RadioVisor: A Slicing Plane for Radio Access Networks

Sachin Katti† Li Erran Li*
Bell Labs, Alcatel-Lucent* Stanford University†

1. THE NEED FOR FLEXIBLE SHARING OF RADIO ACCESS NETWORKS

To cope with the exponential traffic growth, increasingly diverse traffic mix including voice, video, machine-to-machine(M2M), and the spectrum shortage, wireless networks have to get densely deployed and dynamically adapt to meet the distinct requirements of diverse traffic classes. However, current network architectures are ill-equipped to support a dense and dynamic wireless infrastructure. First, since it will be impossible to obtain regularly placed cell sites for an infrastructure with higher density, basestations will be deployed wherever possible in a chaotic fashion. However, a chaotic and dense wireless deployment will be very complex to manage, since it will experience highly variable loads and unpredictable inter-cell interference among other things. Further since spectrum is limited, very likely all the basestations will be operating on the same frequency (referred to as frequency reuse factor of one). This leads to a tremendous amount of inter-cell interference, and that becomes the limiting factor for network capacity. Second, a dense infrastructure is very expensive to deploy and operate. Current deployments are unaffordable except to the largest operators, so a deployment with significantly higher density will likely be enormously expensive even for the largest operators, preventing smaller operators from expanding and offering consumers the choices they need.

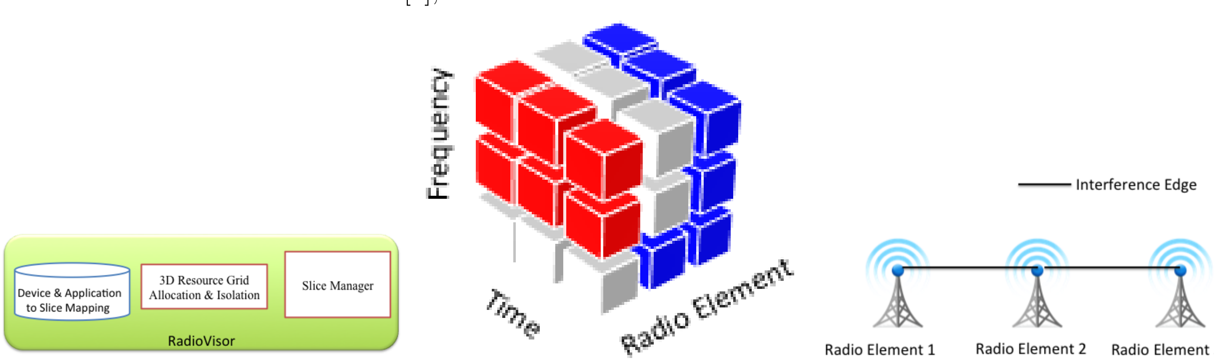
Rather than looking at the radio access layer as a collection of independent base stations, SoftRAN [1] proposes that all base stations deployed in a geographical area should be abstracted as a virtual big-base station which is made up of radio elements (the individual physical base stations). A logically centralized control plane makes all decisions regarding handovers and interference management, while the radio elements are simpler devices with minimal control logic. Since all neighboring base stations are allocating from a fixed set of shared resources, SoftRAN abstracts the radio resources as *a 3D resource grid* of space, time, and frequency slots; and program them in a software defined fashion through a logically centralized radio access control plane.

Rather than having a single entity controlling radio access networks which limits sharing as standardized by 3GPP on LTE [2], we build on SoftRAN and argue that the 3D resource grid should be dynamically sliced based on traffic among virtual operators. This will enable virtual operators to innovate in scheduling, interference management and even in physical layer (PHY). Operators should be able to flexibly define slices based on subscriber attributes and application types (e.g. voice, video) to support a wide range of application requirements.

Such architecture raises unique challenges compared to data-center and enterprise networks. Indeed, radio resources are inherently coupled due to the shared nature of wireless media. Unlike FlowVisor [3] which slices the flow space and easily isolates the disjoint subspaces. Slicing radio resources would need to consider interference.

2. RADIOVISOR DESIGN

To address these challenges, we present RadioVisor, a very flexible slicing plane to enable innovative sharing of network resources. Akin to FlowVisor [3], RadioVisor enables each controller to access a slice of the radio access



(a) RadioVisor Architecture (b) Example: Resource Grid Slicing (c) Example: Radio Element Interference Graph

Figure 1: RadioVisor Architecture, and Subgrid Allocation and Isolation

network infrastructure. RadioVisor ensures isolation of the different slices in terms of control channel messages, radio element resources such as CPU, and radio resources. Each controller can provide customized services, similar to platform-as-a-service in cloud computing. For example, one controller can specialize in providing services to the fleet management industry with specialized features such as group mobility. RadioVisor allows each entity to directly control their radio resources.

Architecture: RadioVisor system architecture consists of three key components as shown in Figure 1(a): the device and application to slice mapping, the radio resource allocation and isolation function and the slice manager. We focus on isolation of radio resources. RadioVisor needs to demultiplex traffic to and from the controllers of virtual operators. If each virtual operator's ID is broadcasted through the physical broadcast channel of each allocated radio element (LTE RAN sharing supports this), that makes demultiplexing of signaling traffic among virtual operators easy.

Subgrid allocation and isolation: Static splitting the spectrum band among virtual operators is not efficient. For example, suppose we have two virtual operators and a spectrum band of 20 MHz; Each operator gets a dedicated 10 MHz band. Even if one operator has no traffic, the resource can not be used by the other. We want to enable flexible resource sharing while preserving control of resources by the virtual operators. We assume each operator is entitled to a certain fraction of the 3D resource grid in the coverage area it chooses based on service level agreement. We assume RadioVisor makes resource allocation decisions every T time window. Every T time window, each operator presents its resource request based on traffic prediction.

RadioVisor slices the 3D resource grid in a max min fashion according to resource requests and their entitled fraction. The key challenge is how to make efficient allocation while ensuring isolation. Isolation is the key to guarantee that each operator can make independent decisions on their resources. We illustrate using the example in Figure 1(b). There are two virtual operators. The red virtual operator only has demand on radio element 1. The blue virtual operator has demand on radio element 2 and 3. Figure 1(c) shows the interference graph of radio elements. Radio element 2 interferences with radio element 1 and 3. Radio element 1 and 3 do not interfere with each other. Suppose RadioVisor allocates 2/3 of frequency band at radio element 1 to the red operator. To ensure isolation of virtual operators, 2/3 of frequency band at radio element 2 (shown as gray blocks in Figure 1(b)) will not be used. Note that, even a single operator controlled network needs to manage interference by coordinating frequency allocation among radio elements. 1/3 of frequency band at radio element 2 and the whole frequency band at radio element 3 are allocated to the blue virtual operator. Note that, the interference problem among radio element 2 and 3 is left to the blue operator itself.

Slice Algebra: Third parties or virtual operators need flexible slice operations. These can be supported by the RadioVisor or controllers.

- Slice merge: A virtual operator specializes in smart meter applications may gain a customer. This requires the merge of two slices.
- Slice split: A virtual operator may split its slice into two to load balance.
- Slice (un)nest: A virtual operator may delegate one sub-slice to a third party. For example, a virtual operator decides to let someone specialize in fleet management to handle its fleet monitoring devices.
- Slice duplicate: Slice duplicate allows testing of a new controller.

Each slice can be defined using predicates on subscriber attributes. For example, a slice can be all M2M devices, or all video traffic of a customer. RadioVisor provides an API for a slice to interact with the slice manager. For example, if a virtual operator wants to split its slice into two, it will invoke the split API of the slice manager by passing the two new slice definitions and the state of each slice.

Per Slice Controller, Applications, PHY and MAC: Each slice can deploy its own controller and applications (e.g. interference management, handover) in the control plane independently. Each slice can also deploy its own PHY and MAC (e.g. scheduler) layer independently. To support multiple non-contiguous frequency bands or carriers and different PHY technologies, mechanisms such as [4, 5] that can flexibly slice spectrum and radio frontend, and program wireless data plane are needed.

3. REFERENCES

[1] A. Gudipati, D. Perry, L. E. Li, and S. Katti, "SoftRAN: Software defined radio access network," in *ACM HotSDN*, 2013.

[2] G. T. 23.251, "Network sharing; architecture and functional description." `http://www.3gpp.org/DynaReport/23251.htm`.

[3] R. Sherwood, G. Gibb, K. Yap, G. Appenzeller, M. Casado, N. McKeown, and G. Parulkar, "Can the production network be the testbed?," in *USENIX OSDI*, 2010.

[4] S. S. Hong, J. Mehlman, and S. Katti, "Picasso: Flexible RF and spectrum slicing," in *ACM SIGCOMM*, 2012.

[5] M. Bansal, J. Mehlman, S. Katti, and P. Levis, "OpenRadio: A programmable wireless dataplane," in *ACM HotSDN*, 2012.