Network Virtualization for Mobile Operators in Software-Defined Based LTE Networks

Omer Narmanlioglu
P.I. Works,
Istanbul, Turkey 34912
E-mail: omer.narmanlioglu@piworks.net.

Engin Zeydan
Türk Telekom Labs,
Istanbul, Turkey 34770
E-mail: engin.zeydan@turktelekom.com.tr.

***Abstract*—In this paper, we propose a novel cellular network architecture including network virtualization controller for mobile core and backhaul sharing. Software-Defined Networking (SDN) based network virtualization is applied into Evolved Packet System (EPS) architecture of Long Term Evolution (LTE) networks. After virtualization of all evolved Node-Bs (eNodeBs) associated with different Mobile Operators (MOs) as a consequence of mobile core and backhaul sharing, the performances of eNodeB assignment mechanisms with the use of quality-of-service (QoS)-aware and QoS-unaware scheduling algorithms are investigated and compared with currently deployed static eNodeB distributions through Monte-Carlo simulations. Jain's fairness index, Shannon capacity and satisfied-MO-ratio are considered as the key performance indicators (KPIs). The results reveal that our proposed architecture outperforms the currently deployed network architecture as depending on proper scheduler selection.**

***Index Terms*—Software-Defined Networking, Network Virtualization, Virtualization Controller, Long Term Evolution.**

I. INTRODUCTION

Developing new innovative solutions inside current network infrastructure with respect to today's requirements is becoming difficult every day due to the high complexity of networks [1] whereas backhaul of Mobile Operators (MOs) is expected to be similar to data centers with mesh network topologies. Therefore, currently utilized network structure has been posing several challenges and MOs have been looking for new solutions in order to overcome the increasing demands of network dynamics [2]. In respect to this, Software-Defined Networking (SDN) and virtualization paradigms are the major candidates to be further adopted into the next generation networks. SDN provides powerful and simple approaches to manage the complex networks by creating programmable, dynamic and flexible architecture, abstraction from hardware and centralized controller structure. In addition to SDN, network virtualization is another important paradigm for using network resources efficiently.

SDN and network virtualization paradigm based new cellular network architectures have been investigated in the literature [3], [4], [5]. In [3], software-defined based mobile network architecture that increases the operator innovation potential is presented. In [4], SDN-based control plane architecture with a showcase including mobility, hand-off and routing management is provided for 5G cellular network. SoftRAN [5] abstracts all base stations in a local area as a virtual big base station that is managed by centralized controller to perform load balancing, resource allocation, handover etc. It should be noted that in both currently deployed and above architectures, none of the MOs are sharing any resource or equipment and each one of them has deployed its own network equipments independent of each other (except as in a few countries where infrastructure is shared for both 3G and 4G cellular networks). Taking into account these facts, there have been several drawbacks of those network structures. Deploying infrastructure network equipments all the time at high capacity of operation is both costly and inefficient for both infrastructure providers (Backhaul Transport Providers (BTPs) that are deploying and providing the infrastructure) and infrastructure users (MOs that are paying for the infrastructure). In respect to this, network sharing in the context of relationship between third parties and MOs has been widely discussed, most of the related works [6], [7] are in the context of economic advantages that network sharing can introduce. On the other hand, applying both virtualization of mobile core/backhaul and as a consequence dynamic assignment of virtualized resources such as evolved Node-Bs (eNodeBs) to different MOs based on their traffic demands which come basically from their respective subscribed user equipments (UEs) can provide several opportunities. None of the above works, however, consider this type of sharing architecture.

In this paper, we propose an SDN based virtualization controller architecture for not only RAN equipments but also mobile core and backhaul sharing. After achieving the virtualization of core/backhaul network equipments, all eNodeBs associated with different MOs become a part of resource allocation problem for BTP. In the proposed architecture, a network virtualization controller that is directly connected to the SDN controllers of each MO and managed by BTP is used to adaptively perform eNodeB assignment among MOs under the consideration of time-varying numbers and locations of associated UEs and MOs' demands. Quality-of-service (QoS)-aware and QoS-unaware schedulers executed in virtualization controller are used while assigning eNodeBs to each MO. The performances of proposed architecture using several scheduling algorithms are compared with currently deployed static eNodeB distributions through Monte-Carlo simulations and the results reveal that our proposed architecture outperforms the static assignment in terms of Jain's

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fairness index, Shannon capacity and satisfied-MO-ratio as depending on proper scheduler selection.

II. PROPOSED SYSTEM ARCHITECTURE

SDN allows the capability of adaptive virtualization based on different scenarios including topology, hardware, device central processing unit (CPU) and bandwidth of the individual links with priority settings within the network amongst MOs. The network virtualization can readily apply to the provisioning of a shared Evolved Packet System (EPS) architecture of Long Term Evolution (LTE) networks where the streams of different MOs are isolated from one another and each MO can control its own allocated slice of the network without any regard to the other MOs sharing the same network. The network slices allocated to the individual MOs can be managed by an entity called BTP which controls the network infrastructure via a Virtualization Controller (e.g. OpenVirteX [8]). This controller acts as the transparent proxy between multiple controllers and forwarding elements that can create multiple slices of network resource based on different slicing dimensions such as bandwidth, topology, forwarding table or device CPU. It provides addresses for keeping address spacing separate and topology virtualization for enabling tenants to specify their topology with resiliency for underlay networks. Note that SDN controllers inside each MOs control the demand requests of each user as well as establish bi-directional communications with virtualization controller where OpenFlow proxy is present.

In currently deployed Radio Access Network (RAN) architecture, the location and number of eNodeBs associated with each MO are predetermined under the consideration of several parameters such as average UE distributions and traffic loads, and they cannot be instantaneously changed with a remote controller. However, when all eNodeBs are virtualized as a consequence of virtualization of core and backhaul networks and managed by a virtualization controller, dynamic eNodeB assignments to each MO with respect to their active UEs numbers associated with different MOs, their time varying traffic demands and locations can provide many benefits. These benefits can be efficient usage of network devices (e.g. eNodeBs, Serving Gateways (S-GWs) and Packet Data Gateways (P-GWs)), balancing traffic demand/usage behaviour via dynamic scaling of the network, automation of provisioning and multi-tenancy opportunities. However, with the increased number of MOs, eNodeBs or UEs, increment of the eNodeBs allocation delay compared to existing architecture is one of the drawbacks of the proposed architecture. The amount of allocation delay is a bottleneck to meet the QoS requirements in the areas which have a high dynamicity in very short time scales since slicing allocation interval (SAI) (which will be explained in the following section) cannot be lower than this amount of delay.

In our scenario (see Fig. 1), a network virtualization controller which is owned by BTP is also directly connected to the SDN controllers of each MO. This virtualization controller is used to adaptively perform eNodeB assignment and sharing between different MOs by dynamically slicing the network infrastructure thanks to advancements via SDN. In this architecture, virtualization is performed in two levels. First, BTPs manage the network slices assigned to each MO using network virtualization controller. Second, sub-virtualization for all MO's applications are performed within a mobile operator's slice. In this SDN-based EPS architecture, traffic of multiple MOs is converged to run on a common backbone network infrastructure while each stream of each MO is kept virtually separate. In shared RAN, all UEs are assumed to be under the coverage of multiple eNodeBs whose combination is abbreviated as District$-i$ for $i = \{1, 2, ..., N\}$ (pool of eNodeBs) and each eNodeB can be assigned to different MO.

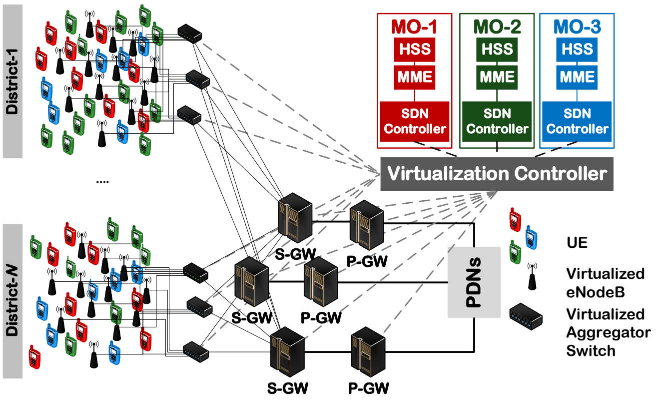


Fig. 1: The shared SDN based EPS architecture for LTE networks with multiple MOs.

The SDN framework allows for the BTP to act as a broker in this setting to modify and adapt the slices in real time based on the agreements between the BTP and the MOs. The individual MOs can then control their own slices via their dedicated control plane architectures (i.e. via their own Mobility Management Entity (MME), Home Subscriber Station (HSS) and Policy and Charging Rules Function (PCRF)). Every time a new rule needs to be pushed by an MO's controller, the virtualization controller first checks the integrity and validity of the rule and then forwards the rule to the corresponding forwarders in the network. The SDN framework with the virtualization controller allows all nodes, including the network forwarding hardware and network gateways (S-GWs and P-GWs), packet data networks (PDNs) and backhaul to be shared by the MOs. It also provides granularity in what is shared in the network. In the shared network, the MOs may maintain their own eNodeB's, gateways, and PDNs and they may also share some of the gateway elements and PDNs. All MOs participating in the shared network maintain their own control plane (MME, PCRF and HSS) and this is used to control the network slice they are allocated by the virtualization controller that is maintained by the BTP. Using with this scenario, sharing of mobile network backhaul equipments among multiple MOs and dynamic assignments of each eNodeB to different MOs based on their instant traffic demands through appropriate scheduling algorithms may result in lower capital expenses and operational costs to both MOs and BTPs. Note that after BTP installs the connections between eNodeBs and MOs with respect to the assignment decision of virtualized eNodeBs, all other RAN related eNodeB control functionalities are managed by the virtualization controller of BTP that is connected to the virtualized eNodeBs through the virtualized aggregator switches. The virtualization controller also communicates with associated MOs for those functionalities since all MOs still maintain their own control planes including MME, PCRF and HSS.

In the aspect of RAN architecture, the requirements of proposed architecture are new interfaces that enable the connections between eNodeBs and each S-GW. During each eNodeB assignment period, each UE behaves as if in a cell search period. Connection drop may be problematic during those assignments, however, this can be easily avoided by excluding a few number eNodeB or its carriers from the assignment mechanisms under the consideration of coverage issues. In LTE and previous generation networks, the operating frequency spectrum as well as the locations of base stations have been pre-determined under the consideration of several parameters. Similarly, in our proposed architecture, eNodeBs will continue to be used at the same spectrum and locations. In currently deployed architecture, MOs' eNodeBs operate at the different frequencies. Our proposed architecture ensures sharing of those eNodeBs so that dynamic spectrum sharing among MOs can be exploited.

III. SCHEDULERS FOR DYNAMIC E-NODEB ASSIGNMENT

In this section, we describe the scheduling algorithms that are used in conjunction with SDN-based virtualization controllers. Schedulers distribute the available resources to users according to their allocation mechanisms which allocates k^{th} resource to i^{th} user, if its metric ($m_{i,k}$) is the biggest one such as, $m_{i,k} = \arg\max_j \{m_{j,k}\}$ at the beginning of each allocation interval [9]. In our case, allocated resources are eNodeBs and users are MOs and, this allocation interval is defined as SAI. Generally, schedulers may be classified into mainly three categories, namely, *channel-unaware*, *channel-aware/QoS-unaware* and *channel-aware/QoS-aware*.

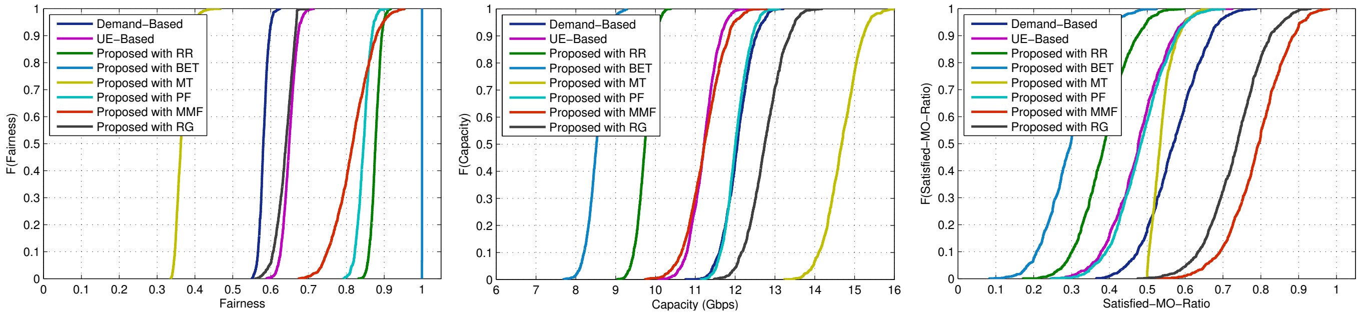
Channel-unaware schedulers such as Round Robin (RR) and Blind Equal Throughput (BET) use simple algorithms to allocate the resource to users without considering channel quality indicators (CQIs) or QoS requirements. RR has fair allocation mechanism serving in a cyclic order whereas the metric of BET allocates eNodeBs inversely proportional to average data rate of MOs. In contrast, *channel-aware* schedulers require CQIs. Maximum Throughput (MT) and Proportional Fair (PF) schedulers fall into this category. The metric of MT scheduler is directly instantaneous data rate and it maximizes the total system throughput, however, it is totally unfair. PF scheduler partially satisfies both system throughput and fairness using the past average throughput of users as a weighting factor while allocating resources for next SAI. However, none of MT and PF consider QoS requirements. In the category of QoS-aware schedulers, we consider rate guarantee (RG) scheduler [10] and max-min fairness (MMF) algorithm [11].

IV. PERFORMANCE EVALUATIONS

In our simulation environment with three MOs, the number of UEs associated with MO-1, MO-2 and MO-3 are set to 300, 500 and 200. Relatively, the overall demands of MO-1 and MO-2 that come from their respective UEs are uniformly distributed (unif) between $0-8$ Mbps and $0-12$ Gbps, and MO-3 is considered as best-effort (BE) service provider. Additionally, aggressiveness parameter of RG are selected as 10 and 9.5 for MO-1 and MO-2, respectively. UEs are uniformly and the locations of 31 eNodeBs with transmit power of 46 dBm are deterministically distributed in the considered district with the radius of 35 km, as shown in Fig. 3. Each UE has 5 MHz bandwidth and noise power spectral density is -179 $\mathrm{dBm/Hz}$. We consider two cases for static deployed architecture called as *demand-based* and *UE-based* assignments. In *demand-based* assignment (see Fig. 3 (a)), the numbers of eNodeBs associated with MO-1, MO-2 and MO-3 are set to 12, 18 and 1 as proportional to their demands. On the other hand, in *UE-based* assignment (see Fig. 3 (b)), the numbers of eNodeBs associated with MO-1, MO-2 and MO-3 are set to 9, 16 and 6 as proportional to the number of associated UEs. In both *demand-based* and *UE-based* static assignments, eNodeBs are homogeneously distributed in considered district structure. Similarly, our proposed architecture including virtualized eNodeBs is depicted in Fig. 3 (c).

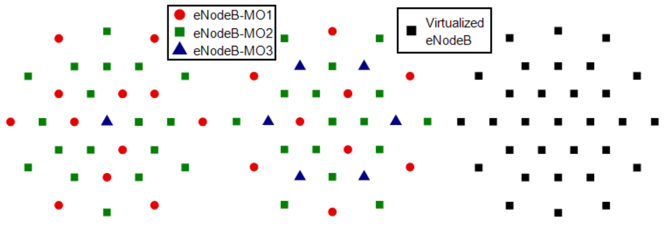
We assume that proper frequency spectrum sharing and advanced modulation techniques that ensure the interferences from neighbor eNodeBs to be insignificant, and only path loss and shadowing effects of the channel between UEs and eNodeBs are considered. Under the consideration of urban and suburban areas in macrocell structure and the carrier frequency of 2 GHz, the path loss gain can be calculated by $H = 128.1 + 37.6\log(d) + \psi$ dB, where d is the distance to eNodeB in km and ψ (in dB) is log-normal distributed (with $\mathcal{N}(0,64)$) shadowing effect. Totally 1000 independent simulations in which locations of UEs are uniformly selected are performed. Each simulation has 1000 SAIs, in which shadowing effect varies independently per UE in each SAI and overall MOs' demands vary in each 50^{th} SAI.

Using this setting, in Fig. 2a, we show Jain's fairness index performances of static assignments including *demand-based* and *UE-based* and our proposed architecture with the use of RR, BET, MT, PF, MMF and RG schedulers in terms of cumulative density function (CDF) denoted by $\mathrm{F}(.)$. The results show that our proposed architecture with RR, BET, PF and MMF outperforms both *demand-based* and *UE-based* assignments and improve the fairness index with the ratios of 52%, 71%, 47% and 41% responding to *demand-based* and 35%, 52%, 31% and 26% responding to *UE-based*, respectively. The reason of this improvement is the fact that the metrics of all four schedulers consider fairness issue and adopt the assignment mechanism with respect to time-varying UE locations while static assignments do not



(a) (b) (c)

Fig. 2: (a) Fairness, (b) capacity and (c) satisfied-MO-ratio performances of traditional and proposed SDN-based LTE networks.



(a) (b) (c)

Fig. 3: Locations of eNodeBs when (a) *demand-based*, (b) *UE-based* static assignments and (c) virtualized architecture.

react to the time-varying factors. When we turn to Shannon capacity performance (see Fig. 2b), our proposed architecture shows improvement using of MT and RG schedulers compared to both static assignments with the ratios of 23% and 6% responding to *demand-based* and 31% and 14% responding to *UE-based*, respectively. This is due to the fact that MT and RG schedulers guarantee to maximize the system throughput and satisfy the demands, respectively. In Fig. 2c, we compare the average satisfied-MO-ratio performances of different assignments. Note that the satisfied-MO-ratio is the ratio of the total number of MOs who are allocated with an amount of resource which is equal to or higher than their demand to the total number of MOs. The satisfied-MO-ratio performances are improved with the ratios of 30% and 20% responding to *demand-based* and 55% and 43% responding to *UE-based*, using MMF and RG schedulers, respectively. This is because only these two scheduling algorithms consider MO demands.

V. CONCLUSIONS

An SDN-based novel cellular network architecture serving both MOs and BTPs, where virtualization controller assigns the virtualized eNodeBs to each MO has been proposed. In this architecture, we investigate fairness, capacity and satisfied-MO-ratio performances of different QoS-aware and QoS-unaware scheduling algorithms and compare the results with currently deployed static cellular network architecture. The performance improvements by our proposed architecture are shown by Monte-Carlo simulations.

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