The Euro-NF Vision for Future Networks and Contributions from the Specific Joint Projects

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I. Introduction

Users will consider the Networks of the Future (NF), often termed as the *Future Internet (FI)*, as a network of smart applications, services and content [1]. Predicting exactly the technologies and applications of the NF, however, is debatable. For example, the success of smartphones platforms has overwhelmed both, manufacturers [2] and operators [3]. Thus, the quest for providing a detailed vision for the FI is almost impossible. However, a vision that suits as a research guideline will be useful if this vision consists of a stable, long-term framework for researching network technologies and design methods and of an adaptive, short-term schedule, which allows for integrating recent achievements.

In this contribution, we outline first the long-term framework for research in the European FP7 Network-of-Excellence "Euro-NF" [4] (a more detailed decription of the Euro-NF vision can be found in [5]). Then, we detail recent advances from short-term Euro-NF "Specific Joint Research Projects" (SJRP) and "Specific Joint Development and Experimentation" (SJDE) projects in view of the vision. Hence, the "S" in "SJRP" stands also for the "strategic" nature of these projects. They should be perceived as small (even in funding) but striking visionary projects which might develop into full-scale projects which fit into the vision of future networks. Likewise, the SJDE represent strategic steps towards the use of new approaches in practice, i.e. for FI applications and services.

Future Network Use and Requirements

The main usage domains of future networks and their smart applications will be in the everyday life of people. Examples for such domains are health services, energy usage and distribution, environmental sensing or logistics [1].

Smart applications stand out through abilities of combining data, content, information and services in ways such that new relationships among data and services are exploited. Thus, they enable new benefits for the users and the society. Smart applications are characterized by:

- highly autonomous operation;
- use of very different types of data (e.g. from very low volume sensor data to interactive video streams with strict real-time requirements and very high data volumes);
- peer-to-peer or machine-to-machine communication which requires highly scalable mechanisms (billions of devices);
- use of application-specific networks with own topologies, naming, routing and resource management schemes;
- being holistic (e.g. addressing multiple stake-holders);
- use of very different transmission modes even in parallel (yet any mix of intermittent and delay tolerant, multi-hop, packet- and circuit-switched transmission);
- smart provider and connectivity selection (e.g. based on economic competition and ecological considerations);
- being agnostic to mobile or wired connections.

Moreover, smart applications have to fulfill long-time desired features, such as high reliability and user satisfaction.

II. A Systematic and Holistic Design for Smart Applications and the Future Internet

Smart networks and applications require a holistic engineering. This feature means that the design systematics have to comprise typical network research tasks (i.e. addressing networking hard- and software) as well as research tasks for targeting the needs of users and operators with their *socio-economical* requirements, e.g. personal benefits and experiences or business requirements (e.g. legal, economical, or ecological constraints).

The Euro-NF approach for facilitating smart applications and future networks aims at not only providing the foundations for the research on future networks, but also at the engineering of systems to become operable in real-worlds.

A. A New Separation of Concerns

In order to enable a new systematic and holistic design for future smart application, the Dijkstra's paradigm of the separation of concerns [6] might be re-applied to the design pattern and building blocks of future systems as well as to the design methodologies. We suggest that the usage and technology areas can be separated in three areas of concern, cf. the rows in Fig. 1:

- Future smart applications (see above);
- Future smart mediation techniques (e.g. former routing tasks, now enabling mediation for Publish/Subscribe techniques, delay-tolerant networking, application-specific topologies and resource management, etc.);
- Future smart connectivity techniques (e.g. convergence of optical and wireless transmission and energy efficiency).

The separation of design methodologies for future networks has also to be adapted for a holistic design. The separation might categorize the methods into, cf. the columns in Fig. 1:

- Design methods for networking architectures, e.g. which separation is appropriate (e.g. layering vs. heaps);

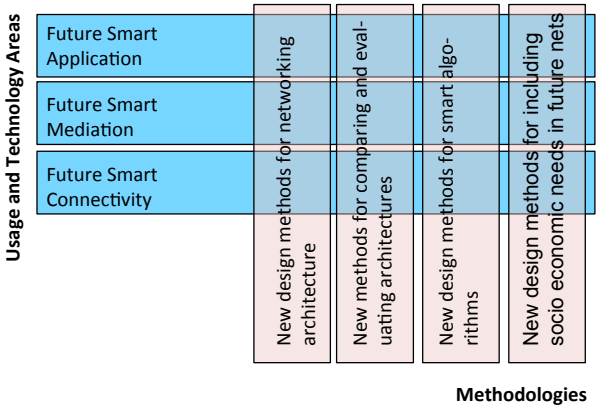

Fig. 1. A new separation of building blocks and design methods.

- Methods for comparing and evaluating architectures, e.g. new metrics for flexibility, adaptivity, expandability, quality of cooperation, quality of pricing, etc.;
- Design methods for smart algorithms (e.g. models for self-organization, smartness etc.);
- Design methods for including socio-economic needs in future networks, e.g. resource efficiency, business models greenness, security, governance or QoE.

B. Weaving a Technological and Methodological Fabric for the Future Internet and Smart Applications

The aim of future network design is to build a systematic network system that enables smart applications to become a commodity for people. We call this approach the *weaving of the technological fabric*. The metaphors of "weaving" and of a "fabric" can be transferred to establishing relationships of the above outlined new areas of concerns and the corresponding new separation of methods. The weaving of the fabric might be materialized by *enablers*, which are physical entities or mechanisms, but also intellectual methods or algorithms, or operational procedures. In particular, the concepts of how to achieve smart combinations of future technologies and methodologies are at the core of the Euro-NF vision.

III. Recent Contributions from SJRPs

Euro-NF Specific Joint Research Projects (SJRP) aim at improving knowledge in targeted topics considered of main importance, with a significant visionary and innovative potential and not sufficiently covered at present. They shall be sharply focused on disruptive ideas on the networks of the future and orient themselves along the Euro-NF vision. SJRPs shall be designed to explore the need for more research effort, anticipating scientific and technological needs that, for example, could motivate the proposal of FP7 projects in upcoming calls. Visionary, creative, ground-breaking, strategic and potentially controversial approaches and proposals are highly welcome. SJRPs shall anticipate tomorrows needs to research in the domain and explicitly combine technologies with methodologies. In particular, joint strategic publications should be targeted as outcome of the joint work and as ground for new fields of research.

So far, Euro-NF has issued four calls for SJRPs. 19 SJRPs have been executed, and five are currently in progress. The examples below show four examples, one from each call.

A. The ASPECTS Project

We witness growing interest in more efficient spectrum utilisation and availability of on-demand broadband wireless access to the NF through Cognitive Radio, which involves dynamic and opportunistic access to so-called agile spectrum. The "Agile Spectrum Security" (ASPECTS) project [7] identified security and privacy issues of agile spectrum access, as well as vulnerabilities against misuse and potential countermeasures. It further targeted a security and trust framework, enabling the detection and reporting of misbehaving nodes. As the underlying problems related to cooperative usage of the same physical resources are of similar nature, the ASPECTS results also extend into the direction of network virtualisation.

B. The EnergyOPAL Project

Research within the project "Energy OPtimal ALgorithms for mobile Internet: stochastic modeling, performance analysis and optimal control" (EnergyOPAL) [8] focused on algorithms which can enable an energy-friendly future mobile Internet. Turning off the electronics of a wireless device is understood to be crucial for saving energy over idle periods. On the other hand, the responsiveness of the wireless network should not be compromised. Each node should try to adapt its power consumption profile to the traffic running through it. If each node is seen as an entity, cooperation among nodes is needed in order to achieve an efficient performance in terms of energy. Scheduling and power control plays a big role in this context. Important tradeoffs were identified, and optimal control was proposed as a solution to the above problem.

C. The VDTN Project

The project "Vehicular Delay-Tolerant Networks" (VTDN) [9] proposed a novel architecture for VDTN. Besides positioning the bundle layer below the network layer, it employs out-of-band signaling and devises the separation of the control plane and data plane. A laboratory prototype was created to demonstrate this approach. The project also developed new applications, fragmentation mechanisms, content storage and retrieval mechanisms, dropping and scheduling policies, and routing protocols for VDTNs.

D. The CAVE-NET Project

Given the growing population of mobile devices and onboard units, the project "Context-aware Information Dissemination in Vehicular Networks" (CAVE-NET) [10] has identified the need for new approaches to performance modelling in vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) scenarios. In particular, it investigates how information about the vehicular context can be taken into account in order to improve information dissemination performance in vehicular networks. The first contribution addresses the vehicles through characterisation of vehicular flows – through a new,

macroscopic and generic model – and its impact on the information dissemination. The second contribution tackles the challenge of the deployment of road-side units for a vehicular communication infrastructure by defining and evaluating a game-theoretical model. The model has been validated by simulations.

IV. Recent Contributions from SJDE Projects

Euro-NF Specific Joint Developments and Experiments (SJDE) are part of the Euro-NF work package IA.2.1 "Development and coordination of software tools and platforms". They aim at promoting and supporting joint developments and joint experiments, in the context of the research work carried out inside Euro-NF. The results of the three projects run so far are made available to the research community. Below, two SJDEs are presented.

A. The Multi-Next Project

In FI, federation of resources will be the norm. The plethora of access and application-specific networks suggests to combine their resources in the form of building blocks in order to increase availability, reliability and performance of an end-to-end network path. On this background, the project "Measuring Concurrent Multipath Transmissions in an Experimental Facility" (Multi-Next) [11] validated a performance model for the concurrent use of virtual resources in the context of network federation. Furthermore, a use case within OneLab was performed, which demonstrated the potential of federation of experimental facilities, made use of the sophisticated measurement facilities provided within OneLab, and provided valuable feedback to OneLab in form of requirements for the federation.

B. The VNREAL Project

Network virtualization is recognized as an enabling technology for the Future Internet that overcomes network ossification. However, it introduces a set of challenges. In any network virtualization environment, the problem of optimally mapping virtual resources to physical resources, known as virtual network embedding (VNE), is a critical challenge. Several algorithms attempting to solve this problem have been proposed in literature, so far. However, a comparison of existing and new VNE algorithms is hard, as each algorithm focuses on different criteria. To that end, the project "Virtual Network Resource Embedding Algorithms" (VNREAL) [12] project introduced ALEVIN, a framework to compare different algorithms according to a set of metrics, easily incorporate new VNE algorithms, and evaluated these algorithms on a given scenario for arbitrary parameters.

V. Conclusions

The Euro-NF Vision on NF and FI postulates the need for (1) the separation of concerns into technology and methodology; (2) the weaving of a technological and methodological fabric in order to support NF, FI and future smart applications. It was shown how Euro-NF Specific Joint Projects (SJRP and SJDE) materialise that vision on a short-term, yet strategic scale by addressing key technology issues by advanced methodologies. As demonstrated by the examples, their scope ranges from the identification of open, tangible research issues via theoretical research to implementations, demonstrations experimentations and validations of new approaches. Thus, they exemplify how the weaving of the technological and methodological fabric is becoming a reality.

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