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4WARD: A European Perspective towards the Future Internet

Marcus BRUNNER[†a)], **Henrik ABRAMOWICZ**[††], **Norbert NIEBERT**[†††], *and* **Luis M. CORREIA**[††††], ***Nonmembers***

SUMMARY In this paper, we describe several approaches to address the challenges of the network of the future. Our main hypothesis is that the Future Internet must be designed for the environment of applications and transport media of the 21st century, vastly different from the initial Internet's life space. One major requirement is the inherent support for mobile and wireless usage. A Future Internet should allow for the fast creation of diverse network designs and paradigms and must also support their coexistence at run-time. We detail the technical and business scenarios that lead the development in the EU FP7 4WARD project towards a framework for the Future Internet.

key words: *future Internet, network architecture, virtualization, self-management, information-centric networking*

1. Introduction

Driven by the encouragement for new approaches from some of the "fathers of the Internet" (e.g. [1], [2]), the discussion on the "Network of the Future" is gaining in intensity due to increasing concerns about the inability of the current Internet to address a number of important issues affecting present and future services and to the impetus provided by "clean slate design" research initiatives launched in the US, Europe and Asia. Many problems with the current network architecture have been recognized for a long time but have not received a satisfactory solution (see e.g. [1], [3]). The issues like security, manageability, dependability, mobility, etc. result both from initial design flaws as well as the wide set of applications over the Internet that could not be envisioned from the beginning. In this paper, we present the approach taken within the 4WARD project (www.4ward-project.eu, [7]) to address these problems by researching different aspects of the Future Internet design.

2. Motivation and Scenarios

The Internet was initially developed for a limited number of trusted nodes interconnected by copper based transmission technology implemented supporting applications like file transfer and message exchange. The initial architecture developed for this purpose was essentially simple but open for new applications. Its evolution has led to a tremendous success — the Internet as we know it today. It is however far from clear that it is still the optimally evolvable solution, able to meet the challenges of fibre optics and radio transmission technology, real-time multimedia and file-sharing applications and exposure to an untrustworthy world. Furthermore the Internet, starting as a simple set of protocols and rules, has over the decades reached a state of high complexity with regard to interoperability, routing, configuration and management.

Within the research community the need for change is largely acknowledged although there is not yet agreement on how this change should take place. Some propose a clean slate approach, which aims at investigating new architectural concepts with new requirements in mind and which initially doesn't need to consider legacy, while others are advocating an evolutionary approach, introducing new solutions incrementally. It seems likely that both approaches will migrate the current Internet technologies towards a Future Internet.

The identification of key drivers is one of the most difficult prerequisites in the development of the Future Internet. By analyzing the key driving forces and challenges in the Future Internet business environment, the 4WARD scenarios were built. These scenarios cover aspects of technical as well as non-technical areas. The general frame for the scenarios can be summarized as follows: 4WARD addresses the worldwide potential telecommunication market in 2020, maintaining an end-to-end view with respect to service, usage, business, and technology development.

Within this section four scenarios are described which focus on different aspects of the possible future evolution.

The scenario 1 "Looking back from 2020: What made the 'old' Internet break" outlines, which technical and non-technical developments will have been decisive for the understanding that the smooth evolution of the existing Internet concepts will no longer be applicable in the communication world. This includes the analysis of infrastructure problems, innovation restrictions, and the limitations in economic incentives.

The second scenario "Novel applications that are not possible with current Internet" identifies and evaluates from end user's view, which challenges will be posed from conceivable new applications to the Internet and how they overstrain the existing Internet concepts. This includes enablers for more user orientation, mobility support and augmen-

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[†]The author is with NEC Europe Ltd., Heidelberg, Germany.
[††]The authors is with Ericsson Research, Sweden.
[†††]The author is with Ericsson Research, Germany.
[††††]The author is with Institute of Telecommunication, Portugal.
a) E-mail: brunner@nw.neclab.eu
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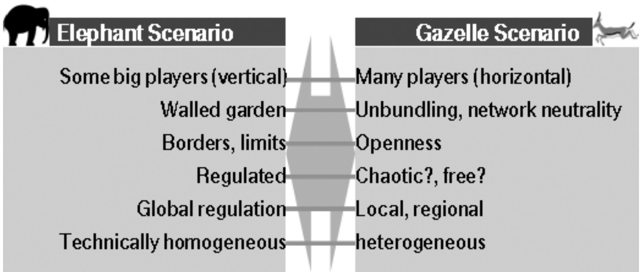

Fig. 1 Extreme Scenarios characterized by six drivers with uncertain development.

tations. Some examples are networks that fit perfectly to users' likes, dislikes, preferences, and so on, even if users temporarily use someone else's terminals. Sometimes they are possible only 'in principle', but wide-spread adoption is not possible due to complexity or scalability issues, lack of usable devices or other restrictions.

Scenario 3 "Managing the Future Internet — Benefits for operators" concentrates on network management issues which come up with the broadening of the traditional one-stop-shop operator to an environment with several partly competing, partly collaborating network operators and a multitude of service providers. Major themes covered are the blurring boundaries between operators and other players in a future Internet, the growing complexity of infrastructure and services and the associated need to find new ways of network/service management, the new capabilities provided to operators, based on innovative future Internet technologies.

The last scenario focuses on the non-technical aspects of the Future Internet. It evaluates the impact of social, economic and political trends on the telecom business to work out the most decisive elements which will govern the future business environment. The most important questions are:

- Will the Internet arena be dominated by a limited number of big players or is it more feasible that a multitude of specialized small companies will satisfy the increasing demand for individual services?
- Will centralisation (e.g. big server farms) or decentralisation (peer-to-peer networks) determine the direction of future developments?
- What will be the main inhibition of growth: regulative intervention, compatibility problems of technical solutions or a mismatch in market power?
- How can the global usage and accessibility of the Internet be assured under different market environments without global regulation?
- Will heterogeneity in technology accelerate or retard technical innovation?
- Is the coexistence of multiple heterogeneous platforms (may be operating on the same physical system but separated by virtualisation) a good alternative?

First answers on these questions have led to two opposite borders, i.e. "Elephant" and "Gazelle", Fig. 1.

3. Migration

A major issue will be the migration of the various approaches or the overall common architecture framework. Various approaches for migration exist including (1) incrementally enhancing the existing internet paradigm by adding extension to present protocols, there will be no fundamental change of Internet and the problems with the current Internet will remain. (2) Another approach is to make use of overlay or underlay techniques which have been used for many years in traditional telecom as well. (3) A third option would be making use of network virtualization techniques and by this separating the network into virtually independent "slices," operating several network architectures in parallel including the IP.

There is of course the possibility to deploy a completely new network in parallel with the current Internet. We do not believe that this is a viable commercial option.

4. Key Components for a Future Internet

4.1 Architecture Framework of a Future Internet

To enable innovation and rapid deployment of new networking solutions, the development of new architectures suitable for a specific environment (e.g. a LAN or a new type of radio access network or a specialised application), should be facilitated and the reuse of common components made possible. The 4WARD project develops a new architecture framework that must be able to accommodate changes in business and technology environments. Such agility is emerging in the software area with service oriented architectures and design patterns. 4WARD generalizes these approaches, and develops an architecture framework by which different network architectures, which are tailored for various purposes and environments, can be derived and implemented. The aim is to end up with lean and dedicated instantiations of network architectures that remain interoperable and evolvable.

The design of an architecture framework started with defining a set of invariants. They must generally concern the performance objectives, scalability, extensibility, as well as the consistency and coherency of communication systems throughout the lifetime of the architecture framework. Implicit invariants usually emerge by overloading functions intended for other purpose(s), making the adaptation/replacement of these functions impossible. Indeed, according to Ahlgren et al. [4], if invariants are not explicitly defined, the design will be deficient in the long term, despite its superficial flexibility. The properties and aspects that, for instance, a specific sensor network and a MAN, or any other network of the future, will have in common, still need to be identified and investigated. Through the architecture framework it should be possible to instantiate, e.g. a very light-weight network architecture suitable for low-energy networks, with a very limited set of features implemented. Similarly, one should be able to instantiate a network architecture suitable for a MAN, for example, with built-in features such as security, privacy, QoS, and mobility.

One concept of such an architecture is the “Generic Path,” which abstracts away from the implementation of a communication path through the network, but allows a generic use of such a construct at application to network interface for the easy creation of application communication. Only later in the instantiation in certain network architectures, that “empty” hull will be filled with the required functionality depending on the environment and operational policies.

Because cross-layer information is available, new transmission techniques can be used inside a “Generic Path.” This is especially interesting for the introduction of network coding into fixed and wireless networks. Here, multipath routing needs to be combined with specific capabilities of nodes (e.g., bit-wise XOR of two frames).

Reconciling such diverse aspects as discussed above will be a challenge. Thus, explicit invariants, principles, properties, and design patterns shall be carefully designed into the architecture framework. They are, by definition, the specific characteristics that determine the options as well as limitations for how network architectures can develop and evolve over time.

4.2 Towards Networking of Information

The traditional role of networking has been to interconnect remotely located devices like computers or telephones. This function is increasingly recognised to be ill-adapted and inadequate for the information-centric applications that currently generate the vast majority of Internet traffic.

The 4WARD Networking of Information (NetInf) takes a different approach. Instead of the traditional node-centric paradigm, we adopt an information-centric paradigm. In this paradigm, the communication abstraction presented to applications is based on the transfer of application data objects instead of end-to-end reliable byte-streams as used today.

The current semantic overload of the IP-address as both node identifier and locator (e.g. [5], [6]), indicating the current point of attachment in the network topology, is replaced by a clear separation of information self-certifying object identifiers and locators. 4WARD designs a networking architecture where mobility, multi-homing and security are an intrinsic part of the network architecture rather than add-on solutions. It also allows users to gain increased control over incoming traffic enabling new possibilities for defending against denial of service attacks. The self-securing property also intrinsically facilitates possibilities for effective content protection and access rights management.

The increasing number of overlays created for the purpose of information dissemination (e.g., Akamai CDN, BitTorrent, and Joost) clearly shows the need for an information-centric approach. These overlays massively distribute information and move the load away from any central server, scaling automatically to any group size. 4WARD integrates much of the functionality of these overlays, including caching. This is done in a common and open information networking service that integrates networking and storage and is generalised for use by applications.

4WARD extends the networking of information concept beyond “traditional” information objects (e.g., web pages, music/movie files, streaming media) to conversational services like telephony, and store-and-forward services like email. Special attention is paid to how services can be made to work in an environment with a heterogeneous and disruptive communication infrastructure. Furthermore, we investigate how networking of information can extend to include real world objects, and by this enabling new types of services.

4.3 Network Virtualization

To introduce clean slate solutions like information-centric networking and novel on the fly created network architecture instances, we have to allow them to coexist with existing and other new approaches. Virtual networks can enable new protocols and architectures to be deployed independently without disruptions. Virtualization has been used in test-bed environments and is now being proposed as the basis of commercial networks. Virtual networks are ideally suited to allow the coexistence of different network architectures, legacy systems included. Virtualization is thus not only the enabler for the coexistence of multiple architectures, but it is also a smooth path for the migration towards evolutionary approaches. The goal of 4WARD is to develop a systematic and general approach to network virtualization. The virtualization of individual resources is the basis of the framework as depicted in Fig. 2.

While the virtualization of many types of resources, such as servers and links, is well-known and already widely used today, we aim for a generalized approach that allows the use of a broad diversity of resources with higher flexibility and security. Virtualization of both wireless and wireline resources is expected to play a key role in the Future Internet. In particular, the secure, flexible, and efficient exploitation of wireless spectrum resources and wireless infrastructure is expected to significantly improve cost-effectiveness and utilization of expensive wireless infrastructures.

Virtualization allows an evolution of communication technology while largely reusing deployed infrastructure; thereby it reduces the economic barrier for technical evolution. It further provides a general framework for network sharing: providing different networking services of different network service providers on a common physical infrastructure. This is particularly beneficial in network domains where the deployment costs per network user are predominant and an obstacle for frequent technology replacement.

Furthermore, virtualization may significantly change the business environment for infrastructure owners and operators’ business models and incentives for use in a commercial setting need to be carefully considered.

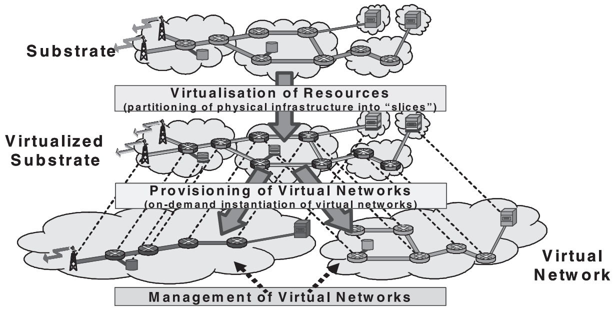

Fig. 2 Virtualization framework.

4.4 In-Network Management: A New Network Management Paradigm

The diversity of technologies and business models envisioned in previous sections can only be supported in operative networks if adequate management functions are integrated to initiate and maintain the network infrastructure. Management capabilities in current networks typically reside outside the network. Research has focused on solutions for self-management but so far these are mainly algorithms solving specific problems. Most of these solutions lack scalability imply considerable integration costs with central management stations and — most important — are not suitable to cope with the complexity and dynamicity of tomorrow's networks.

In order to address these issues, the 4WARD project follows a new paradigm to network management. The basic concept of the new paradigm that is called In-Network Management is (1) to have network management functions as embedded 'default on' management capabilities of network devices and (2) to allow these devices to interact in a peer-to-peer fashion to enable network-wide management functions. We envision management functions as inseparable capabilities of the device and the network itself. This leads to a novel, strongly decentralized architecture where management operations are localized in the network components. As a consequence, faults can be identified more quickly and isolated using cross-layer techniques, and control loops can be enforced more efficiently than in traditional management architectures. Benefits from this approach are to access embedded functions to cope with diverse technologies, different business models and the rich mix of services instead of adding complex management systems into the networks. We believe that In-Network Management is particularly beneficial in large-scale, dynamic network environments.

The new embedded management functions are accessed through a management plane inside the network that organizes itself and automatically adjusts to different network sizes and configurations. It executes a set of distributed, self-stabilizing protocols for monitoring and control, enabling a range of self-management functions inside the network. This is accomplished first of all through the definition of models of interactions between network components and the inclusion of self-organizing algorithms inside network devices. Secondly, the behavior and objectives of the network as a whole is modeled. This includes outer control loops between different components and operators' interfaces to support network-wide processes, including monitoring of aggregated states and policy enforcement.

5. Conclusion

Considerable research effort is clearly necessary to address the challenges raised by the design of a Network of the Future. This effort is currently underway with many Future Internet activities across the world. The main thrusts of 4WARD, a new architectural design including the information-centric paradigm, network virtualization, and embedded in-network self-management, provide candidate solutions, which, after careful evaluation, should be appropriately incorporated into the architecture.

References

[1] D. Clark, K. Sollins, J. Wroclawski, and R. Braden, "Tussle in cyberspace: Defining tomorrow's Internet," Proc. ACM SIGCOMM, Pittsburgh, USA, Aug. 2002.
[2] V. Jacobson, M. Mosko, D. Smetters, J.J. Garcia-Luna-Aceves, "Content-centric networking," Whitepaper Describing Future Assurable Global Networks, 2007.
[3] R. Tafazolli, ed. Technologies for the Wireless Future: Wireless World Research Forum (WWRF), vol.2, Wiley, 2006.
[4] B. Ahlgren, M. Brunner, L. Eggert, R. Hancock, and S. Schmid, "Invariants — A new design methodology for network architectures," SIGCOMM Workshop on Future Directions in Network Architecture (FDNA'04), Portland, USA, 2004.
[5] B. Ahlgren, J. Arkko, L. Eggert, and J. Rajahalme, "A node identity internetworking architecture," 9th IEEE Global Internet Symposium, Barcelona, Spain, April 2006.
[6] I. Stoica, D. Atkins, S. Zhuang, S. Shenker, and S. Surana, "Internet indirection infrastructure," Proc. ACM SIGCOMM 2002, Pittsburg, USA, April 2002.
[7] 4WARD Public Deliverable, http://www.4ward-project.eu