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Corresponding 5G Network Slicing: How Constructive Interference Can Boost Network Throughput

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ABSTRACT: RAN slicing is a virtualization technique that separates a radio access network's radio resources into a number of independent virtual networks. Next-generation (5G) systems have long hoped for high-throughput and low-latency communications due to the customizability of RAN slicing to match specific performance requirements. Radio resources must be divided so that numerous base stations may work together to increase throughput; and (ii) interference across various slices must be reduced to ensure each slice is isolated and the network does not slow down. For the purpose of this study, we are looking for algorithms that can satisfy both of these requirements. As a starting point, we discus that this quadratic-proportional programming issue may be conceived of as an NP-hard problem. We've come up with a perfect solution for small-scale 5G network installations. To ensure that our algorithms are working correctly, we perform simulations. Then, using a standard-compliant LTE testbed comprised of two base stations and six smartphones, we discus how well they perform in real life. Our techniques not only effectively split RAN resources, but they also boost network speed by 27% and the signal-to-noise ratio by 2x..

KEYWORDS: Network slicing, 5G, radio access network (RAN), interference management.

I. Introduction

By the year 2025, it is predicted that there will be 8.9 billion mobile subscribers worldwide [1]. [2] The present commercial wireless infrastructures and frequency bands can't manage this amount of data [2]. We need new techniques to establish quicker, lower-latency wireless cellular connections since standard resource allocation algorithms do not allow for dynamic, effective, and efficient radio access tactics [3], [4].

Radio access network (RAN) slicing has been recommended as a solution to these issues [5–15]. For the first time ever, numerous mobile virtual network operators (MVNOs) may use the same physical infrastructure, creating a game-changing vision for the future of mobile communications. Because spectrum is a finite resource that cannot be over-provisioned and (ii) interference may make it difficult to distinguish slices belonging to various mobile virtual network operators, RAN slices provide a unique set of challenges.

Figure 1 depicts this. Each MVNO is responsible for a different "slice" in applications where RAN slices are utilised. The Infrastructure Provider may provide or take away slices (IP). The IP determines which slices are permitted into the system, and how many resources each slice is given. The slicing policy specifies how spectrum resource blocks (RBs) should be allocated, thus that must be done first. To ensure that an MVNO receives a sliver of 15 percent of the spectrum resources, an issue known as the "RAN slicing enforcement problem" (RSEP) [10] must be solved.

Real-world performance depends on the implementation of RAN slicing enforcement techniques that are designed and tested. Interference reduction solutions including IBSPC (inter-base station power control) [10, 19, 20], MIMO (multiple input multiple output) [21], and coordinated multi-point transmission (Joint Transmission) [24, 25] must be supported by the RAN slicing enforcement algorithms if they are to be effective. BSs competing for customers must use slicing algorithms that allocate the same or comparable RBs to the same MVNOs on a time-and-frequency basis.

Figure 1 depicts a cellular network scenario to illustrate this point. Two BSs and sixteen RBs are under the IP's control here. Each of the BSs is assumed to be near enough to interfere with the other's activities (i.e., 4 frequency units during 4 time units). Consider the scenario in which M1, M2, and M3 each get a 25 percent, 50 percent, and 25 percent share on each of the two BSs. There is no inter-MVNO interference seen in Fig. 1a's two RB allocation matrices (RBAMs) (i.e., MVNOs control the same RBs at the two BSs). By adopting IBSPC, an MVNO may simply prevent mobile phone users from interfering with each other in two distinct cellular service providers (CSPs). There are several RBAMs in Fig. 1b that aren't optimal, which may lead to inter-MVNO interference during the 12 RBs shown in the figure Poor interference management will have a negative impact on performance as a consequence of this.

We conducted a series of experiments on the LTE-compliant phones that we discussed in Section VIII to demonstrate that inter-MVNO interference may have a detrimental impact. Set up the same two LTE base stations and two RAN slices as seen in Fig. 1. In each slice, a set of cell users is served by half of the available RBs (i.e., commercial LTE smartphones). There is a graph depicting the network's performance in Fig. 2. Measured throughput with and without slice isolation is compared. Inter-MVNO interference is minimised in Fig. 1a, where the RBs are located. There is no slice isolation in Fig. 1b. With a throughput increase of up to 3 Mbps, slice isolation has a significant influence on network performance. In Section VIII, we demonstrate how our algorithms outperform alternative slicing enforcement techniques, such as the one seen in Fig. 1b, in terms of network performance.

The issue of assigning spectrum resources to mobile virtual network operators (MVNOs) has received considerable attention [7–9], [11–15], [26–29], but only a few studies have examined it at the physical level [10]. Because of the unique nature of cutting enforcement algorithms, they run into difficulties not seen in more typical RAN resource allocation models. So, it's clear that this isn't a mishap:

1) To make 5G systems work, they'll need a lot of new signal processing and radio transmission technologies like IBSPC and JC. These techniques make the network run a lot better, but they need a lot of coordination between the BSs that are near each other. For this reason, the allocation of RBs should make it easier and more likely for coordination to happen;

2) Figure 2 shows that in order to be more efficient, each RAN slice must be orthogonal to each other. Because of this, each RB should only be used by one MVNO to avoid interference and other things that could hurt performance[7], [30], [31];

3) In order to maintain control over the quantity of resources available, MVNOs enter into agreements with the IP. You must follow the slicing policy. To ensure that if an MVNO obtains 30 percent of the spectrum resources and pays for them, it should also get 30 percent of the total RBs.

For this article, the main purpose is to develop and evaluate RAN-slicing enforcement methods that solve the three difficulties mentioned earlier in the article The following changes are made in this paper:

- People tend to cut one other off while they're trying to communicate. This is referred to as the RAN slicing enforcement issue. For this reason, we provide approximation and heuristic methods for various network sizes, efficiency, and timeliness concerns;
- The suggested algorithms may take as little as a few hundred microseconds to complete their task, but this will not have a significant impact on the efficiency of their outcomes. For this, we used computer simulations. Slice orthogonality reduces inter-MVNO interference, resulting in a twofold increase in the network's total signal-to-interference plus noise ratio (SINR);
- Using an LTE-compliant testbed with two LTE base stations and six COTS customers, we demonstrate that the suggested algorithms function effectively. Our strategy outperforms others that do not segregate RAN

  slices during slicing, as seen by the results. Slicing solutions that increase SINR and throughput by as much as 27% are among the algorithms we've developed.

Below is a breakdown of the remainder of this document: Section II examines the relevant literature. The RAN model may be seen in Section III. The RSEP issue is introduced in Section IV, and the best, approximated, and heuristic solutions are shown in Section V. Efforts to reduce the time it takes to devise enforcement measures are discussed in Section VI. Sections VII and VIII illustrate statistically and experimentally how effectively the suggested methods operate. Section X, which concludes the article, contains the last paragraphs.

II. RELATED WORK

RAN slicing, or how many resources should be allocated to each slice of the RAN, has been a hot subject in recent years. To get a good overview of current research, the reader might consult [26] and [27]. Optimization [11], game theory [38–40], and artificial intelligence [13, 41] have been recommended as theoretical techniques. There is no mention here of putting RAN slices on top of the actual network.

Research groups are interested in how RAN slicing rules are implemented as a result of this. Before, resources were pooled and virtualized to be shared and apportioned among MVNOs. The MVNOs then share and distribute these resources. IBSPC, CoMP, and beamforming, on the other hand, may not be able to benefit from this approach because of the necessity for fine-grained management of physical layer resources.

The RAN slicing enforcement challenge has been examined from a resource allocation perspective in recent research. A stochastic model is used by Mancuso et al. in [9] to determine the impact of various enforcement procedures on the overall performance of the sliced cell. As proposed by Chang et al. [30], a partitioning algorithm distributes RBs to the most satisfied MVNOs while handing out the fewest RBs possible. As Han et al. [44] suggest, MVNOs should be given the greatest long-term usefulness by employing genetic algorithms to allocate the available RBs to MVNOs. When there is just one BS in the network, [9], [30], and [44] don't pay attention to the issue. Because of this, MVNOs can't utilise them in multi-cell networks when they desire varying amounts of resources on each base station. One strategy to ensure the seamless operation of 5G networks is to ensure that the various mobile virtual network operators (MVNOs) do not interfere with one another, as described in [31], [45]. It's important to keep in mind, however, that neither [31] nor [45] provide a method for enforcing slicing regulations to improve network efficiency.

(iii) maintain inter-MVNO interference to a minimal across several BSSs; (iv) enable sophisticated coordination based communication strategies were some of the algorithms we came up with in our past work. Improved: Here, we describe an improved heuristic approach for solving the RSEP in a few milliseconds while still obtaining a tiny optimality gap, to demonstrate how to improve [10]. Our findings also demonstrate how various enforcement policies alter the network's interference. The SINR of the system is improved by two times using the suggested method. We demonstrate this by putting our algorithms into action on an LTE testbed that complies with industry standards. Furthermore, we demonstrate that our strategy can be simply implemented in typical 5G networks, boosting total network throughput by 27%.

III. PROPOSED WORK

The new (5G) network model places a greater focus on business than earlier generations of mobile networks have. For the network as a whole, meeting [19–22]'s criteria is very difficult or costly. For example, it's extremely difficult or costly to achieve all of the network's requirements simultaneously, such as bandwidth above 300 Mbps, very low latency of a few milliseconds, and support for up to 200,000 devices/km2 with a 99.999 percent

dependability level. These needs may be met by network operators by creating logical networks with differing network efficiency and attributes. However, it is feasible to achieve some of these requirements. Splitting a physical network into logical ones makes sense for this reason. Services with certain attributes (such as KPIs and QoS/QoE parameters, for example) may be developed on top of this virtual 5G environment [23]. They all have a particular application (phone communication, video streaming, or the Internet of Things), as well as a specific set of attributes that are tailored to the business requirements of each service that will be given over them [19, 24, 25, 26]. There are likely to be several subsets of criteria that cannot be satisfied simultaneously. That is because to a variety of factors including the expense, the constraints imposed by existing technology and the physical limitations of the human body. As a result, today's network operators often have a general-purpose network, which is more difficult to supply than simply one or two demands. A logical network with fewer needs might increase the quality of the service offered by this network.

A. ***The isolated slices***

Network slicing is based on the logical networks shown above. In this concept, the network and available resources may be split into multiple slices, each of which corresponds to a service and a set of requirements. For each slice, there is at least one path of communication. Network slicing and orchestration go hand in hand rather often. To help service providers, other network operators, and other authorised users, orchestration offers interfaces (northbound interface, API—application programming interface) for managing slices (creating slices, altering their attributes, reconfiguring a slice's network, and so on). It is the purpose of this feature to increase the adaptability and flexibility of services and networks in order to better meet the demands of companies and users alike.

Slice isolation, a kind of generic slicing, is discussed in this study, which may be useful to network administrators and users alike. Section 4 provides a more thorough explanation of the isolation property's significance.

B. ***Security in sliced network***

With this new design, there are increased security concerns due to the addition of more components There is a possibility that the addition of these additional components may lead to new types of security risks. If an orchestrator (or other modules that enable network modifications via an interface) is used without defining restrictions about who may use it and how, there may be a security concern. As a result, it's critical to establish guidelines for who and how may utilise it. Self-destruction is a security threat. Slicing systems may be used by attackers. Due to its flexibility in terms of layers and abstraction levels, slicing may be used to a broad variety of platforms and solutions. Virtualization software systems may include slicing components that are implemented in firmware, on the OS kernel level (e.g., as a kernel module), or in the virtualization environment (e.g., a plug-in that allows communication between a slice and selected host's applications, like orchestrator or opportunist). The slicing pieces might originate from a variety of sources in this broad spectrum of situations. As a result, it might be difficult to ensure that various apps, such as this one that use the slicing principle, meet the same degree of security standards.

As a result of adding unique attributes to slices (such as isolation, protection, etc.), it may be possible to exploit weaknesses in a system that offers isolation to access resources allocated to another slice with better parameters in order to save costs or intercept sensitive data streams. These attributes might be targeted as part of a larger assault (it could be the subject of an attack in the Attack Jungle concept [26]).

Some network services or operations, such as mobility management or AAA (Authentication, Authorization, and Accounting) [27], may be shared across 5G slices of a network. In contrast to the notion of being secluded, this concept makes sense. For example, in 5G networks, there are more common functions than there are in typical wired networks.

C. ***The major challenge in sliced 5G network***

5G networks need the 5G RAN to be operational. The mmWave's use of tiny cells may provide a solution to certain additional issues [28]. A signal might take a lengthy time to travel via this frequency spectrum compared to typical wireless networks (2G to 4G). It's possible to build a tiny cell with a reach of 200 metres in specific windows thanks to favourable propagation factors. This implies that cell-to-cell traffic is inherently stifled by the fact that this is so. Macro cells send certain data (such as that from C-Plane, as described in [28]), while tiny cells carry the remainder (like data from U-Plane, which has been explained in [28]). This is a unique meta-slice for UE communication with the RAN and CN in terms of slicing.

This influence on isolation or the ease of slicing a network is not present in all new technologies. Since numerous UEs are likely to receive the same message in the same time slot and on the same frequency channel, it is assumed that

NOMA (non-orthogonal multiple access) recognises messages based on the signal strength level. When receiving frequencies, codes, and time slots, the e-NodeB must consider whether the UEs are in slices. Isolation must be maintained at all times. Cognitive radio is a potential 5G network technology that is both advantageous and a potential hindrance to communication. [28] In certain circumstances, it allows you to communicate utilising a frequency range that is not intended for that purpose. A 5G UE (or RAN node) may only access this band when it is not being used by other systems (not just mobile networks but also military networks, radio, TV systems, etc.). Separating the isolation of a slice from other systems should be considered as well as the isolation between slices.

D. ***Minor problems***

Many problems arise when it comes to network slicing and slicing isolation in 5G networks, such as how slices are created and isolated, how services and slices are connected, who has the authority to administer what sections of the network? Hopefully, in the parts that follow, we'll be able to provide some of those answers or at the very least point out some connected questions.

E. ***Heuristic Solution***

Although Problem RSEP-EQ has lower complexity than Problem RSEP-QP, in the worst case it still requires exponential time with respect to the number of vertices, which spurred us to design polynomial-time algorithms. Given Problem RSEP-QP maximizes the number of shared RBs, we can allocate as many linked RBs as possible to those MVNOs that request the highest amount of RBs on multiple interfering BSs. Indeed, MVNOs that request the

Algorithm 1 RSEP-MLF

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Input $\mathcal{B}$; $\mathcal{M}$; $\mathbf{Y}$; $\mathbf{L}$;
Output A MLF RBs allocation $\mathbf{x}^G = (x^G_{m,b,n,t})_{m,b,n,t}$;
Set $x^G_{m,b,n,t} = 0$ for all $m \in \mathcal{M}, b \in \mathcal{B}, (n,t) \in \mathcal{R}$;
Compute the linking index $\mathbf{l} = (l_m)_{m \in \mathcal{M}}$;
$\mathcal{M}^G \leftarrow$ Sort $\mathcal{M}$ by $l_m$ in decreasing order;
while $\mathcal{M}^G \neq \emptyset$ do
    for each BS $b \in \mathcal{B}$ do
        Update $x^G_{m,b,n,t}$ by allocating $L_{\mathcal{M}^G(1),b}$ subsequent RBs to MVNO $m$ on BS $b$;
    end for
    $\mathcal{M}^G \leftarrow \mathcal{M}^G \setminus \{\mathcal{M}^G(1)\}$;
end while
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greatest number of resources on different interfering BSs are also expected to produce a high number of linked RBs. Accordingly, for each MVNO m we define the linking index l_m as,

$$l_m = \sum_{b \in \mathcal{B}} \sum_{b' \in \mathcal{B} \setminus \{b\}} \min\{L_{m,b}, L_{m,b'}\} y_{b,b'}$$

The linking index is used to sequentially allocate RBs to those MVNOs with the highest linking index.

IV. Experimental Results

Consider the scenario in which two MVNOs share eNB resources in order to create radio access network (RAN) slices. In our tests, we focus on two key performance metrics: network throughput and the SINR that UEs perceive. The RSEP-QP approach in Section V-A was used to compare it to the conventional one (i.e., without isolation), which does not employ network topology information or ensure that slices are isolated. On the testbed indicated in Section VIII-A, we performed ten experiments. In MATLAB, we create a random slicing profile named L for each trial. For L-slicing profiles, we choose K = 9, since this is a big enough number to ensure synchronisation of the vast majority of random bits (RBs) across neighbouring binary streams (BS). Unfortunately, this happens from time to time due to equipment malfunctions. For two minutes, mobile users execute a speed test to ensure that transmission buffers and slices are constantly full with downlink packets. SINR and throughput are both included in their reports. This paper's approach (RSEP-QP) and more standard ones are both used to determine RAN slicing enforcement rules for each L. (i.e., without isolation). We'll be able to do a more accurate comparison of various approaches this way. The speed-test server is also situated on the Arena testbed in order to eliminate time-varying performance loss caused by Internet connection. As a result, a fair comparison of the two approaches may be made.

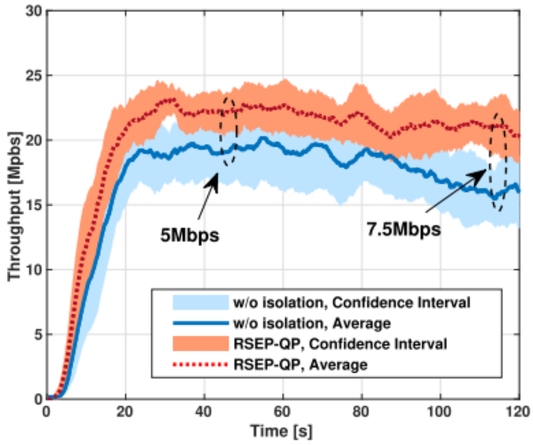
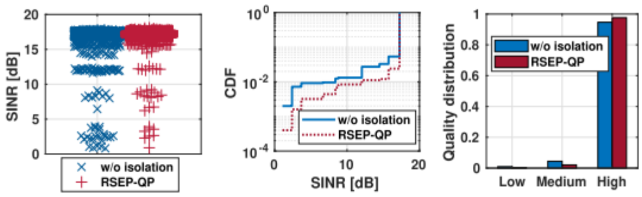


Fig. 3. Experimental throughput comparison.



(a) SINR measurements. (b) CDF. (c) SINR Quality.

Fig. 4. Experimental SINR analysis.

Figure 3 shows the average throughput for the 10 tests. There is a 27% boost in throughput when using our methodology dubbed RSEP-QP, compared to typical interference-free methods (about 5Mbps). It was possible to attain peak throughput improvements of up to 7.5Mbps.

Fig. 4 shows the results of the SINR measurements obtained by UEs using the two approaches that we studied in this article (Fig. 4a). As demonstrated in Fig. 4b, the CDF of SINR is an excellent technique to demonstrate that conventional approaches struggle to achieve acceptable SINR due to the excessive interference across distinct RAN slices. Our approach, on the other hand, effectively eliminates this kind of interference and boosts the SINR that UEs can pick up. Figure 4c shows how many persons have a low SINR, a medium SINR, or a high SINR, which is interesting. There are more persons who report greater SINR levels using our method than the previous method, which results in more people reporting low and medium SINR levels.

V. Conclusion and Future Work

RAN slicing enforcement in 5G networks is a challenging and crucial problem that we've discussed in this post. To begin, we formulated and demonstrated the NP-hardness of the resource slicing enforcement problem (RSEP). As the task grows more complex, we came up with three approximation and heuristic techniques that make the problem simpler to solve. Finally, we conducted simulations to demonstrate the algorithms' performance on a real-world testbed comprised of two LTE base stations and six mobile phones. Many individuals may benefit from our methods, and the outcomes are close to ideal. If you're looking for ways to eliminate inter-MVNO interference and enhance throughput and SINR by up to 27% or 100%, our solutions are ideal for RAN slicing strategies.

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