the proposed initial approach unsuitable for deployment in large scale inter-networks.

Proposals for a separate flat identifier space are often combined with a public/private key infrastructure to enable the authentication of the sender of a packet. For example, HIP [8] allows a receiver to start an authenticated Diffie-Hellman exchange before accepting a connection and establishing state information. With this, initiating distributed denial of service attacks becomes more difficult.

3 Core Network: Overlays and Virtualization

As pointed out in the introduction, a general objective of the future Internet is its flexibility to adapt to changing requirements. This is in particular true for the IP core network, which suffers most from the strict Internet design that prevents solutions to the above problems. Therefore, overlay networks have been applied successfully to overcome some deficiencies on the application layer. Most prominent are overlays for multicast applications such as the mbone, content distribution networks such as Akamai, application layer virtual private networks, and Peer-to-Peer (P2P) overlay networks.

Distributed overlay networks such as P2P-based information lookup and delivery networks are very attractive as they can be deployed easily, without requiring any change of the underlying infrastructure. Moreover, they are very flexible in terms of supported applications, including diverse applications such as content sharing, streaming, and voice over IP. It should be noted that overlay concepts and in particular P2P overlay concepts are originally only end system based and not core network concepts. However, these concepts have an impact on the design of future core networks with respect to their advantages regarding ease of deployment, distribution, self organization, and thus cost efficiency.

For practical operations, however, it is a huge disadvantage of overlay networks, that they usually lack any management function to monitor or control their operation to achieve certain requirements such as cost optimality, quality of service, etc. Further, heterogeneity as a requirement of a mobile Internet is not supported sufficiently in current approaches. We briefly look into these requirements in more detail.

As an illustration, [3] describes an analytical framework for distributed management of P2P overlays with respect to cost optimality according to the total number of messages exchanged as a measure of traffic load. It is based on the concept of a hierarchical distributed hash table (DHT), consisting of high capability superpeers forming a DHT structure and leaf nodes (e. g., mobile phones) (Fig. 1). Such an architecture is well suited to support mobile communication systems. Cost optimality can be achieved by tuning the number of superpeers in the overlay network. As illustrated in Fig. 2, the total network traffic increases monotonously with the ratio of superpeers due to higher maintenance traffic. At the same time we have to prevent overloaded superpeers from causing system failures. Dynamically adjusting the superpeer ratio relying only on the partial view of the network at a single peer allows managing the overlay in a distributed way.

Overlay networking concepts provide a simple and efficient way to enhance the functionality of the underlying network, but they cannot be used to address all of the

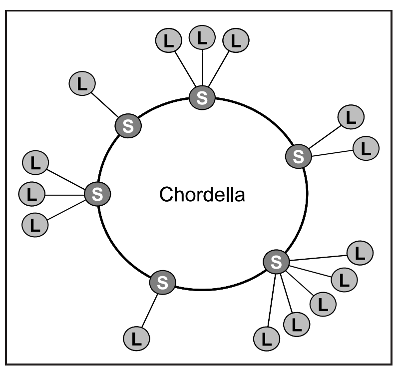

Figure 1 Hierarchical P2P overlay network Chordella [3].

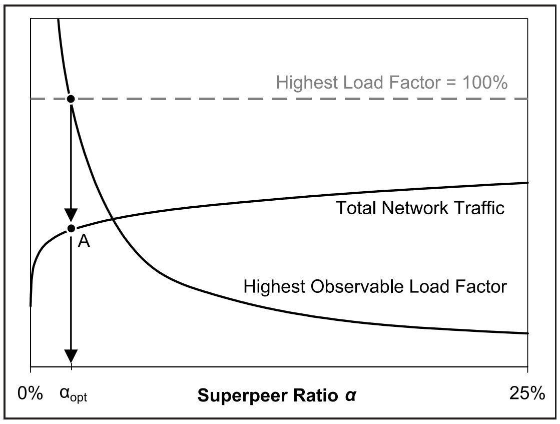

Figure 2 Overlay network cost optimization: determining the optimum superpeer ratio as a function of the trade-off between minimizing total network traffic and individual superpeer load (highest observable load factor).

aforementioned problems. For example, an overlay can attempt to work around parts of the Internet suffering from a denial of service attack, but it cannot prevent or mitigate such attacks on the underlay. At the same time, proposals to solve such problems directly by changing the network architecture were not deployed by operators in production networks, often due to the lack of a financial incentive to do so or the requirement for coordinated simultaneous deployment everywhere in the Internet. Network virtualization may provide a path out of this stalemate [10]. Virtualization of processing and storage resources is already widely used, and the flexibility it provides is highly useful, e. g., for the operation of data centers and server farms. It has also been applied to networking in the form of virtual private networks (VPNs), but these are usually confined to a single ISP and do not offer resource guarantees.

Network virtualization brings this concept one step further by allowing for isolation of network resources on all layers of the protocol stack. The virtual network created by the interconnection of virtual routers through virtual links is called a slice. Slices can be used to facilitate experimentation with different future Internet architectures [11], but it may even be that no single future Internet architecture will emerge, and different new architectures are permanently run side-by-side (along with the current Internet architecture).

Network infrastructure providers may thus give much greater flexibility to service providers for the creation of services that are not possible with today's Internet architecture [12]. For this vision to become true, it is necessary to develop tools and business models for the interconnection of slices of different operators to provide end-to-end connectivity with specific resource guarantees and network characteristics.

As an example, virtualization can be used for a more radical implementation of overlay networks. The latter constitute their own part of the solution space for a future Internet design, but they can also be considered as a seed for new, more radical designs. Here virtualization would be the mechanism to allow overlay network techniques to be implemented in lower layer protocols for higher efficiency. Similar considerations hold for other technologies such as network coding [13] or content based routing [14].

The flexibility offered by network virtualization is also of particular interest to a mobile operator, where the mobility of terminals creates high (but partially predictable) fluctuations in traffic demand over time and space. Relocation of virtual resources can be used to reduce the required physical resources, e. g., by powering off equipment when it is not needed [15].

Network virtualization may be combined with virtualization of storage and processing resources which is very appealing, for example, for the design of efficient content distribution networks.

4 Access Networks

In contrast to the urgent requirements for new architectures for the future Internet, wireless access networks have seen a steady evolution of existing technologies and emergence of new wireless standards, mainly to support higher data rates. In addition to well established wireless access technologies, WiMAX may play a significant role to fill the gap between cellular networks and Wireless LAN in terms of coverage and supported data rates. An important trend is the integration of many of these wireless technologies in a single mobile device. This has implications on future Internet architectures to support the multitude of heterogeneous wireless technologies that are emerging. It also requires decision mechanisms which of these technologies to use alternately or concurrently, depending on the current situation. For example, to conserve cellular resources, parts of the content may be streamed to some device of a cluster, and devices use local communication inside the cluster to exchange information until all users have all the content they are interested in [16].

In addition to technologies for global connectivity, local communication standards and systems demand their integration to the mobile Internet: Bluetooth, UWB, Near Field Communication, ad hoc networking, sensor networks, femto cells, as well as special purpose networks such as DVB, MediaFlow, etc. Here, the use of software defined radios is a promising technology to avoid the problem of integration of many different radio transceivers on a device [17]. With the integration

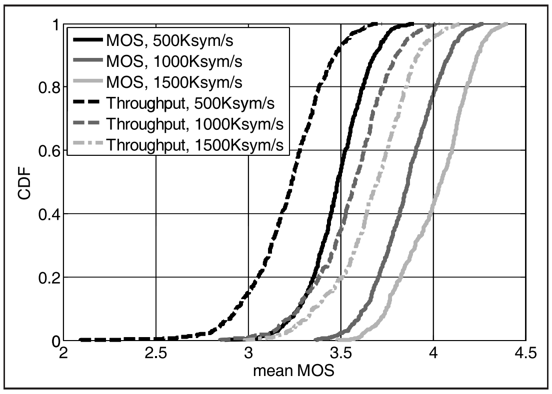

Figure 3 Typical simulation result for a cross-layer optimized transmission system (MOS) compared with a conventional throughput optimized system (Throughput) with three application classes (voice, video, ftp) for different symbol rates.

of local or personal area networks, mobile phones are no longer constrained to serve only for personal communications, but are used as a hub for information gathering and dissemination. As such, mobile phones can play the role of gateways between local networks and the global network.

Access networks are usually under the control of one operator who can implement proprietary solutions to overcome Internet deficiencies. One example is Wireless TCP employing a dedicated proxy where TCP is split running a modified protocol over the wireless link [7].

Further future Internet requirements for access networks include support for user perceived quality of service, which demands for a better awareness of the diverse application characteristics by the wireless resource management. Cross-Layer Optimization [4] is one approach to jointly optimize upper and lower network layers. Figure 3 illustrates that gains of up to 1 on the scale of the subjective measure of Mean Opinion Score (1 = dissatisfied; 4.5 = excellent) can be achieved for a joint optimization of voice, video, and ftp users in one cell. As the user perceived quality (expressed in MOS) of each transmitted application has a different sensitivity to changes of parameters, a resource or quality optimized parameter setting can be determined when knowing the application model, and signaled to the respective layers.

It has to be carefully considered to what extent the existing layering should be broken up or if cross-layer information exchange as in the above example is enough to realize full application awareness in a future Internet design.

5 Service Platforms

Traditional telecommunication systems have focused on rather closed, service specific networks in order to ensure the right service performance. One of the main advantages of the Internet from a service perspective is that it constitutes an open service platform where everybody can contribute service offers. A future Internet is expected to foster this evolution of service provisioning by shaping itself as a service integrating network, intelligently orchestrating service offers from a multitude of providers on an open platform.

Currently we are experiencing a migration from traditional client server service provisioning towards interactive web services that allow for community building and for satisfying societal needs. A central role in this fast changing environment is played by a new user behavior. The uptake of community based service scenarios and information sharing in, for example, a P2P environment shows that the user is changing from a service consumer to an active service and content provider. User's self advertising such as life logging and the desire for information sharing will become a strong promoter of this new trend.

Moreover, services that have a large impact on the society as a whole, for example, in electronic health care, force us to rethink traditional Internet service provisioning, adding specific requirements regarding privacy, security, and reliability – requirements which the Internet of the past, as it has been pointed out, fell short to provide.

The future mobile Internet will have to support new methodologies for discovering services and information, in particular when the new service world allows for a unification of information services with real world objects through the "Internet of Things".

The Next Generation Network concept and in particular the IP Multimedia System are possible enablers for such an open service platform. From an operator's point of view, they bring more intelligence to the Internet-based network, to allow for an easy service deployment by the operators. These platforms are expected to be integrated into a wider range of service platforms in the Internet, bringing the operator into the position of a service orchestrator rather than providing all services by itself.

With the emergence of all-IP packet-based networks and service platforms such as IMS, the telecommunications world has finally turned away from service specific networks to an integrated services network. However, this comes at the cost of less tight integration of services and higher overhead of managing services and ensuring their performance. It is the strong belief of the authors that a cleverly managed Future Mobile Internet, where different service specific protocol stacks may run in parallel in different slices of a virtualized network, will be able to combine the advantages of service specific and integrated services networks and thus prevail over the shortcomings of today's Internet design.

6 Summary

In order to overcome deficiencies of the current Internet architecture a fundamental reconsideration of its design is discussed in academia and industry. Based on a general summary of the requirements of a future Internet design, this article highlights solutions and mechanisms for their implementation from a mobile operator point of view. In particular, we have discussed address and mobility management concepts. For the implementation of such concepts, overlay networks as well as network virtualization are considered as viable tools. Their application is discussed along examples such as a managed hierarchical overlay network. Whereas wireless access networks themselves are rather closed systems where changes could be applied independently, the integration of multiple emerging wireless access standards such as WiMAX and WLAN with the cellular dominated mobile communication systems is a major challenge for the future Internet. With the dominance of Internet technologies in communication networks, packet-based service platforms have emerged. A major challenge for the future is to open these platforms to integrate services from a multitude of providers.

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1 Dr. Wolfgang Kellerer is Senior Manager of the Ubiquitous Networking Research Group at NTT DOCOMO's European Research Laboratories in Munich, Germany. He holds a MS degree and PhD from Technische Universität München. His research interests include service platforms, P2P overlay networks, multimedia networking, and cross-layer design.
Address: see below, E-Mail: kellerer@ieee.org

2 Dr. Jörg Widmer is Project Manager of the Ubiquitous Networking Research Group at NTT DOCOMO's European Research Laboratories in Munich, Germany. He holds a MS degree and PhD from Universität Mannheim. His research is concerned with MAC layer design, network coding, and algorithms for wireless multi-hop networks.
Address: see below,
E-Mail: widmer@acm.org

3 Dr. Hendrik Berndt is Chief Technology Officer and Senior Vice President at NTT DOCOMO's European Research Laboratories in Munich, Germany. He also serves as Visiting Professor at the GITI of the Waseda University, Tokyo. His research interests include next generation mobile systems, service provisioning, and Future Internet design.
Address: DOCOMO Communications Laboratories Europe GmbH, Landsberger Str. 312, 80687 München, Germany,
E-Mail: berndt@docomolab-euro.com