Wireless software-defined networks (W-SDNs) and network function virtualization (NFV) for 5G cellular systems: An overview and qualitative evaluation

Abstract

(SDN) has been proposed to efficiently create centralized network abstraction with the provisioning of programmability over the entire network.

(NFV) has been further proposed to effectively separate the abstraction of functionalities from the hardware by decoupling the data forwarding plane from the control plane.

Introduction

The main ideas of SDN are (i) to separate the data plane from the control plane; and (ii) to introduce novel network control functionalities based on an abstract representation of the network.

Another important concept in the context of SDN is NFV. As highly complementary to SDN, NFV effectively abstract network functionalities and implement them in software. By such way, network functions, e.g., routing decisions, can be separated from the local devices and be implemented at remote servers or Cloud. SDN and NFV are mutually beneficial but are not dependent on each other.

The overview of several state-of-the-art solutions as well as their strengths and weakness are summarized and compared with our proposed solution, called SoftAir.

Regarding our proposed SoftAir architecture, the **control plane** consists of network management and optimization tools and is implemented on the network servers. The **data plane** consists of software-defined base stations (SD-BSs) in the RAN and software-defined switches (SD-switches) in the cellular core network (CN). Their control logic, e.g., physical/MAC/network functions, are implemented in software on general purpose computers and remote data centers. Our proposed SoftAir architecture offers five core properties:

(1) Programmability
(2) cooperativeness
(3) virtualizability
(4) openness
(5) visibility

The above five properties provide functionalities that are essential to enable 5G systems to possess the following promising features:

(1) evolvability and adaptiveness,
(2) infrastructure-as-aservice,
(3) maximal spectral efficiency,
(4) convergence of heterogeneous networks,
(5) low carbon footprints.

State-of-the-art wireless software-defined network (W-SDN) & network function virtualization (NFV)

1. Major problems with the current cellular architectures

The major problems with the current cellular architectures lie as follows: (1) *Scalability challenges* and (2) *Vendor-specific device configuration.* In short, existing commercial cellular systems rely on closed and inflexible hardware-based architectures both at the radio frontend and in the CN. To tackle these problems, in the following, we summarize the design of flexible network architectures for 5G cellular systems, which are realized by the SDN paradigm with NFV.

2. Trends to W-SDN and NFV

1. *OpenRoads:* The main idea of this design is to separate the network service from the underlying physical infrastructure and allow rapid innovation of network services. In particular, OpenRoads uses OpenFlow to separate control from the data path through an open API,FlowVisor
2. *OpenRadio:* Two major contributions of OpenRadio's design are as follows. First, it decouples wireless protocol definition from the hardware, even while ensuring that commodity multi-core platforms can be used for implementing the protocols. Second, the design of software abstraction layer that exposes a modular and declarative interface to program wireless protocols.
3. *CloudMAC*: is a network architecture aimed at having a programmable MAC layer without resorting to software radios. CloudMAC enables several new applications, such as dynamic spectrum use, on-demand AP, and downlink scheduling.
4. *Odin:* is an SDN framework that proposes to simplify the implementation of high level enterprise WLAN services, such as authentication, authorization and accounting (AAA), by introducing light virtual access points (LVAPs).

3. Integrated W-SDN & NFV solutions

In this section, the fully integrated W-SDN and NFV solutions are introduced for practical implementations of 5G cellular systems.

1. *CellSDN:* summarizes the network architecture of cellular SDN (CellSDN), which aims to achieve a centralized control plane for cellular CNs.
2. *ADRENALINE:* provides a cloud computing platform.
3. *SoftRAN:* SoftRAN introduces a software-defined centralized control plane for RANs that abstracts all BSs in a local geographical area as a virtual big-base station comprised of a central controller and radio elements.
4. *Cloud-RAN (C-RAN)*: An emerging distributed RANs, connects SD-RANs to virtual BS pool through fibers and provides centralized control solution upon the BS pool.
5. *DOCOMO:* DOCOMO exploits C-RAN concept in 5G RAN design to split Control (C) and User Data (U) Plane, and to move control functionality in far-end cloud for centralized network architecture with remote radio equipment.
6. *SK Telecom:* introduces a softwarebased 5G enabling platform which is an industrial solution for 5G cellular systems that provide software-oriented framework and Telco asset-based interface, while jointly considering SD-RAN and SD-CN.
7. *CONTENT:* CONTENT (Convergence of Wireless Optical Network and IT Resources in Support of Cloud Services) is a 3-years European co-funded (FP7) project, It aims at

offering a network architecture and overall infrastructure solution to facilitate the deployment of conventional cloud computing as well as mobile cloud computing

SoftAir: A software-defined networking architecture for 5G cellular systems

The **data plane** is an open, programmable, and virtualizable network forwarding infrastructure*,* which consists of SD-RAN and SD-CN. The SD-RAN consists of a set of SD-BSs, while the SD-CN is composed of a collection of SD-switches. The **control plane** mainly consists of two components: (1) network management tools, and (2) customized applications of service providers or virtual network operators. In the following, we present the scalable SoftAir architecture in detail, explain the network virtualization, and introduce three essential management tools, namely mobility-aware control traffic balancing, resource-efficient network virtualization, and distributed/collaborative traffic classifier.

1. Network function virtualization (NFV)/scalable network function cloudification

a. *Scalable SD-CN:* By SD-CNs, the customized SDN applications, can be designed, deployed and updated on the network controller to fit the specific and ever-changing needs.
b. *Scalable SD-RAN:* the proposed SD-RAN follows a distributed RAN architecture. Here, each SD-BS is split into hardware-only radio head(s) and software-implemented baseband units
Fine-Grained BS Decomposition: SoftAir adopts a new fine-grained BS decomposition architecture by leaving partial baseband processing at the RRH (e.g., modem), while implementing the remaining baseband functions, e.g., MIMO coding, source coding, and MAC, at the BBS.
Seamless Incorporation of OpenFlow: In our SD-RAN design, we implement an OpenFlow interface for each SD-BS by utilizing Open vSwitch (OVS) , which is an OpenFlow-capable software switch that can easily be realized in BBS.

2. Network virtualization

SoftAir implements three functions: network hypervisor for high-level virtualization as well as wireless hypervisor and switch hypervisor for low-level virtualization.

1. *Network Hypervisor*: It focuses on high-level resource management, which determines how to distribute non conflicting network resource blocks among virtual network operators based on their demands.
2. *Wireless Hypervisor:* It is a low-level resource scheduler that enforces or executes the resource management policies determined by the network hypervisor by employing a variety of wireless resource dimensioning schemes.
3. *Switch Hypervisor:* Enabled by OpenFlow protocol, switch hypervisor (or switch fabric) focuses on bandwidth partitioning in a single SD-switch.

3. SoftAir management tools

To support cloud orchestration in SoftAir, three essential and general management tools need be developed: (1) mobility aware balancing, (2) resource-efficient virtualization, and (3) distributed and collaborative traffic classifier.