O-RAN next Generation Research Group (nGRG)

Research Report

Spectrum Sharing based on Shared O-RUs

Report ID: RR-2023-05

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Release date: 2023.10

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Executive summary

New spectrum is increasingly more difficult to secure than it was for prior generations of mobile networks. It is now more important than ever that all available spectrum can be efficiently utilized. While radio spectrum can be licensed for the exclusive use of a single operator, an operator may share licensed spectrum with multiple other operators. Shared use of spectrum among multiple operators can lead to better utilization of spectrum without the constraints associated with non-exclusive use of spectrum, resulting in economic benefits for operators and end users alike. Unlicensed spectrum may be used by anyone as long as the access rules are followed. In general, unlicensed spectrum, while essentially designed to enable spectrum sharing, is often unsuitable, or at least very challenging for operator use due to relatively low power limits and sensing requirements leading to inability for operators to manage KPIs for service quality. 3GPP standardized RAN sharing is a method for operators to share equipment and spectrum while maintaining the same service quality associated with the exclusively licensed spectrum. The downside is that a very high level of cooperation is required among cooperating operators for planning, equipment selection, siting, and operation. The result is less room for operators to differentiate their services and the ability to upgrade, balance, or enhance the equipment is less agile. Finally, 3GPP RAN sharing is not as amenable to sharing between operators and non-operator networks (e.g., Private Networks, government networks, non-3GPP incumbents, …).

A framework based on sharing O-RUs among system operators for spectrum sharing, which builds upon the O-RAN Open Fronthaul's innate shared O-RU capabilities, addresses many of these limitations and the drawbacks associated with unlicensed spectrum or 3GPP RAN sharing. Power limits can be relaxed, and quality of service can be controlled. The result is a user experience that is comparable to the exclusively licensed spectrum deployments.

A "neutral host" like deployment of an O-RU can support shared use from multiple independent O-DUs accessed dynamically via standardized fronthaul interfaces. This can support differentiation between operators. In addition, it retains for MNOs and Private Networks alike all of the cloud-based, complete, centralized control capabilities of the Open RAN system. This includes all of the functionality of the O-DU, O-CU, RIC, and advanced network automation capabilities inherent in the O-RAN architecture.

A shared O-RU architecture relies on prioritized use of resources to guarantee service quality and allows statistical multiplexing of traffic among operators, private networks, and other spectrum stakeholders, resulting in more efficient overall use of spectrum resources.

In order for such a scheme to work effectively for all of the cooperating spectrum users, the improvement in efficiency is critically dependent on how fast the shared O-RU procedure to allocate idle resource among spectrum users is. The proposed shared O-RU spectrum sharing framework is applicable to sharing between spectrum users including public, private, and government. Additionally, it is radio technology agnostic, i.e., not all of the cooperating systems need to deploy the same 3GPP radio technology

versions, and non-3GPP radio technologies can potentially be accommodated using the same O-RAN Open Fronthaul-based shared O-RU mechanisms. Shared O-RU with spectrum sharing feature can create opportunities for new spectrum for the next generation networks. In addition, it can lead to sustainability improvements and reduction to CapEx and OpEx for operators.

List of abbreviations

3GPP	3rd Generation Partnership Project
CBRS	Citizen Broadcast Radio Service
KPI	Key Performance Indictor
MOCN	Multiple Operator Core Network
MNO	Mobile Network Operator
NPN	Non-Public Network
NR-U	New Radio Unlicensed
NTN	Non-Terrestrial Networks
O&M	Operation & Maintenance
O-CU	Open Central Unit
O-DU	Open Distributed Unit
O-RU	Open Radio Unit
OTA	Over The Air
RAN	Radio Access Network
RIC	RAN Intelligence Controller
UE	User Equipment

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1 Introduction

Wireless spectrum is critical for the success of wireless systems, and he spectrum for the future next generation wireless networks is becoming increasingly difficult to find. Therefore, it is necessary to mobilize all spectrum types and bands. Exclusively licensed spectrum remains the best option for the next generation terrestrial mobile networks. However, spectrum bands that can provide capacity/coverage tradeoffs suitable for the wide area coverage are scarce. Unlicensed spectrum (e.g., WiFi, 3GPP NR-U, etc.) is suitable for some specialized spectrum sharing use cases but is limited by relatively low power limits due to the ad hoc nature of the deployments and sensing based access mechanisms. Moreover, the medium access procedure makes it impossible for the MNO or other Private Network operator to fully control service quality. However, inability to control service quality is not an inherent drawback of spectrum sharing, but rather a consequence of a distributed medium access procedure optimized for ad hoc deployments with little or no planning.

3GPP standardized RAN sharing [1] provides methods for the operators to share equipment and spectrum. The same control of service quality associated with the exclusively licensed spectrum can be achieved. A limitation of this approach, however, is that the same equipment is utilized by all operators, and there is very little room for operators to differentiate their service or to control their own deployment destiny in a timely manner. O-RAN enabled spectrum sharing [2][3] addresses the limitations of RAN sharing and the drawbacks associated with the unlicensed spectrum. Power limits can be relaxed as the deployments are planned and sensing is not required. The quality of service can be controlled since access to resources can be negotiated and managed so that the user experience is comparable to the exclusively licensed spectrum deployments. The Open Fronthaul protocol is a critical component that provides means to manage spectrum sharing in a shared O-RU framework. Operators can share O-RUs and at the same time differentiate service by utilizing dedicated implementations for the other parts of the network.

In addition to enabling sharing of spectrum resources among many operators (Private Network, governmental, and incumbent stakeholders), a Spectrum Sharing implementation based on the O-RAN O-DU/O-RU functional split has the benefit of synergy with many economic and ownership deployment models. For example, the O-RUs, edge infrastructure, cell sites, cloud infrastructure, and software entities in the O-DU and O-CU. can potentially be owned, deployed, and/or operated by different business entities. Furthermore, an O-RAN solution can be dynamically managed and orchestrated using advanced RAN automation capabilities provided by the O-RAN RIC, O&M, and rApps/xApps architecture.

2 Spectrum sharing

It is very common to assume that reliance on exclusively licensed spectrum enables operators to provide the best service possible. That is certainly true when system bandwidth is limited by the radio and network technologies, and not the available spectrum. However, when the technology allows system bandwidth to grow beyond the spectrum available to a single operator in an economically viable way, exclusive licensing may also lead to the fragmentation of spectrum and poor return on investment in expensive licensed spectrum assets. In such scenarios, the user experience becomes limited by the allocated spectrum and not the technology and the motivation and ability to introduce new technologies and support new use cases adequately diminishes or becomes infeasible. At the same time, resources assigned to one licensee may be fully utilized, while resources of the others may be idle, leading to inefficiencies.

Efficient and quick resource allocation is necessary to achieve required performance when spectrum is shared. **Error! Reference source not found.** demonstrates the need to facilitate fast sharing with very low latency. When spectrum is exclusively licensed, the resource availability is fixed, and the spectrum allocation is static. Semi-static spectrum sharing allows slow resource adaptation, but the resources cannot be fully reused. Due to slow adaptation, some resources need to be set aside for time critical data arrivals. As illustrated in the figure, in some cases, semi-static sharing can lead to worse performance than static allocation. Fast dynamic spectrum sharing allows rapid, dynamic reuse of resources, and offers better performance than static or semi-static spectrum sharing.

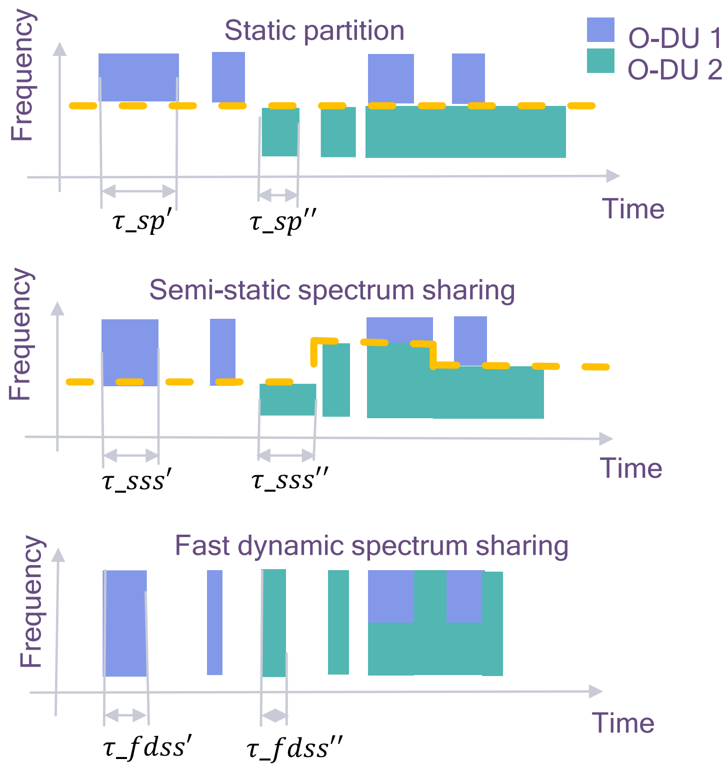

Figure 1: Spectrum sharing leads to reduced service time and hence improved user experience.

Spectrum sharing	Symbol	Constraints
Static	τ_sp	

Semi-static	τ_sss	τ_sss may be less or more than τ_sp (τ_sss' < τ_sp' but τ_sss'' > τ_sp'')
Fast dynamic	τ_fdss	τ_fdss always less than or equal τ_sp (τ_fdss' < τ_sp' and τ_fdss'' < τ_sp'')

It is apparent that spectrum sharing that leverages the O-RAN Open Fronthaul and builds upon its inherent shared O-RU framework, as illustrated in Figure 2, offers potential for coordinated access, which would lead to greater spectrum utilization without the loss of service quality control.

Research area: Procedures to enable controlled reuse of otherwise idle resources.

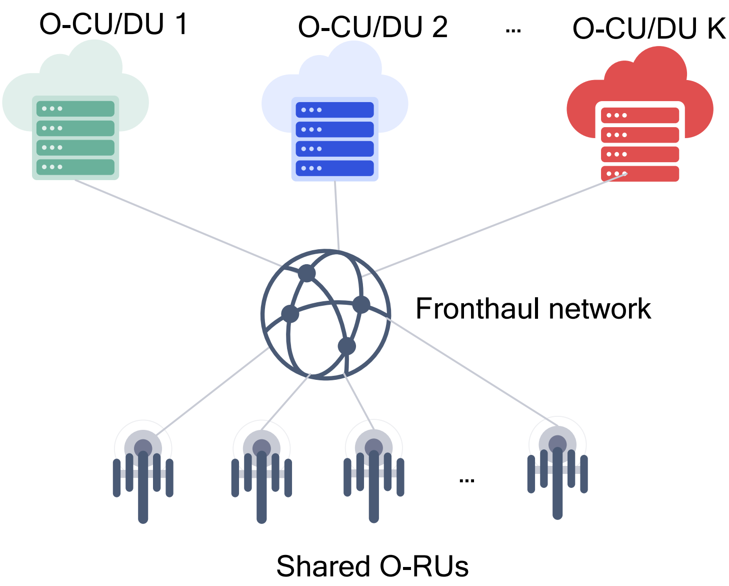

Figure 2: Shared O-RU network architecture.

Priority licensing can be leveraged in the design of procedures for coordinated shared spectrum access that allow all coordinating system operators to maintain control of service quality. The primary spectrum license holder would be allowed to access its priority resources at any time (subject to contractual arrangements), while secondary licensees/users could access the same resources only if those resources are idle.

One of the major benefits of the O-RAN Open Fronthaul interface and a shared O-RU architecture is that multiple operations can share spectrum while still differentiating their services through operator specific implementations of the remainder of the network. An alternative to shared O-RU based spectrum sharing is RAN sharing as currently standardized in 3GPP. Typical RAN sharing scenario refers to sharing of the RAN among multiple MNOs (e.g., MOCN deployments). This deployment scenario implies sharing of the spectrum as well. However, in this scenario, at least the radio resource management and the scheduler functions need to be implemented by a single vendor and shared by all operators. Therefore, the services among MNOs cannot be differentiated as flexibly or dynamically. 3GPP RAN sharing is more amendable to large, sophisticated MNOs that are operating the same RAN services and 3GPP radio technologies in a highly coordinated manner.

Shared O-RU spectrum sharing requires management of coordinated priority access to spectrum resources. As it can be inferred from Figure 2, the O-RU is in a unique position to coordinate access since it is connected to multiple O-DUs over low latency fronthaul network connections. While the shared O-RU is the node most suitable to manage coordinated access, this does not mean that the O-RU must be responsible for complex radio resource management and scheduling decisions. On the contrary, in the context of priority-based licensing, the role of the O-RU can be limited to a simple resource access arbiter function that determines which operator has access to resources based on provisioned policy. That policy can be orchestrated (dynamically) by the O&M and RAN automation systems of the primary owner or manager of the O-RU. A typical basic rule is to always grant access to the priority spectrum license holder, while secondary licensees/users are granted resources, only if the priority licensee is not using them (subject to business agreements). As illustrated in Figure 2, shared O-RU based spectrum sharing is not limited to one primary and one secondary user. The benefits of spectrum and O-RU sharing increase as the number operators grow. Therefore, the scalability of O-RAN procedures for spectrum sharing based on shared O-RU needs to be taken into account.

Research area: Scalability of O-RAN procedures for shared O-RU based spectrum sharing as the number of operators.

3 Deployment scenarios

Shared O-RU based spectrum sharing can apply to many different deployment scenarios. Sharing of O-RUs and spectrum should be of interest to other system operators. The possibility to acquire additional resources in real time allows MNOs greater flexibility to meet the KPIs associated with the service quality. And when the resources are idle, sharing spectrum allows MNOs to monetize idle resources. The implementation allows O-RU and spectrum owners to allocate resources based on long-term or short-term contracts, or even to conduct millisecond level auctions and assign the resources to the highest bidder. This could be facilitated by various financial settlement methods or even using blockchain-based solutions.

3.1 Shared cell site

The shared cell site case, or scenario A is illustrated in Figure 3. In this scenario, each operator owns an O-RU and the associated spectrum in which that O-RU operates. This is a common scenario where, e.g., a “tower company” owns the cell site and leases slots in the base station tower to system operators.

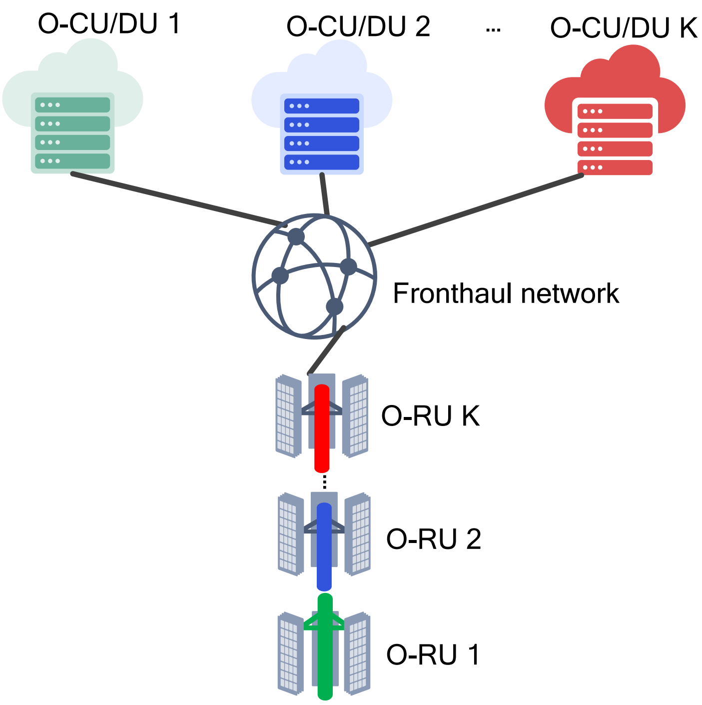

Figure 3: Scenario A - Operators own O-RU and spectrum.

3.2 Shared O-RU

A shared O-RU framework also allows operators, including MNOs, to not own the shared O-RU. In this scenario, referred as scenario B and illustrated in Figure 4, the O-RU could be owned by a “tower company” or other third-party entities.

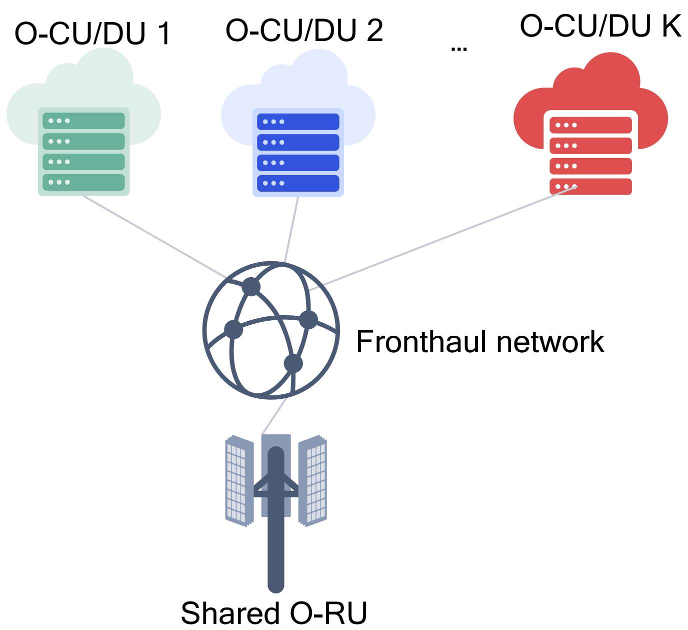

Figure 4: Scenario B - Third party owns O-RU or O-RU is jointly owned.

In scenario B, one option is that the spectrum is owned by each operator, and each operator can lease spectrum to another operator in real time and monetize resources that are unused. An alternative is that a tower company or another third party owns spectrum. The spectrum owner can lease spectrum to all operators and set in place the policy that would determine the O-RU arbiter policies. Sharing of O-RUs does not have to apply for all carriers.

3.3 Hybrid shared and non-shared O-RUs

Scenario C, illustrated in Figure 5, refers to a scenario where operators own O-RUs and spectrum used as the primary cell group, while O-RUs may be shared and owned by a third party on spectrum used for the secondary cell group. That spectrum could be owned (or at least managed) by a third party as well.

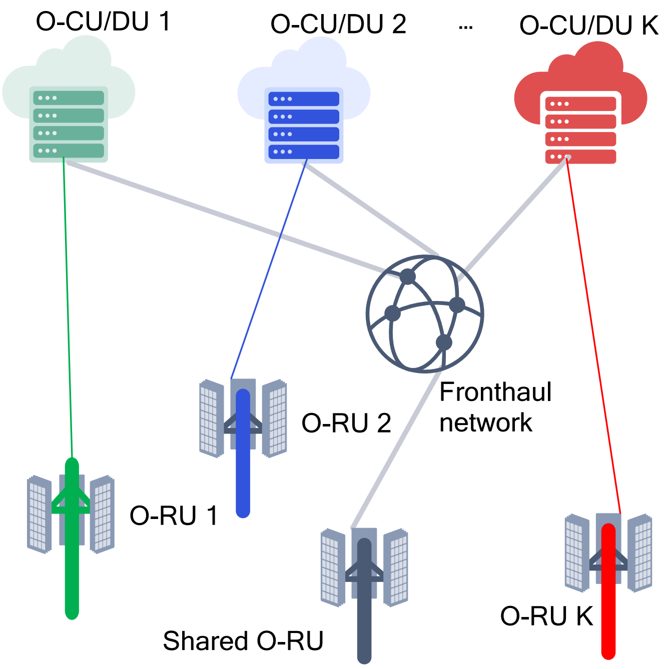

Figure 5: Scenario C - Shared O-RU and spectrum on SCell only.

3.4 Hybrid public and private O-RUs

Shared O-RU framework can also be a way for operators to leverage private network deployments (e.g., provided by an enterprise facility owner), illustrated as Scenario D in Figure 6. Operators can, e.g., during peak loading or when its network coverage is poor, lease in real time private network O-RU resources and local spectrum access. Allowing spectrum to be leased can enable improvements to the existing less flexible and dynamic spectrum sharing methods, such as US CBRS.

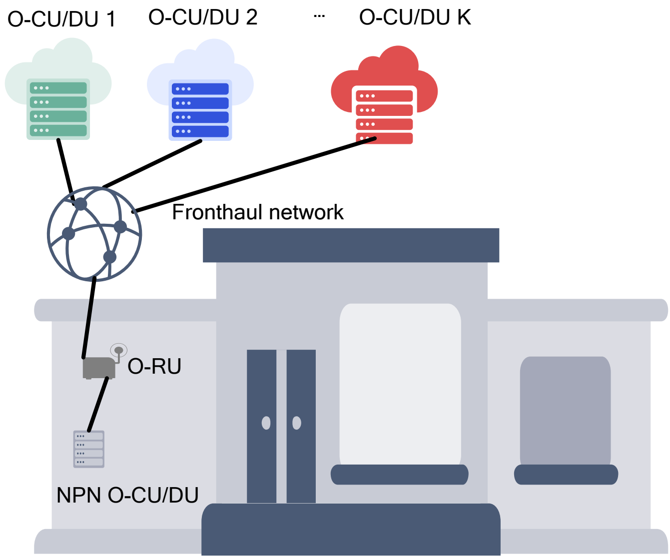

Figure 6: Scenario D: O-RU and spectrum owned by non-public (private) network (i.e., a 3GPP NPN).

3.5 Hybrid with priority access

In addition to sharing of commercial equipment and spectrum, the shared O-RU spectrum sharing implementation can also apply to sharing between government and commercial users as is illustrated as Scenario E in Figure 7. Government users may own spectrum, to which they might have regulatory priority access but might allow access to commercial public or private network operators. This deployment scenario could allow government users to have quick real time and direct control over the radio units (O-RUs) utilizing existing open protocols without the addition of any other open (or proprietary) interfaces in the radio network.

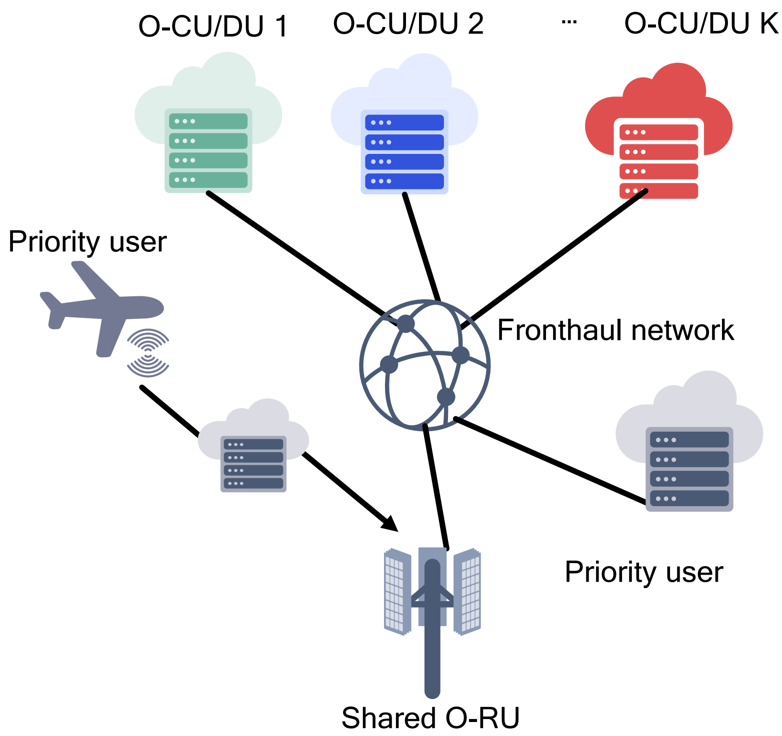

Figure 7: Scenario E - O-RU and spectrum shared between commercial and government users.

3.6 Other options

Other deployment scenarios that leverage shared O-RUs and the Open Fronthaul should be considered. New deployment scenarios can create opportunities for new spectrum for the next generation networks. These use cases could include sharing spectrum with, or protecting incumbent priority access licensees for spectrum, and other radically different deployment models such as drones, satellites (NTNs), etc. These use cases are for further study but offer great potential in the opinion of the authors.

Research area: Deployment scenarios for shared O-RU spectrum sharing.

In addition to enabling operators to realize performance benefits of accessing more bandwidth, the shared O-RU has potential to improve sustainability and reduce to CapEx and OpEx. The savings will vary based on the actual deployment scenario and may determine the how shared O-RU spectrum sharing could be deployed in practice.

Research area: Shared O-RU spectrum sharing impact on sustainability.

4 Resource reservation procedure

Unlicensed spectrum utilizes distributed, Over-The-Air (OTA) medium access procedures that are subject to collisions and uncontrolled interference. For that reason, resource availability and signal quality are difficult to accurately predict. The goal of shared O-RU spectrum sharing framework is to allow spectrum sharing and at the same time predictability of available resources.

4.1 Policy-based reservation

The O-RAN shared O-RU framework enables shared O-RU or its agent to manage resource sharing based on policy established by the O&M and RAN automation features of the O-RAN architecture. This approach ensures predictability of the available resources and signal quality. It is also suitable for use in high Tx power deployment scenarios, which are required for macro coverage and economical deployments of wide area wireless networks.

Shared O-RU spectrum sharing utilizes fast resource allocation procedure to minimize idle time for resources and resource allocation delay. A secondary user needs to request resources before secondary resources can be utilized. The O-RU or its agent can grant or deny resource allocation based on policy that protects primary user resources... An example of the resource reservation procedure by the secondary user (O-DU 2) is illustrated in Figure 8. When the primary user stops sending data to O-RU, the secondary user (O-DU 2) is notified and at that point it can start using the O-RU's time or frequency domain resource allocations for its own traffic. As illustrated in the figure, this procedure may lead to a few unused scheduling intervals at the O-RU due to scheduling delays at the O-DU 2.

4.1.1 Pre-notification to maximize resource utilization

A possible method to eliminate idle scheduling intervals is pre-notification from the primary user or tighter timeline, both of which are feasible given the high-speed/low-latency links between the O-DU and the O-RU. Figure 9 illustrates the benefits of prenotification for the opposite scenario, where primary user (O-DU 1) reclaims resources. Prenotification helps the O-RU to be aware of upcoming traffic so it can notify the secondary user (O-DU 2) to stop scheduling traffic on the appropriate resources.

Research area: Open Fronthaul signaling to accommodate pre-notification and O-RU notifications to O-DUs.

4.1.2 Alternatives to pre-notification

The same scenario without pre-notification is illustrated in Figure 10. In this case, in order not to have both O-DUs send data to the O-RU for the same time/frequency domain resources, it is necessary that the timing window for data arrival of O-DU 1 is moved forward. This allows O-RU to notify O-DU 2 to stop sending data to O-RU. The notification should arrive at O-DU 1 prior to the deadline to send data to avoid the arrival of conflicting data from multiple O-DUs. It should be noted that even if such a collision occurs, the O-RU's arbitration policies would assign access to the highest priority O-DU/operator, and existing radio stack mechanisms would compensate for the dropped I/Q samples.

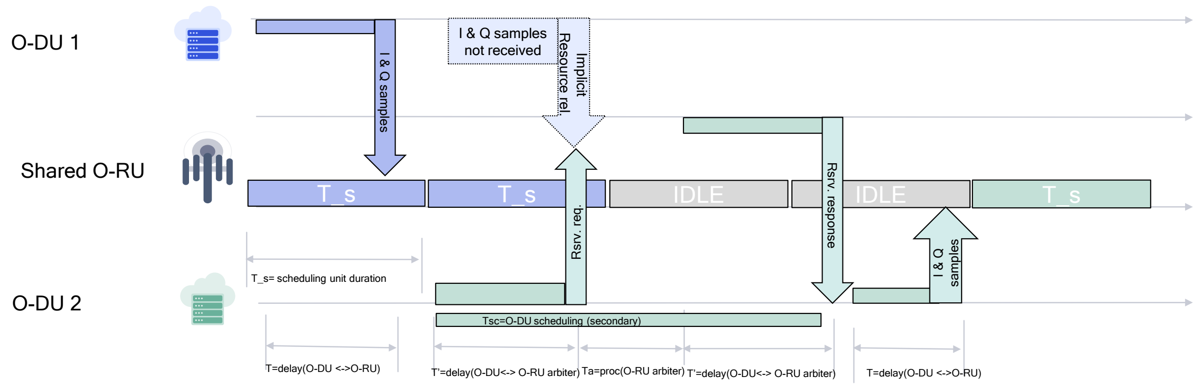

Figure 8: Primary user resource release and secondary user resource reservation.

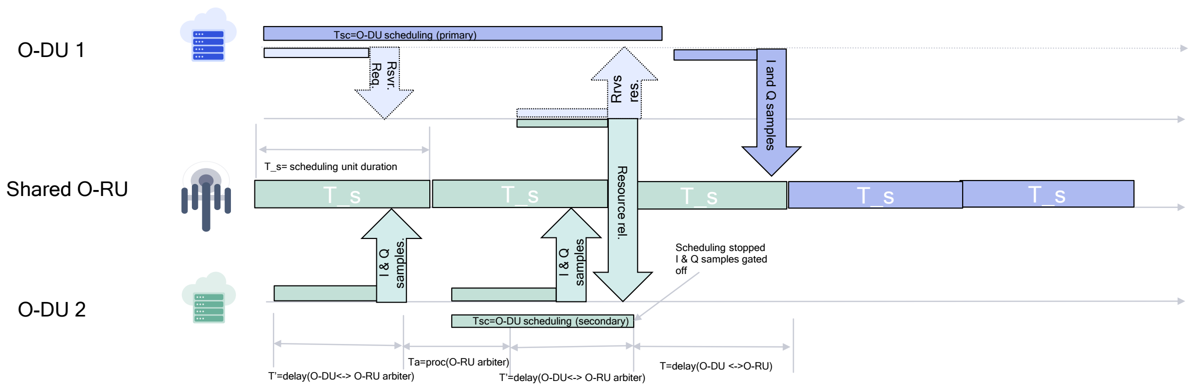

Figure 9: Reclaiming of resources by primary user with pre-notification.

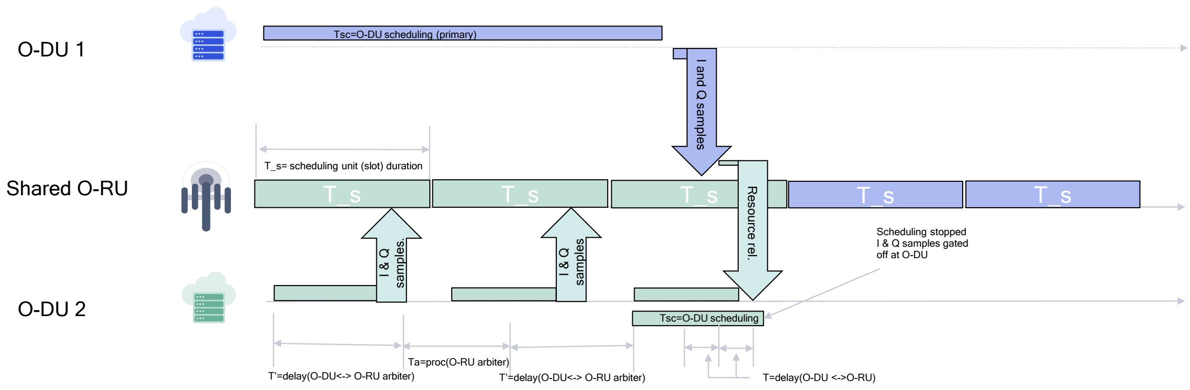

Figure 10: Reclaiming of resources by primary user without prenotification.

4.2 Observations

As the figures suggest, a fast reservation procedure is an essential requirement for the secondary user and the O-RU, but not for the primary user, whose interests are always protected by the O-RU arbitration policy. The primary user does not have to implement any part of the procedure. In fact, the primary O-DU does not even need to be aware that O-RU sharing is occurring. In this sense, the proposed mechanisms are backward compatible to existing O-RAN O-DU deployments. However, enhancements to all of the O-Dus to support pre-notification of the upcoming traffic would help the O-RU to coordinate resource use more efficiently.

Research area: O-RAN architecture that enables upgrade path for fast dynamic reuse of idle resources without requirements on O-DU that does not support fast dynamic spectrum sharing.

5 Performance results

System simulation study was conducted to demonstrate the benefits of the shared O-RU and fast dynamic spectrum sharing. 3GPP system simulations assumptions [4] are adopted for this analysis and illustrated in Table 1.

Table 1: System simulations parameters

Parameter	Value
Carrier freq.	3.5 GHz
Channel model	UMa
Inter Site Distance	500m
Bandwidth	100 MHz for O-RU spectrum sharing, 50 MHz for frequency domain multiplexing (FDM)
The number of sectors per gNB	3
The number of UEs per sector	10
gNB height	25m
Min. gNB - UE distance (2D)	35m
Indoor UE location	80%
UE height: general equation	$h_{UT}=3(n_{fl}-1)+1.5$

UE height: n_{fl} for outdoor UEs	1
UE height: n_{fl} for indoor UEs	n_{fl} ~ uniform(1,N_{fl}) where N_{fl} ~ uniform(4,8)
UE mobility (horizontal plane only)	30km/h for outdoor UEs, 3km/h for indoor UEs
gNB Tx power	53 dBm for O-RU
gNB noise figure	5dB
UE noise figure	9dB
Out to In building penetration loss	Follow TR 38.901
Out to In car penetration loss	Follow TR 38.901
N	Number of 0.5 ms scheduling slots

The performance results in terms of median and 5%-ile tail User Perceived Throughout (UPT) are illustrated in **Error! Reference source not found.**Figure 11 and Figure 12, and summarized in Table 2. The results indicate that with shared O-RU, significant performance gain is achievable, not only for very light loads, for also heavy load typical for busy hour traffic. The results also indicate that fast sharing procedures are critical.

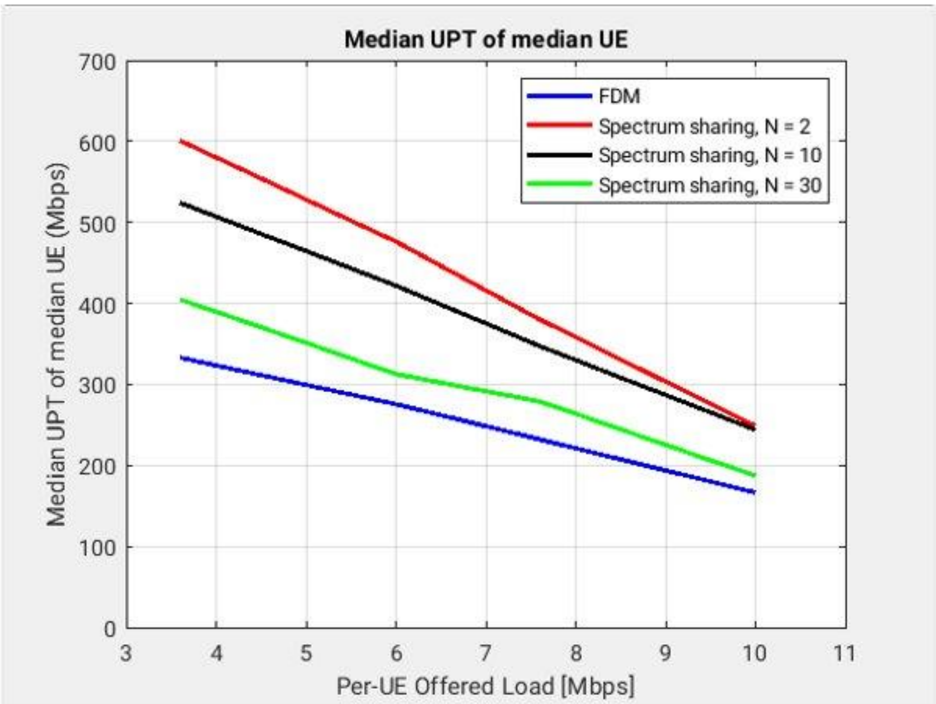

Figure 11: Median UPT of median UE as a function of offered load.

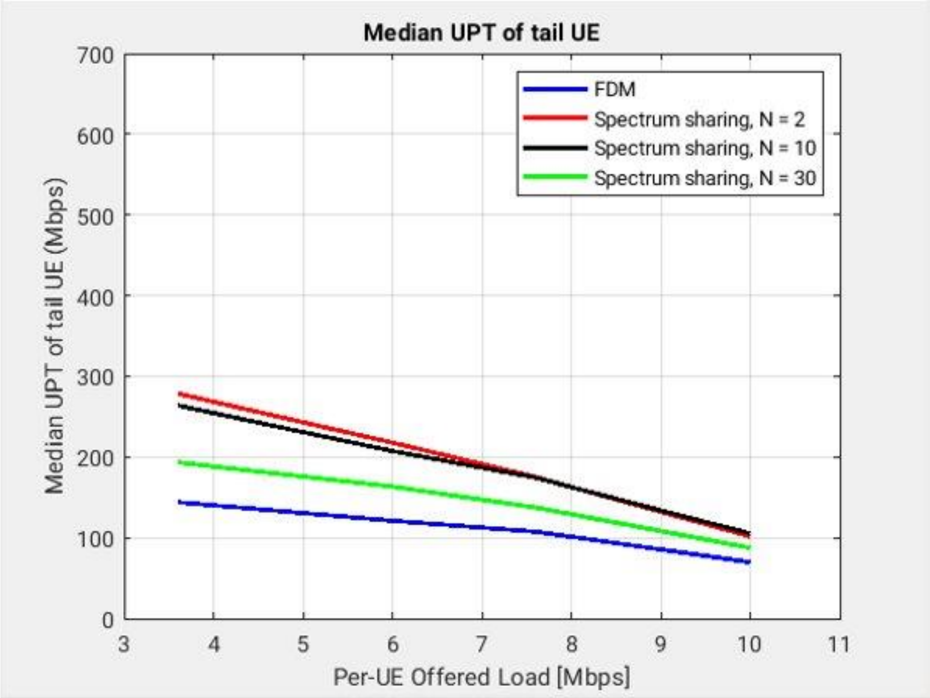

Figure 12: Median UPT of 5%-ile tail UE as a function of offered load.

Table 2: Summary of the performance results

Resouece utilizaiton	Per UE offered load	Median UE gain			Tail UE gain		
		N = 2 [1ms]	N = 10 [5 ms]	N = 30 [15 ms]	N = 2 [1 ms]	N = 10 [5 ms]	N = 30 [15 ms]
11%	3.6 Mbps	81%	57%	22%	93%	83%	34%
30%	7.6 Mbps	64%	50%	20%	63%	62%	28%
44%	10 Mbps	50%	46%	13%	46%	51%	25%

6 Conclusion

Statistical multiplexing of traffic among operators can lead to more efficient use of spectrum while at the same time preserving predictability of available resources. “Neutral host” like deployment of shared O-RUs can greatly enhance spectrum utilization by statistical multiplexing, while preserving the ability for service differentiation among operators. Furthermore, these capabilities can be dynamically managed and orchestrated by straightforward extensions to the O-RAN O&M, RIC, RAN automation, and xApp/rApp architecture. 3GPP standardized RAN sharing alone cannot fully provide the economic benefits and flexibility for many use cases, along with the ability for operator service differentiation that the Shared O-RU based upon extensions to the O-RAN Open Fronthaul provides. These extensions and mechanisms can be easily standardized in O-RAN Alliance with no essential dependencies on standards or implementation changes to the 3GPP RAN[1].

Further research is needed on O-RAN architecture and procedures for spectrum sharing. New applicable deployment scenarios should be analyzed and considered. Shared O-RU spectrum sharing may be facilitated either by an operator that “owns” spectrum or by third party. Shared O-RUs extended to facilitate spectrum sharing have the potential to improve sustainability, with reduced energy consumption, and reduced CapEx and OpEx for all operators.

[1] It is worth noting that 3GPP RAN enhancements could be devised to facilitate even more dynamic sharing, but these are incremental improvements beyond the scope of this study and for further study outside of O-RAN Alliance.

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