On Active, Fine-Grained RAN and Spectrum Sharing in Multi-Tenant 5G Networks

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***Abstract*—An important target for 5G networks is to enable resource sharing among network tenants such as Mobile Virtual Network Operators and Service Providers. Several domains of resource sharing have been considered including infrastructure (compute, storage and networking), transport, Radio Access Network (RAN) and Radio Frequency (RF) spectrum. RAN and spectrum sharing are expected to be an integral part of a multi-tenant 5G network. In this paper, a centralized, fine-grained active RAN and spectrum sharing approach has been presented and analyzed using a modified SimuLTE model. The presented model can be used for analyzing active RAN and spectrum sharing models considered in a multi-tenant 5G network. We present the core modules that enable dynamic allocation of RAN slices with dedicated spectrum and resource scheduling functions. We also present preliminary simulation results that give an insight into the actual benefits and trade-offs of active spectrum sharing among RAN tenants at different time-frequency granularities.**

I. INTRODUCTION

The global network traffic is increasing at an unprecedented rate along with demands for more innovative and immersive applications [1]. In addition, new technologies such as Software-Defined Networking (SDN) and Network Function Virtualization (NFV) have created scope for a new network architecture and resource management & control practices. The 5G networks development roadmap targets a convergence of new technologies, including SDN/NFV, to address the capacity and QoS challenges but also create an elastic network infrastructure for efficient service addition and delivery. SDN and NFV in particular, make it easier to bring new services to the end-users in a time and resource efficient manner. They also enable new players (service providers, virtual network operators etc.) to use a shared (Multi-tenant) network infrastructure. Important resources that can be shared in the context of multi-tenant 5G networks include the RAN and RF spectrum, for which, several models of sharing can be realized including mutual renting, co-primary sharing and spectrum leasing [2]. In a software-defined, multi-tenant network architecture, where distributed control elements deployed at different end-points communicate with a centralized network controller, these sharing models can be realized actively with a fine-grained time/frequency granularity. In this paper, we investigate a centralized, active RAN and spectrum sharing approach for a multi-tenant 5G network using a modified and extended "SimuLTE" model. SimuLTE is an open source LTE/LTE-A user-plane simulation framework for OMNeT++ [3]. The extensions to this model presented in this paper, enables an LTE eNodeB to support multiple virtual tenant operators using their own slice-specific radio resources and scheduling functions. Additionally, each tenant can share its dedicated radio resources with other tenants in different time-frequency granularities controlled by a centralized spectrum manager. We present details of the extensions made to the SimuLTE model together with simulation results of the initial study on active fine-grained RAN/spectrum sharing. In the remaining text, section II presents related work followed by section III presenting the extended SimuLTE model for multi-tenant RAN sharing and its utilization for analyzing several time-frequency granularity options. Section IV presents preliminary results and analysis of the performed simulations. A summary and scope for future work is presented in section V.

II. RELATED WORK

Spectrum sharing has received considerable attention in the cognitive radio research domain where dynamic spectrum access models have been investigated extensively [4]. However, most of the opportunistic and dynamic spectrum access concepts have not materialized for reasons including rigidity of the legacy network architectures, deficient spectrum sensing and the competitive nature of network operators. RAN sharing has also been considered, albeit mostly passively, in the form of base-station location, mast, power and cooling infrastructure sharing. The 5G network architecture is expected to change this with the realization of multi-tenant networks including shared RAN. This has the potential to

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achieve significantly more benefits than the RAN sharing options considered thus far such as Multi-Operator Core Network (MOCN), Multi-Operator RAN, and GateWay Core Network (GWCN) [5]. Several recent works have focused on realizing the cognitive radio concepts of spectrum sharing within the context of 5G multi-tenant RAN. In [6], the authors present an active RAN sharing approach with partial resource reservation for each RAN tenant. Improved spectrum utilization is demonstrated through QoS metrics of the end user traffic classes when radio resource are actively shared. Another similar solution, albeit at a higher abstraction level than the base-station/eNB is presented in [7]. The authors present *CellSlice*, an approach to allocate shared radio resources to several slices through a centralized slice-scheduler. CellSlice focuses on compatibility with existing infrastructure by avoiding modifications to the eNB/Base-station functions. However, with this approach, only a coarse-grained resource sharing model can be realized. In the scope of 5G RAN development, spectrum sharing has received renewed attention in the form of Licensed Assisted Access, LTE-Unlicensed, Licensed Shared Access, LTE-WiFi Aggregration and Multefire [8] [9] [10]. However, most of these approaches do not aim for a fine-grained federation of spectrum, that is, networks and services are isolated and segregated. This potentially creates the same problems, albeit at a lesser degree, which the Cognitive Radio aimed to solve i.e, spectrum scarcity and under-utilization. In a multi-tenant 5G RAN, a fine-grained, active spectrum sharing approach can be realized where micro-transactions of spectrum favors are carried out among RAN tenants while being controlled at a higher abstraction by a centralized spectrum management application. However, understanding the benefits of such an approach to spectrum sharing by means of real implementation or deployment is a challenging task. At the same time, simulation models that can analyze system level performance of multi-tenant RAN and active spectrum sharing are almost non-existent, forcing most researcher to resort to theoretical analysis, physical layer simulations, limited prototype demonstrations or a combination of these. This paper presents an active fine-grained spectrum sharing approach where RAN tenants allow their dedicated spectrum to be allocated to another tenant at different time-frequency granularities. We also present a system level simulation model that supports multi-tenancy and and can analyze the benefits of different models of spectrum sharing.

III. ON FINE GRAINED SPECTRUM SHARING

Figure 1 presents, at a higher abstraction, a centralized network control and management architecture where control applications such as spectrum manager and mobility management use a centralized network control and coordination layer. This centralized layer, exposes network state information to the control applications at desired abstraction levels (see [11] for detailed description). For example, the spectrum manager application may only want spectrum utilization and interference information as an aggregate of the RAN elements such as base stations. The abstract network state is formed using status reports from control elements/functions deployed in a distributed manner in network entities such as base stations (gNB in 5G). With this outlined architecture, the spectrum management application sitting on top of the centralized control layer make high level configuration decisions such as bandwidth allocation to RAN tenants, allowing/disallowing spectrum sharing in network segments and etc. At the same time, control entities located in gNB translate those higher level directives into low-level control decisions related to spectrum sharing. We now present the details of our modified SimuLTE model which supports active RAN and spectrum sharing with this centralized architecture.

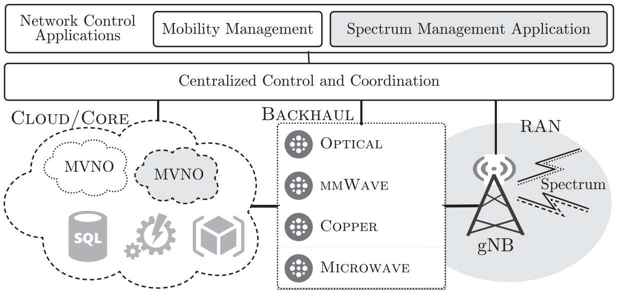


Fig. 1. Centralized network management & control architecture

A. *Modified SimuLTE Model*

This section assumes basic familiarity with LTE/LTE-A network architecture [13] and fundamental modeling approach of OMNeT++ simulation platform [14]. SimuLTE is an open source, system level LTE/LTE-A User-Plane simulation model for OMNeT++ [3] and has been used in several research works to demonstrate its correctness and network modeling potential [12]. In its most recent version (v1.0.1 at the time of this writing), the model can simulates LTE/LTE-A (RAN and ePC) in Frequency Division Duplexing (FDD) mode with heterogeneous nodes using omni-directional antennas including realistic channel models and resource scheduling in both Uplink (UL) and Downlink (DL) directions. At its core, the SimuLTE provides User Equipment (UE) and Base Station (eNodeB) nodes along with some additional modules to form system level simulation scenarios.

1) UE and eNodeB Architecture: Figure 2 shows the fundamental functional components and internal architecture of the core SimuLTE nodes i.e, the UE and eNodeB. The common functions are shown in solid boxes while the optional components (either in UE or eNodeB) are shown in dotted boxes. Fundamentally, the LTE/LTE-A functions are enclosed in an LTE-NIC com-

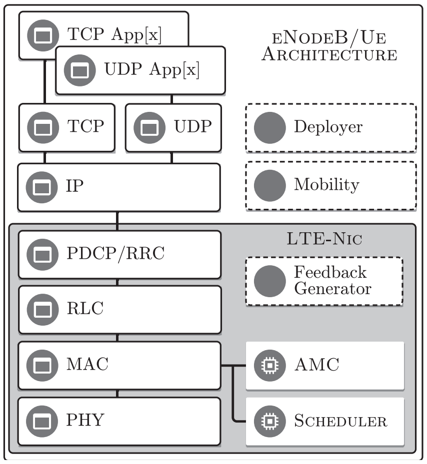


Fig. 2. SimuLTE nodes (UE and eNodeB) functional components

pound module that brings the main LTE stack operations into a single box. The UE node uses additional modules for end-user applications (TCP and UDP Applications) and for sending channel status reports (Feedback Generator) to the associated eNodeB. The eNodeB uses a "Deployer" module for many of the physical layer resource specifications (LTE frame structure, Antenna specification, etc.) and UE association details. While the complete details and capabilities of the SimuLTE model and implementation are beyond the scope of this paper, we present a short example simulation work-flow involving the main functional components and their uses.

2) Simulation Workflow: A SimuLTE network is described using a number of cells/eNodeBs and UEs which can be configured dynamically. At the start, a configuration file is used to set the main parameters for the functional components (UE, eNodeB) including configurations for their internal sub-modules (MAC, PHY, Mobility model etc.). The association of UEs with a particular cell is also configured statically with runtime handover support being developed. At instantiation time, a UE begins cell association based on the configuration file provided. The UEs send frequent channel feedback messages to the eNodeB and once a UE application requires some uplink/downlink data, it starts the resource acquisition procedure. The eNodeB receives the feedback reports and channel access requests from the UEs and performs the uplink and downlink scheduling at the MAC sub-module. Most of the modules above the LTE-NIC are taken from INET-framework [15] including TCP/IP and Application layer modules such as VoiP.

3) RAN Multi-Tenancy & Spectrum Sharing: The 5G multi-tenant RAN concept is expected to manifest itself in the form of shared base stations with a certain degree of tenant-specific resource isolation guarantees. While this can be realized at several abstraction levels above the physical layer, a well qualified option is maintaining radio resource segmentation and management using distinct slice-specific medium access control procedures including resource scheduling. To realize this abstraction level in SimuLTE, we have modified the existing structure of the nodes to enable multi-tenant eNodeB having tenant-specific MAC modules and physical layer resources. Figure 3 shows the added and modified submodules (in dashed boxes) in the LTE-NIC compound module. Each eNodeB supports a user-defined array of tenant-specific MAC submodules which are coordinated by two new submodules called "Slice Coordinator" and "PHY Coordinator". The MAC modules have been modified from the SimuLTE model to support new communication (interfaces and messages) and maintain distinct set of physical layer resources. Each MAC module maintains its own set of scheduler and Adaptive Modulation and Coding (AMC) sub-modules to manage uplink and downlink traffic of slice-specific UEs. The layers including and above the RLC have not been modified significantly and the large set of options available to configure these modules have been maintained from the original model. The Slice-Coordinator is a real-time controller and coordinator of the resources configured for each tenant MAC module. It receives higher level configurations from the spectrum manager application (an application outside the eNodeB architecture) and configures parameters that control spectrum sharing among RAN tenants. It monitors the resource utilization in each slice and if enabled, facilitates the sharing of spectrum among the tenants in an active, fine-grained manner. In the DL, it segments the incoming traffic and directs it to the appropriate MAC module and vice-versa in the UL direction. To manage spectrum exchanges, it receives offers and requests from the managed MAC modules and coordinates the resulting increment and decrement of slice-specific bandwidths. The Phy-Coordinator module is more generic and only coordinates the access to the physical layer module in DL and segmentation of traffic in UL towards the appropriate MAC module.

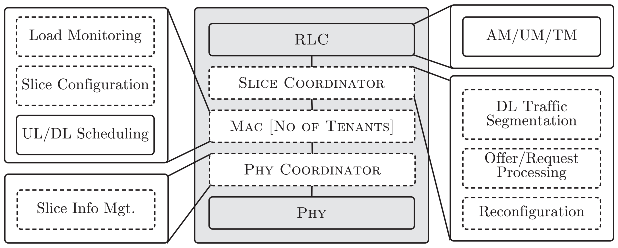


Fig. 3. New and modified sub-modules in eNodeB structure.

4) Time-Frequency Granularity of Spectrum Sharing: Spectrum sharing among RAN tenants guarantees quantifiable benefits in the overall cell performance metrics. However, identifying and using the most suitable time-frequency granularity is not trivial and depends largely on real-time network load and interference situation. In

```
numberOfTenants          = default(2);
enableResourceSharing    = default(false);
componentCarrierSharing  = default(false);
keepReserve              = default(false);
reserveValue             = default(6);
sharingInterval          = default(10);
calculationMethod        = default(Avg);
```

Listing 1. eNodeB configuration settings.

time-domain, as LTE networks use a well-defined frame structure for radio resource allocation, the most fine-grained option of spectrum sharing is one Transmit Time Interval (TTI), which is equal to $1ms$. However sharing radio resources at this time granularity does require real-time computation of tenant-specific network load and almost no latency to communicate/expose any offers or requests. Specifically, a tenants will need to compute its UL/DL spectrum requirement per TTI, determine if excess is available and can be shared, expose it to other tenants, and the cell has to make the necessary re-configurations to scale up or down the resource pool of the involved tenants. While physical or technological constraints might be a hurdle, this granularity level guarantees the most effective use of overall spectrum resources. In simulations however, this granularity of resource sharing has been made possible through message exchanges involving tenant-specific MAC modules and the Slice-Coordinator module. Each tenant can compute its UL/DL resource block requirements from the data buffers, the attached UEs and the channel feedback reports and offer excess resources, if available, to the other tenants in real-time via the Slice-Coordinator. The Slice-Coordinator module can coordinate the resource exchanges among tenants by doing runtime reconfiguration of the bandwidth allocated to each tenant. The higher end of the time-scale granularity is subject to many consideration including its benefits (e.g., achievable throughput) and interference concerns. Furthermore, in multi-cell dense deployments, identifying the most suitable cells and tenants for shared resource allocation becomes a non-trivial problem to solve. In the frequency-domain, the most fine-grained spectrum sharing option in LTE/LTE-A is a single physical resource block (equal to 180kHz). Beyond this minimum, the frequency domain sharing is constrained by the overall dedicated bandwidth available to the slice and the rules for spectrum exchanges. Listing 1 shows the basic configurations options available at the eNodeB considered for active spectrum favors exchanges. While most of the configuration options are self-explanatory, the options that control the time-frequency granularities are the *componentCarrierSharing*, *keepReserve*, *reserveValue*, *sharingInterval* and *calculationMethod*. The *componentCarrierSharing* controls the conformance of the shared bandwidth to the LTE/LTE-A standard i.e., when set to true, 6 Physical Resource Blocks must be shared at the very minimum between RAN tenants. The *keepReserve* parameters allows tenants to enable spectrum sharing in a subset of its dedicated resource blocks with its reserved bandwidth controlled by *reserveValue* parameter. The *sharingInterval* (given in TTI) is the main time-domain granularity parameter and controls the duration of spectrum sharing offers/requests. Finally, the *calculationMethod* controls the estimation function used by a tenant MAC to estimate its offer and request granularity in frequency domain rather than relying on real-time load.

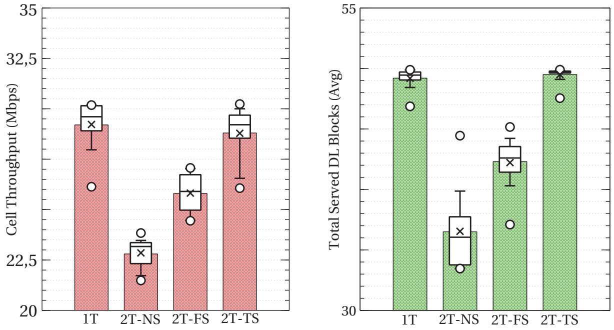
TABLE I

CONFIGURATION PARAMETERS FOR SIMULATION ANALYSIS

	Parameter	Value	Parameter	Value
General	No. of Cells	1	No. of UEs	5-20
	No. of Tenants	1-2	UE Mobility	RandomWP
	Sim Area	1 Sq Km	Geography	Urban Macro
PHY Layer	eNB Tx Power	10W	Frequency	2100MHz
	eNB Bandwidth	10-20 MHz	Slice Bandwidth	5MHz
	Antenna config	Omni-directional	eNB Height	25M
MAC Layer	eNB Scheduler	Max CQI	Queue Size	1MB
Application	Apps per UE	1	UE Application	Video
	App Packet Size	1500B	Pkt Send	2ms

IV. SIMULATION RESULTS

We have carried out simulation analysis using the modified SimuLTE model to analyze the benefits of active spectrum sharing. Table I presents the main configuration parameters used for the simulation results and analysis. A single cell having two tenants has been considered to analyze the potential benefits and trade-offs of different time-frequency granularities. The following set of configurations for the eNodeB have been used. (a)**1T**: Single cell with one tenant taking all the available bandwidth and simulated UEs. This is similar to a traditional eNodeB having no multi-tenancy feature. (b)**2T-NS**: Single eNodeB having two tenants taking equal cell bandwidth but not allowing any exchange of spectrum favors. (c)**2T-FS**: Single eNodeB having two tenants allowing spectrum sharing per alternate radio frame. In this configuration, each tenants evaluates its average DL resource block utilization in a single frame i.e., 10ms and offers the excess, if available, to the other tenant. The other tenant may or may not accept the offer depending on its own real-time traffic in the slice. (d)**2T-TS**: One cell and two tenants allowing resource sharing at each TTI i.e., 1ms time-interval. In this configuration, no latency is assumed in the overall sharing process. Figure 4 (A) shows the joint average cell throughput (sum of both slices) of the four different configurations described above. The figure clearly shows the benefits of resource sharing including the effects of realizing this at different time-intervals. In the 1T configuration, all resources and UEs belong to a single scheduler which makes scheduling decisions using maximum CQI based scheduler. All things being equal, the 1T scenario



(A) (B)

Fig. 4. Average cell throughput and DL allocated resource blocks

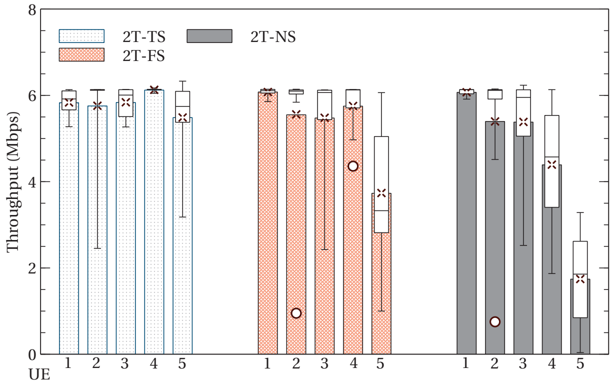


Fig. 5. Average UE application layer throughput

serves as an optimum reference for the spectrum sharing scenarios. This result confirms that the more granular the spectrum sharing, the more closer we get to the optimum. The same can be said for figure 4 (B) where the average DL resource block utilization increases with the granularity of spectrum sharing. Figure 5 which depicts the impact of spectrum sharing granularity on the UE application layer throughput further strengthens the argument that in multi-tenant RAN, the most granular levels of spectrum sharing should be pursued. Figure 6 shows the impact of slice-specific load variance (given in number of UEs per slice) on the achievable cell throughput. As the load in a particular slice goes down, simple RAN multi-tenancy without spectrum sharing results in wastage of RF spectrum. This gives further arguments for RAN tenants or infrastructure-providers to aim for achieving the most fine-grained active, RAN and spectrum sharing implementation practically possible. However, competition, isolation concerns and complex RF environments will make the selection of optimum time-frequency granularity a complex problem and an important research topic to investigate.

V. CONCLUSION & FUTURE WORK

This paper presented an active RAN and spectrum sharing approach together with a new system level simulation model that is capable of simulating multi-tenant RANs. The details of spectrum sharing approach and the simulation platform were presented in addition to presenting preliminary results highlighting the benefits of spectrum sharing in a fine-grained manner. The future work will focus on extending the dynamic slice-creation to an end-to-end solution involving back-haul segment and more complex deployments. Moreover, a self-organized approach to realize an automated scaling of resources allocated to tenants will be investigated.

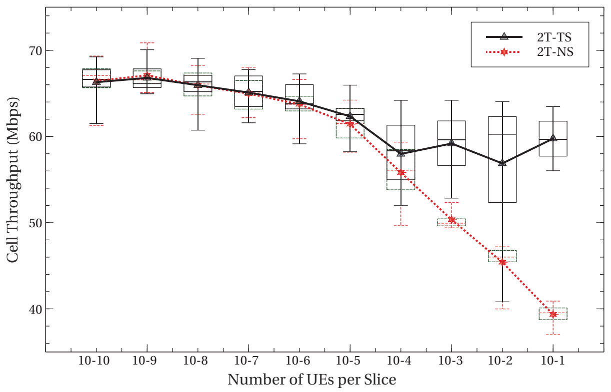


Fig. 6. Cell throughput against slice-specific load variance

REFERENCES

[1] CISCO: The Mobile Enconomy, whitepaper, GSMA, (2016)

[2] C. Yang, J. Li, M. Guizani, A. Anpalagan and M. Elkashlan, ”Advanced spectrum sharing in 5G cognitive heterogeneous networks,” IEEE Wireless Communications, vol. 23, no.2, pp.94-101, 2016

[3] SimuLTE: ”An Open Source LTE User-Plane Simulation Model”, Online: http://simulte.com/. Accessed: July 9th (2017)

[4] B. A. Fette, “Cognitive Radio Technology”, 2nd Ed. Elsevier 2009

[5] 3G-PPP TS 23.251, ”Network Sharing Architecture and Functional Description”, 2017.

[6] T. Guo and R. Arnott, ”Active LTE RAN Sharing with Partial Resource Reservation,” 2013 IEEE 78th Vehicular Technology Conference (VTC Fall), Las Vegas, NV, 2013, pp. 1-5.

[7] R. Kokku, R. Mahindra, H. Zhang and S. Rangarajan, ”CellSlice: Cellular wireless resource slicing for active RAN sharing,” 2013 Fifth International Conference on Communication Systems and Networks (COMSNETS), Bangalore, 2013, pp. 1-10.

[8] S. Han, Y. C. Liang, Q. Chen and B. H. Soong, ”Licensed-Assisted Access for LTE in Unlicensed Spectrum: A MAC Protocol Design,” in IEEE Journal on Selected Areas in Communications, vol. 34, no. 10, pp. 2550-2561, Oct. 2016.

[9] Nokia Whitepaper: ”Alternative LTE Solutions in Unlicensed Spectrum: Overview of LWA, LTE-LAA and Beyond”. 2016

[10] MulteFirte: A new Way to Wireless. Multifire Alliance: Online: https://www.multefire.org. Accessed 2017

[11] EU-H2020, Coordinated Control and Spectrum Management for 5G Heterogeneous Radio Access Networks. Online: http://www.ict-coherent.eu/

[12] Mohammad S.O, Tuncer Ö., Janusz K., Joaquim F.: Simulation and Modeling Methodologies, Technologies and Applications. Springer International Publishing Switzerland (2015)

[13] C. Cox, ”An Introduction to LTE, LTE-A, SAE, VoLTE and 4G Mobile Communications” John Wiley & Sons, Ltd. UK. 2014

[14] Andras V.: OMNeT++: Discrete Event Simulator. Online: http://omnetpp.org: Accessed: July 9th, (2017)

[15] INET-Framework: An open-source OMNeT++ model suite for wired, wireless and mobile networks. Online: https://inet.omnetpp.org/ Accessed: July 9th, (2017)