Software Defined Wireless Network Architecture for the Next Generation Mobile Communication: Proposal and Initial Prototype

Guolin Sun[1], Feng Liu[1], Junyu Lai[2], and Guisong Liu[1]
[1] School of Computer Science and Engineering, Univ. of Electronic Science and Technology of China, Chengdu, China
[2] School of Aeronautics and Astronautics, Univ. of Electronic Science and Technology of China, Chengdu, China
Email: {guolin.sun, laijy, lgs}@uestc.edu.cn; eric_liufeng@163.com

Abstract —In this paper, we propose a network architecture and a methodology to implement a network simulator and a system prototype for the software defined wireless networks with the reprogrammable capability brought by a SDWN controller. The software defined wireless network architecture oriented for the 5G network is defined with a multi-tiered cloud controller and the Openflow interface. The implementation architecture of system prototype for the software defined wireless network is based on Openflow. Finally, we evaluate and implement some new features and scenarios as applications and services with the Floodlight controller. The new features and scenarios include the cloud radio access/handover, the radio topology discovery, the extended location monitoring and the energy management. The experiments results show us that the proposed network architecture and the implementation methodology works well in this prototype.

Index Terms—5G, software defined network, openflow;

I. Introduction

With the trend of network design moving from the network-centric to the client-centric, the new concepts of software defined network (SDN) and network function virtualization (NFV) are two of the candidate disruptive techniques for the next generation Internet as well as mobile communication [1]. The service-oriented network envisions people access the information just like the electricity, water and gas in the daily life, so we argue that the radio infrastructure is also a service in this paper. Unfortunately, the current environment of radio access networks is fundamentally heterogeneous and they are isolated each other, such as LTE, Wi-Fi and W-CDMA. Therefore, we believe that the SDN/NFV architecture is potential to enable the novel radio infrastructure sharing in the next generation mobile internet or 5G.

The traffic volume and the massive mobile terminals for the future mobile Internet increase in form of orders of magnitude in the coming years and leads the eve of big data. The physical transmission and spectral efficiency is difficult to get promoted further, because the spectrum efficiency of LTE has reached within the twenty percent, which is very close to the Shannon’s capacity limit [2]. As a result, the heterogeneous radio access is a good way to offload traffic for the macro-cell networks to the dense deployed femtocells or Wi-Fi networks in the 5G. The dense small cell deployment without network planning appears to provide more opportunities per user through reducing the number of users per cell. However, it makes the network management complex under such an network architecture. Therefore, the SDN/NFV technique provides us a promising way to manage heterogeneous networks.

The second issue is the quality of user experience (QoE) is very important for the future user-centric and the service-oriented 5G mobile communication system. The challenge of inter-operability arises by the heterogeneous devices with the various data formats for the modeling information and the diverse protocols for the machine-to-machine (M2M) data exchange, which is often dictated by the legacy needs and the specific application scenario. The system capacity is not the unique metric for more and more applications till now, but the strict latency and reliability requirements. In fact, some of the future applications require the end-to-end delay to reach a few milliseconds. In this way, the varying throughput, latency and jitter requirements of application enhance the complexity of state capture and resource provisioning. In addition, with the dynamics of traffic load from the mobile clients on the time and spatial domain, the efficient energy management of APs can enable a green communication system.

With the observations above, we are motivated to propose a Software Defined Wireless Network (SDWN) architecture for the 5G communications to simplify the network management. The main contribution in the paper can be summarized as two. One is a proposal of multi-tiered cloud controller architecture and event processing mechanism design proposed for the SDWN based 5G networks. The other is a methodology of prototyping with the scenarios under the defined SDWN architecture. Four typical scenarios have been implemented initially and envisioned for the SDWN based 5G networks.

The organization of this paper is defined as following: In the Section II, we reviewed the background of SDWN and the new concept of 5G mobile communication. Then, we defined a multi-tiered software defined architecture

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Corresponding author email: guolin.sun@uestc.edu.cn
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for the heterogeneous RANs in the Section III, which enables the coexistence of multi-RANs and decouples the data/control planes with an Openflow interface on the radio infrastructures. Section IV presents an initial system prototype design and implementation of SDWN based 5G mobile system with new features. In the end, we make conclusions of the paper in the Section V.

II. Background of SDWN and Openflow Research

The vision of 5G mobile communication is dedicated to meet the new requirements of huge capacity, massive connectivity, high reliability and low latency. The more detailed requirements on quantity in the 5G/2020 mobile network from the EU project METIS was envisioned and summarized in the Table I.

TABLE I: Requirements and Application Examples[3]

Requirement	Desired Value	Application example
Date Rate	1 to 10 Gbps	Virtual reality office
Data Volume	9 Gbyte/hour in busy period 500Gbyte/month/s ubscriber	Stadium Dense urban information society
Latency	Less than 5 ms	Traffic efficiency/ safety
Battery Life	One decade	Massive deployment of sensors and actuators
Connected devices	300000 devices per AP	Massive deployment of sensors and actuators
Reliability	99.999%	Tele-protection in smart grid network, Traffic efficiency and safety

The Openflow is initiated at Stanford University and it is a protocol to enable switches on the wired networks programmable via a standardized interface [4]. Openflow protocol was standardized by the ONF to mitigate the OpEx and CapEx, simply the network management and speed up the network innovation [4]. In this paper, a multi-tiered SDWN architecture is proposed for the 5G considering the coexistence of heterogeneous wireless networks with the Openflow. Most recently, the SDN and Openflow techniques have been extended to the wireless network area [5]. OpenRadio suggests an idea of decoupling control plane from data plane to support ease of migration for mobile users from one type of network to another easily in the physical and MAC layers [6]. CellSDN enables policies for the cellular applications dictated by the subscriber needs, instead of the physical locations, providing a better control of data flows than before [7]. The OpenRoad prototype supports a seamless handover between the WiFi and WiMax networks when video data is streamed, the OpenFlow controllers [8]. The SDWN controller deals with the seamless handover problem between the Wi-Fi and WiMax successfully. Till now, Openflow has been used in wireless mesh network [9], sensor networks [10], and cellular networks [6], [11]. The flowvisior maybe an initial NFV technique for SDWN [12], [13]. In addition, SDWN has been proposed to manage the multiple networks of the internet of things (IoT) [14]. The abstract mechanism out of the network heterogeneity in IoTs is also be supported. Furthermore, the framework must support the north-bound higher layer interactions to the various heterogeneous applications and requirements. In this paper, we propose a 5G mobile network oriented software defined network architecture and provides a methodology of prototyping.

III. Architecture Design in Software Defined Wireless Networks

A. *Multi-tiered Cloud Controller Architecture*

With the vision of ubiquitous cloud radio access for the next generation mobile communication, we assume that eNodeBs or STAs can be reconfigurable on the baseband and the radio in a large range of frequency spectrum with software defined radio techniques. We attempt to analyze the requirements with our vision. The proposed control plane is expected to manage the radio resource in a cubic space in the coexistence environment of heterogeneous wireless networks. The interference appraisal mechanism and the event detection mechanism are provided with the network state monitoring. Once the controller detects the event happened, controller will decide to send clients the specific command. This kind of decision method should be apparent to clients, and the QoE should be considered within it.

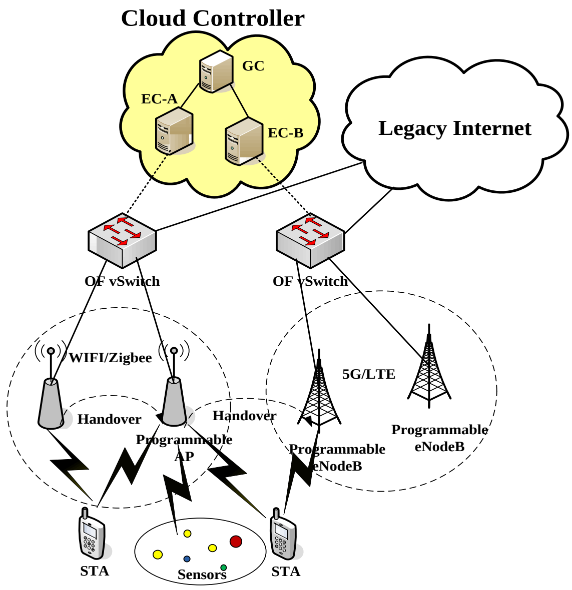

Fig. 1 SDN-based 5G oriented network architecture

In order to reduce the response latency and balance the network load for a cloud of controllers, we propose a layered cloud net architecture for multiple controller deployment with two entities: Edge Controller (EC) and Global Controller(GC). The EC processes the event within single a RAN domain, and the GC deals with the inter-domain events across various RANs. For example, the EC-A manages the RAN1 in the Fig. 1, e.g. Wi-Fi network. The EC-B controls RAN2 in the Fig. 1, e.g. 5G/LTE programmable eNodeBs, The GC will deal with the events generated across at least two heterogeneous networks, e.g. Handover between LTE and Wi-Fi. The GC is also an entrance of access backbone Internet. For example, the EC-A, which is a Wi-Fi network controller, scans the spectrum on 2.4GHz, 5.8GHz or UHF TV white spaces and then makes a decision for a STA to handover from the 2.4GHz band, a very crowded band, to the UHF TV white space based on the network load monitoring [15]. If no more "right" APs found, the EC-B will send this request to the GC, GC knows a LTE HeNB available to connect to this STA. Thus, it allows the STA access any spectrum bands on any radio infrastructures around it ubiquitously and roams among any type of RANs around it without any prior knowledge.

The QoE aware radio resource management is an essential function in the GC and the EC, as shown in the Fig. 1. The event processing in the SDWN controller fulfills a cognitive procedure. First, the EC can gather the statistics at all of the APs within a network into database, as is known as network monitoring. Second, the EC will parse, dispatch and handle the coming events from the monitoring server and mobile clients. According to the event type, EC will deliver it to the on-line transaction processing (OLTP), the on-line analytical processing (OLAP) block, or redirect it to the GC. The component of OLTP as well as OLAP handles the events with some predefined algorithms, called as an algorithm platform in the prototype. Normally, the OLTP handles the time-constraint and the low-level events with the real-time measurements, e.g. event of spectrum access. The OLAP handles the high-level events due to the historical data changes in network, e.g. load balance on mobile handover. Third, the EC often makes decision to issue the specific control command on network with the aid from a volume of historic statistics. For example, the LC sends a control command to an AP to instruct it to update its working frequency band. The cognitive resource manager and the event_handler could be defined with software and programmable.

Furthermore, NFV extends the capability of SDWN based 5G network to allow the multiple virtual operators sharing the infrastructures and resources. As an example, the NFV maybe decouple the network operating from the physical owning. New spectrum usage paradigms will be enabled such as the spectrum slice leasing and trading. Each slice could be tagged in their defined name space according to some attribute of subscribers, policy and so on. The slice in a virtual cloud of RANs allows dynamic spectrum access on demand for the clients, just like our daily water drinking and gas firing. The client can access Internet and information around it without care of the type of radio access networks and the network operator.

B. Monitoring and Event Handler

Network monitoring is a fundamental component and the source of network intelligence the future 5G networks. The network monitoring includes two: the collection protocols and the network statistics. In this paper, we define the monitoring with types of controller, e.g. Inside-domain EC and Inter-domain GC, with the event handler type, e.g. OLTP/OLAP. As an example, we summarize some potential statistics for a cloud radio access/handover scenario in the Table II.

TABLE II: THE STATISTICS FOR CLOUD RADIO IN OLTP/OLAP

Event-Handler	Scenarios	Statistics collection for cloud radio access/handover
OLTP	Radio Cloud Access	RSSI, Policy/Interest
	Proactive cloud handover	Policy/Interest, RSSI
OLAP	Reactive Cloud Handover	Traffic load/Power saving/ Channel quality report/ Channel utilization rate
	QoS aware Cloud Traffic Engineering	End-to-end latency /Packet error rate

The SDN architecture provides us the context sensing capability with network intelligence in the future network. The controller can manage and coordinate radio resources in an user-centric manner, including spectrum utilization rate, the number of associated clients, the traffic load of each AP, the SINR/RSSI of each client are all potential statistics in the monitoring component. On the other hand, the collection protocol design is an important issue in the network monitoring. The basic requirements of scalability, efficiency and latency should be considered. The SNMP protocol is a basic design option in the prototype due to its popularity on the industry products. The snmp_agent on each AP collects statistics from the radio environment and the signal characteristics based on the specific air interface, e.g. 3GPP. The snmp_mod gathers the statistics from the Openflow enabled APs as a SNMP manager. The algorithm platform queries information from the database with a configurable period via Jason, XML etc.

C. Data/Control Plane Decouple

The mobility and radio resource management are two of the most important function entities in the defined 3GPP architecture. The decouple of control plane from the data plane on the original infrastructures will migrate to the cloud of controller, so the Home-eNB and Wi-Fi AP are pure infrastructures for physical transmission and data transfer. In the Fig. 2, the data and control paths are drawn separatedly in blocks. As the Security Link (SSL) channel transfer the control and the data packets without entries in the flowtable both, it includes control/data path both. Furthermore, the physical transmission is assumed to be reconfigurable with software defined radio(SDR) techniques in the Fig. 2, such as 5G, LTE, CDMA and Wi-Fi.

The data plane forwards data packets via the Openflow datapath. Openflow protocol provides a flexible flow-based forwarding management method to allow operators to distribute their own data plane rules over the cheaper switches and handle the traffic controls over radios. However, the abstraction of data operation command for the 5G wireless network is still open to extend Openflow. The infrastructures include Openflow switches and radio APs. Each AP is configured with various radio interfaces, e.g. 5G, LTE and Wi-Fi. The common Ethernet card should support two logical interfaces, e.g. SSL for the event reporting and SNMP for the monitoring. A sensing agent is used to collect the MIB info. from each protocol layer, e.g. SNMP. For example, *SNMP_agent*, defined in the prototype, provides us the throughput and the packet error rate within the physical and radio modules and channel utilization rate in the registers of CPUs. The control agent, *CtrlActor*, is implemented in the simulator. It is employed to carry out the decision on network control. The control signaling will be decoupled from data transmission to enable cloud MAC via the SSL to a cloud of controllers. The logical architecture in the Fig. 2 provides a paradigm of transparent resource slicing and allows each slice its own separated radio and base-band.

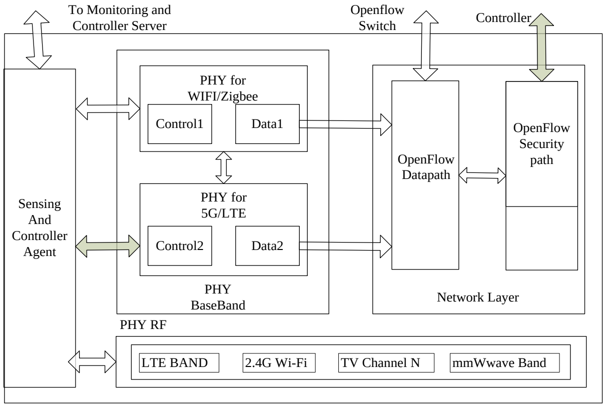

Fig. 2. Data/Control decouple architecture of OF-AP.

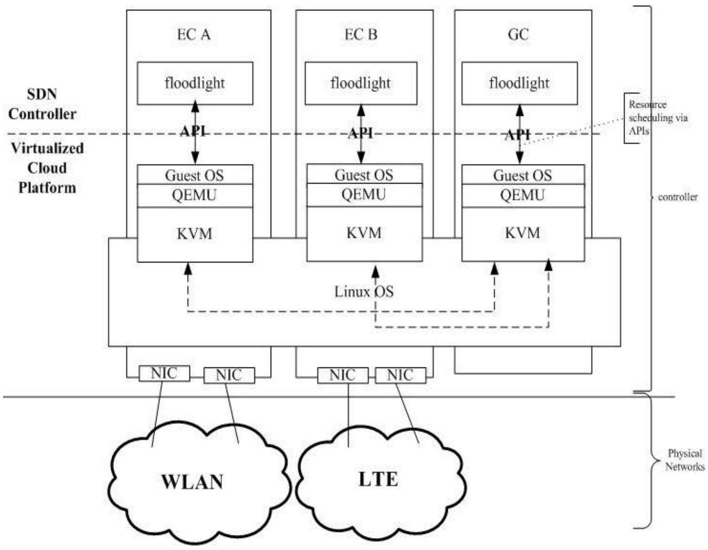

Fig. 3. Virtualization architecture of a cloud-controller.

IV. Implementation of SDWN Prototype and Simulator

The current prototype includes a cloud of controllers, an open-flow switch, and a network simulator. One GC and two ECs are implemented in this cloud of controllers in this prototype with the virtualization techniques, as is shown in Fig. 3.

The system architecture of prototype with a multi-tier cloud of controllers and an open-flow enabled network simulator is illustrated in the Fig. 4. The data flow is drawn in a red line but the control flow in blue line. Till now, four new applications have been supported for the 5G network in this prototype: the ubiquitous cloud radio access/proactive/reactive handover, the wireless topology discovery, the extended monitoring of localization, and the energy management. In general, a cloud radio access is defined as a real-time event, however, the proactive handover based on load balance is a non-real-time event.

A. Cloud-Controller Virtualization Implementation

In the virtualized cloud controller platform, the KVM and the QEMU are combined together to implement the virtualized cloud platform. The KVM project maintains a fork of QEMU as qemu-kvm [16]. Till now, it provides the best performance and certain additional features for using KVM with QEMU on x86 [17]. Floodlight is an enterprise-class, Apache-licensed, Java-based controller developed from the Big Switch Networks with Openflow [18]. In the prototype, two ECs communicate with the GC via virtualized 'bridges'. The cloud of controller provides two south-interfaces to the physical networks, e.g. 5G, LTE, WLAN with the NICs. With the absence of radio infrastructures with Openflow, we implement a software network simulator on a computer to mimic the behaviors in the scenarios of the future networks with an Openflow interface and a SNMP interface.

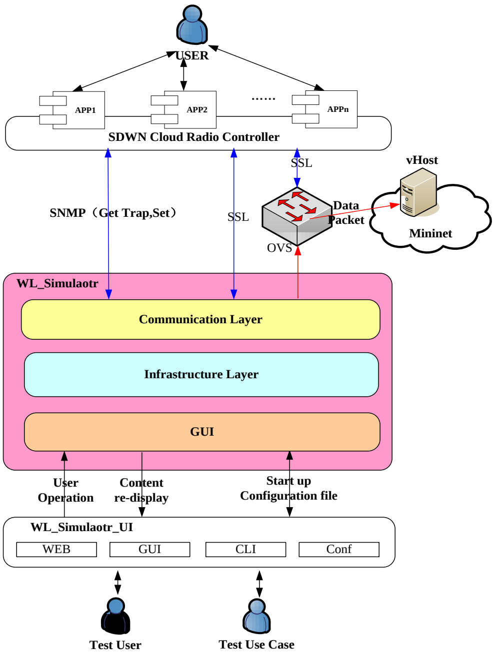

Fig. 4. System architecture for SDWN simulator prototype

B. Controller Architecture for 5G Wireless

The module-level software architecture of controller and the network simulator is given in the Fig. 5(a) and Fig. 5(b). Communication layer is responsible for message exchange function with the forwarding infrastructure as a southern-interface to the controller. In this system, the communication layer provides us two function entities: SNMP_Mod and SSL_Mod. SNMP_Mod provides for Get, Set and Trap functions defined in SNMP. SSL_Mod completes a SSL channel to interact with the network simulator as a SSL server. The control message is encapsulated in an Openflow frame. Logic control layer is responsible for the wireless related logic control functions. Based on the specific configuration defined by algorithms, Monitoring module collects the state statistics and the properties of radio devices periodically, sends and stores information from the communication layer to the database. Algorithm module takes messages from the real-time monitoring modules, e.g. proactive handover. Then it makes decision, and notifies the instruction_set module what is the specific action. In accordance with the requirements, Algorithm module queries the related data in the database and computes with the algorithm. With the calculation result, it sends a specific command to the module of instruction_set and it encapsulates operation instructions of network control in the command to the forwarding pieces via the appropriate APIs. Persistence layer does data operations, which persists to the database and provides an user-friendly API to user. Presentation layer provides user a visualized profile of network view.

C. Open-Flow Wireless Network Simulator

The WL_Simu_Comm is responsible for the message delivery and communication among the controller, Open-Flow Virtual Switches (OVS) and the network simulator. The device emulation layer WL_Simu_dev receives the control messages from the WL_Simu_Comm, and also sends data packets to the OVS. Therefore, there are two separated channels between the communication layer and the device emulation layer, a control message channel and a data transfer channel. Since the control messages come from the SSL/SNMP communication mechanism, so there are two agents in this WL_simulator, the SNMP agent and the SSL agent. However, all of the control instructions should go through the CtrlActor sub-modules into a unified device emulation layer. CtrlActor will collect the measurements of each pair (STA, AP) once it received the SNMP_get commands. The Packet_builder will generate the data packets based on commands of AP and STAs. WL_simu_confparser is an interface provided for users to configure the initial network when it starts up. The WL_simu_user_api allows users to modify scenario configuration dynamically after it begins to run.

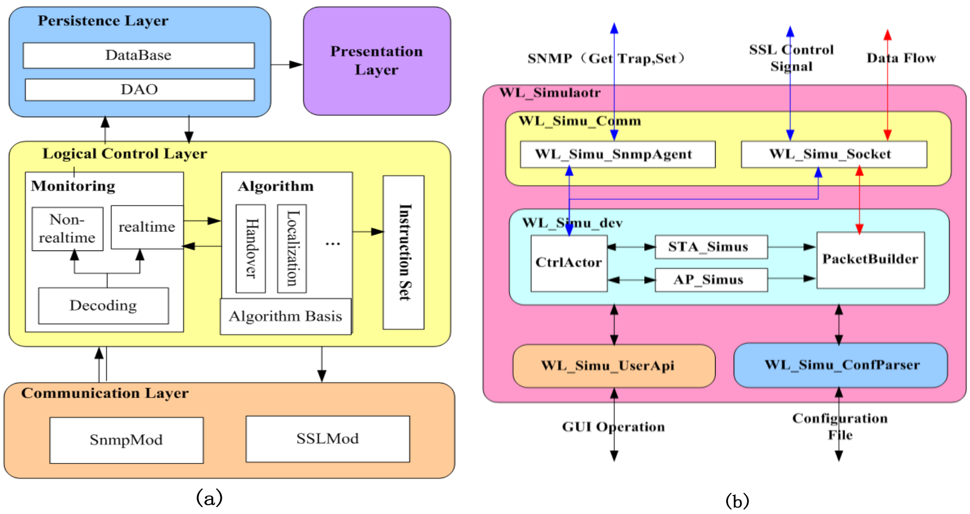

Fig. 5. Software architecture for controller and simulator

V. Services and Application Scenarios

A. Scenario: Cloud-MAC and Handover

The overall handover procedure is divided into 3 parts: network statistics collection, switch decision, perform operation. The initial scenario is configured with two APs and two STAs, as shown in the Fig. 6. The two STAs are both associated with one common AP. The decision algorithm is executed to switch this STA to another AP with the lightest load, because the handover rule is to choose a STA with the worst signal quality under an AP with the heaviest load.

The scenario B has shown us the handover procedure when an AP is power on/off in the Fig. 7. Once an AP is down in order to save power in a green network operation, the STAs associated with this AP will be switched to another AP with a more light load. Both of the STAs will be off-line when all of the APs around are down. Once another AP is up again, the free STAs will connect it. However, the problem of cloud MAC is still open for the 5G networks. To promote resource utilization efficiency, a cloud-MAC is proposed for wireless network [19].

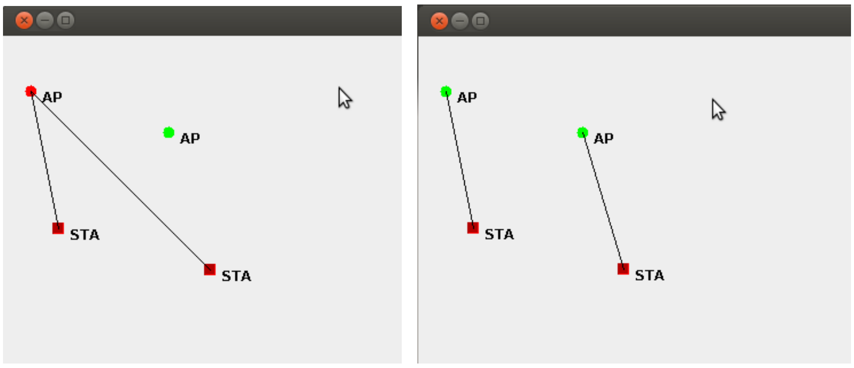

Fig. 6. Use case: Cloud radio handover scenario A

Fig. 7 Use case: Cloud radio handover scenario B.

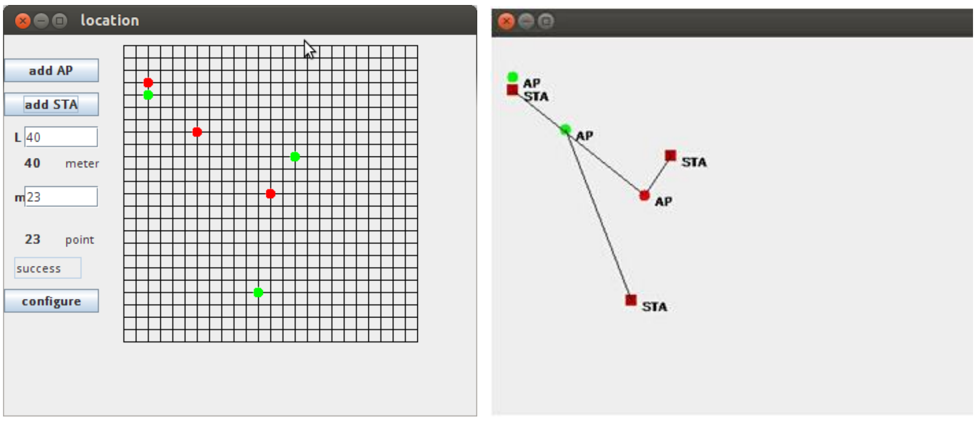

Fig. 8. Use case: Extended radio topology discovery

B. Scenario: Radio Topology Discovery

Topology discovery has already been an module in the popular SDN controllers, e.g. NoX. In this prototype, we extend the network topology discovery in the open-source controllers to wireless support.

We configure the radio topology with the GUI in the left of the Fig. 8. The controller draws the radio topology by querying data from the database. In the Fig. 8, a green circle point means an AP and a red circle point is a STA. If a STA is associated with an AP, there will be a straight line among them. The entire topology keeps tracking the actual network state. However, the latency and scalability of SNMP is not good in our experimental test. This is still an open problem for the 5G network.

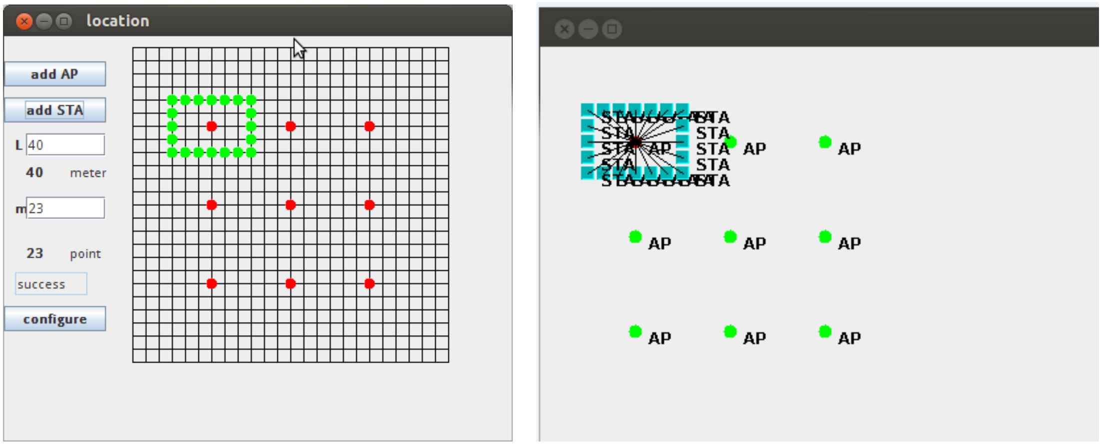

Fig. 9. Use case: Extended group localization monitoring

C. *Scenario: Localization Monitoring*

The GUI of scenario configuration is shown in the left of the Fig. 9. We define an area of length 40X40 meters with 23X23 grid points in the scenario. We can click the add_AP and add_STA button to add APs and STAs on the grid. In the Fig. 9, we configure 9 APs and 20 STAs. All of the STAs associated with a common AP on the up-left corner. The right figure is the estimation result shown on the controller side. The blue points are the estimated positions of STAs with the compressed sensing method.

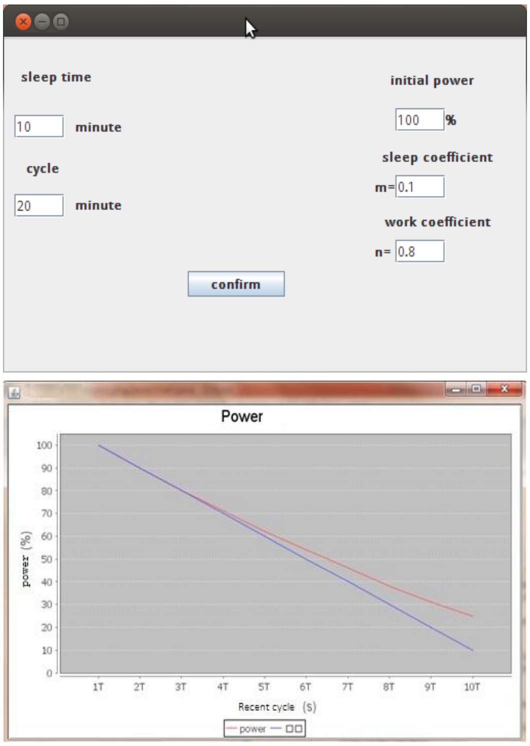

Fig. 10. Use case: Power saving for network management

D. *Scenario:Green Network*

The configurable parameters in the simulator include sleep time, cycle period, coefficient of sleep duration and initial power of AP/nodes. The snmp_manager gets the current power of APs through the get method provided by SNMP each cycle. The snmp_agent queries the power value of a specified AP and sends it to the snmp_manager using the response method in the snmp. snmp_manager draws the curve with the data through an interface, jfreechart. The curve in red is a test result of sleep mode. snmp_manager sets a sleep cycle for the AP with the set method. The curve in blue is a test result without sleep mode. In this figure, there is an apparent difference between two curves. The energy consumption of APs with the sleep mode can be reduced than the APs without the sleep mode. In fact, this feature can be used by energy management for the green 5G networks.

VI Conclusion

This paper presents a critical study on an user-centric, service-oriented, Openflow enabled SDWN architecture for the 5G network. We proposed a network architecture with decoupling data/control planes on the Openflow enabled infrastructures in this paper. Then, we provide a methodology to develop a prototype platform with this proposal. Furthermore, an initial system prototype with new features is developed for the 5G network. In the future, we prototype the Openflow enabled hardwares for Wi-Fi networks, e.g. Openflow Wi-Fi APs.

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Guolin Sun was born in Hebei Province, China, in 1978. He received the B.S., M.S. and Ph.D. degrees all in Comm. and Info. System from the University of Electronic Sci.&Tech. of China (UESTC), Chengdu, China, respectively in 2000, 2003 and 2005. Since the Ph.D. graduation in 2005, Dr. Guolin has got eight-year industry working experiences on wireless research and development for LTE, Wi-Fi, Internet of Things (ZIGBEE and RFID, etc.), Cognitive radio, Location and navigation. Before he join the School of Computer Science and Engineering, University of Electronic Sci.&Tech. of China, as an Associate Professor on Aug. 2012, he worked in Huawei Technologies Sweden. Dr. Guolin Sun has filed over 30 patents, and published over 30 scientific conference and journal papers, acts as TPC member of conferences. Currently, he serves as a vice-chair of the 5G oriented cognitive radio SIG of the IEEE (Technical Committee on Cognitive Networks (TCCN) of the IEEE Communication Society. His general research interest is 5G/2020 oriented wireless network, including software defined wireless networks, network function virtualization, 5G oriented cognitive radio.

Feng Liu, was born in Beijing China. He received his B.S. in the Telecommunication Engineering from the Tongji University, Shanghai, China in 2005. Since 2013, He is pursuing a master's degree at the School of Computer Science and Engineering in the University of Electronic Sci.&Tech. of China (UESTC), Chengdu, China. After graduation, he worked with Huawei Technologies first, and has got five-year industry working experiences on the embedded system development and architecture design for router, switch and Wi-Fi access controller. After that, he worked for ZTE Communications, and research for OS virtualization. Till now, he has filed 2 patents. His general research interest is system architecture design on the communication equipment, including software defined networks, OS virtualization.

Junyu Lai was born in Sichuan Province, China, in 1981. He received the B.S. and M.S. degrees in Computer Science from Chongqing University in 2003 and 2008, respectively. Starting from 2008, he has been in the Computer Science Department, University of Hamburg, Germany, doing his Ph.D. After getting the Ph.D. in Sep. 2012, Dr. Lai carried out his new job in NEC Labs China, acting as an associate researcher and a project manager on the research topics, such as cloud data center and software-defined wireless networking (SDWN). Starting from Feb. 2014, Dr. Lai became an associate professor in the University of Electronic Sci.&Tech. of China (UESTC), Chengdu, China. His current research interests focus on Software-defined networking, more efficient video transmission technologies on the next-generation mobile networks (5G), etc.

Guisong Liu received his B.S. degree in Mechanics from the Xi'an Jiao Tong University, Xi'an, China, in 1995, the M.S. degree in Automatics and the Ph.D. degree in Computer Science both from the University of Electronic Science and Technology of China (UESTC), Chengdu, China, in 2000 and 2007, respectively. Now He is an associated professor in the School of Computer Science and Engineering, UESTC. His current research interests include computational intelligence, pattern recognition and machine learning.

