Towards Cloud-based Multi-operator Core Networks (MOCN) for Infrastructure Sharing

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***Abstract*—The cost associated with telecommunication infrastructure acquisition and deployment remains a primary inhibitor to market entry by new operators who lack the capital to deploy competitive infrastructure. This entry barrier has resulted in the monopolisation of the telecommunication industry by established network operators. To cope with the growing user demands, existing operators are looking for strategies to cost-effectively expand and improve their existing infrastructures. Network virtualisation and technologies for infrastructure sharing play paramount important roles in reducing the deployment and operational costs of future mobile networks and fostering healthy competition in the market. The prospects of reducing the cost of network deployment offers some flexibility in adjusting retail prices and extending broadband access to rural areas. This paper proposes a network sharing architecture called cloud-based multi-operator core networks (C-MOCN), derived from a well-known specification where the radio access network (RAN), and spectrum, are shared among multiple mobile network operators. The technical implementation details of the architecture and acceptance tests conducted to ensure strong traffic isolation are described. The test results show that it is possible for multiple operators to co-exist on the same RAN while ensuring strong traffic isolation and high quality of experience for end-users.**

***Index Terms*—Infrastructure sharing, Multi-operator core networks (MOCN), Spectrum sharing, Isolation**

I. INTRODUCTION

The telecommunications industry has a great potential of driving the socio-economic transformation in the country. It also plays a critical role in digitalisation. However, the current telecommunication landscape in the country is vertically integrated, i.e., it is dominated by few players with their own end-to-end infrastructures. The telecommunication infrastructure is broadly composed of a core and a radio access network (RAN), where the former is located at the head office, and it is typically run from specially developed hardware servers. The RAN is the visible part of the network that installed on masts across the country, and finally, these are connected by a backhaul network to the core. Each operator in the incumbent network owns the entire network elements from its core to RAN. This leads to inefficient usage of both external resources (power and spectrum) and infrastructural resources (compute, networking and storage), resulting in high cost of deploying and running a network. By extension, this contributes to high cost of broadband to the end-user.

Network infrastructure sharing has been cited as a silver bullet solution towards reducing network deployment costs and opening up barriers to market entry for small, medium and micro enterprises (SMMEs) [1]. This cost reduction is achieved by allowing SMMEs to fold their operations into a shared network infrastructure. This sharing will potentially stimulate service-level competition (instead of infrastructure-level competition) and innovation, resulting in a better quality of service and lower cost of broadband services [2].

The concept of network sharing is not entirely new; it was introduced in the earlier generations of mobile communication. However, its implementation has always been confined to passive infrastructure such as site locations, radio equipment, and masts. As such, it was never fully explored from the technology perspective. In recent times, the network sharing concept has and continues to find prominence due to mobile technologies' advancement and evolution. It finds expression in the multi-tenancy [3] network paradigm, which in the main, is driven by recent and emerging technologies such as network function virtualisation (NFV)[4] and software-defined networking (SDN) [5]. Network sharing is anticipated to accelerate network rollouts and open new business opportunities for mobile virtual network operators (MVNO), over-the-top providers (OTT) and other vertical industry players.

This paper demonstrates a practical implementation of a 3GPP compliant network infrastructure sharing testbed, which we have codenamed cloud-based multi-operator network (C-MOCN). C-MOCN was developed using cloud native core network functions running as microservices and proprietary RAN. C-MOCN was developed to allow multiple network operators (each having its own core network) to co-exist on the same RAN by adopting both the active and passive RAN sharing models, where multiple operators not only share the passive radio infrastructure but also share active radio elements such as spectrum and computing resources.

A. Contribution

To date, there have been numerous research studies directed towards the network infrastructure sharing paradigm. Table I summarises the contributions of the research works related to infrastructure sharing testbed implementations found in the literature. However, most studies relied on emulation and simulation tools for their testbed implementation. This includes simulated LTE stacks such as base stations and air interfaces which does not fully represent a real service provider environment. Also, these works do not provide

TABLE I: Related Work

References	Main Contribution
Kokku et al. [6]	Proposed a remote RAN sharing solution by inserting a slice scheduling broker between the RAN and core networks. A testbed was built using simulation.
Ksentini et al. [7]	Proposed a dynamic RAN sharing architecture design and admission control approach. The design was implemented on an emulation platform called OpenAirInterface.
Lin et al. [8]	Proposed a transparent RAN sharing approach by inserting a "RAN proxy" which acts as a broker between the RAN and multiple core networks. The authors also tested a scenario where multiple RAN proxies are deployed, one between the small cell and macrocell and the other between the macrocell and core network.
Turk et al. [9]	Tested the effects of RAN sharing on a live LTE network with two sharing partners.
Markendahl et al. [10]	Carried out a techno-economic analysis of RAN network sharing for indoor deployments using femtocells and distributed antenna systems.
Calero et al. [11]	Conducted an empirical study of the techno-economic and performance implications of sharing the RAN infrastructure between multiple network operators.
Alaez et al.[12]	Proposed an open-source testbed design to demonstrate RAN sharing. The network components were simulated using NS-3.

information on the acceptance tests they conducted to ensure strong traffic isolation between mobile network operators. This paper describes the acceptance tests carried out on C-MOCN to make sure that it meets the basic isolation requirements in a typical shared network environment. The main contributions of this paper can be summarised as follows:

- Provides an architecture for RAN sharing leveraging virtualization technologies
- Presents the acceptance test plan for traffic isolation in shared RAN environment
- Highlights the benefits and beneficiaries of RAN sharing

B. *Organisation*

The paper is organised as follows. Section II describes different network sharing architectures ratified by the 3GPP. Section IV presents the key building blocks of our C-MOCN and reveals the implementation details. Section V describes the acceptance tests that we performed. Section VI discusses the results from the acceptance tests. Finally, Section VII concludes the paper and provides future research direction.

II. NETWORK SHARING ARCHITECTURES

3GPP has ratified and defined two architectures with varying degrees of sharing, namely the multi-operator core networks (MOCN) and multi-operator RAN (MORAN). The MOCN architecture enables a mobile network operator to provide services to its subscribers as one of the multiple operators that share both the radio carriers and passive radio equipment, while the core network remains proprietary to each operator. With MORAN, only the passive elements of the RAN, except for the radio carries, are shared between multiple operators. A prerequisite when entering into the MORAN contract is for each operator to have acquired a dedicated spectrum license, making MORAN resource inefficient. MOCN brings incremental benefits over MORAN in that it offers mobile operators the opportunity to pool and share their spectrum allocations for better utilisation of resources and improved trunking efficiency. For both these sharing approaches, mobile operators can decide whether or not to share the backhaul connecting to their respective core networks. Table II summarizes the differences between MOCN and MORAN architectures.

TABLE II: A comparison summary between MORAN and MOCN

Component	MORAN	MOCN
Civil works	Shared	Shared
Frequency spectrum	Independent	Shared
Network operations and management	Independent	Shared
Core Network	Independent	Independent
RAN equipment	Shared	Shared
Backhaul	Shared or Independent	Shared or Independent
Feature deployment (e.g. transmission power cell range, interference)	Independent	Shared

III. BENEFITS OF INFRASTRUCTURE SHARING

Infrastructure sharing is becoming a standard for good broadband policy, so much so that the South African government has promoted it in the national policy South Africa Connect. Infrastructure sharing is indeed the most economically compelling approach to mobile operators for meeting the everincreasing broadband demands. Civil engineering costs constitute the dominant part of overall network deployment and infrastructure expansion costs, and naturally plays a significant part in consumer pricing decisions, which typically results in high-cost broadband services. With proper infrastructure sharing policies, it may be possible for operators to save heftily on network deployment and potentially lower retail prices. Another compelling benefit of infrastructure sharing is broadband extension to unserved and poorly served regions. The current monopilized business model makes it very costly and unprofitable for operators to cover rural areas. However, network operators are under universal service obligations and associated geographic coverage mandates, and so they are looking for a way to extend coverage at a reasonable cost. Infrastructure sharing may significantly improve the business case for these areas and encourage broadband extension to rural areas. The current monopolistic business model in telecoms has created a huge barrier to entry for entrant operators. Incumbent operators continue to dominate the market. At the same time, entrant operators are unable to penetrate due to a lack of capital to rapidly build networks and sustain losses before profitability is reached.

Infrastructure sharing offers a more rapid and economically viable option to compete based on service-level instead of infrastructure-level. Such a competition is necessary to stimulate creation of value-added services, and potentially improve the quality of service delivered to end-users. Other benefits of infrastructure sharing are environmental such as reduced carbon footprint, visual pollution and so forth. Table III summarises the benefits and beneficiaries of infrastructure sharing.

TABLE III: Benefits of Infrastructure sharing

Benefits	**Beneficiaries**
Network deployment and operating cost savings	Incumbent Operators, SMMEs
Lower barriers to market entry	SMMEs
Increased coverage	Incumbent Operators, SMMEs, Citizens
Value-added services	Citizens
Decreased time-to-market	SMMEs, Incumbent Operators
Lower retail prices	Citizens
A smaller environmental impact	All
Public resources savings	All

IV. C-MOCN DESIGN AND IMPLEMENTATION

C-MOCN (as depicted by Figure 1) constitutes four main components, namely, the user equipment (UE), the RAN, the backhaul and core networks. The design and implementation details of these components are outlined in the following sections.

1) Cloud Platform: Our testbed uses OpenStack to host virtualised network functions of the core networks. OpenStack is an open-source cloud computing platform used to build and manage public and private clouds. Our OpenStack deployment was designed to handle core cloud-computing services such as compute, networking, storage, identity, image and orchestration services. The hardware specification of the commercial off the shelf (COTS) servers used to deploy OpenStack is as follows: 1008.3GB RAM, 10TB storage, and 208 virtual CPUs.

2) Core Networks: To study the multi-operator core network (MOCN) architecture, two multi-vendor virtual core networks were deployed. These core networks are cloud-native solutions designed using microservices for each network function. Both these core networks were deployed on top of OpenStack virtual machines. The first core network is from Cumucore, and supports 5G non-standalone (NSA)

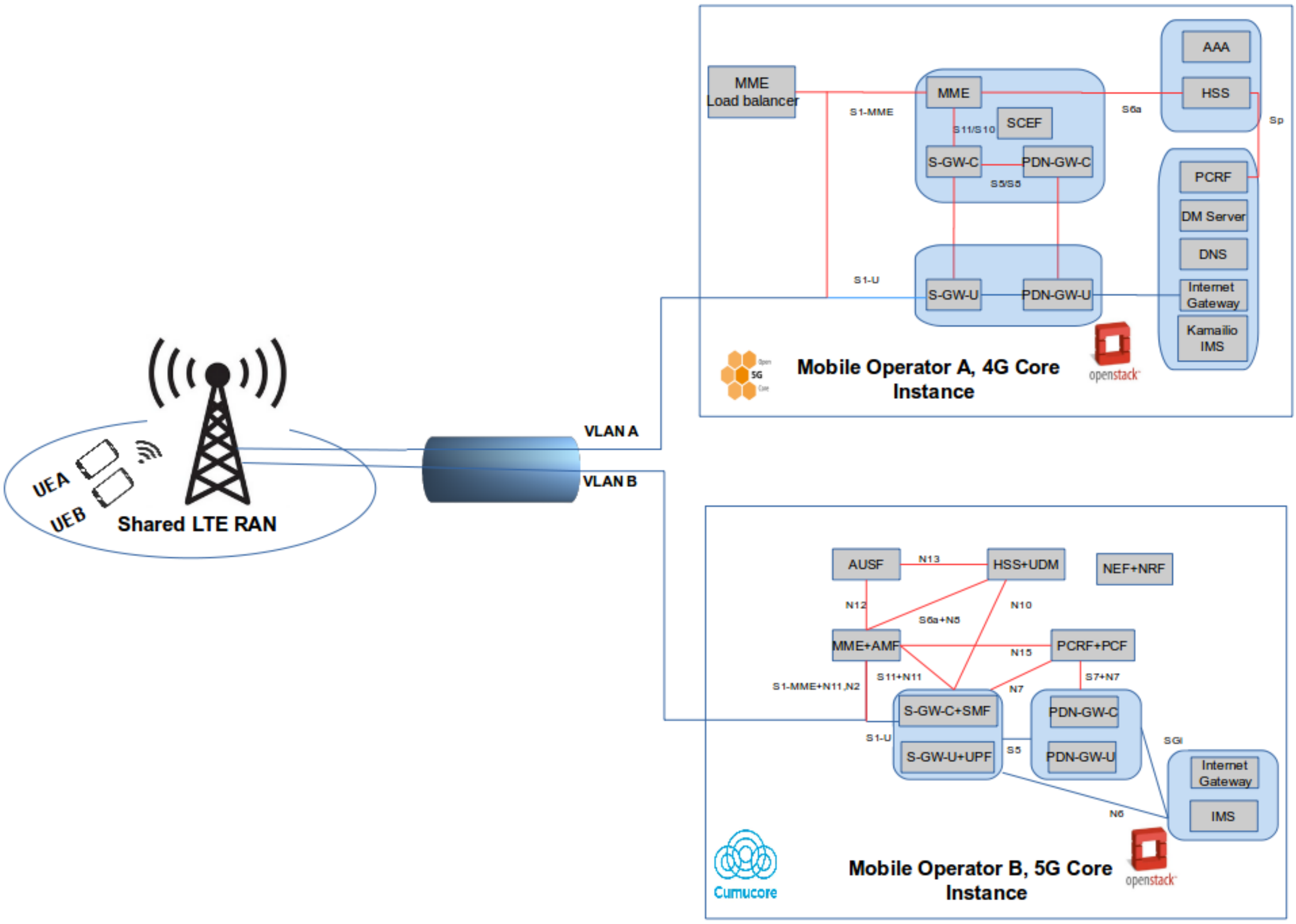


Fig. 1: C-MOCN high level architecture

mode. The second core network is open-source and is from Fraunhofer and supports 4G (LTE) functionality. The virtual machines were each allocated 2GB RAM, 2 virtual CPUs and 60GB storage. To maintain isolation between the mobile operators, there was no interconnection between the two core networks. The network functions of each core network were configured to communicate with each other over localhost. The packet gateway network function of each core network was configured to connect to the local internet service provider with DHCP and NAT enabled. The use of virtualised core networks has the potential to create unprecedented business cases in that instead of operators being locked to vendors, they can utilize open-source solutions which run on commodity hardware, offering operators an opportunity to add new features on-demand and decrease time-to-market new services.

3) RAN: The RAN was deployed using a real Flexi Zone Indoor LTE pico cell from Nokia, operating in the 1800Hz (indoor R&D license) band. The base station supports a maximum of 840 active users with a coverage of 200 meters. The base station was commisioned using the BTS element manager from Nokia [13]. The configured base station parameters included tracking area codes (TAC), public land mobile network (PLMN) identities, application addresses (user planes, control planes and management planes for each operator), NTP servers, routing, transport networks and so forth.

4) User Equipment(UE): For the UE, two Android smartphones from Samsung were used. Each smartphone was equipped with a programmable USIM card from Sysmocom. The USIMs were programmed with subscriber and authentication information. The carrier-specific configuration (such as the PLMN and access point name (APN)) were also added to each UE.

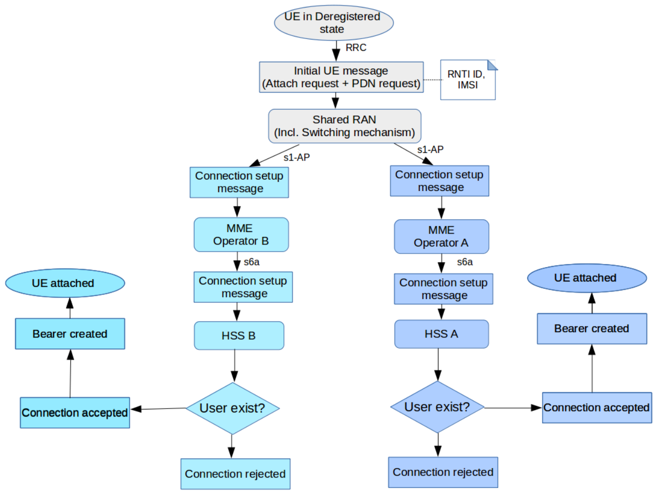


Fig. 2: C-MOCN admission control procedure

5) Backhaul Network: An Ethernet backhaul connection was used to connect the base station and the core network.

6) Isolation: Network traffic for each operator is segregated from the radio access network all the way to the backhaul. Further, unique network settings of each mobile network operator ensure that unintended network access by a subscriber of one operator to another is not possible. These unique settings include PLMN identities, authentication keys and operator-encrypted codes provisioned in the home subscriber servers (HSS). Our testbed capitalizes on the power of VLANs to segregate traffic of each mobile network operator. In order to integrate the two core networks to the shared base station, two virtual LAN (VLAN) interfaces were created on the virtual machines running the core networks and on the base station's backhaul interfaces.

V. ACCEPTANCE TEST PLAN

Considering the need for traffic isolation, the VLAN technique is applied to separate traffic (both control and user traffic) between the core networks. This means that each core network can only register users connected to the VLAN interface that have the same shared type of VLAN (same VLAN ID). To achieve this, two different acceptance tests were executed to validate the VLAN isolation mechanism. This section describes the acceptance tests conducted and the expected outcomes. The admission control procedure is also outlined.

A. Test Case 1: vEPC isolation

In this setup, each mobile network operator activates its own core network services using different virtual machines hosted on a cloud platform. This test case is used to demonstrate that each network operator uses their own mobile core network. Therefore, when the core network is shutdown, all subscribers associated with it must fail to connect.

1) Test procedure::

- Start-up only one mobile core network belonging to network operator A.
- Use UEA (subscriber belonging to network operator A) to establish a connection to the network. **Expected results** Connection should succeed.
- Use UEB to establish a connection to the network. **Expected results** Connection should fail.
- Start up mobile core network belonging to network operator B and attach UEB. **Expected output**Connection should succeed. Note: Repeating the above setup using mobile core network B should give the same results.

B. Test Case 2: Isolation on the backhaul

The C-MOCN only has one backhaul from within the core. This test is used to demonstrate that there is a strong isolation of packets from one network to the next.

1) Test procedure::

- Attach UEA and UEB. Expected results successful connection to the respective networks.
- Generate traffic from UEA.
- Connect network packet sniffers (Wireshark or tcpdump) on VLAN of network B on the interface connecting the core network to the backhaul. **Expected results** no packets of UEA should be visible.

- Connect network packet sniffers (Wireshark or tcpdump) on VLAN of network A on the interface connecting the core network to the backhaul. **Expected results** only packets of UEA should be visible.
  Note: Repeating the above setup using network B should yield the same results.

C. Admission Control

The target of the admission control procedure is to register the UE to its home network and for the UE to be able to send and receive data to and from the packet data network (PDN). The admission control procedure (see Figure 2) for C-MOCN in 4G mode is as follows: first the UE is initially in deregistered state, meaning it is not connected to the network. The UE sends a radio resource channel (RRC) connection request to the base station on random access channel (RACH) to establish a signalling radio bearer. After succesful creation of the radio bearer, the UE then sends an initial UE message, containing an attach request and PDN connectivity request, subscription information (such as the IMSI), and security information to the MME via the base station. In order to send the connection request to the correct MME, the base station checks its PLMN, and VLAN application address configurations and make sure the configuration matches the values embedded in the attach request. The communication between the MME and base station is using the s1 application protocol (S1-AP). Upon receipt of the connection request, the MME uses Diameter transport protocol (over s6a interface) to forward the connection request to the HSS. The HSS then checks if the UE has been provisioned in its database. If the UE exists, then the connection request is accepted and a bearer (tunnel) between the UE and MME is created. At this stage, the UE is now connected to the network and its status changes to registered. Once registered, the UE can start consuming broadband services. If the HSS could not authenticate the UE on its database, then the connection request is rejected.

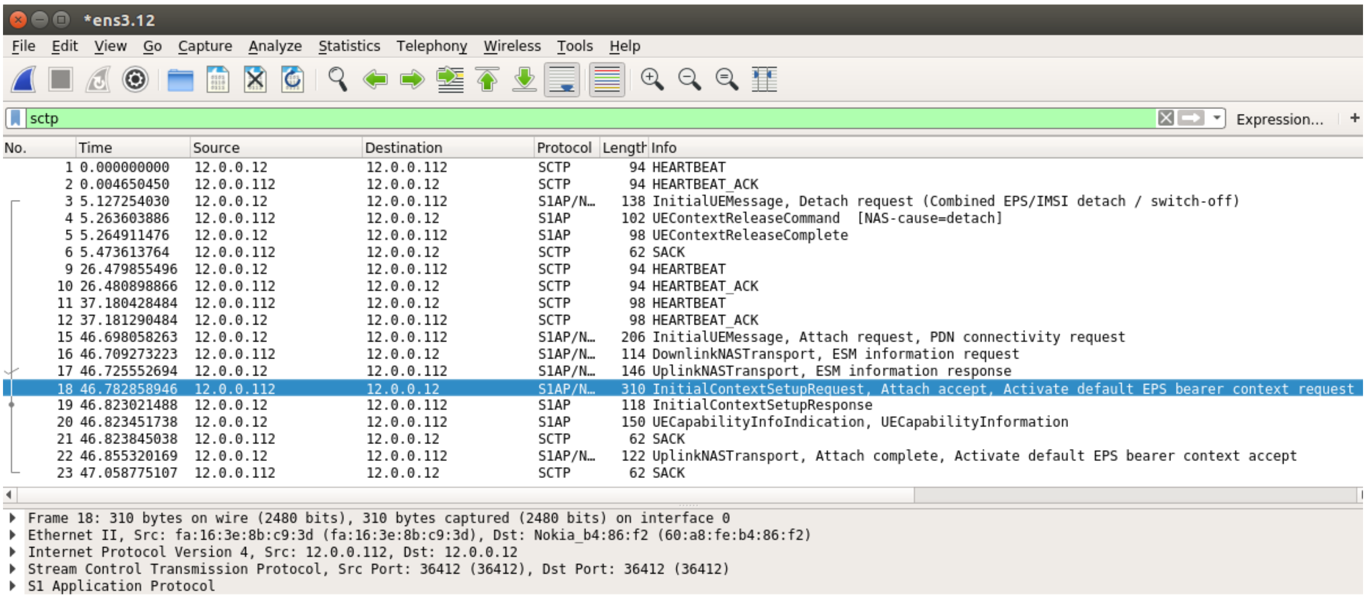
VI. RESULTS

This section discusses the results observed after executing the test cases described in section V. The subnet mask details of each operator are as follows: mobile operator A is allocated a subnet mask of 11.0.0.0/24, whereas mobile operator B's allocation is 12.0.0.0/24. The IP address of the configured VLAN interface on the virtual machine running operator A's core network is 11.0.0.111, and the corresponding VLAN interface on the base station is assigned an IP address of 11.0.0.11. Similarly, operator B's core network and its corresponding base station VLAN interface are assigned 12.0.0.112 and 12.0.0.12 respectively. As shown in Figure 3 and Figure 4, C-MOCN passed the isolation on the backhaul test (see section V-B). The UE attach requests are only visible to the operators each UE is subscribed to and not to others.

On execution of Test Case 1 (section V-A), the base station could not attach to operator B's core network resulting in an SCTP ABORT message from the core network. Subsequently, UE B could not connect to the network and remained in a deregistered state. As expected, the PCAP logs on Operator B's core network (see Figure 5) did not include any packets from UE B. This validated the strong isolation levels in C-MOCN.

In order to evaluate the end-user quality of experience (QoE) on C-MOCN, we performed video streaming, web browsing and voice over IP (VoIP) tests and compared the test results with the QoE delivered by commercial networks. The test results indicated no visible performance differences. However, it is noteworthy that C-MOCN was deployed in a semi-sterile indoor environment with direct line of communication, and negligible interferences in the air interface. Thus, different results may be observed under a fair benchmarking environment.

Speed tests were also conducted to measure the upload and download speeds of each sharing mobile network operator.



sctp

```
No.   Time          Source        Destination   Protocol  Length Info
    1 0.000000000   12.0.0.12     12.0.0.112    SCTP        94 HEARTBEAT
    2 0.004650450   12.0.0.112    12.0.0.12     SCTP        94 HEARTBEAT_ACK
    3 5.127254030   12.0.0.12     12.0.0.112    S1AP/N…    138 InitialUEMessage, Detach request (Combined EPS/IMSI detach / switch-off)
    4 5.263603886   12.0.0.112    12.0.0.12     S1AP       102 UEContextReleaseCommand  [NAS-cause=detach]
    5 5.264911476   12.0.0.12     12.0.0.112    S1AP        98 UEContextReleaseComplete
    6 5.473613764   12.0.0.112    12.0.0.12     SCTP        62 SACK
    9 26.479855496  12.0.0.12     12.0.0.112    SCTP        94 HEARTBEAT
   10 26.480898866  12.0.0.112    12.0.0.12     SCTP        94 HEARTBEAT_ACK
   11 37.180428484  12.0.0.112    12.0.0.12     SCTP        98 HEARTBEAT
   12 37.181290484  12.0.0.12     12.0.0.112    SCTP        98 HEARTBEAT_ACK
   15 46.698058263  12.0.0.12     12.0.0.112    S1AP/N…    206 InitialUEMessage, Attach request, PDN connectivity request
   16 46.709273223  12.0.0.112    12.0.0.12     S1AP/N…    114 DownlinkNASTransport, ESM information request
   17 46.725552694  12.0.0.12     12.0.0.112    S1AP/N…    146 UplinkNASTransport, ESM information response
   18 46.782858946  12.0.0.112    12.0.0.12     S1AP/N…    310 InitialContextSetupRequest, Attach accept, Activate default EPS bearer context request
   19 46.823021488  12.0.0.12     12.0.0.112    S1AP       118 InitialContextSetupResponse
   20 46.823451738  12.0.0.12     12.0.0.112    S1AP       150 UECapabilityInfoIndication, UECapabilityInformation
   21 46.823845038  12.0.0.112    12.0.0.12     SCTP        62 SACK
   22 46.855320169  12.0.0.12     12.0.0.112    S1AP/N…    122 UplinkNASTransport, Attach complete, Activate default EPS bearer context accept
   23 47.058775107  12.0.0.112    12.0.0.12     SCTP        62 SACK

▸ Frame 18: 310 bytes on wire (2480 bits), 310 bytes captured (2480 bits) on interface 0
▸ Ethernet II, Src: fa:16:3e:8b:c9:3d (fa:16:3e:8b:c9:3d), Dst: Nokia_b4:86:f2 (60:a8:fe:b4:86:f2)
▸ Internet Protocol Version 4, Src: 12.0.0.112, Dst: 12.0.0.12
▸ Stream Control Transmission Protocol, Src Port: 36412 (36412), Dst Port: 36412 (36412)
▸ S1 Application Protocol
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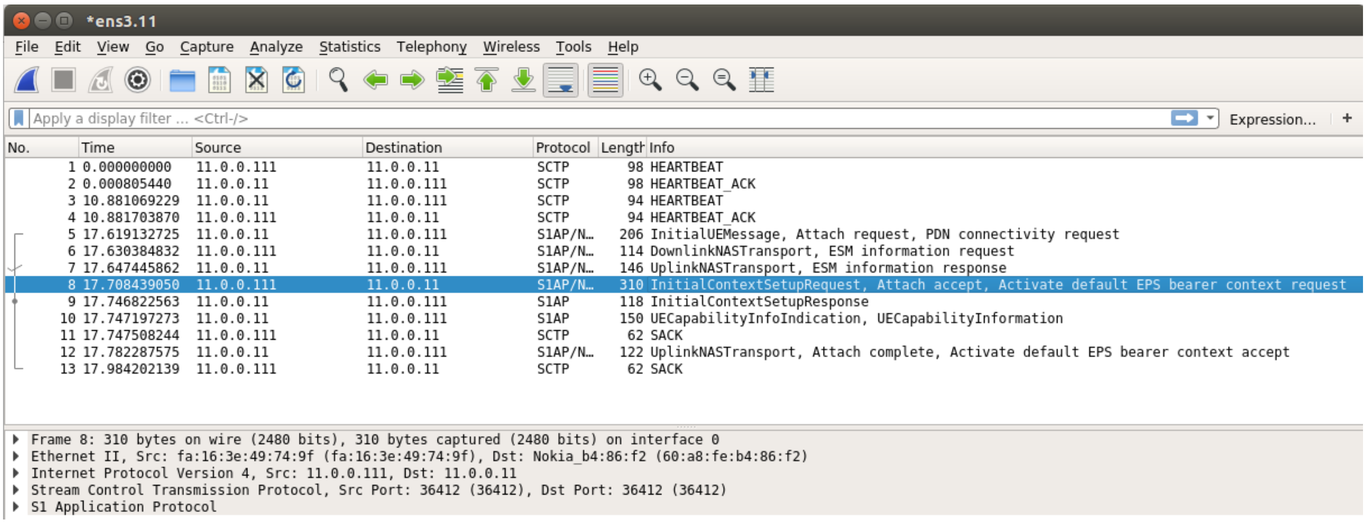
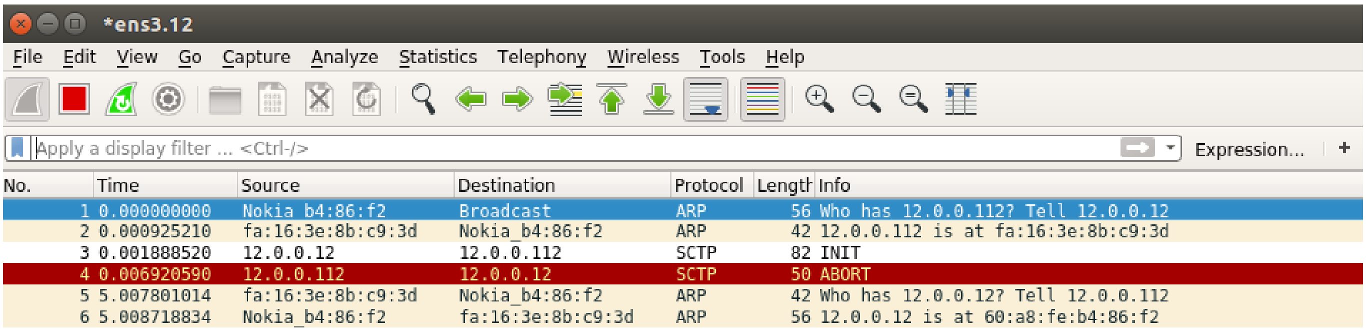
Fig. 3: Packet capture (PCAP) Logs with Wireshark on Core Network A



```
No.  Time          Source       Destination  Protocol Length Info
   1 0.000000000   11.0.0.111   11.0.0.11    SCTP       98 HEARTBEAT
   2 0.000805440   11.0.0.11    11.0.0.111   SCTP       98 HEARTBEAT_ACK
   3 10.881069229  11.0.0.11    11.0.0.111   SCTP       94 HEARTBEAT
   4 10.881703870  11.0.0.111   11.0.0.11    SCTP       94 HEARTBEAT_ACK
   5 17.619132725  11.0.0.11    11.0.0.111   S1AP/N…   206 InitialUEMessage, Attach request, PDN connectivity request
   6 17.630384832  11.0.0.111   11.0.0.11    S1AP/N…   114 DownlinkNASTransport, ESM information request
   7 17.647445862  11.0.0.11    11.0.0.111   S1AP/N…   146 UplinkNASTransport, ESM information response
   8 17.708439050  11.0.0.111   11.0.0.11    S1AP/N…   310 InitialContextSetupRequest, Attach accept, Activate default EPS bearer context request
   9 17.746822563  11.0.0.11    11.0.0.111   S1AP      118 InitialContextSetupResponse
  10 17.747197273  11.0.0.11    11.0.0.111   S1AP      150 UECapabilityInfoIndication, UECapabilityInformation
  11 17.747508244  11.0.0.111   11.0.0.11    SCTP       62 SACK
  12 17.782287575  11.0.0.11    11.0.0.111   S1AP/N…   122 UplinkNASTransport, Attach complete, Activate default EPS bearer context accept
  13 17.984202139  11.0.0.111   11.0.0.11    SCTP       62 SACK

▸ Frame 8: 310 bytes on wire (2480 bits), 310 bytes captured (2480 bits) on interface 0
▸ Ethernet II, Src: fa:16:3e:49:74:9f (fa:16:3e:49:74:9f), Dst: Nokia_b4:86:f2 (60:a8:fe:b4:86:f2)
▸ Internet Protocol Version 4, Src: 11.0.0.111, Dst: 11.0.0.11
▸ Stream Control Transmission Protocol, Src Port: 36412 (36412), Dst Port: 36412 (36412)
▸ S1 Application Protocol
```

Fig. 4: Packet capture (PCAP) Logs with Wireshark on Core Network B



```
No.  Time          Source             Destination        Protocol Length Info
   1 0.000000000   Nokia_b4:86:f2     Broadcast          ARP        56 Who has 12.0.0.112? Tell 12.0.0.12
   2 0.000925210   fa:16:3e:8b:c9:3d  Nokia_b4:86:f2     ARP        42 12.0.0.112 is at fa:16:3e:8b:c9:3d
   3 0.001888520   12.0.0.12          12.0.0.112         SCTP       82 INIT
   4 0.006920590   12.0.0.112         12.0.0.12          SCTP       50 ABORT
   5 5.007801014   fa:16:3e:8b:c9:3d  Nokia_b4:86:f2     ARP        42 Who has 12.0.0.12? Tell 12.0.0.112
   6 5.008718834   Nokia_b4:86:f2     fa:16:3e:8b:c9:3d  ARP        56 12.0.0.12 is at 60:a8:fe:b4:86:f2
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Fig. 5: Packet capture (PCAP) Logs with Wireshark on Core Network B

The tests were carried out using the an LTE speed test application called SpeedTest [14]. The speed tests were performed in parallel. The results are as shown in Figure 6). Both core networks produced the same download speed and almost the same upload speeds.

Fig. 6: LTE speed test results

VII. CONCLUSION

This paper demonstrated the paradigm of network infrastructure sharing (including spectrum sharing) by building a prototype based on MOCN architecture. There is a general consensus that infrastructure sharing presents the possibility of reducing the cost of network acquisition, deployment and operation which is likely to stimulate small and medium businesses penetration to the telecoms business market and foster a healthy competition. Our paper presents the emperical validation of the network sharing architecture leveraging virtualization technologies in core network deployment and traffic isolation. The performance evaluation of the sharing architecture was also conducted based on quality of experience. The beneficiaries of the results of our work include small operators, incumbent operators, regulatory bodies who can use this work as evidence of the technical feasibility of infrastructure sharing to unlock cost savings and to improve broadband penetration rates in developing countries that are still plaqued by the digital divide.

Our work primarily employed VLANs as a traffic isolation mechanism.The VLAN-based sharing mechanism is still highly vendor-dependent and lacks transparency in terms of QoS management and allocation between sharing partners. In future we plan to extend our testbed with an open RAN capability running on commercial off the shelf hardware to build a full-fledged multi-RAN virtualised solution.

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