Spectrum Management Application - A Tool for Flexible and Efficient Resource Utilization

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***Abstract*—Dynamic spectrum access and management is one key enabler to constitute the foundation for a multi-service architecture with a high level of flexibility. In this work, we design and implement the spectrum management application (SMA) as an efficient tool to manage and process different policies and rules defined by various stakeholders such as national regulatory authorities, operators and licensed shared access. The SMA is an open-source and clean-slate replacement for legacy platform-dependent spectrum management solutions and can provide custom control programmability and agile resource utilization. We also elaborate on the design details of the SMA and show how it can dynamically select the optimal spectrum offers based on different applied rules in time-series. Finally, we demonstrate two specific use cases via integrating the implemented SMA prototype on top of the Mosaic5G and OpenAirInterface platforms.**

I. INTRODUCTION

Fifth generation (5G) wireless networks will apply various abstraction and virtualization techniques. Spectrum utilization however is still challenging and plays a critical role to improve the area spectral efficiency [1]. Moreover, available spectrum shall be utilized efficiently to enable extreme network densification, e.g., ultra-dense networks, without introducing undesirable interference between neighboring (small) cells. Although the static licensing for exclusive spectrum use among operators on one side and the license-exempt solutions on the other side are widely-adopted solutions nowadays, the aforementioned driving factors indicate precisely the need for a more flexible spectrum management approach. This observation is of particular importance for 5G networks, where the applied network function virtualization (NFV) concept enables the logic functions to be separated from the underlying hardware. To this end, the access, assignment and deployment of available radio spectrum resources can be treated as the new virtualized network functions (or services).

Moreover, another challenge in 5G is to fulfill various service provider requirements via exploiting resources across multiple domains, in which the radio spectrum shall be managed properly to satisfy various defined policies by stakeholders, e.g., national regulatory authority (NRA), operators, licensed shared access (LSA) [2]. Also, the characteristics of different spectrum bands will largely impact the radio access network (RAN) performance. For instance, millimeter wave (mmWave) spectrum has a larger bandwidth (e.g., E-band) to serve the scenario with small cells and low user mobility. In contrast, the low carrier frequency case (e.g., lower than 2 GHz) brings a larger and deeper coverage area but with limited bandwidth, while the sub-6GHz case (e.g., 3 to 4 GHz) is a compromise between above two options. On the other hand, network operators aim to utilize all available spectrum bands to maximize their revenue while maintaining the user experience. In this regard, the pricing model shall be given to the service provider depending on several criteria, such as carrier frequency, bandwidth, time duration among the others. To sum up, the spectrum shall be flexibly and efficiently managed to satisfy the goals of both service providers (e.g., service availability and reliability) and network operators (e.g., resource utilization and revenue) dynamically.

In this work, a dedicated Spectrum Management Application (SMA) is designed and implemented, based on the generic concept in [3], as a network common control service that operates on top of the softwarized mobile network. The SMA can manage and process different defined policies and rules. For instance, the NRA can define some specific policies for spectrum usage in a certain geographical area to facilitate decent service delivery during a scheduled mass event. Another possibility is that one license owner (operator) may define its own policies for spectrum sharing with other interested players, or two collocated operators can define their mutual agreements for spectrum sharing in between. In all cases, the SMA can interpret these policies and make decisions on the eligible ways of spectrum use; which are weighted based on a set of rules defined by the service providers to describe the desired relationships among the interested parameters (e.g., bandwidth, available time). Finally, the control decisions are enforced toward the underlying RANs by the logically centralized coordinator and controller. To the best of our knowledge, the SMA is the first open-source spectrum management tool implemented with a high level of flexibility.

In summary, this article makes the following contributions:

- We review the state-of-the-art regarding spectrum management softwarization (Section II);
- We outline the proposed SMA in term of the high-level architecture and processing flow exploiting the underlying software development kit (SDK) (Section III);
- We elaborate on several design elements of SMA and show how this application works (Section IV);
- We present two specific use cases via integrating the implemented SMA with the Mosaic5G [4] and OpenAirInterface (OAI) [5] platforms. (Section V).

II. RELATED WORKS

Traditionally, the usage of a certain frequency band shall follow the set of policies defined by the authorized regulatory authorities, e.g., NRA, and typically controlled by the dedicated licensing mechanism. Two distinct variants are practically applied in contemporary wireless networks, mainly *license-only* and *license-exempt*. In the former case, the licensee has the only right for exclusive spectrum use what guarantees that the licensed system is protected from the uncontrolled interference within the same band. Contrarily, in the license-exempt case, specific spectrum bands are relaxed from any constraint, and thus anyone who owns certified devices can use these bands. A well-known example is the allocation of WLAN communication in the industrial, scientific and medical (ISM) and unlicensed national information infrastructure (UNII) bands, around 2.45 GHz and above 5 GHz, respectively. However, the average spectrum occupancy is still low, even in densely populated areas, and thus various approaches to enable the flexible spectrum access can be applied [6], such as sensing, prediction and inferring. Hence, a compromise between above two identified cases can be made, and many solutions have been provided [7], such as LSA, licensed assisted access (LAA), and spectrum access system (SAS) for citizen broadband radio service (CBRS).

To accommodate aforementioned cases, the frequency resource management approach shall be flexible and policy-compliant relying on two principles: softwarization and programmability [8]. Note that such approach will require not only accurate and plausible spectrum sensing but also the deployment of dedicated databases (DBs) to store context information (e.g., geo-location, radio environment maps). Several architecture proposals as policy-based and database-oriented solutions have been discussed so far. One proposal provided by the Defense Advanced Research Projects Agency (DARPA) is the next generation (XG) communication program [9], in which two key entities can formulate transmission queries and accept transmission requests: system strategy reasoner and policy reasoner. Another option defined by the IEEE 1900.5 working group [10] provides a policy-based control architecture for dynamic spectrum access network. Further, the COGEU project provides the system architecture for spectrum trading, spectrum commons and prioritization in TV white spaces [11]. The hierarchical spectrum management architecture provided by the SPEED-5G project [12] aims to exploit benefits on both distributed and centralized approaches.

We can observe that above solutions request a complete replacement and are not agile to dynamically plug and play specific spectrum management rules and customized control logics. In contrast, as proposed in [3], SMA can bring several benefits. Firstly, it is conceived as a network function (virtual or physical) that can be customized based on the requirements of service providers while retaining the resource utilization agility from the operators' perspective. Moreover, SMA serves as a tool for flexible and efficient spectrum management and can maintain the conformance with existing standards and commercial-off-the-shelf (COTS) devices. Finally, the SMA can expose context-aware semantic information to facilitate reasoning of generated knowledge.

III. SMA OVERVIEW

The SMA aims to provide the flexible and agile control logics for utilizing radio spectrum resource in heterogeneous networks. It processes several types of input information (i.e., short-term and long-term policies, sensing data) aggregated through well-defined interfaces, derives spectrum management control decisions (called hereafter *SMA-policy*), and enforces the applied policies via interacting with local or remote RAN real-time controller (RTC). The development of SMA relies on the platform SDK with well-defined application platform interfaces (APIs) to reveal the virtualized network information and provide network programmability.

Following [3], a high-level architecture of SMA is shown in Fig. 1, which includes the spectrum management rules and decision making algorithm. The former relies on several criteria (e.g., from input spectrum management rules) to manage available spectrum offers. For instance, it can pre-exclude some ineligible spectrum offers when their price (e.g., Euro per second) is larger than a pre-defined maximum value. The latter can generate the output *SMA-policy* based on the input short/long-term policies and sensing data to be applied toward the underlying heterogeneous RAN. To enable SMA, we rely on the aforementioned platform SDK to provide a software development environment to simplify the design, development, test and update of applications. It also includes a group of libraries to provide specific functions/methods to be accessed through one or more API calls. As for the RAN controller, it provides the required control functionalities and interfaces to abstract the underlying network (i.e., north-bound interface [NBi]), deploy the spectrum management and sharing policies to the underlying networks through dedicated agents (i.e., south-bound interface [SBi]), and exchange information for coordinating spectrum management decisions between network domains (i.e., east-west interface [EWi]). Finally, the underlying agents can enforce the *SMA-policy* on the heterogeneous RAN, either being macro cell, small cell or radio unit (controlled implicitly through the centralized and distributed unit [CU/DU][1]).

In Fig. 2, the processing flow of SMA is shown. First of all, the DB located at the SDK can collect and populate the spectrum related information, and the SMA can utilize the SDK to load the policy and rules that shall be followed when generating its control logics. Then, the RTC can register to the agent in order to get the latest status that can be loaded from the underlying RANs. These status include the spectrum information such as available bandwidth, sensing data to be exposed to the SMA to make the control decisions. After all, the *SMA-policy* will be provided by SMA, validated by RTC, and enforced by agent to the underlying RANs. Further,

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[1] Defined by third generation partnership project (3GPP) in TR38.801.

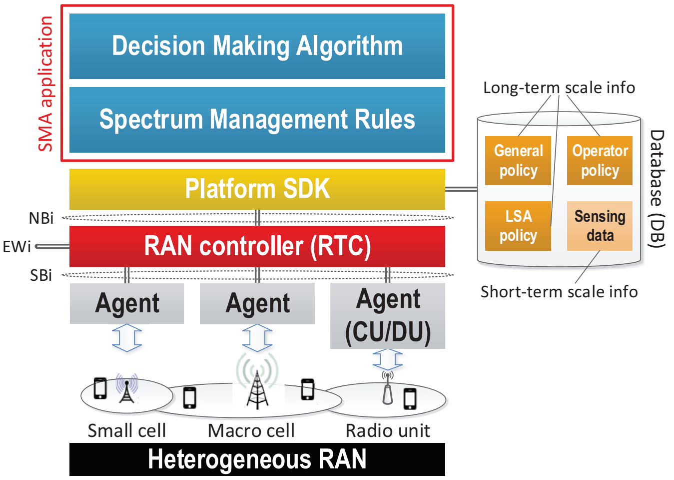


Fig. 1: High-level architecture of SMA.

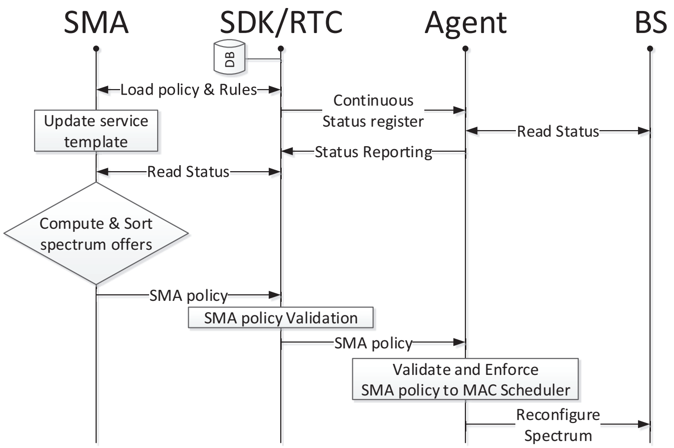


Fig. 2: Processing flow of SMA.

the base stations (BSs) can optionally provide feedback information (e.g., unfeasible policy, conflict decision) back to the SMA in order to adapt the decisions.

To sum up, SMA can leverage the underlying SDK, RTC and agents to utilize available spectrum resource. Specifically, it takes into account various entries stored in the dedicated DBs and it can analyze the following information:

a) General policies defined by the NRA for a given region and time,
b) Mutual agreements between any two (or more) operators regarding the spectrum sharing,
c) Open (for public) spectrum sharing rules, such as those following the LSA, or CBRS approaches, that define how any allowed stakeholder may bid or request from the spectrum licensee on a certain amount of spectrum resources, and
d) Priorities to be applied while allocating the spectrum among the BSs (for instance, the operator and frequency preferences).

More design and implementation details of SMA are given in the next section.

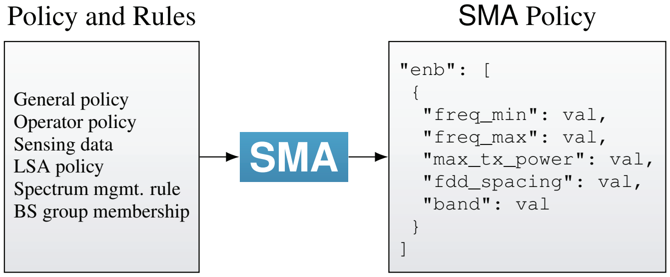
IV. SMA DESIGN AND IMPLEMENTATION

We hereby provide the design details of SMA and show how the implemented SMA can dynamically select optimal spectrum offers based on different applied rules.

A. Input & Output

In Fig. 3, the inputs of SMA include policy and rules. Based on the input policies defined by interested stakeholders, various opportunities for spectrum usage are created, i.e., spectrum offers. Moreover, the input rules can provide the patterns to calculate the weight of each spectrum offer that is defined for each group to select the optimal offer.

- **General policy**: It contains a list of general spectrum usage policies of a specific region or country (provided by Federal Communications Commission [FCC] for US, and Electronic Communications Committee [ECC] for Europe). More specifically, `freq_min`, `freq_max`, `frame_type` and `max_tx_power` correspond to the minimum carrier frequency, maximum carrier frequency, applicable frame type (e.g., frequency-division duplexing [FDD] or time-division duplexing [TDD]) and maximum transmission power, respectively.
- **Operator policy**: It contains the parameters for a list of spectrum offers. These spectrum offers can be shared by several operators with certain utilization rules, which is defined by the same group of operators. Followings are the specific parameters for each spectrum offer:
  - `operator`: Name of operator that defines this policy
  - `freq_min`: A list of lower boundaries of possible bands
  - `freq_max`: A list of higher boundaries of possible bands
  - `busy`: Option that will be used when the activity of other BSs of the same operator is detected between `freq_min` and `freq_max`
  - `idle`: Option that will be used otherwise
  - `sub_freq_min`, `sub_freq_max`: Define a band (possibly sub-band) which can be used when in the “`busy`” state
  - `power_mask`: Define the transmission power mask (interference to the narrowest channels/bands)
  - `min_lease_time`: It serves as the minimal time interval (for example, in the level of millisecond [ms]). After this time interval, new spectrum request (query) has to be send. Such mechanism can provide the periodic update scheme like the CBRS model.
  - `max_lease_count`: Maximum count of intervals (for example, 200×100ms) that such band can be used
  - `max_time_to_leave`: Maximum time to leave this band when detecting other BSs using the same band
  - `price`: The price (for example in Euros) to use such band for a single `min_lease_time` time duration
  - `sensing_sensitivity`: Sensing sensitivity in dBm
- **Sensing data**: It contains the detected BS information (i.e., not controlled by the same RTC) with specific frequency spectrum range and the corresponding operator name. It can be used to identify aforementioned “`busy`’ or “`idle`’ state.



```
"enb": [
 {
  "freq_min": val,
  "freq_max": val,
  "max_tx_power": val,
  "fdd_spacing": val,
  "band": val
 }
]
```

Fig. 3: Input and output of SMA.

- **LSA policy**: It includes the same parameter set as in the **Operator policy**, but without breakdown for option `busy` and `idle`. Such policy is used to identify the ways to activate licensed spectrum sharing.
- **Spectrum management rules**: Include several parameters:
    - `mvno_group`: Name of the set of rules
    - `pattern`: A custom pattern to calculate the weights of spectrum offers when one does not want to use the default pattern, for instance, custom costs
    - `use_pattern`: It indicates whether to use the aforementioned custom pattern; otherwise, the default pattern will be used.
    - `cost`: It includes the weights for each parameter in the spectrum offer as the default pattern. This parameter is ignored when using the custom pattern.
    - `operator_preference`: It represents the preferences among different spectrum owners. This value can be set to a "do-not-care" value to be fair among operators.
    - `criteria`: It includes a list of criteria that can pre-exclude some offers beforehand. For instance, the maximum "price" value can be set and some offers will be excluded when their price is larger than this value. The same mechanism can be set for other parameters.
    - `freq_preference`: It indicates the preference of band in term of the absolute normalized distance (Hz in frequency domain) between offered frequency bands and the preferred band. For instance, if there are two feasible offers over 3.5 GHz and 2.6 GHz and we prefer 2.8 GHz frequency, then the 2.6GHz offer is more preferable.
- **BS group membership**: It determines to which mobile virtual network operator (MVNO) group, a given BS (with a particular cell identity) belongs to.

As for the output of SMA in Fig. 3, the *SMA-policy* includes several parameter values: `freq_min`, `freq_max`, `max_tx_power`, `fdd_spacing`, `band` correspond to the minimum frequency, maximum frequency, maximum transmission power, spacing between uplink and downlink direction in FDD mode, and the band identity, respectively. Such *SMA-policy* output will then be applied through the RAN controller and agent toward the underlying BSs.

B. Decision making algorithm of SMA

Afterwards, we design the decision making algorithm of SMA shown in Alg. 1. All spectrum offers, criteria and parameters are formed in the set $\mathcal{L}$, $\mathcal{C}$ and $\mathcal{P}$, respectively. Before computing the weights for each offer, we firstly exclude ineligible offers s_j from $\mathcal{L}$ as mentioned in Section IV-A. For the k-th parameter (e.g., `price` and `min_lease_time` mentioned in the **Operator policy**), we multiply its normalized value v_k by the cost c_k and sum all resulted products to get the weight (i.e., w_j for the j-th offer). Moreover, we apply the preference in terms of the operator and frequency via `operator_preference` and `freq_preference` mentioned beforehand. Finally, the optimal offer s_{opt} is selected as the output SMA policy *SMA-policy*.

Algorithm 1: Decision making algorithm of SMA

```
Input  : Policy is the input policy and rule
Output: SMA-policy is the output SMA policy
begin
    for $bs \leftarrow 1$ to number of BSs do
        Add all spectrum offers in Policy to the offer list $\mathcal{L}$;
        $cId \leftarrow$ getCellId($bs$);
        $rules \leftarrow$ getRules($cId$, Policy);
        Add all pre-excluded criteria in rules to the criteria list $\mathcal{C}$;
        Add all parameters in rules to the parameter list $\mathcal{P}$;
        for $c_i \in \mathcal{C}$ do
            for $s_j \in \mathcal{L}$ do
                if $\sim$ CheckOffer $(s_j, c_i)$ then
                    $\mathcal{L} = \mathcal{L} \setminus s_j$; /* Pre-exclude offer $s_j$ due to criteria $c_i$ */
        for $s_j \in \mathcal{L}$ do
            if use_pattern then
                /* Use custom pattern to compute weight */
                $w_j \leftarrow$ calcWeightUsingPattern $(rules, s_j)$;
            else
                $w_j \leftarrow 0$;
                for $p_k \in \mathcal{P}$ do
                    /* Get normalized value of $k^{th}$ parameter from offer $s_j$ */
                    $v_k \leftarrow$ GetNormParam $(s_j, p_k)$;
                    /* Get cost of the $k^{th}$ parameter from $rules$ */
                    $c_k \leftarrow$ GetCost $(rules, p_k)$;
                    $w_j \leftarrow w_j + c_k \times v_k$;
                $w_j \leftarrow w_j \,/\, \left(\sum_{k=1}^{|P|} c_k\right)$; /* Normalized to cost sum */
                /* Apply normalized operator & frequency preference */
                $w_j \leftarrow w_j \times$ operator_preference $(s_j) \times$ freq_preference $(s_j)$;
        $opt \leftarrow \arg\max_j w_j$; /* Select optimal offer based on weights */
        $SMA\text{-}policy_{cId} \leftarrow s_{opt}$; /* Apply offer $s_{opt}$ to cell $cId$ */
```

C. Implementation

Following aforementioned design, we implement the SMA prototype from scratch. Specifically, the SMA is developed as a virtualized network function (VNF) in Python 2.7 and can be found in the Mosaic5G Store repository[2]. The implemented SMA can be executed on top of the FlexRAN and OAI platforms as a local or remote application, and thus supporting the LTE/LTE-A radio access technology (RAT). Note that to dynamically apply a new *SMA-policy*, a "soft-restart" operation[3] is performed for the considered LTE BS (eNB).

D. SMA selection results for different rules

Based on our implemented SMA, we show how different spectrum offers can be selected according to different applied

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[2] https://gitlab.eurecom.fr/mosaic5g/store

[3] Such "soft-restart" refers to restart only the RAN part of LTE eNB, without affecting the connections to the core network or the controller.

rules. Via applying different rules, a given LTE eNB can be associated to different MVNO groups in order to select the most suitable spectrum offer to be deployed. In particular, there are four considered rules as follows:

1) **Rule A**: Select the cheapest spectrum offer regardless of the bandwidth;
2) **Rule B**: Select the spectrum offer with the largest bandwidth regardless of the cost;
3) **Rule C**: Select the spectrum offer with the lowest minimum lease time;
4) **Rule D**: Select the spectrum offer with the highest minimum lease time.

Note that aforementioned rules are spectrum-oriented and user-agnostic, and more complex rules can be derived to further incorporate the perceived user performance. In Fig. 4, we can see that there are five available spectrum offers with respective prices in terms of Euros per second from 2.6 GHz to 2.7 GHz. These five offers will be selected from time to time based on aforementioned rules applied in the order: Rule A → Rule B → Rule A → Rule B → Rule C → Rule D. Fig. 5 shows the costs spent on the selected band based on above time-varying applied rules.

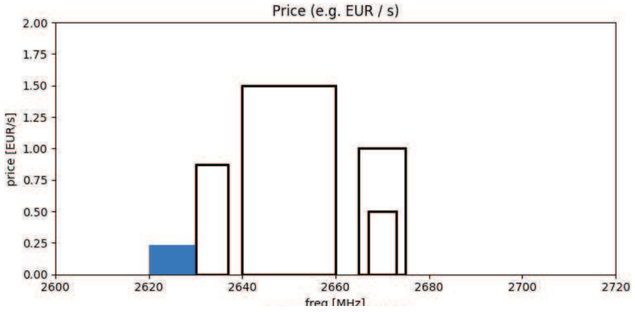
When applying Rule A (refers to 5s to 75s and 100s to 155s in Fig. 5), the one with the lowest price (refers to the highlighted band in Fig. 4a) is selected. Further, when Rule B is applied (refers to 80s to 95s and 160s to 265s in Fig. 5), the one with the largest bandwidth (refers to the selected band in Fig. 4b) is chosen. Rule C (refers to 270s to 350s in Fig. 5) aims to select the offer with the lowest minimum lease time to match its desired utilization duration (e.g., a service may only need a short peak throughput to carry a single big file) as highlighted band sown in Fig. 4c. Finally, the selected band (highlighted band in Fig. 4d) of Rule D (refer to 365s to 480s in Fig. 5) is the one that can last longer in terms of the lease time. To sum up, SMA can act as a key tool to easily adapt different rules.

V. SMA USE CASES

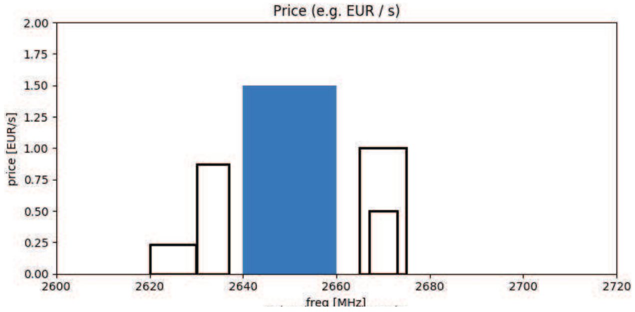
The implemented SMA is integrated locally on top of the Mosaic5G [4] and OAI [5] platforms to manage the spectrum usage in a real-time manner. Once the new *SMA-policy* is decided by SMA, it will be validated and enforced toward controlled eNBs (cf. Fig. 2). Afterwards, these affected BSs will be reconfigured and "soft-restarted", thus a new cell is switched on. Each eNB has a single antenna and is operated in FDD mode to serve the COTS user equipments (UEs). In following, we show how the SMA can be applied in two use cases: (a) phantom cell and (b) cell zooming.

A. Phantom Cells

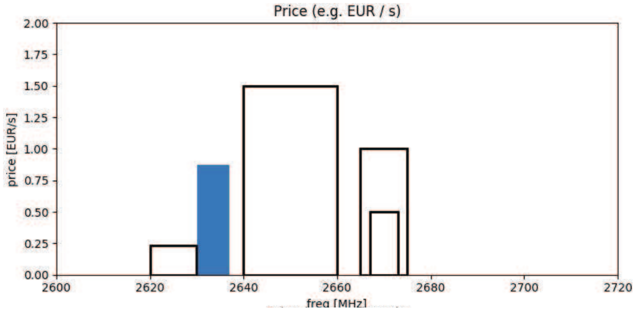
The *phantom cell* [13] notion separates control plane (C-plane) and user plane (U-plane) processing to be provided through macro and small cell, respectively. The C-plane is served in a low frequency band to maintain better connectivity and mobility, while the U-plane is mainly provided by small



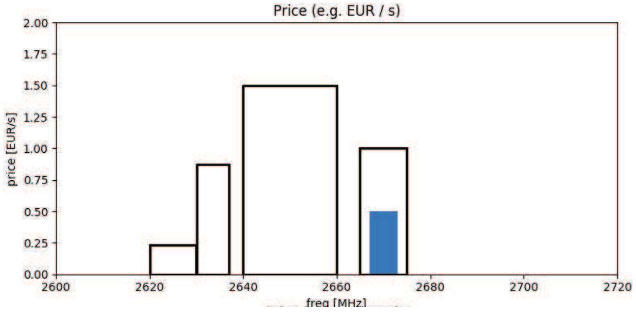
(a) Rule A



(b) Rule B



(c) Rule C



(d) Rule D

Fig. 4: Selected bands for different rules.

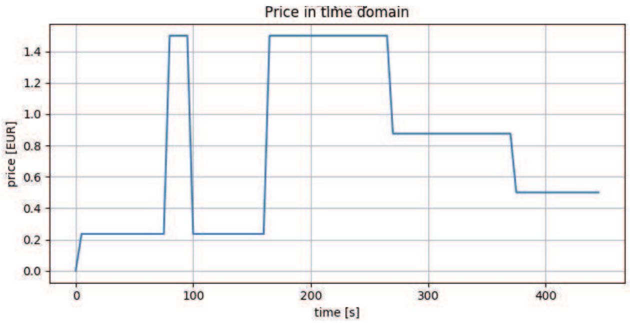


Fig. 5: Normalized spectrum costs based on dynamic rules.

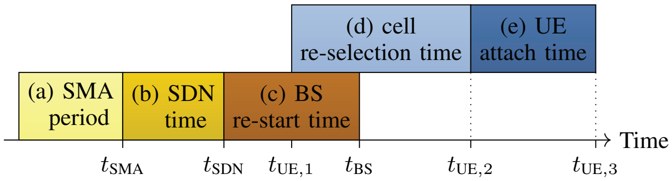


Fig. 6: Reconfiguration time-line.

cells utilizing high frequency bands to boost user data rate[4]. Note that these small cells are not configured with cell-specific signals or channels, and hence termed "phantom" cells.

The SMA can provide dynamic policies toward phantom cells in specific situations, e.g., more capacity has to be offered to the UEs. Before examining the benefits of such dynamicity, we firstly review the time spent on reconfiguring *SMA-policy*. In Fig. 6, the overall reconfiguration time is made up of five components in the time-line. First of all, the SMA period represents the duration to collect sensing data for decision making by SMA. Then, the SDN time from t_{SMA} to t_{SDN} is to deliver the new *SMA-policy* through controller and agent (cf. Fig. 2) toward underlying BS, depending on the collocation of SMA, controller and agent (e.g., locally or remotely). While the BS re-start time from t_{SDN} to t_{BS} aims to "soft-restart" the RAN part at BS as mentioned in Section IV-C. It depends on the underlying RAN service platform and software-defined radio (SDR) infrastructure. The average value is 4 second when we integrate SMA over OAI platform with USRP B200mini SDR. Finally, there are two UE-related components, i.e., cell re-selection time ($t_{\text{UE},1}$ to $t_{\text{UE},2}$) and UE attach time ($t_{\text{UE},2}$ to $t_{\text{UE},3}$). An overlapping between BS re-start time and cell re-selection time is observed due to the UE radio connection loss at $t_{\text{UE},1}$ before "soft-restart" is completed.

To quantitatively see the impacts of reconfiguration on UE side, we measure these two UE-related components on two different COTS UEs with different numbers of supported band and UE category, i.e., Samsung Galaxy S6 (UE category 6, supports 13 LTE bands) and Samsung Galaxy S5 (UE category 4, supports 6 LTE bands) in three respective trials as shown in Fig. 7. A larger delay for Galaxy S6 is observed, which may be due to the number of supported band, i.e., Galaxy S6 spends more time to measure all supported bands to decide the best one for cell re-selection[5].

Next, we reconfigure the underlying eNB via SMA and compare two scenarios to show the advantages of phantom cell. First of all, the phantom cell is deployed at a higher frequency band and can utilize larger bandwidth to boost the U-plane performance when compared with the macro cell. Specifically, the phantom cell is deployed at band 7 (2.6 GHz) and can utilize a larger bandwidth (i.e., 10 MHz), while the macro cell is deployed at band 13 (750 MHz) and can only use a smaller bandwidth (i.e., 5 MHz). The measured good-put and delay jitter at the UE side are provided in Fig. 8a using the Nexus 6p COTS UE that receives the UDP traffic in the downlink direction. We can see that using phantom cell can show a better user experience via exploiting a larger available bandwidth. This benefit would be more distinct when the phantom cell uses a much higher carrier frequency (e.g., mmWave) with an even larger radio bandwidth.

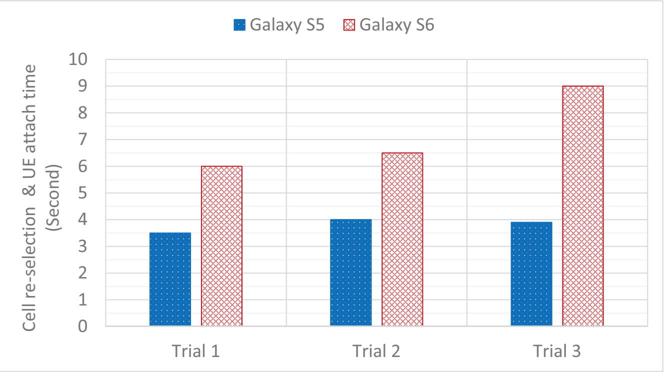


Fig. 7: Indicative UE-related delay for different COTS UEs.

In the second scenario, we consider another benefit of phantom cell. For macro cell, it shall support more users as it has a larger coverage area; however, the phantom cell can serve users in a limited range with regard to the macro cell thus boosting the experience of nearby users. Specifically, the phantom cell is deployed at band 7 (2.6 GHz) with 5 MHz bandwidth to serve a single UE and the macro cell is deployed at band 13 (750 MHz) with 5 MHz bandwidth to serve two UEs at the same time. Here, we use identical Nexus 6p COTS UEs for fairness comparison and the downlink UDP traffic is transported toward the UEs. The results for these two cases are shown in Fig. 8b. We can see that both UE1 and UE2 in the macro cell individually have a lower good-put when compared with the phantom cell case. Even though the sum of good-put from these two UEs in the macro cell is close to the UE1 in the phantom cell case; however, a larger delay jitter is still seen for these two UEs.

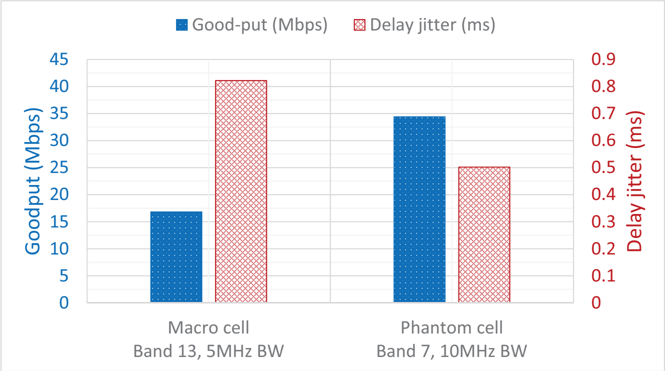
To sum up, aforementioned benefits of phantom cell can be simply enabled via adapting dynamic spectrum allocation through implemented SMA.

B. Cell Zooming

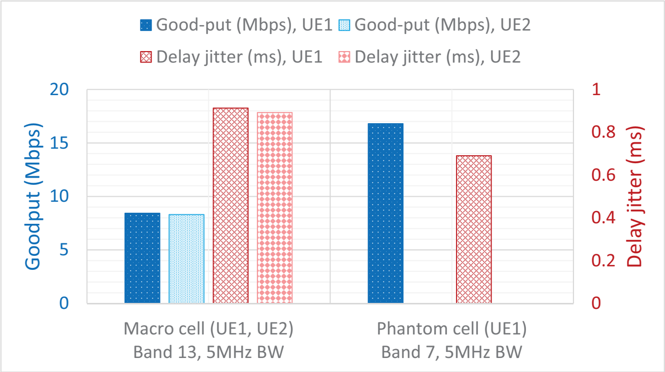
The cell zooming concept stems from [14], aiming to adaptively adjust the cell size (i.e., zoom in and zoom out) in order to solve the problem of traffic load imbalance and to reduce the energy consumption in cellular networks. Note that the SMA paves the way for cell zooming by adjusting the corresponding *SMA-policy* (cf. `max_tx_power` in Fig. 3) to underlying BSs. This adjustment relies on the latest status from BSs (e.g., traffic load, energy consumption) and/or UEs (e.g., positioning, traffic quality of service [QoS]), and also the cell-zooming decision making algorithm running in SMA. In our experiment, a simple positioning-based cell-zooming mechanism is applied to adjust the transmission power according to the UE distance toward the phantom cell site. Such phantom cell uses the same setting mentioned in Section V-A at band 7 (2.6 GHz) with 5 MHz bandwidth.

[4] Macro cells support both C-plane and U-plane signaling.

[5] Average UE attach time is normally less than 500 ms in our measurement.



(a) Different applied bandwidths for macro/phantom cell



(b) Different numbers of connected UE for macro/phantom cell

Fig. 8: Benefits of phantom cell via applying SMA.

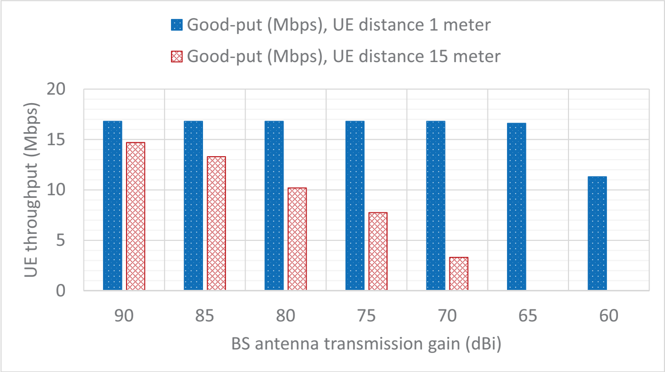


Fig. 9: Cell zooming impacts on different UE distances

In Fig. 9, we examine two different UE distances from the cell site with line-of-site (LOS) environment: (a) 1 meter and (b) 15 meters. Note that the value of eNB transmission antenna gain is adjusted in dBi form and we inspect the impact on the U-plane performance. Few impacts can be seen on the good-put when UE is close to the cell site (i.e., 1 meter), unless the antenna gain is decreased till 60dBi. In contrast, distant UEs suffer more drastically and will even loss connection when the antenna gain is reduced to 65dBi. In summary, SMA is the enabler for cell zooming case via naturally applying its control logics toward underlying eNBs.

VI. CONCLUSIONS

We propose the SMA as the first open-source tool for spectrum management with high flexibility. Further, we highlight its interactions with the underlay network components (SDK and RAN controller), describe the design details, and examine its functionalities to dynamically select the spectrum offers based on applied rules. Finally, the SMA is implemented on top of OAI and FlexRAN platforms to be applicable in two use cases: (1) phantom cell and (2) cell zooming.

In the future, we plan to chain SMA with other control applications (e.g., radio resource management, handover) to provide a more sophisticated control logic that can serve the needs for multiple services.

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