Software Defined and Virtualized Wireless Access in Future Wireless Networks: Scenarios and Standards

Future wireless networks are expected to provide augmented and data-intensive services in a multi-vendor multi-proprietor scenario. This scenario introduces relevant challenges to the networking infrastructure, especially in terms of flexibility and interoperability that could be addressed by extending the concept of Virtualization and Software Defined Networking to the wireless or wired-cum-wireless world.

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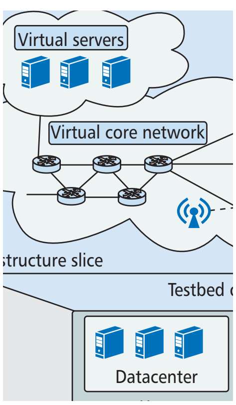

Abstract

Future wireless networks are expected to provide augmented and data-intensive services in a multi-vendor multi-proprietor scenario. This scenario introduces relevant challenges to the networking infrastructure, especially in terms of flexibility and interoperability, that could be addressed by extending the concept of Virtualization and Software Defined Networking (SDN) to the wireless or wired-cum-wireless world. This paper provides a review of the perspectives to the extension of the SDN paradigm in the wireless domain by identifying current trends and proposed solutions, and providing the existing major standardization efforts and future trends in the field.

Introduction

Wireless communications and networks nowadays are playing an integral role in how people interact and communicate, as well as how businesses operate and offer services to end customers. The increasing growth in the number of wireless devices and the introduction of a vast amount of applications, which are being used over the wireless access network, have led to an increasing demand for more bandwidth and have dictated the need for more powerful and faster networks.

With the introduction and enablement of unified communication services, wireless access networks have to be able to handle huge amounts of traffic nowadays, including data, voice, and video. There has been tremendous momentum in the advances in wireless technologies in recent years, due to the fact that they offer mobility and access to resources from almost anywhere. In support of these technologies, different standards have been introduced and coexist in order to serve different purposes and needs. The variety of these standards results in the creation of complex wireless heterogeneous networks, which has a negative effect on the way these networks operate and are being managed, increasing the overall complexity.

In order to deal with the aforementioned challenges, the focus of both the industry and the research community has shifted, in an effort to define and develop the next generation of wireless networks, namely 5G networks. 5G promises to support a massive number of simultaneously connected devices, high system spectral efficiency (data volume per area unit), low outage probability (better coverage), low latency, high versatility and scalability.

To achieve such goals, emerging technologies such as network virtualization and software defined networking (SDN) are being considered as technology enablers. These advancements are promising the introduction of programmability, flexibility, and elasticity for the managed networks, in order to better manage the high demand for enhanced IT resources and to satisfy customers' requests. Indeed, in wireless access networks, virtualization is expected to become an essential functionality, which will enable scaling and efficiency, resulting in easier network management in an effort to smooth the process of achieving interoperability and coexistence of different wireless technologies [1]. The need is to have a service oriented architecture (SOA) for convergence and a smooth transition between different wireless technologies, as it is currently being done in cloud computing and wired networks.

In the IT world, virtualization of resources (e.g. servers, compute, storage) has been prevalent and has changed the way IT services are being developed and offered. Following the same logic in recent years, the concept of network function virtualization (NFV) has been introduced, in order to enable the virtualization of network components. Thorough research has been conducted and various architecture definitions for virtualization of functions of the wireless access networks are being proposed. Various standards have been published on this issue, and the most relevant ones are discussed later.

In parallel with the research around NFV, in 2008 the OpenFlow protocol was introduced as part of university research and became the basis on which Open Networking Foundation (ONF) released the first version of the OpenFlow protocol in 2011, which enables the decoupling of the control plane from the data plane in networks. This led to an exponential increase in research and made possible the development of the concepts and technologies of SDN. Actually, SDN was originally oriented toward wired networks, but an increasing interest is driving the research of its application in wireless access networks as well, due to the inherit benefits offered by SDN approaches.

The current article provides an overview of the perspectives of using the software defined network paradigm at the service of the future wireless access networks, including both 5G mobile technologies and wireless local area networks (WLANs). The reported work is based on the activities developed under the framework of the recently established IEEE Standardization Research Group on Software Defined and Virtualized Wireless Access.[1]

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[1] http://community.comsoc.org/groups/rg-software-defined-and-virtualized-wireless-access

The article is organized as follows. We provide an overview of the future directions and opportunities in SDN/virtualized wireless access, while we address specific aspects related to the application of the SDN concepts to wireless access networks: enabling protocols and architectures for virtualization of wireless networks and end-to-end SDN in wired-wireless scenarios. We provide a list of current related standardization efforts as well as some real life examples and future trends. We then conclude the article.

Perspectives of Software Defined and Virtualized Wireless Access

The introduction of NFV for wireless access networks, complimented by the introduction of SDN technologies, offers tremendous opportunities and allows a number of benefits to be realized within the areas of deployment, operation, and management of wireless access networks [14, 15]. One of the main benefits is the decoupling of the network control and management function from data forwarding, which takes place in the hardware. Essential functions for the control and management of the network that previously had to be embedded in the hardware's ASIC, now can be deployed and developed in software, and by applying DevOps techniques these functions can be optimized further and faster. Furthermore, a number of network functions can now be implemented in the cloud and incorporated with other network access domains through the use of SDN. This flexible infrastructure reduces the dependency of emerging wireless technologies on hardware, enables better exploitation of the available infrastructure, and correspondingly shortens the research and development cycle of wireless technologies.

Based on the suggested architecture models and the various technologies of wireless access virtualization, three main perspectives of wireless access virtualization can be identified [1].

Flow Oriented Perspective: In this perspective, the wireless access domain can be defined as the data exchange and distribution network. This is the most common wireless access virtualization perspective that focuses on the management, scheduling, and service differentiation of different data flows from different slices. This perspective is commonly defined as mobile network virtualization. This can be implemented in two ways: either as an overlay over the wireless hardware, such as OpenRoads and virtual Base Transceiver System (vBTS), or it can be implemented as an internal scheduler inside the wireless hardware, such as Network Virtualization Substrate (NVS) and virtual Long Term Evolution (LTE).

Protocol Oriented Perspective: The protocol oriented perspective aims to isolate, customize, and manage the multiple wireless protocol instances on the same radio hardware. If the protocol processing is done purely in software for the all protocol layers, then software-based resources must be sliced. On the other hand, if the protocol processing is done purely on hardware, then the hardware resources must be sliced. In [2] a partial implementation of the protocol oriented perspective allows for the sharing of the same radio resources for different instances of the wireless protocol stack, while OpenRadio and Sora make the radio hardware fully customizable by introducing the full implementation of the protocol oriented perspective and allowing different protocols to operate on the same hardware.

Spectrum Oriented Perspective: In the spectrum oriented perspective, the resources to be sliced are radio frequency (RF) bands and raw spectrum. This perspective decouples the RF front end from the protocol, allowing multiple front ends to be used by a single node, or for a single RF front end to be used by multiple virtual wireless nodes. In this perspective the scheduling is done in a flow oriented approach, whereas the protocol oriented perspective can be overwritten by reshaping the signal.

Although the main idea and basis of virtualization is the same for both wired and wireless networks, the approaches used for the controllable medium (wired) have to be modified and adapted for the wireless medium and the time-varying characteristics of the mobile environment. In the related literature, different approaches have been proposed in order to have better control over wireless virtualized networks for a wide range of applications. We now summarize some of them.

Wireless Access Virtualization and Software Defined Networking: The main concepts, such as service awareness and function modularity, which have been introduced by SDN and virtualization in the wired network, can be extended to the wireless virtualized access. Furthermore, the fact that through SDN technologies one can achieve programmability, flexibility, and elasticity of the network makes SDN directly applicable to wireless networks in an effort to deal with the challenges of the increasing number of mobile devices. Overall, SDN and virtualization in wireless access networks can be considered as an extension of the wired network. One of the options is to consolidate the wireless functions in a centralized software controller, where the decoupling of a management and data plane is achieved by using a protocol such as CAPWAP (Control And Provisioning of Wireless Access Points). The Openflow extension of wireless access points is suggested in OpenRoads, where the data plane of the wireless access is virtualized through the use of FlowVisor. The configuration of the wireless access point is controlled using the Simple Network Management Protocol (SNMP).

Wireless Virtualization using SDRs: Software defined radio (SDR) offers the same functionalities for wireless networks as SDN does for wired networks. OpenRadio was proposed as an extension of SDN for the wireless domain, where baseband processing is separated into the processing plane and decision plane. The programmability of both planes increases the flexibility of hardware to be shared among different protocols.

WLAN Virtualization: IEEE 802.11 wireless LAN access points are virtualized by taking advantage of the existing functions of IEEE 802.11 WLAN (sleep state of power save mode

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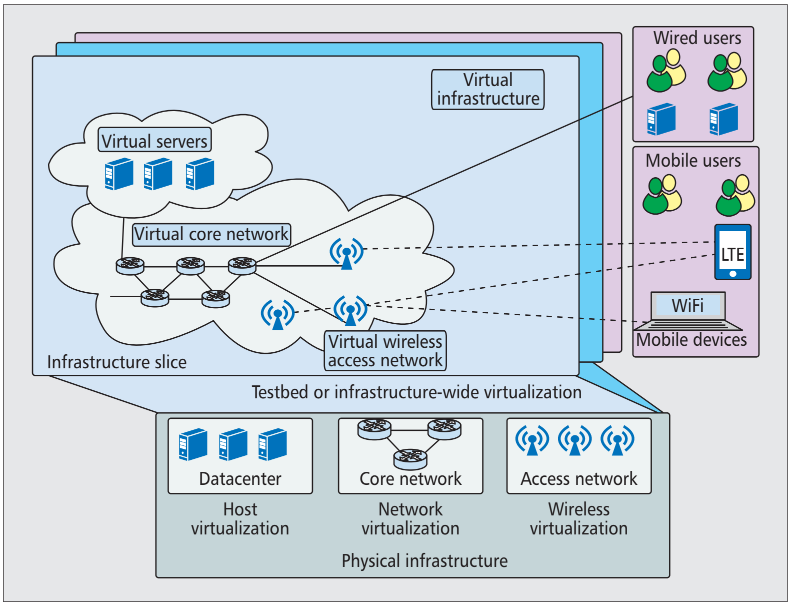

Figure 1. The extension of the concept of NaaS in the wireless domain.

(PSM)) to enable the network interface card (NIC) to communicate with different networks at the same time. Such heterogeneous networks are managed through a common mesh function management layer by using the interface management function and IEEE 802.21 extensions to the MAC abstraction layer. Another promising solution to WLAN virtualization is the decoupling of IEEE 802.11 MAC frames, which can be processed in the cloud, using the OpenFlow protocol. The MAC frames are processed in virtual access points (APs), which are present in the cloud. The technique is known as CloudMAC in the literature [3].

Cellular Base Station Virtualization: In the area of base station virtualization, each tenant can have its own scheduler over its slice. Different architecture models have been proposed in the literature to provide slice isolation, which can be based upon modifying the medium access technique. For WiMAX virtualization, a virtual base transceiver (vBTS) [4] and network virtualization substrate (NVS) [5] were proposed. Similarly, a modification in the MAC of LTE eNB is proposed in [6] for LTE virtualization to separate the traffic of different slices based on SLAs of each slice. In real life, this method is very prevalent in the telco on cloud applications, with some of the biggest global telco operators currently deploying these technologies in their network.

Wireless Spectrum Virtualization: Wireless resource virtualization can be performed below the physical layer using the spectrum virtualization layer (SVL) [7]. The SVL uses spectrum reshaping techniques to share the same RF front end on different portions of the spectrum.

In reality, different virtualized domains exist in the same geographical area and are interconnected to form the modern network infrastructure. These virtualized domains can be integrated with one another to form a cloud infrastructure. The logic of the domain results in the infrastructure sharing the same kind of resources and performing the same kind of functionalities. For example the wireless virtualization domain can be integrated with others. In this way, the wireless access network can be an extension of network as a service (NaaS), a concept borrowed from cloud computing. The concept is shown in Fig. 1, where an application or a service is no longer bounded to a domain or layer. Although both the industry and the research community have generally accepted the concept of the NaaS, a number of challenges and open problems still remain. Different domains are going to be managed by different controllers, and in a number of situations different protocols and standards would be applicable. This raises the question of how these different domains will be orchestrated and managed in a harmonized approach and view, offering to business users the end-to-end manageability that virtualization and SDN are promising.

Enabling SDN and Virtualization over Wireless Networks

In order to boost network capacity and efficiency in a self-automated manner while reducing CAPital EXpenditure (CAPEX) and OPerational EXpenditure (OPEX), the 3rd Generation Partnership Project (3GPP) introduced the concept of self organizing networks (SON). The main goal of SON is to make *planning*, *configuration*, and *optimization* of heterogeneous and mobile radio access networks simpler and faster in an automated manner with a minimum need of manual intervention. In [8], SON techniques are applied to multi-radio access technologies (RATs), targeting deployment optimization. Four different use-cases are described, depending on the deployments of the RATs, i.e. whether the communication services are transmitted from the same cell-site over *the same* or *different* antennas. This leads to different types of configurations and implementations of the SON objective functions and controllers (e.g. one centralized RAT objective functions and multiple controllers dedicated to each RAT, multiple RAT SON objective functions, and multiple dedicated controllers).

In a fairly similar goal to SON, SDN promises innovation in terms of network programmability by allowing network control and management whereby a high level of abstractions exist. Implementing SDN over wireless represents a challenging task, since it introduces many issues related to link isolation or channel estimation that are not necessary in wired networks. However, SDN is very promising in the wireless domain and carries great potential according to future perspectives, since it provides functions that could promote a better cooperation between access points/base stations in order to reduce interference or to enhance security.

The concept of network virtualization is defined as the process of combining hardware and software network resources and network functionality into a single, software-based entity called a *virtual network*. Network virtualization improves the resource utilization scheme by sharing the same hardware in a controlled and an isolated manner (i.e., each virtual network believes it has its own hardware). To achieve these functionalities, a clear abstraction of the underlying hardware should be provided to the software-based entity. The virtualization of the underlying infrastructure (it could be of different RATs) allows *multiple service providers* to simultaneously control and configure the underlying infrastructure. Moreover, service evolutions as in the vision of future 5G networks could be achieved easily by gradually applying the changes in each network slice, which also mitigates the issues related to backward compatibility with the existing legacy infrastructure. Therefore, the concepts of SDN and virtualization will have a huge potential impact toward realizing future wireless network deployments.

In the following paragraphs we provide some frameworks and architectures that may be helpful for future SDN developments in the wireless domain.

One proposed approach to enable SDN over wireless is to integrate the SDN principles in wireless mesh networks (WMNs), formed by OpenFlow switches with one or multiple wireless interfaces, typically based on IEEE 802.11 protocols. A wireless mesh software defined network (wmSDN) can take advantage of OpenFlow and utilize the optimized link state routing (OLSR) protocol to route OpenFlow control and data traffic to avoid operating issues in the unwanted sudden scenario of controller unreachability. This wmSDN toolkit implementation is composed by a POX controller, Open vSwitch, OLSR daemon, Bash, and Python Scripts. Moreover, a wireless mesh router (WMR) is also needed to provide connectivity to the different access networks, as well as provide connectivity to the Internet and operate as a gateway. The WMR is connected to an OpenFlow controller through a wireless/wired connection interface. The SDN paradigm that is implemented by OpenFlow could foster WMNs as it provides simple management and flexibility. Wireless resource utilization can be enhanced by a central server that can perform processing actions on multiple levels of the protocol stack. Actually, wmSDN utilizes OLSR, Linux-based OpenFlow tools and scripts that can easily be developed in Linux-based wireless IP routers that operate in WMNs. A similar approach has been followed by the Clemson Openflow program, which has developed and deployed an outdoor mesh network on which GENI researchers can conduct experiments.

Figure 2 represents the concept of WMNs . As shown, the WMN includes several WMRs in order to provide Internet access to a group of APs, and a wireless or wired connection interface to end users as well. In this scenario, the SDN connections are represented by the dotted arrows from the OpenFlow controller in the top of the figure to each WMR. Such connections can be wired or wireless.

A very relevant scenario for 5G networks is the implementation of SDN for extremely dense wireless networks. In particular, SDN has been identified as a solution for this scenario since it tackles two key challenges of wireless dense networks: interference and mobility management.

The architecture proposed in the CROWD research project[2] offers the tools to orchestrate network elements in a way that intra-system interference is mitigated, channel opportunistic transmission/receipt techniques can be enabled, and energy efficiency can be boosted. An extremely dense and heterogeneous network composed of two domains of physical network elements, the reconfigurable backhaul and radio access network (RAN). The functionality of network optimization is entitled from the network elements to a set of controllers, which are virtual entities deployed dynamically over the physical devices (taking into account the actual network load and the capacity constraints). The control plane consists of two types of controllers: the CROWD regional controller (CRC), which is a logically centralized entity that executes long-term optimizations; and the CROWD local controller (CLC), which runs short-term optimizations. As energy efficiency is essential for operators as well as for environmental issues, CROWD is proposing a power cycling control application to dynamically reconfigure the network and the status of network nodes according to traffic demands. Ultimately, the CROWD project proposes control applications for networks consisting of both LTE and IEEE 802.11 devices (e.g., the offloading control application envisions the utilization of load balancing and relay techniques that span across multiple RATs and multiple technologies).

Figure 3 represents the concept of the CROWD architecture under an extremely dense and heterogeneous network. As shown in the figure, there is a control plane, which consists of two types of controllers (CRC and CLC) with the help of OpenFlow and CAPWAP as well. The data plane consists of two heterogeneous network physical elements, the reconfigurable backhaul and the dense radio access network where the forwarding is being held.

Moreover, as mentioned earlier, OpenRadio

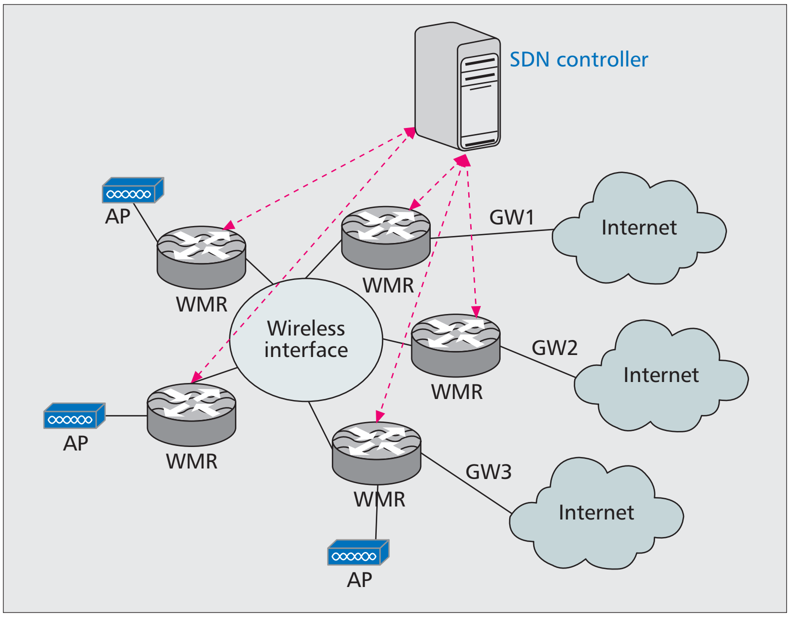

Figure 2. SDN over a wireless mesh network, where the SDN controller connects to WMRs.

[2] http://www.ict-crowd.eu

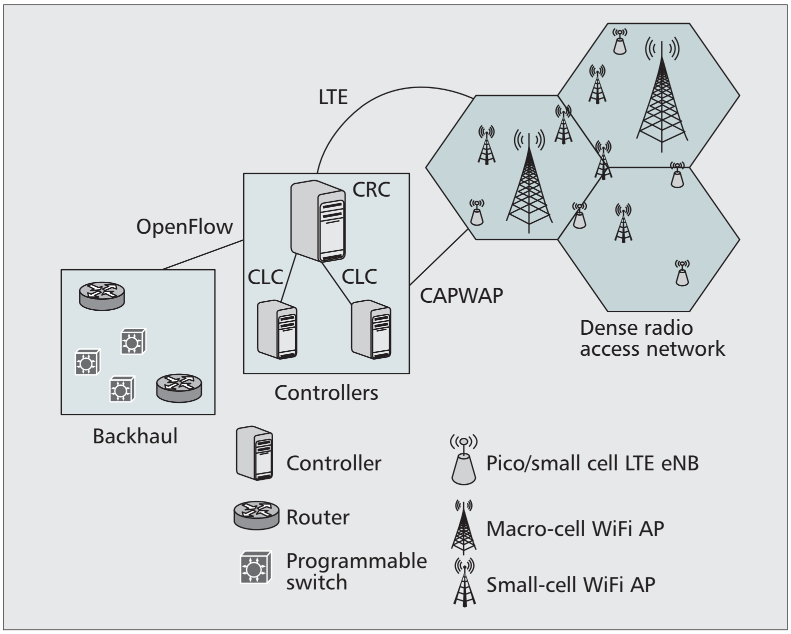

Figure 3. Overview of the CROWD network control architecture.

gives a modular and declarative programming interface by separating the wireless protocols into two planes, processing and decision planes, providing the right abstraction in-order to balance the trade-off between performance and flexibility. Following a similar concept, SoftRAN aims to build a centralized control plane for radio access networks (RANs) to address the issues related to radio resource allocation, interference reduction, handover, and load balancing. It achieves those goals by aggregating base stations as a virtual big-base station with a centralized control system.

The concept of a virtual cell (V-Cell) architecture is proposed in [9], aiming to overcome the technical limitations of *Layer 1* and *Layer 2* of the conventional wireless networks. In a similar analogy to SoftRAN, the V-Cell abstracts all the resources provided by a pool of base stations into a single large resource space to a centralized control-plane (i.e., the SDN RAN). In LTE, the resource space (also known as *Resource Pool*) is a *3-dimensional* (time, frequency, and space) matrix of the resource blocks (RBs). Furthermore, the authors introduce the concept of *no handover zone*, where the user equipment (UE) is assigned to different RBs from the centralized resource pool allowing the UE to jump from one base station to another without instantiating a handover procedure. In [10] the SDN approach is exploited by exposing the lower layers (i.e., PHY and MAC) of the LTE protocol stack to a centralized controller, such that it is possible to dynamically reconfigure the network by means of specifically designed algorithms.

Another approach, MultiFlow [11], aims at enhancing IP multicast over IEEE 802.11 networks. MultiFlow is based on the conversion of multicast transmission to a group of unicast transmissions. The MultiFlow implementation on SDN and the OpenFlow protocol can be carried out without the need for adopting any proprietary software or hardware. The programmable OpenFlow controller in the MultiFlow architecture is used to implement a multicast controller that will be responsible for detecting multicast packets. The use of OpenFlow further allows the efficient implementation of interfaces and mechanisms of a centralized WLAN controller protocol (e.g., CAPWAP) as part of the multicast controller. The estimation of the network wireless conditions is the main functionality of the controller. MultiFlow can provide an enhancement of the channel availability as well as a more efficient handling of the multicast load (this significantly improves the transmission of high definition multimedia over IEEE 802.11 WLANs). Moreover, when MultiFlow is utilized, the delay performance of the system is improved (especially when the AP is already overloaded) and enhanced power saving can be achieved.

Figure 4a represents an architectural network approach that implements the MultiFlow protocol. This scenario includes a set of multicast servers, a multicast router, a MultiFlow controller, and a typical network scenario with connected AP's to a switch. The MultiFlow controller is composed of an OpenFlow controller in order to create a multicast controller, which operates the multicast to multiple unicast conversion as shown in the Fig. 4b.

A very specific scenario is represented in the case of deploying SDN over wireless sensor networks (WSNs). The main weaknesses of WSNs are related to resource limitations, such as processing power, memory, energy, and communication capabilities. Those weak points may be addressed by smart management of network resources through SDN. Under WSN's scenarios, SDN can reach a higher potential since it provides functions that can allow a better collaboration between the base station and the forwarding nodes. The deployment of SDN can be useful for issues such as energy saving, sensor node mobility, network management, localization accuracy, and topology discovery. The proposed framework in [12] considers a WSN that includes a base station and a number of sensor nodes. In this framework, sensor nodes do not have to make routing decisions. Actually, they forward or drop packets according to a set of pre-installed rules stored in a special data-structure (known as the flow table) maintained at every sensor node, and the best routes are calculated by the controller according to specific matching criteria. Under this framework, the controller makes use of location information gathered by any localization technique for identifying the best routes. The controller then transforms these decisions to a set of rules that are to be imported into the flow tables of each node. The controller does not necessarily need be a stand alone node; it can also be implemented as a part of the base station. The controller architecture of the base station can address several issues in the management area such as mobility and localization, and simply provides reconfiguration abilities. This improves management features such as energy saving and topology discovery. The controller (base station) node maintains its functionality through the following five layers: physical, medium access control, network operating system, middleware, and application. For

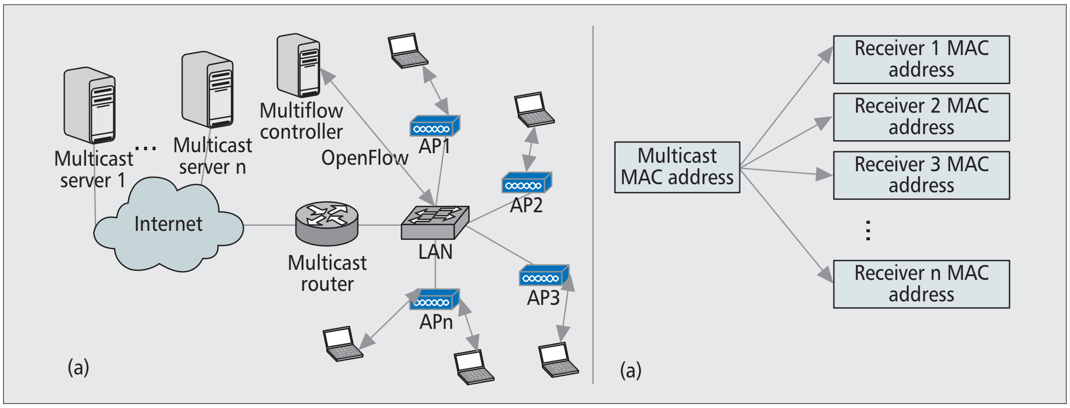

Figure 4. Architectural concept of a network that operates with a) MultiFlow; b) multicast to multiple unicast conversion.

certain applications a WSN needs to be deployed to cover a certain area and needs to maintain continuous monitoring. Using the proposed architecture, system behavior could be changed in an easier and more efficient way. This could be achieved by modifying the forwarding rules in the base station (controller), and thus new action policies would be sent to the network devices. Furthermore, maintaining the system's scalability becomes a simpler task. In order to extend the network to another area, new devices could be linked to the same WSN (same base station) that should allow for network policies to be sent to the new devices.

Figure 5 depicts a possible software defined wireless sensor network framework. There is no need for sensor nodes to make routing decisions. Decisions are made centrally at the base station and new rules are allocated to sensor nodes, e.g. add, remove, or update flow. From the software defined perspective inside the base station there is a logically-centralized controller because the control logic is implemented as part of the base station.

Despite the fact that the concepts of network virtualization are extensively explored in the wired domain, it cannot be directly applied to the wireless domain. For example, the bandwidth achieved by a particular virtual wireless network segment from a given amount of radio resources varies depending on the channel quality of the users. When a certain bandwidth is reserved for a particular network segment (slice), the dynamic nature of the air-interface should be properly considered. In addition, another limiting factor (i.e. interference) needs to be taken care off as well. Wireless network virtualization is in its very early stage and attracting a huge interest of research.

End-to-End SDN in a Wired-Wireless Scenario

As mentioned previously, one potential use case of SDN and virtualization is the enablement of end-to-end connectivity between wired and wireless networks. Two main networking scenarios have been considered for SDN-based wired-wireless integration and are described in this section.

The first scenario refers to future 5G mobile systems. Effective solutions for high-rate radio transmissions will have to be combined with advanced management functionalities, enabling a fully integrated solution between both the wireless and the wired part. The wireless network side will experience increased traffic volumes, higher data transmissions rates, and the emergence of new services based on cloud applications. This translates into the need to have an integrated, flexible, and programmable backhaul/fronthaul segment able to guarantee the necessary adaptability to service requirements and traffic conditions. In order to accomplish a programmable backhaul and to ensure smooth interoperation between the fronthaul and core layers, the industry is suggesting the use of SDN capabilities, to separate the bearer and control functions and to centrally manage and automatically configure the cell site gateway (CSG) and the small cell site gateway (SCSG) on the aggregation site gateway (ASG).

The second scenario where SDN can be used from an end-to-end perspective refers to wireless LAN systems. In LANs, wireless is becoming the primary access method. Also in this case, enhancements in network throughput have to be combined with offering better agility and flexibility, aiming at providing the same responsiveness and SLA of wired connections.

Overall, it is apparent that SDN represents the most suitable candidate technology to provide combined management of the wireless and wired segment, toward achieving an end-to-end network deployment and provisioning. Provided that an integrated SDN architecture will be adopted, a number of benefits are expected, as detailed below.

Unified Management of the Wired and Wireless Network. A single SDN orchestrator, equipped with different and technologically-specific southbound interfaces, is expected to provide a common view and control of the wired-wireless network. SDN solutions for mobile/backhaul/fronthaul access segments are expected to simplify network operations, lower total cost of ownership, and introduce manual-free operations. Similarly, SDN orchestration in Wi-Fi and wired LANs is expected to simplify operations

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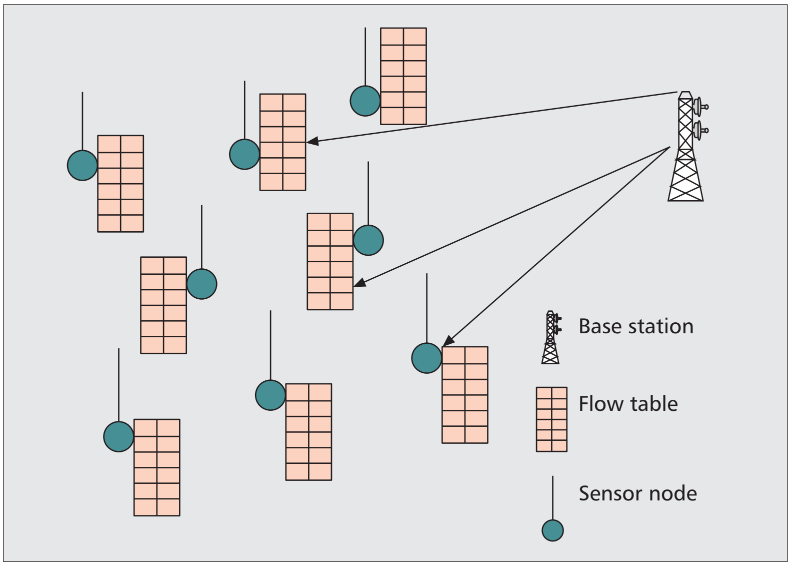

Figure 5. The software defined wireless sensor network framework.

and management functionalities that nowadays are still handled separately.

Unified Policy Enforcement. A common management of wireless and wired technologies will simplify IT policy enforcement. In particular, policies can be defined and enforced only once and applied across the whole network. Such functionality, already present in some advanced management tools, is becoming the standard approach integrated within SDN solutions that are using the group-based policy model.

Network Programmability and Network Function Virtualization. With a common SDN orchestration, the integration between the wired and wireless segments will enable more effective adaptation and virtualization strategies as well as the capability to dynamically react, in a coordinated way, to application and business needs, achieving the concept of offering the network as a service (NaaS).

Performance Improvement. The advanced programmability enabled by a common SDN architecture has the potential to improve overall network performance. For example, network throughput can be improved when users are located in overlapped service areas by enabling advanced programmability of migration and handoff strategies. Moreover, download rates can be increased by activating multiple parallel streams originated in the wired network and delivered, in a coordinated and synchronized way, by the wireless network. In addition, a common SDN orchestration could implement advanced power saving solutions (e.g., traffic migrations and sleep configurations) during off-peak traffic conditions.

Vendor Interoperability. The open standard and open source implementations of southbound SDN interfaces will significantly facilitate interoperability among different vendor devices. However, due to the different solutions and approaches that various vendors are offering, interoperability between them still remains an open issue.

Customized Applications. Standard northbound and open APIs will provide support to new SDN applications, enabling customized network behavior through the SDN controller.

To meet such high expectations, SDN has to guarantee open programmable access to the wireless infrastructure, adopting controller modules, abstraction layers, and enhanced northbound/southbound interfaces, able to be fully integrated within the open SDN-based solutions designed and operated in wired networks.

Related Standardization Efforts

This section provides an overview of ongoing standardization efforts in the framework of SDN/network softwarization that also include wireless networks and devices. It must be emphasized that currently most standards on SDN are technology- or data-transport-agnostic, therefore they specify interfaces and management approaches without specifically addressing the wireless/mobile scenario.

The International Telecommunications Union — Telecommunications Standardization Sector (ITU-T) is actively involved in the framework of standardization for future networks. Relevant standards by ITU-T are aimed at SDN in future networks, as in the case of ITU-T Recommendation Y.3300 (2014) — Framework of Software-Defined Networking. However, the document describes the framework of SDN by providing definitions, objectives, capabilities, and architecture at a high level. Wireless networks are included in the overall SDN deployment picture, but not explicitly addressed in the document.

The European Telecommunications Standards Institute (ETSI) is involved in standardization efforts with the publication of the framework of the Industry Specification Group for Network Function Virtualization (ETSI NFV SIG). The current version of document ETSI GS NFV-INF 001 addresses wireless (and specifically mobile base stations) as a possible domain for virtualization, and specifies standard interfaces and use cases, without addressing how virtualization should be performed.

The Internet Engineering Task Force (IETF) is also actively developing RFCs for standards on SDN and network virtualization. Most relevant documents in the framework of SDN standardization in mobile networks are related to the concept of Service Function Chaining (SFC) and especially to the SFC Architecture (draft-ietf-sfc-architecture-01) and SFC Use Cases in Mobile Networks (draft-ietf-sfc-use-case-mobility-01). The documents describe an architecture and related use cases for usage of SFC, i.e. a carrier-grade process for continuous delivery of services based on network function associations in mobile networks (3GPP as a reference).

The ONF explicitly addresses the scenario of SDN in wireless networks in the white paper "OpenFlow-Enabled Mobile and Wireless Networks." The proposed use cases include intercell interference management and mobile traffic management, outlining benefits in terms of additional flexibility in a 4G multi-vendor scenario as well as improved granularity in resource management.

IEEE is active in such a scenario, with the participation to the IEEE SDN Initiative and the definition of Standardization Working Groups and Research Groups on Virtualization in Wireless Networks. Relevant activity is being carried out in the framework of the Research Group on Software Defined and Virtualized Wireless Access and the Research Group on SDN/NFV — Structured Abstractions.

Future Research Trends and Real Life Scenarios

The evolution of wireless networks to 5G will change consumers' habits in using the Internet. The efficient management of frequency spectrum and bandwidth in 5G technology will face inevitable challenges in the future. Software defined wireless networking represents a valuable choice for integration between frequency spectrum and bandwidth, between suppliers and consumers, QoS and security. Both SDN and SDR have the capability to reconfigure, allowing network administrators to move forward to a self-adaptive environment by collecting signals and changing parameters at the packet level and quickly finding a suitable communication path and frequency band.

The key open issues to be addressed can be summarized as wireless network abstraction, programmability, security, quick reconfigurability, mobility, and orchestration. Some of the recent research topics and real life scenarios are discussed below which require further exploration to meet future needs.

SDN Performance in Dense Mobile Networks

Mobile networks tend to be more dense and large scale to meet the future needs of increased bandwidth and better QoS. Some of those issues are addressed by SoftCell [13] and CROWD [8], but the corresponding performance is not clear in all scenarios. An SDN enabled cross-layer MIMO solution could be necessary to meet the future bandwidth needs.

Internet of Things (IoT) and SDN

SDN, with its ability to intelligently route Internet traffic and efficiently use network resources, will make it easy to eliminate bottlenecks and efficiently process the data generated by IoT without placing a strain on the network. SDN capabilities of service changing, bandwidth calendaring, and dynamic load management will be particularly useful for IoT.

SDN Based Mobile Data Offloading

The rapid growth of wireless networks has created increased demand for mobile data services. The problem of energy consumption has also become more significant for mobile devices where battery time is a crucial factor. The need is to separate the computationally intensive and memory intensive applications and offload them to nearby servers using software defined networking, enabling programmable offloading policies that take into account real time network conditions and the status of devices and applications.

SDN Orchestrator

The employment of SDN in wireless networks raises the question of how these different domains will be orchestrated and managed in a harmonized approach and view, offering to business users the end-to-end manageability that virtualization and SDN are promising. This represents a huge challenge nowadays, because such a single orchestrator does not exist and efforts toward a common approach have not been successful due to the existence of different SDN solutions.

Conclusions

Software defined networking represents a promising paradigm in both the wireless and the wireless-cum-wired scenarios. As discussed in this article, targeted effort is being allocated to extend the benefits of virtualization and softwarization to the wireless domain. Such features make SDN over wireless a relevant technology to manage scenarios including multi-vendor and multi-owner setups, such as those envisaged in the framework of the current discussion on 5G and future wireless networks.

This article discussed standardization efforts on how to extend SDN to the wireless sections of the end-to-end path as well as how to control and manage wireless resources. Indeed, harmonization of current efforts will be useful to enable interoperability and seamless access to the wireless infrastructures of the future.

Targeted effort is being allocated to extend the benefits of virtualization and softwarization to the wireless domain. Such features make SDN over wireless a relevant technology to manage scenarios including multi-vendor and multi-owner setups, such as those envisaged in the framework of the current discussion on 5G and future wireless networks.

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