The Way 4WARD to the Creation of a Future Internet

(Invited Paper)

Norbert Niebert¹, Stephan Baucke¹, Ibtissam El-Khayat¹, Martin Johnsson², Börje Ohlman², Henrik Abramowicz², Klaus Wueestl³, Hagen Woesner⁴, Jürgen Quittek⁵, Luis M. Correia⁶

¹Ericsson Research, Corporate Unit, Ericsson GmbH, Ericsson Allee 1, D-52134 Herzogenrath, Germany  
²Ericsson Research, Corporate Unit, Ericsson AB, 164 80 Stockholm, Sweden  
³Alcatel-Lucent, Bell Labs, Lorenzstr.10, D-70435 Stuttgart, Germany  
⁴Telecommunication Networks Group (TKN), TU Berlin, Einsteinufer 25, D-10587 Berlin, Germany  
⁵NEC Laboratories Europe, Kurfürsten-Anlage 36, D-69115, Heidelberg, Germany  
⁶IST/IT – Technical University of Lisbon, Av. Rovisco Pais, P-1049-001 Lisbon, Portugal

Abstract — In this paper, we describe the approaches taken in the 4WARD project to address the challenges of the network of the future. Our main hypothesis is that the Future Internet must allow for the fast creation of diverse network designs and paradigms, and must also support their co-existence at run-time. We observe that a pure evolutionary path from the current Internet design will not be able to address, in a satisfactory manner, major issues like the handling of mobile users, information access and delivery, wide area sensor network applications, high management complexity, and malicious traffic that hamper network performance already today. Moreover, the Internet’s focus on interconnecting hosts and delivering bits has to be replaced by a more holistic vision of a network of information and content. This is a natural evolution of scope requiring nonetheless a re-design of the architecture. We describe how 4WARD directs research on network virtualisation, novel InNetworkManagement, a generic path concept, and an information-centric approach, into a single framework for a diversified, but interoperable, network of the future.

Keywords - Future Internet, Network Architecture, Network Virtualisation, Self-Management, Information-centric Networking.

I. INTRODUCTION

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 recognised for a long time, but have not received a satisfactory solution (see, e.g., [1], [2], [3]). Issues like security, manageability, dependability, mobility, etc., result from both 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 [4] to address these problems by researching different aspects of the Future Internet design.

In section 2, we first discuss societal and business forces that must guide our technical choices. Section 3 introduces our ideas on how to arrive at a suitable and flexible architecture framework for the new network. A major reason for rethinking the architecture is the need to shift from the current paradigm of interconnecting nodes to a future paradigm of interconnecting information objects themselves. This new paradigm is discussed in Section 4, while Section 5 outlines the planned research on new approaches to forwarding and multiplexing the information flows. Section 6 introduces a virtualisation framework, which allows new approaches to coexist temporarily or permanently with existing or alternative solutions. Finally, Section 7 presents a novel management approach for the Network of the Future, largely relying on self-management techniques.

II. MOTIVATION AND BUSINESS PERSPECTIVE

The Internet was initially developed for a world in which a limited number of trusted nodes interconnected by copper based transmission technology implemented distributed applications, mostly some kind of 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 dominating 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, 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 redesigning the Internet from the ground up with the new requirements in mind, while others are advocating an evolutionary approach, introducing new solutions incrementally. It seems likely that both approaches will exist in parallel, and even have to coexist over a longer transition time.

Far-reaching technological innovations, like those of 4WARD, can only be successfully deployed if their non-technical issues and business potential are taken into account.
Any new technology, no matter how excellent, can only succeed in the market if it satisfies, in a sustainable way, the needs of current or potential future users. Therefore, one of the non-technical areas covered in 4WARD emphasises usage and services. Therein, priority is given to the investigation of how the users (human or machines) will benefit from the technology advances of 4WARD.

A further aspect is the overall socio-economic context, which can significantly boost or hamper the success of an innovation – issues include the "degree of mobility" in the lifestyle, the balance of "privacy vs. sharing", the need for security, the importance ascribed to health, the distribution of wealth, etc.. The impact of new technologies on various segments of society, such as the young or the elderly, has to be appraised with the aim of maximising benefits for the users.

Traditionally, the field of telecommunications is strictly regulated, as opposed to the Internet. When Internet and telecommunications merge towards the Networks of the Future the required minimum set of regulatory constraints must be defined (issues like privacy, dependability, neutrality etc.). To address these questions, the third focus area of 4WARD covers policy and governance. This work also includes a view on governance of the network itself, which is especially prominent today with regard to address assignment and network neutrality. All these non-technical driving forces, combined with the technological advances, will have a major impact on future commercial success [5]. We start by taking these major driving forces into account, and by analysing the business models and value chains of today’s ICT players. We will then evaluate alternative business models, to try to predict future developments. By moving away from local, regional and national solutions towards global businesses, 4WARD’s technology will enable new players to enter future global market segments of society, such as the young or the elderly, has to be appraised with the aim of maximising benefits for the users.

A key enabler for the support of network and technology heterogeneity is to facilitate the definition and design of a new network architecture suitable for a specific environment (e.g., a LAN, or a new type of radio access network, or a specialised application). The development of new architectures should be facilitated, and the reuse of common components made possible, since both are critical for enabling innovation and rapid deployment of new solutions. We intend to develop 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. They have been tested in customised application protocols (e.g., [6], [7]), and have performed well. We plan to extend and generalise these approaches, and develop 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 efficiency in reuse is definitely important, even if it could be argued that the problem can be overcome without an architecture framework. Keeping in mind the overall need to support interoperability as a key major driver for such a framework, the reuse aspects should also be reflected and supported. The interoperability that has been solved naturally by IP becomes a concern without the universal presence of design principles. Without such principles, in the long, it will run hard to interconnect and to interoperate the resulting networks. The design principles need to express aspects and properties that pertain to naming, addressing, routing, QoS, (self-)management, security, as well as overall performance objectives. Given the coexistence of heterogeneous network environments and different (and still unknown) technologies, it is very important to carefully analyse gatewaying principles for interconnecting networks having implemented different network architectures. It is likely that a modular and scalable approach to gatewaying should be considered.

The design of an architecture framework starts with defining common requirements as well as 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. Such a set needs to be explicitly defined to strengthen the architecture. 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. [8], if invariants are not explicitly defined, the design will be deficient in the long term, despite its superficial flexibility. The properties and aspects that different networks will have in common still need to be identified and investigated. Through the architecture framework, it should be possible to instantiate, for instance, 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.

Reconciling such diverse aspects will be a challenge. Thus, explicit invariants, principles, properties, and design patterns shall be carefully designed into the architecture framework ([9]). 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.

IV. MOVING FROM NETWORKING OF NODES TO 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.

In 4WARD, we take a different approach. Instead of the node-centric paradigm, we adopt an information-centric one. In this paradigm, the communication abstraction presented to
applications is based on transfer of application data objects instead of the end-to-end reliable byte-stream used by the majority of applications today, Figure 1.

![Figure 1. Networking of Information.](https://example.com/figure1)

The current semantic overload of the IP-address as both node identifier and locator, indicating the current point of attachment in the network topology, is replaced by a clear separation of information self-certifying object identifiers and locators. Several models for abstracting the location and focusing on networking between (mobile) hosts have been proposed, e.g., the Host Identity Protocol (HIP) [10], the Internet Indirection Infrastructure (I3) [11] and [12], the Layered Naming Architecture [13] and the NodeID proposal [14]. 4WARD will build on this prior work, and by taking it one step further, we will be able to design a networking architecture where mobility, multithoming, and security is an intrinsic part of the network architecture rather than add-on solutions. It will also allow users to gain increased control over incoming traffic enabling new possibilities for defending against denial of service attacks. The self-securing property also facilitates, intrinsically, possibilities for effective content protection and access rights management.

The need for information-centric networking is manifested by the increasing number of overlays that are created for the purpose of information dissemination (e.g., Akamai CDN, BitTorrent, Skype, and Joost). Their objective is to distribute information by relying on users to exchange pieces of data between themselves, massively distributing the load away from any central server, and scaling automatically to any group size. 4WARD will integrate much of the functionality of these overlays, including caching functions where the ‘copies’ are treated as the originals. This will be done in a common and open information networking service 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 will be paid to how this affects wireless communication, and to how services can be made to work in an environment with a heterogeneous and disruptive communication infrastructure. Furthermore, we will investigate how networking of information can extend to include real world objects, and by this enabling new types of services.

V. NETWORKING ACROSS MULTIPLE PATHS AND LAYERS WITH THE GENERIC PATH

Networks have the task of delivering information between sources and sinks, which typically do not have a direct physical connection and are dependent on other nodes acting as relays. The sequence of relaying nodes is called a path. The construction of a path in the current Internet takes place on multiple layers. In fact, a port of an IP router in the backbone will, today, typically, be connected to an SDH or Ethernet layer, which then works on top of an optical layer. GMPLS has been introduced as control plane for multi-layer networks ([15] and [16]). Here, for the first time, the otherwise lower-layer agnostic IP routers may perceive the notion of a changeable topology, leading away from pure overlay networks with separate control to an integrated and possibly distributed management of data transport.

The valuable features of GMPLS, together with forwarding and multiplexing mechanisms that realise quality transport at higher layers, must be systematically incorporated in the future Internet. Our approach is to define the notion of a “Generic Path”, able to efficiently realise "networking of information" by exploiting cross-layer optimisation and multiple network paths.

We define a Generic Path (GP) as “means to organise the accessibility of a sufficient number of parts or copies of information objects stored in a group of hosts".

Incorporating the paradigm of information-centric networks means that a GP is actually hiding the physical location of information objects. It does not matter where chunks or copies of information are stored, but the GP takes care of delivering it to a sink.

Because cross-layer information is available, new transmission techniques can be used inside a GP. This is especially interesting for the introduction of network coding into fixed and wireless networks. Here, multipath routing, Figure 2, needs to be combined with specific capabilities of nodes (e.g., bit-wise XOR of two frames) [17].

![Figure 2. The Generic Path as a hull organising data transport over multiple paths and layers.](https://example.com/figure2)

Generic Paths can thus be seen as a “hull” that is filled with information. One advantage of this concept is that mobility of
information objects and hosts becomes conceptually equivalent and is dealt with by the GP internally.

There are a number of open questions that are addressed inside 4WARD to bring this concept to reality: routing and interaction of generic paths, the control plane for network coding, enhancement of mobility management, and, importantly, the definition of a generic path API that allows the instantiation of a GP similar to today’s sockets. The GP, thus, appears as the fundamental information channel in the future Internet that is sufficiently flexible to adapt to different requirements and available network technologies.

VI. TOWARDS LEAN AND INNOVATIVE NETWORKS THROUGH VIRTUALISATION

To introduce clean slate solutions, like information-centric networking and generic paths, 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. Virtualisation has been used in testbed environments, and is now being proposed as the basis of commercial networks. This approach is, for instance, also being investigated in the Cabo (Concurrent Architectures are Better than One) project [3] as the basis for an innovation-friendly and open architecture. Virtual networks are ideally suited to allow the coexistence of different network architectures, legacy systems included. Virtualisation 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 is hence to develop a systematic and general approach to network virtualisation.

The virtualisation of individual resources is the basis of the framework as depicted in Figure 3. While the virtualisation of many types of resources, such as servers and links, is well-known and already widely used today, we aim for a generalised approach that allows the use of a broad diversity of resources with higher flexibility and security. Virtualisation 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 utilisation of expensive wireless infrastructures.

Virtualisation 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.

A key concern for owners of infrastructure resources and the operators of virtual networks using these resources will be security and trust. The virtualisation framework must ensure the protection of the physical resources, as well as the strict isolation of concurrent virtual networks from each other. Furthermore, virtualisation 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.

VII. INNETWORKMANAGEMENT: 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 we call InNetworkManagement 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. In other words: we envision management functions as inseparable capabilities of the device and the network itself. 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. Operators can benefit from this approach, because they will not need to integrate complex management systems into their networks, and they will access embedded functions to cope with diverse technologies, different business models, and the rich mix of services. We believe that InNetworkManagement will be particularly beneficial in large-scale, dynamic network environments.

The new embedded management functions will be accessed through a management plane inside the network that will self-organise and automatically adjust to different network sizes and configurations. It will execute a set of distributed, self-stabilising protocols for monitoring and control, enabling a range of self-management functions inside the network. This
will be accomplished first of all through the definition of models of interactions between network components and the inclusion of self-organising algorithms inside network devices. Secondly, the behaviour and objectives of the network as a whole will be studied and modelled.

The development of protocols for the management plane can draw on current research on the computability of distributed functions under cost constraints, sensor networks and probabilistic protocols for distributed systems ([19], [20]). However, application to network management calls for progress beyond this research, in order to take into account the particular constraints regarding operational overhead in the management plane, the richer functionality of management operations and the potentially large number of concurrently executing management functions. Therefore, a systematic analysis of network working conditions is required, in order to assess the effectiveness of management operations in different situations and scenarios. Such an analysis will identify the trade-offs for management operations, including protocol overhead, accuracy of monitored data, timeliness of self-healing actions and frequency of self-optimisation actions, which should become tuneable in real-time (e.g., [21]). In addition, mechanisms will be developed that provide control over the relationship between decision quality and the cost of achieving a specific level of situation awareness in the management plane.

VIII. CONCLUSIONS

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, the information-centric paradigm, the generic path network virtualisation, and embedded self-management, will provide candidate solutions, which, after careful evaluation, should be appropriately incorporated into the architecture of the Future Internet. A major issue will be the integration of the various approaches within a common architecture framework. Results of this work are expected over the coming years.

REFERENCES