Leveraging SDN/NFV as Key Stepping Stones to the 5G era in Emerging Markets

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***Abstract*— The proliferation of mobile devices and the advent of bandwidth hungry applications are expected to drastically increase in the foreseeable future. This growing trend has been the key motive behind the development of the 5G standard. 5G is envisaged to cater for this rapid growth in user traffic, while providing ubiquitous connectivity for any kind of device and diverse applications with different requirements. However for 5G to be deemed the "silver bullet" technology, it needs to be studied in the context of emerging markets, where there is limited infrastructure to satisfy the requirements of 5G. Software Defined Networking (SDN) and Network Function Virtualization (NFV) have emerged as promising paradigms that can be adopted to pave the way for 5G in emerging markets. In this paper we give an overview of the roles of SDN and NFV in enabling 5G technology specifically for emerging markets and propose a model for rapid rural infrastructure rollout thereof.**

Keywords—SDN; NFV; Emerging markets; 5G

I. Introduction

According to the Cisco white paper, the number of mobile devices has surpassed the total population of the world [1]. In addition to this, the number of mobile devices is anticipated to rapidly increase by 2020. This means in the near future, mobile networks will be subjected to massive traffic volumes with less predictable traffic patterns. This will present challenges on future network management. This is primarily because current mobile networks are monolithic. There is a challenge of vendor-lock in, which presents interoperability challenges between heterogeneous devices and impedes competition in the telco industry, thereby escalating the cost of hardware (e.g. base stations) required for mobile communications. As a result, mobile operators are apt to invest last to increasing the number of base stations because of the cost. Similarly customers are unlikely to want to pay more than they are paying today for services. This problem is more prominent in emerging markets where the high cost of mobile broadband continues to perpetuate the digital divide between rural and urban areas. According to *Johansson et al* [2], billions of people in the world remain offline, with a huge portion of this coming from emerging markets. An important question that must be promptly addressed is how to improve the current mobile network architecture to cater for thousands of mobile devices without increasing mobile broadband costs including CapEx and OpEx.

The fifth generation (5G) technology is envisaged to deliver massive connectivity to enable massive machine type communications (mMTC), ultra-reliable low latency communications (URLLC) to support mission critical applications and enhanced mobile broadband (eMBB) to enable video-related services [3]. At this juncture, the implications of rolling out 5G technology in emerging markets have not been given significant attention. Whether 5G will perpetuate or bridge the digital divide still remains a debatable topic. This is because there is currently not much infrastructure in rural and sub-rural areas thus limiting the deployment of 5G to metropolis, which are in most emerging markets infrastructure rich. Moreover fiber rollout is poor in emerging markets because of its cost, and this is indispensable to meet the ultra-low latency target envisioned for 5G.

To this end, Software Defined Networking (SDN) and Network Function Virtualization (NFV) paradigms have emerged as key enablers of the 5G technology in emerging markets. These paradigms aim to move the mobile network from its vertically integrated monolithic nature to a flexible, vendor-agnostic and programmable service delivery platform. In this paper we outline how these paradigms can be used to enable 5G in emerging markets.

This paper is organized as follows: Section II gives an overview of the vision of the 5G technology. Section III describes how SDN can enable 5G. Similarly, Section IV describes the role of NFV in 5G. Section V presents a model for SDN/NFV to realise 5G in emerging markets. Section VI describes future work, and lastly section VII concludes the paper.

II. Vision of 5G

5G technology is a cellular standard developed specifically to keep up with the proliferation of internet-enabled devices. This technology promises to deliver URLLC for critical IoT (such as remote health care, autonomous cars, smart grid automation, etc.), mMTC for massive IoT (smart metering, smart building, smart agriculture, etc.), and eMBB for video-related services, while enforcing improved security policies. The 5G roadmap constitutes two streams namely, LTE-5G and New Radio-5G (NR-5G) as shown in Figure 1. The LTE-5G stream focuses on enhancing the mobile core in an effort to support as many requirements and use cases of 5G as possible. On the other hand, the NR-5G stream focuses on developing a new interface that targets spectrum at high (mmWave) frequencies.

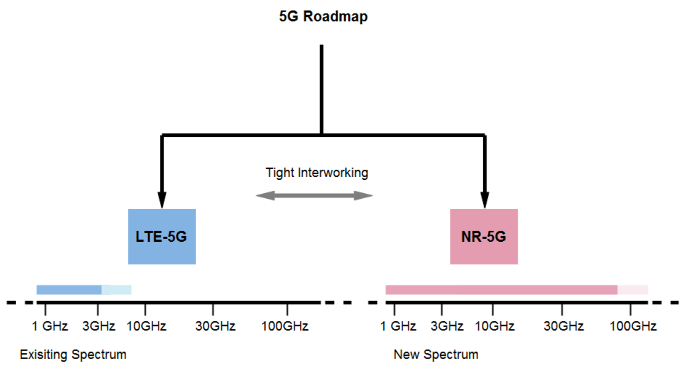

Fig. 1. 5G radio access roadmap

In order to realize its goals, 5G aims to capitalize on advanced technologies such as FD-MIMO and cloud RAN (C-RAN).The adoption of FD-MIMO is expected to significantly improve spectral efficiency of cellular networks. Another 5G enabling technology is C-RAN, wherein the baseband unit (BBU) is centralized and shared among remote radio heads (RRHs).

The fronthaul technology employed between the C-RAN and RRHs is paramount to meet the requirements of delay sensitive applications. A consensus was reached that only fiber coupled with technologies such as dense wavelength division multiplexing (DWDM) and reconfigurable add-drop multiplexer (ROADM) is capable of supporting the staggering data rates between the C-RAN and the remote radio heads [4]. This requirement constitute the shortcoming of C-RAN in that fiber is very expensive, thus limiting the deployment of 5G to areas with existing fiber or areas that can afford to deploy fiber access. Therefore this has a potential to aggravate the digital divide in emerging markets due to lack of fiber infrastructure in rural/sub-rural areas.

5G is envisaged to be built in a way to enable network slicing. This approach involves the partitioning of a single physical network into isolated virtual end-to-end networks with virtual network performance guarantees. Mobile networks have traditionally been optimised primarily for phones. However since 5G aims to converge diverse devices (such as sensor networks, vehicles, and mobile phones) it is reliant on network slicing to serve different devices maintaining fair QoS. We strongly believe that SDN/NFV are attractive paradigms that may be leveraged by emerging markets to pave a way for the 5G era.

III. SOFTWARE DEFINED NETWORKING (SDN)

SDN is bringing about a paradigm shift through the separation of the control intelligence from the forwarding elements, which conventionally have been fully coupled. The control intelligence is logically centralized in an entity called a controller which is directly programmable by applications via northbound interfaces. The controller uses a southbound interface (e.g. OpenFlow) to enforce new policies and program packet forwarding instructions. SDN's promise for commoditization of the forwarding elements opens unprecedented opportunities to network virtualization. We see this as cornerstone to realize 5G in emerging markets.

Currently, operators are reluctant to extend quality broadband internet to rural and sparsely populated areas because of the potential low return on investment (ROI) and the difficulty in upgrading the required hardware. Recently there have been many technical and regulatory innovations aiming to increase broadband penetration in rural areas. These innovations include but are not limited to long-distance Wi-Fi and TV White Spaces (TVWS).We believe SDN is the most attractive solution in comparison with the aforementioned alternatives. This is largely because the separation of the intelligence from the network construction will enable network commoditization which has significant cost benefits in terms of CapEx and OpEx. Furthermore this decoupling means that emerging markets can have infrastructure providers (RInPs) who are specially committed to the physical construction and maintenance of the rural network, with network management and configuration conducted remotely by a separate established telecom company [5]. This opens up new business models in that RInPs would, rather than directly providing service to subscribers, lease their infrastructure to multiple existing established ISPs. The role of RInPs is thus reduced to simply building the physical infrastructure and ensuring that it can be managed by an SDN controller. Leasing to multiple ISPs will be enabled by network slicing also known as network virtualization, which is a use case of SDN. This model is beneficial to rural subscribers since it reduces barrier to entry for new entrants, thus enhancing quality of service (QoS) and cost of broadband in rural areas.

Another opportunity presented by SDN in emerging markets involves skills sets required for infrastructure construction, maintenance and configuration. The skills required for these tasks are completely different and infrastructure providers must either maintain separate staff for each or invest on training its staff on both areas. The latter would mean more money spent on staff wages while the former will reduce specialization which may compromise quality of service (QoS). Therefore outsourcing network management and configuration will significantly reduce OpEx while maximizing profit margins.

IV. NETWORK FUNCTION VIRTUALIZATION (NFV)

NFV has emerged as a complimentary technology of SDN. The aim of NFV is to replace the conventional, expensive and dedicated network functions such as firewall, load balancer, and DPI with software running on high volume commercial off-the-shelf (COTS) servers. The software functions are stitched and chained dynamically to create the same services provided by legacy networks. Due to the surging demands in mobile connectivity, the conventional approach of using black box network appliances inevitably extends service deployment time (CapEx) and requires a competitive staff (OpEx) to deploy and run new appliances. The use of COTS hardware improves time-to-market new services and it enables convergence of heterogeneous network appliances.

One of the important use cases of NFV is the virtual evolved packet core (vEPC) [6], where the EPC software is run on COTS instead of proprietary hardware. This means that the EPC can be deployed on small efficient COTS servers in rural areas, with additional servers added when needed. This approach will result in a flexible, robust, and easily manageable core; a core that can be scaled on-demand. Thus leveraging NFV to virtualize the mobile core creates new revenue streams for the telco industry through improved service agility (shorter deployment cycles, dynamic capacity) and operational efficiency (minimal staff, vendor-agnostic hardware). This is likely to foster broadband penetration in rural areas.

As introduced in section II, another use case of NFV which is important to pave a way for 5G in emerging markets is C-RAN. NFV enable a new level of sharing RAN resources by pooling the baseband processing resources from multiple base stations and centralize them in commodity hardware. This means that new BBUs can be easily deployed, thereby improving scalability and simplifying network maintenance. It has been reported that a large percentage of energy consumption comes from the RAN [7]. This directly increases both the carbon footprint and energy cost. Unlike the monolithic traditional RAN architecture, C-RAN enables energy efficient network operation which directly lowers OpEx and carbon footprint. Another benefit of C-RAN is the capability to manage and dynamically allocate spectrum on-demand. This is especially important to optimize allocation of spectrum resources in multi-tenant networks, where the network infrastructure is leased to multiple MVNOs and ISPs provisioning diverse services to rural areas.

In the 5G era, carrier-grade networks will no longer use the closed, proprietary devices to provision as single service which presently proves to multiply CapEx and OpEx. Instead, carrier-grade networks will make use of open, flexible, vendor-agnostic white boxes, leveraging the dynamic service chaining approach to provide end-to-end services. The use of white boxes will expedite service deployment time, foster innovation, reduce entry barrier for new entrants and ultimately improve quality of service. This is especially important to meet the 2020 broadband targets in emerging markets.

V. PROPOSED MODEL

It is important that emerging economies reap the full benefits of 5G while enforcing ICT equality between rural and urban areas. The main obstacle to ICT equality in emerging markets is the lack of infrastructure in rural areas and poor infrastructure in urban areas and metropolis. This has resulted in lack of competition whereby established operators offer vertically integrated services and have the liberty to escalate broadband costs. This lack of competition impedes innovation, meaning that internet users are charged unfair prices for poor quality services. Therefore there is a need for rapid roll out of ICT infrastructure to help bridge the digital divide. This is inevitable to realize 5G in all areas of emerging markets, which will potentially improve the pace of economic growth [8].

We propose a model to enable 5G in emerging markets. This involves rapid deployment of infrastructure to the rural part of emerging economies, as depicted by Figure 2. In this model, there are four players namely, the Rural Infrastructure provider (RInP), the tenants (MVNOs, ISPs), the management and configuration IT company and the mobile subscribers. The RInP is responsible for the physical network construction and maintenance and has a contractual agreement with an external IT company, to manage and configure their network from a central location leveraging SDN. The RInP capitalizes on NFV to build their mobile core (vEPC) and C-RAN (RRH and BBU) for service agility and operational efficiency. Instead of using proprietary serving and packet gateways (S/P-GWs), the S/P-GWs along with the mobility management entity (MME) are virtualized and packaged as mobile applications running on top of the SDN controller [9]. Therefore the data plane only constitutes strategically located OpenFlow compliant switches (virtual and/or physical). The SDN controller is used for programmatic control of the mobile network. This includes programming forwarding instructions, dynamic resource allocation between slices and management of link layer resources on the fronthaul, all done via the southbound interface. The RInP leases the capacity of its physical network to different tenants enabled by the network slicing paradigm. Each tenant is allocated a slice of RAN assets (RRH and BBU), where resources such as spectrum, CPU and bandwidth are shared on-demand [10]. In addition to that, the RInP leases the mobile core (vEPC) to its tenants on-demand.

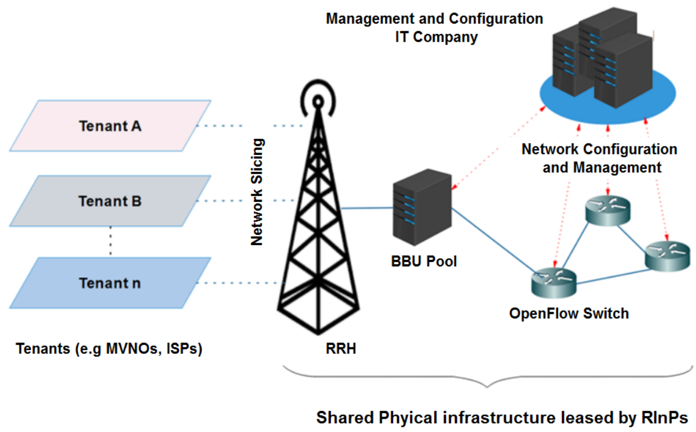

Fig. 2. SDN/NFV-based infrastructure deployment in rural areas

The principal benefit of infrastructure sharing includes CapEx and OpEx savings in that RInPs can subsidize the cost of rolling out and maintaining their network infrastructure by leasing capacity to virtual tenants, whilst the tenants can benefit from not investing on the own network infrastructure. Infrastructure sharing will offer RInPs the ability to package and lease spectrum more flexibly and in smaller chunks than has previously been possible. This will increase network capacity, thereby reducing barrier to entry for new entrants such as start-up companies and entrepreneurs thereby creating new revenue streams. Another potential yet important benefit of sharing infrastructure is service-centric networks which stimulates a shift from competition on the basis of network coverage to service-level competition amongst ISPs, MVNOs, and IT companies, promoting innovation and thus improving QoS and reducing the cost of broadband access in emerging markets. Lastly, infrastructure sharing is a greener option compared to the conventional monopolized model, because instead of deploying multiple infrastructures (e.g. antenna masts and BBUs), a common infrastructure is utilized by different tenants which reduces energy consumption especially during periods of low loads.

VI. Future work

While the promises of 5G are attractive, there is still a lot of work to be done in order to actualize these promises in emerging markets. To this end, there has been limited research on the implications of enabling 5G in emerging markets and the technical challenges thereof. Based on our proposed model, we have identified the following research challenges and it is our intention to study and try to address them.

A. C-RAN placement

Considering the fact that most rural areas are sparsely populated, optimal C-RAN placement is paramount. Thus to optimize metrics such as delay and jitter, it's is important to analyze the effects of placing the C-RAN at a particular location on performance of the radio access network to cater for delay sensitive applications in the 5G era. Optimizing C-RAN placement will not only optimize performance but is likely to reduce cost of deployment. This is called the RAN placement problem. We intend to build a testbed to enable the study of this research challenges and potential solutions.

B. Controller placement

To outsource network management and configuration, RInPs will require guaranteed QoS. Therefore it is important to evaluate the effect of controller location on the service quality with respect to metrics such as delay and jitter. Multiple controllers may be used to control segments of the network. Therefore an efficient placement strategy can deliver benefits such as load balancing and high availability.

C. Energy Efficiency in 5G Networks

Our intention in this space is to look at how energy consumption can be optimized to enable 5G in emerging markets. To this end, network operations have proven to consume a lot of energy resources. This has directly surged the OpEx. Our focus in this area would be exploring the implication of mobile "cloudification" (C-RAN, vEPC) on energy usage and how energy may be optimized in the 5G era.

VII. Discussion and Conclusion

In order to develop better coverage in rural areas, operators need to develop methods for quickly deploying and managing infrastructure at lower cost. This paper presented an architectural model leverging SDN and NFV as the ideal solutions to expedite infrastructure roll out in emerging markets. Furthermore SDN and NFV have proven to be the key enablers of the 5G technology in emerging markets. The underlying technology enabled by these two paradigms is network slicing also known as infrastructure sharing, which is indispensable to achieve the 2020 broadband targets. Adopting slicing for rural broadband will potentially stimulate service level competitions and innovation, resulting in improved broadband quality at reasonable CapEx and OpEx. This will potentially boost the pace of economic growth in emerging markets. However given the 2020 timeframe to deploy 5G and the regulatory challenges instigated by slicing the RAN it can be argued that rolling out the aforementioned infrastructure in all rural areas of emerging markets may not be feasible within the given timeframe. Since most of the ICT infrastructure is concentrated in the metropolis, it may be more beneficial to enable 5G technology on the existing infrastructure in parallel with rolling out the infrastructure to rural areas. However, there are a lot of open research challenges that must be thoroughly studied to effectively realise 5G in emerging markets (both rural and metropolis areas). These include, placement of network elements, security, energy efficiency, migration and regulatory implications. These have been left as future work.

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