International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-03, Issue-08, Nov 2017

Concert: A Software-Defined Architecture for Next-Generation Cellular Systems

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Abstract—In the recent years, mobile cellular networks are undergoing fundamental changes and many established concepts are being revisited. New emerging paradigms, such as Software - Defined Networking (SDN), Mobile Cloud Computing (MCC), Network Function Virtualization (NFV), Internet of Things (IoT), and Mobile Social Networking (MSN), bring challenges in the design of cellular networks architectures. Current Long-Term Evolution (LTE) networks are not able to accommodate these new trends in a scalable and efficient way. In this paper, first we discuss the limitations of the current LTE architecture. Second, driven by the new communication needs and by the advances in aforementioned areas, we propose a new architecture for next generation cellular networks. Some of its characteristics include support for distributed content routing, Heterogeneous Networks (HetNets) and multiple Radio Access Technologies (RATs). Finally, we present simulation results which show that significant backhaul traffic savings can be achieved by implementing caching and routing functions at the network edge. In this paper, we step back and re-evaluate existing wireless network architectures, identifying inherent limitations and offering a new set of architectural principles that, we contend, will lead to significantly improved overall system performance and scalability. Based on these principles, we propose the CROSS Mobile SM architecture1 that is enabled by controlled cross-layer information exchange between radio, network, and application layers (both on-device and in-cloud), coupled with information-owner-based privacy and security controls. We discuss how this architecture can provide increased value to equipment and device manufacturers, application and network service providers, and end users. We close by outlining a number of open research questions.

Keywords* - *Software-defined networking, network function virtualization, cellular network architecture.

I. INTRODUCTION

In the recent years we are witnessing a widespread use of end user devices with advanced capabilities, such as smart phones and tablet computers, and the emergence of new services and communication technologies. This new evolved ecosystem, however, imposes very strict requirements on the network architecture and its functionality. Enabling small end to- end latency and supporting a large number of connections at the appropriate level, is not possible to be achieved in current Long-Term Evolution (LTE) networks. The fundamental limitations of current approaches lie in their centralized mobility management and data forwarding, as well as in insufficient support for multiple co-existing Radio Access Technologies (RATs) [1]. Today, a large variety of RATs and heterogeneous wireless networks have been successfully deployed and used. However, under the current architectural framework, it is not easy to integrate or to enable adequate coordination of these technologies. Despite the fact that the coverage of such wireless and cellular networks has increased by deploying more Base Stations (BSs) and Access Points (APs), the Quality-of-Experience (QoE) of Mobile Users (MUs) does not increase accordingly. For example, the current architectural approach does not enable an MU selecting the best available network in a dynamic and efficient way. It also does not enable simultaneous and coordinated use of radio resources from different RATs. This leads to highly inefficient use of hardware resources (wireless infrastructure) and spectrum, which is worsened even more with almost uncontrollable inter-RAT interference [2]. In this paper, we propose a new architectural framework for next-generation cellular networks. We benefit from the recent advances in Software Defined Networking (SDN) [3] and Network Function Virtualization (NFV) [4], which are natively integrated into the new architecture. Traditionally, SDN and NFV, although not dependent on each other, are seen as closely related and complementary concepts [5]. This integration enables good scalability in terms of supporting a large number of connections and heavy mobility scenarios. Also, the introduction of new services and applications becomes much easier. Decoupling control and data planes, and abstracting network functions from the underlying physical

 DOI : 10.18231/2454-9150.2017.0027

ISSN : 2454-9150 Vol-03, Issue-08, Nov 2017

infrastructure, brings much greater flexibility to efficiently utilize radio and computing resources both in the Radio Access Network (RAN) [6] as well as in the Mobile Core Network (MCN) [7]. Furthermore, our proposed approach enables the incorporation of Mobile Edge Computing (MEC) services in an easy and straightforward way. As our experiments show, by bringing the content and the decision functions to the network edge (RAN level instead of MCN level), significant network capacity savings can be achieved.

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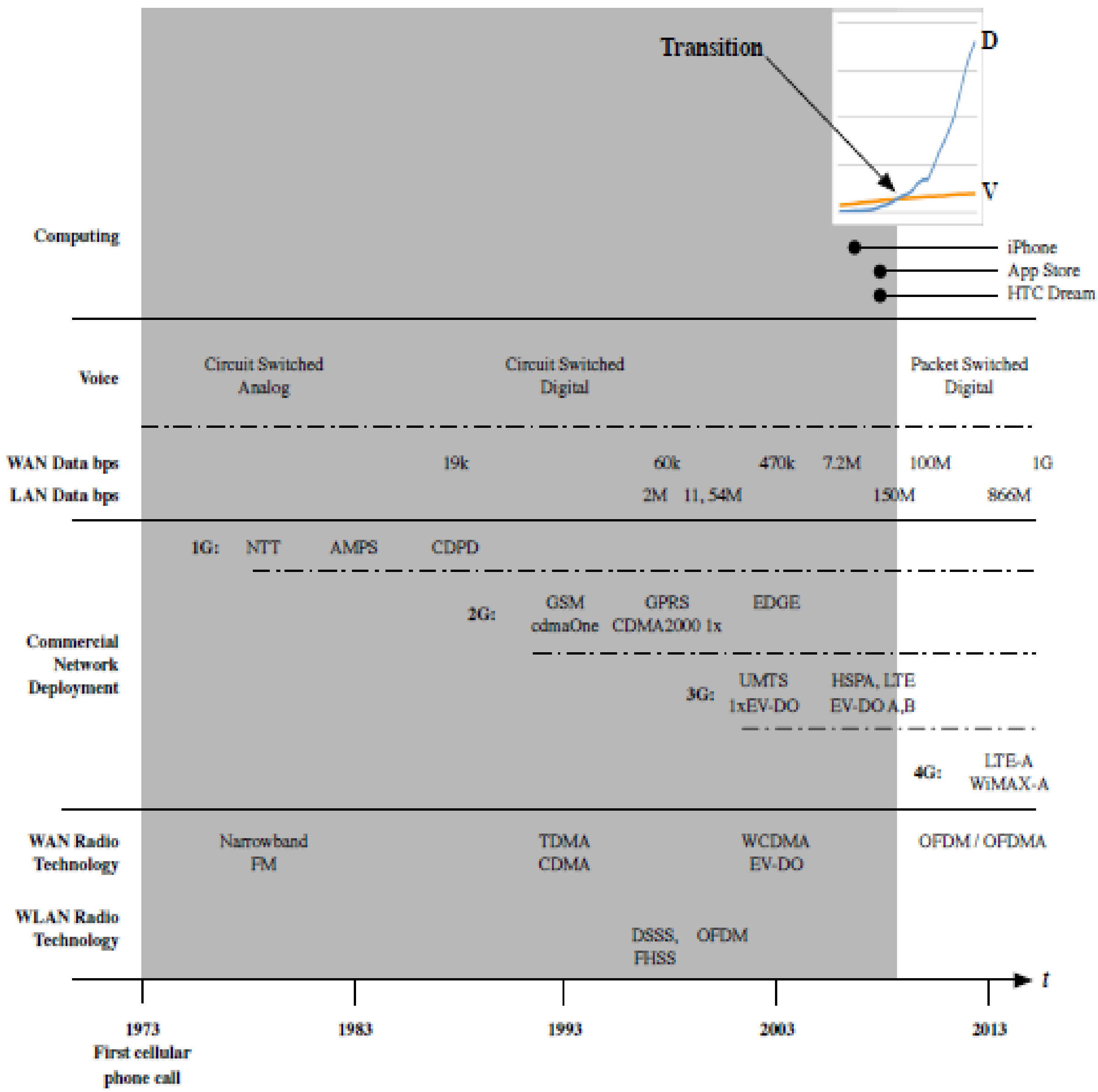

Fig. 1 Framework for Cellular networks

II. CHALLENGES AND PLAYERS

A. Background

A look back at the evolution of cellular networks reveals strong ties to the wired public switched telephone network (PSTN). While commercial mobile phone service of sorts dates back to the 1920's, we focus on the last four decades of cellular mobile telephony (see Figure 1). In their beginning, cellular networks were designed for voice signals carried over analog radio channels. Despite early efforts with low data rate modems, the networks had essentially no significant data handling capability. GSM- and CDMA-based digital networks changed this. These networks offered the raw potential for data transport,

Fig. 2. Evolution of combined uplink plus downlink bandwidth (petabytes per month) in cellular networks for voice and data [1]. but the transformation from analog was motivated more by a desire for increased channel capacity than by a vision to ignite a mobile computing revolution.

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Nevertheless, end-to end digital capabilities did indeed change our thinking, and the bandwidth race was on. Gateways were created to bridge the Internet to these bandwidth-limited networks. Since that time, channel coding efficiencies have improved, spectrum allocations have been increased, and large cells have been split into small ones–resulting in significantly more available capacity. But the basic architecture for data transport has remained relatively unaltered since its inception. Until the end of 2009, voice traffic dominated data traffic, and the underlying network architecture was largely circuit switched–an artifact from the pre-mobile-network era. With the appearance of smartphones and the development of cloud connected mobile applications, this began to change. Today, data traffic dominates voice traffic (Figure 2) [1], and the core network architecture is evolving toward packet switching. In parallel with the evolution of cellular networks, non cellular networking using unlicensed spectra has matured. Wi Fi networking based on the IEEE 802.11 family of standards has become an important component of the mobile landscape. The premise of building this next generation of mobile apps on top of unlicensed networks is alluring when one considers the cost (essentially free), the typical network speeds, and the possibility of actually building a high-coverage network through crowdsourcing.

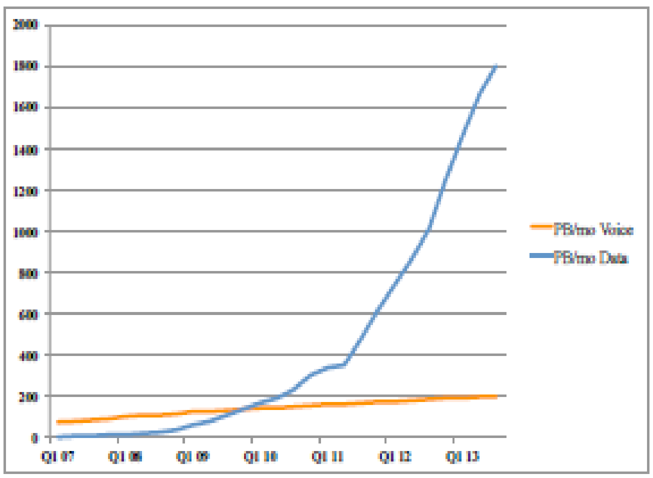

Fig. 2. Evolution of combined uplink plus downlink bandwidth

III. LIMITATIONS OF CURRENT LTE NETWORKS

The main driver behind the design of the current LTE networks was the requirement for supporting all-IP communication paradigm. In particular, the main focus was on supporting IP-based multimedia services via the introduction of the IP Multimedia Subsystem (IMS) [11]. However, the emergence of more advanced mobile services, such as Mobile Social Networking (MSN) [12], Mobile Cloud Computing (MCC) [13], and Internet of Things (IoT) [14], imposes very tight constraints on end-to-end and handover latency. Below, we briefly discuss the main limitations of current LTE networks.

A. Inefficiency of content routing

The current approach demands that all IP traffic passes via the MCN (Evolved Packet Core (EPC) in LTE terminology). This is highly inefficient, since today we have many localized services, where users of social networks or file sharing systems are located in close geographical proximity to each other [15]. The demand for all this traffic to traverse MCN introduces unnecessary delays and consumes scarce network resources.

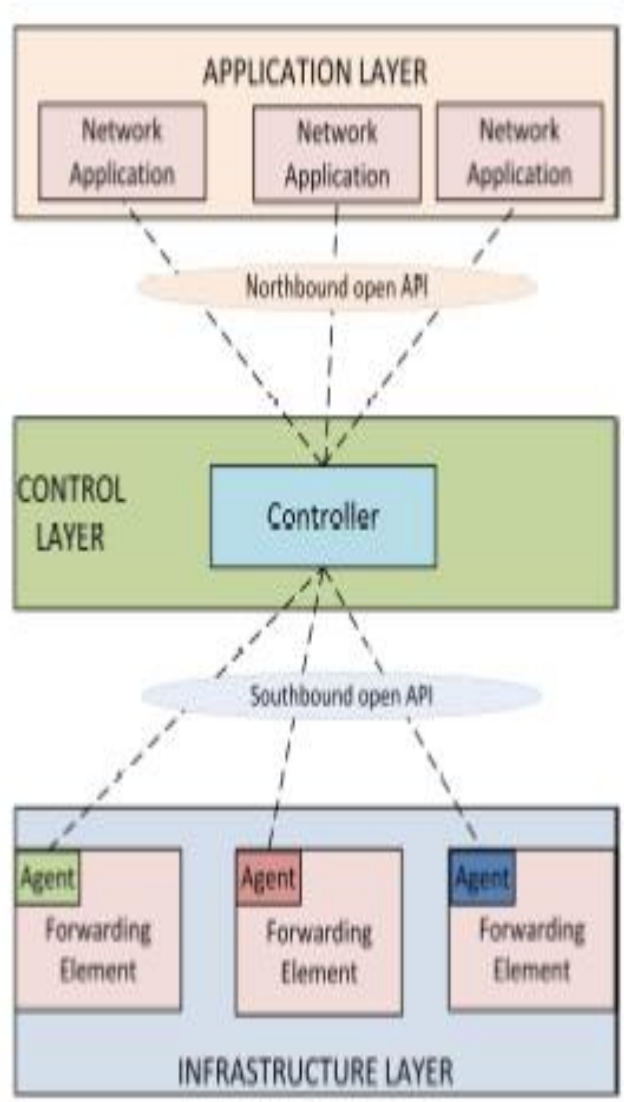

Fig. 3. Layering Concept in Software-Defined Networking.

IV. A SOFTWARE-DEFINED ARCHITECTURE FOR CELLULAR NETWORKS

Motivated by the limitations of current cellular architectures, as discussed in the previous section, and facilitated by the advances in SDN and NFV technologies, we propose a new software-defined cellular network architecture. The layering

DOI : 10.18231/2454-9150.2017.0027

concept of SDN is shown in Fig. 1. The SDN controller provides a global view of available resources to the network applications via the northbound open API. At the same time, the SDN controller configures flow tables at the forwarding elements via the southbound open API. The design objectives for the new architecture are the following. First, it must efficiently support a wide range of services and applications, from those that require high bandwidth and stable connectivity to those that send small

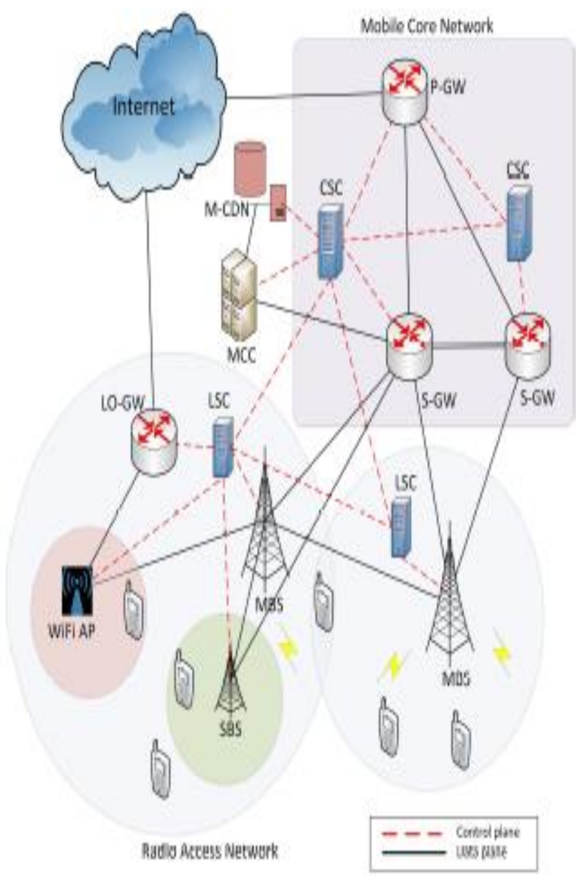

Fig. 4. A Software-Defined Cellular Network Architecture.

A Software-Defined Cellular Network Architecture chunks of data with long periods of inactivity. Second, it must provide content routing and resolution functions that can efficiently and quickly adapt to locality characteristics of the communication, supporting at the same time multiple RATs. Below, we describe the RAN and the MCN of the proposed architecture (see also Fig. 4).

V. CONCLUSION

In this paper, we first discuss the limitations of the current LTE networks. Their poor support for IoT and cloud computing applications, results in inefficient routing, high signaling overhead, overloaded backhaul, and scalability issues. Second, we propose a novel cellular network architecture based on SDN and NFV concepts. We introduce virtualized network functions for both RAN and MCN, to address the problems of mobility management, multi-RAT coordination, and efficient content routing. Finally, we evaluate the proposed approach my means of computer simulations. In particular, we show that by enabling intelligent routing and caching at the network edge, significant savings of the backhaul capacity can be achieved.

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 DOI : 10.18231/2454-9150.2017.0027