RAN SLICING FRAMEWORK AND RESOURCE ALLOCATION IN MULTI-DOMAIN HETEROGENEOUS NETWORKS

Godfrey Kibalya [0000-0002-7053-3756], Joan Serrat and Juan-Luis Gorricho

Universitat Politecnica de Catalunya,
08034 Barcelona, Spain

Godfrey.mirondo.kibalya@upc.edu,serrat@tsc.upc.edu,juan luis@entel.upc.edu

Abstract. The Third-Generation Partnership Project (3GPP) has identified network slicing as one of the key technologies to address the complex communication scenarios in the 5G network. With the 5G commercialization target dates fast approaching, there are a plethora of challenges that need to be addressed regarding 5G slicing especially in the Radio Access Network (RAN). Consequently, this paper highlights the key research challenges being addressed by the Ph.D. thesis proposal. Specifically, we propose a virtualized RAN slicing framework considering a multi-RAT, multi-domain heterogeneous network and a two-level resource allocation scheme at each domain. Within a slice, we adopt a novel concept of slice profiles to address the heterogeneity challenges associated with the 3GPP notion of a slice. We also propose an entity called cross-domain coordinator to coordinate inter-domain resource sharing. The paper discusses the approaches to be adopted in formulating the intra-domain and inter-domain resource sharing algorithms.

Keywords: RAN Slicing, Multi-Domain Resource Sharing, Heterogeneous Network Resource Allocation

1 Introduction

The International Telecommunication Union (ITU) has already classified 5G mobile network services into three categories which are [1]: Enhanced Mobile Broadband (eMBB), Ultra-reliable and Low-latency Communications (uRLLC), and Massive Machine Type Communications (mMTC). Considering that these service categories have different characteristics and technical requirements, the 3GPP proposes to extend a logical dedicated network in form of network slice suitable for meeting the technical requirements of each of the above service classes [2].

Network slicing and virtualization presents a plethora of challenges. Besides the complexity related to how the virtual resources are mapped onto the physical resources, another challenge is on how to effectively allocate the virtualized resources to the different slices with differing requirements. Moreover, the access network wireless resources are highly dynamic and variable both in temporal and spatial domains. This requires that resource allocation mechanisms capture the dynamicity of the physical resources. The problem will further be complicated by the emergency of heterogeneous networks constituted by multiple Radio access technologies (RATs). The different RATs offer different capabilities towards the services supported by the different slices in terms of technical requirements. Consequently, the Base Station (BS) association problem needs to map the slice technical requirements with BS capabilities. Moreover, the different BSs may belong to different operators or domains, which brings in another dimension of inter-domain resource sharing of the virtualized resources. Another unexplored challenge is the heterogeneity within the aforementioned service categories. Within each of these categories, there are users with differing technical requirements hence requiring innovative approaches if these users are to exist in same slice.

The problem to be addressed in the thesis involves how to create and manage slices consisting of a set of radio resources in a multi-technology and multi-domain wireless access network so that services can be deployed on top of these resources. The proposed framework exhibits the following key characteristics: 1) Isolation to safeguard against mutual interference between slices. 2) Elasticity by enabling flexible and dynamic allocation, reclaiming, and release of resources to optimize temporal and spatial resource usage.3) Authentication to enable authorized use of the virtual resources between slices

This paper is structured as follows: Section one has briefly introduced the slicing concept and the key research issues unexplored in literature. Section two presents state of the art in RAN slicing resource allocation. Section three introduces the proposed slicing framework and a summary of proposed contributions indicated in section four. The paper is concluded in section five

2 State of the art

A big number of works treat a slice as a virtual network (VN) belonging to Mobile virtual network operator (MVNO) and the aim is to allocate resources to meet the minimum data-rate requirements in the different VNs as in [3] and references therein, or match the financial contribution of the network operator as in [5]. Besides not addressing the heterogeneity within the 3GPP slice notion, these works do not consider a multi-RAT setting nor do they consider multi-domain resource allocation. Also, the Base station is not considered as a resource to be allocated to users of the different VNs. In addition, these works adopt a single level resource allocation scheme. The work in [12] and the associated references propose a two level slicing model for allocating resources to multiple tenants under heterogeneous network. These works however, consider heterogeneity in terms of only BS coverage thus Macro and small cells and not on basis of RATs. These works also do not address the heterogeneity challenges in the slicing concept. The work considering Multi-RAT network is found in [14] and references therein. These also however, consider the RAT effect in terms of their capacity contribution to the network and not in terms of their capability towards different services.

To the best of our knowledge, there is no work addressing multi-domain resource allocation in RAN slicing. Another novelty in our work is the concept of slice profiles to address the heterogeneity challenges in the slicing concept. Moreover, different from other works we consider the effects of the different RATs towards services supported by slices.

3 Proposal of a slicing management architecture

We propose a two-level resource allocation framework as shown in Fig1. As indicated, the physical radio resources of a given domain are virtualized into a VRRP in a 3-D grid of time, frequency and space. The VRRP of a given domain is under the control of the domain slice manager (DSM) with each domain being characterized by a single DSM.

The proposed framework supports Inter-domain resource sharing through the cross-domain coordinator (xDC) connected to the different DSMs. In particular, whenever the DSM runs out of resources or wants to establish connection in a different domain, it sends request to the xDC specifying possible constraints on the required resources such as type of resources, SLA with its clients etc. The xDC then queries the auction databases of the different DSMs for any resources meeting the specified constraints. If resources are found, then the request is served, otherwise request is rejected. The auction database contains details of resources such as type and amount that a given DSM is willing to auction to another domain at any given instant. This database can be updated upon request from the xDC or updated automatically by the DSM. The DSM may have resource sharing agreements with specific domains and with different sharing terms. Within this regard, we propose to develop an inter-domain resource sharing policy and algorithm capturing these possible aspects.

The DSM is assumed to have global view of the virtual resources available within its domain through the different monitoring modules. It manages resource allocation at upper level by dynamically allocating resources to different slices through the local slice manager (LSM) of the slices. In order to consider isolation between slices, each slice is modeled with maximum fraction of available resources it can use under full domain resource utilization. But when a given slice is not fully utilizing its resource share, these can be borrowed by other slices. In such a case, we shall define an optimal pre-emption mechanism to guide on release of the resources when the entitled slice, requests for them. We intend to formulate the resource allocation problem as an optimization problem so as to maximize resource utilization across the different slices subject to slice requirement constraints and available resources.

At the lower level, the resource allocation is performed by the LSM and this is modeled into three stages thus, BS assignment to the user, associating a user to the appropriate profile of the slice, and assigning radio resources to the user. We envisage two approaches for BS association. In the first approach, the association problem is modeled as a knapsack problem. The second approach will adopt an intelligent online technique to capture more automated intelligence and to enable multi-attribute analysis. We model the effects of different RATs towards the technical requirements of a user belonging to a given slice. With respect to this level, the thesis will develop algorithms for BS and radio resource allocation to the different profiles and users.

The LSM manages a number of modules which are not shown in Fig1 due to space constraints. These include: 1) The monitoring module which captures the network condition such as number and QoS of admitted users, resource utilization etc. This information is stored in local database and used by the learning module to update decisions regarding the BS association, profile association and resource allocation. 2) The RAT selection module responsible for selecting the BS to which to associate the different users considering the user service requirements, RAT capability etc. This module runs the BS association algorithm. 3) The Profile selection module that interacts with the monitoring module and the learning module to decide the slice profile to which to associate the user. Moreover, it is possible to move the user from one profile to another depending on the prevailing network conditions. 4) The resource assignment module in charge of managing resource assignments from the slice resource pool to the different profiles and withdraw of resources from one profile to another 5) The learning module which is an intelligent module that exploits the monitoring information to influence the next decisions regarding user admission, profile selection and resource allocation.

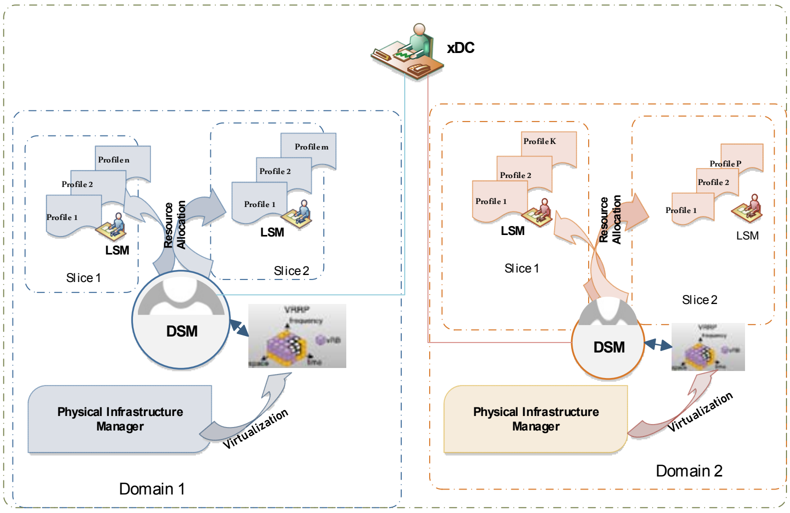

Fig. 1. RAN Slicing Framework

4 Proposed Innovations

The thesis is being developed working on a number of proposals targeting the implementation of RAN slicing in 5G networks. Specifically, we propose the following:

A practical RAN slicing framework that is commensurate with the slicing concept as envisioned by the 3GPP while addressing the heterogeneity challenge that arises within the concept. In particular, we introduce the concept of profiles within a slice. In the profiling concept, users of a slice that have same technical requirements are assigned to the same profile that is associated with a share of virtual resources and priority level.

A two- level resource allocation algorithms. At the upper level, the virtualized resource pool is under the control of an entity called a Domain Slice Manager (DSM) that allocates resources to the different slices of its domain. At the lower slice level, the Local Slice Manager (LSM) is in charge of allocating resources received from DSM to the users of the different profile. We propose algorithms for each of these levels.

A dynamic algorithm to determine the profile to which to attach an admitted user. The algorithm will exploit intelligent learning techniques to capture the dynamic nature of the slice conditions. Moreover, an approach based on prioritization and pre-emption mechanism for congestion and emergency management of critical services is also proposed

A dynamic online resource sharing policy for sharing resources across multiple domains where the domain belong to different entities. Additionally, we propose an embedding algorithm for embedding the virtual radio resources to physical resources

Different from other works, we consider a heterogeneous environment comprising of both small cells and macro cells belonging to different RATs. Towards this direction, we propose an online BS association algorithm that captures the capability of different RATs towards the users of different slices.

4. Conclusion

The slicing of the RAN is envisaged as a key step towards achieving end-to-end network slicing leading to a reduction in CAPEX and OPEX for operators. The slicing solutions should be tailored towards a practical 5G environment in which the slicing is bound to be implemented. However, slicing solutions in literature do not consider the heterogeneity of future networks in terms of cell sizes, RAT types and multi-domain ownership. Moreover, the works do not appreciate the diversity of services that will characterize the 5G network. Towards this direction, once our approaches proposed in this paper are realized, it will contribute towards realizing network slicing in the 5G RAN.

Acknowledgement

This work has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 777067 (NECOS project). This work is also funded by the national project TEC2015-71329-C2-2-R (MINECO/FEDER).

References

1. EU H2020 5G NORMA, “D2.1: Use cases, scenarios, and requirements,” September 2015
2. K. Samdanis et al., “5G Network Slicing: Part 1 – Concepts, Principles, and Architectures.”, IEEE Communications Magazine, Vol. 55, pp 70-71, May 2017
3. S. Parsaeefard, R. Dawadi, M. Derakhshani, T. Le-Ngoc.: Joint User-Association and Resource-Allocation in Virtualized Wireless Networks. IEEE Access, Vol.4, pp. 2738 --2750 (2016). Doi: 10.1109/ACCESS.2016.2560218
4. P. Caballero et al.: Multitenant Radio Access Network Slicing: Statistical Multiplexing of Spatial loads. In IEEE/ACM Transactions on Networking, vol.25, no.5, pp.3044-3058, Oct.2017. DOI:10.1109/TNET.2017.2720668
5. Y. L. Lee, J. Loo, T. C. Chuah and L. C. Wang.: Dynamic Network Slicing for Multitenant Heterogeneous Cloud Radio Access Networks. In *IEEE Transactions on Wireless Communications*, vol.17, PP, no. 99, pp. 1-1. *IEEE Transactions on Wireless Communications*, vol. 17, no. 4, pp. 2146-2161, April 2018. Doi: 10.1109/TWC.2017.2789294
6. S .Khatibi and L.M.Carreia.: A model for virtual radio resource management in virtual RANs. EURASIP J.Wireless Commun.New.vol. 2015, no.68, pp.1-12, Mar.2015. DOI 10.1186/s13638-015-0292-7