A Review on Coordination Techniques for Licensed Spectrum Sharing in 5G Networks

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Abstract – Spectrum frequency is a key drive to wireless communication networks but has limited availability. The upcoming growth of mobile communication networks to support a wide range of mega fast broadband services has led to a great capacity demand of the spectrum frequency. The demand of spectrum frequency has led to a new incitement to find practical solutions to make the most efficient use of scarce licensed bands in a shared manner. Spectrum sharing has been a main focus as is seem to hold promise towards encountering the problem of spectrum scarcity. Spectrum sharing can improve both the spectral efficiency and energy efficiency in a profitable manner, which is anticipated to perform much better than conventional networks. Connectively, spectrum sharing process involves adoption of *coordination techniques* to protect sharing players from interference. So far, various sharing scenarios and techniques has been introduced but still there are challenges which need to be addressed to enhance the efficient utilization of the spectrum henceforth solve the expected problem of spectrum scarcity in 5G communication networks. In this paper, we objectively present the importance of spectrum sharing in the future of wireless communication (5G), we analyze the role of coordination techniques in implementation of spectrum sharing scenario in 5G networks, we illuminate the gaps in the existing coordination techniques. Finally, we suggest solutions (way forward) towards the implementation of spectrum sharing in 5G networks.

Index Terms – 5G Networks, Spectrum frequency, Coordination techniques, Incumbent(s), LSA Licensee(s), Coordinated beamforming, Game Theory, Spectrum sensing, Communication networks, Licensed spectrum sharing.

1. INTRODUCTION

Spectrum frequency is a very essential and valuable resource for wireless communication but has limited availability. The upcoming growth of mobile communication networks to support a wide range of mega fast broadband services has led to a great capacity demand of the spectrum frequency. The demand of spectrum frequency has led to a new incitement to find practical solutions to make the most efficient use of scarce licensed bands in a shared manner. Spectrum sharing not only improve spectrum utilization efficiency but also saves cost[1]. Specifically, the issue of underutilization of the spectrum frequency is one of the prominent issue, that spectrum sharing is expected to solve. However, Spectrum sharing scenario will come with a number of other benefits including; improved spectrum efficiency since one more than one node will be able to use the same spectrum at the same time, increased capacity as more operators (and hence devices/end users) will be accommodated in the network and, reduced costs to sharing players compared to non-shared spectrum frequency usage scenario[1]

1.1. Spectrum sharing

Spectrum sharing is the collective use of a given portion, i.e., frequency band, of the electromagnetic spectrum by two or more parties. However, the shared spectrum can be licensed or unlicensed. From a regulatory perspective, the licensed band is the one which is exclusively allocated to incumbents, while the unlicensed band is the one which is not exclusively allocated to any of spectrum users and can be used or shared without a need of license.

In licensed sharing, sharing can either be *homogeneous* (when sharing parties are of the same nature e.g. Mobile Network Operator (MNO) and MNO) or it can be *heterogeneous* (When sharing parties are of different nature e.g. MNO and a TV station). However Spectrum users are also classified into two classes, namely; *incumbents* and, *License Shared Access (LSA) Licensees. Incumbents* are the ones to which the spectrum band was originally granted and that agrees to share the frequencies with other access seekers (LSA licensees). On the other hand, *LSA licensee(s)* are additional users that are permitted to use the spectrum (or part of the spectrum) in according to sharing rules incorporated in the rights of usage of spectrum dedicated to the licensee(s), thereby allowing all the licensees to provide a certain level of quality of service (QoS)[2].

1.2. Licensed spectrum sharing (Heterogeneous Sharing players)

Basically, there are three parties in Licensed spectrum sharing including; *regulator(s), incumbent(s) and, Licensed Spectrum Access Licensee(s) (LSA licensee(s))*. *Regulators* around the world are generally charged with ensuring adequate and equitable spectrum supply for the commercial marketplace and for societal use at-large, e.g. defense and public safety. In the case of mobile services, regulators also often use spectrum management as a means to promote mobile competition. *Incumbent's* role is to provide spectrum to be shared with the LSA licensees and to abide by the sharing commitments. *Incumbent(s)* receives a number of benefits for his commitment and agreement to share spectrum, the benefits includes; Increased funding through proceeds from spectrum licensing auctions and/or fees, avoided capital expenditures as costs become shared with LSA licensee(s), reduced operating costs and/or enhanced services via offerings rendered by the sharing LSA Licensee(s), potential to upgrade technology and capabilities if sharing necessitates more advanced infrastructure or devices.

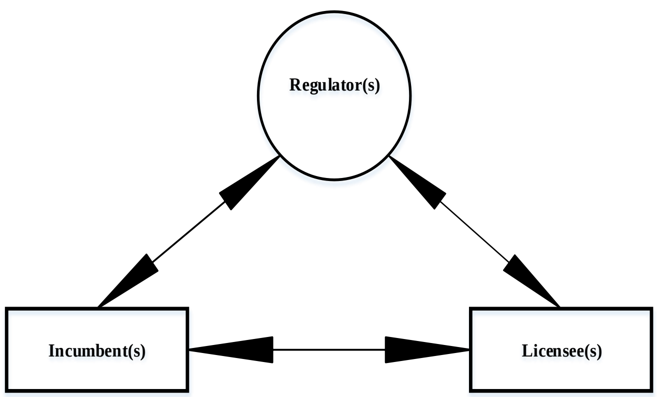

Figure 1 Main parties in licensed spectrum sharing

However, when agreeing to share their spectrum bands, *incumbent(s)* has the potential to bring significant costs and risks to themselves including; smaller geographic spectrum footprint and/or restrictions on day or time of use, reduced freedom of choice and flexibility as to how the spectrum can be used, Increased operational costs and complexity to coordinate and manage use within a shared spectrum environment, potential to be locked into legacy technology or added complexity to introduce new technology and, risk of degradation of incumbent services and capabilities if sharing arrangements do not conform to the regulated or negotiated performance levels. Generally, enabling sharing, *incumbent(s)* will be transitioning from an exclusively licensed spectrum environment to a shared environment, and thus inherently losing flexibility and freedoms of spectrum use. On the other hand, *LSA Licensee(s)* purchase spectrum sharing licenses, provide infrastructure, abide by sharing terms, and effectively use the spectrum

1.3. Basic functionality of licensed spectrum sharing

Licensed spectrum sharing process involves adoption of *coordination techniques* to protect sharing players from interference. However, in the case of Licensed spectrum sharing, more accurate and firm interference management policies are needed, compared to the case of unlicensed spectrum sharing. The current deployments of Licensed spectrum sharing, is thought and focused principally on the database (namely geo-location database) driven approaches (named LSA repository). It can be setup and managed by the incumbent(s) or the respective Spectrum regulator. The database stores the information concerning the shared spectrum availability/usage of the incumbent(s)' network. In cases like cellular network, an additional management entity denoted as LSA controller, has been introduced to interact with the LSA repository through a reliable interface [3].

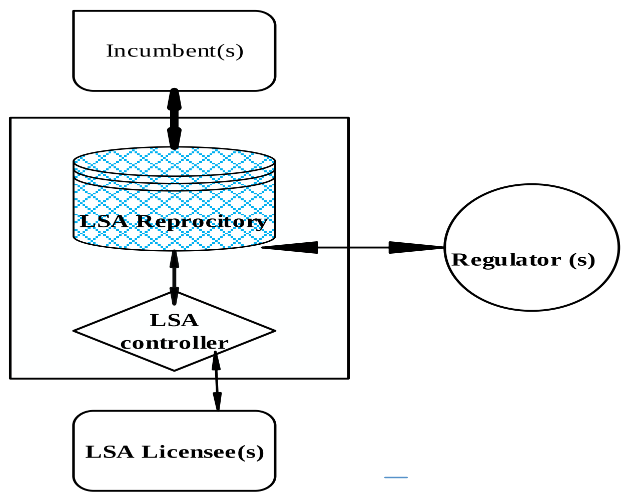

Figure 2 Basic Licensed spectrum sharing process

The LSA controller is responsible for handling the resource request/evacuation procedure among the Operation, Administration and Management (OAM) section in the mobile networks, and the LSA repository[4],[5]. The Licensed spectrum sharing procedure comprising; spectrum request, allocation, and evacuation between *LSA Licensee(s)* and *incumbent(s)*, introduces an additional overhead to the system. The degree of signaling overhead will be considerably increased in the case of near real-time/on-demand sharing. In the case of the long distance between the Licensee(s) and the incumbent(s) network, the coordination requires an interface/backhaul with reasonable speed/capacity. The basic functional architecture is illustrated in Figure 2 above.

1.4. Coordination techniques

As mentioned in the previous sub-section, coordination techniques are important and need to be adopted to in the sharing process to protect sharing players from interference as well as helping in enhancing spectrum sharing efficiency.

Basically, coordination techniques can be categorized two classes which are; centralized and decentralized. Centralized coordination has two types which are; database-driven approaches, centralized management entity, while the decentralized coordination has three types including; *Spectrum sensing, Game Theory (GT) based coordination* and, *Coordinated beamforming.* In the centralized based coordination techniques, sharing players coordinate via a central entity, so that they do not directly interact with each other[6], while in decentralized coordination, sharing players cooperate in a distributed manner.

Although the coordination techniques are important, and have advantages in facilitating the implementation of spectrum sharing, however they do have sensitive drawbacks which need to be attended properly to make spectrum sharing more efficient. The detailed review of some work which has been conducted so far is presented in the following section (related work).

1.5. Why spectrum sharing

In the context of future mobile cellular systems (i.e. 5G) there will be much higher expectation of spectrum sharing advances compared to the currently available methods. The impending cellular system is expected to bump into the following requirements, (some of them which are as briefed below)[7][8]

- HIGH CAPACITY: This due to the fact that the impending wireless network is expected to have 1000-times higher mobile traffic volume comprising Mobile Broadband (MBB), Device-to-Device communications, and Machine Type Communication (MTC) for abundant connectivity, which requires cellular systems to support/provide capacity in the order of terabytes/month per subscriber.
- WIDER BANDWIDTH AND HIGHER RANGE FREQUENCIES : This due to the fact that the impending wireless network is projected to support of 10-100 times of higher typical end-user data rates, i.e., 10Gb/s for low mobility and 1Gb/s for high mobility
- The support for 10-times more energy saving (10% of today's consumption), and therefore longer battery life for low-power devices;
- The support of 5 times reduced End-to-End latency (15ms in current LTE), hence, in the development of efficient spectrum sharing mechanisms, this factor should be considered.

The mentioned requirements for impending wireless networks, and from the spectrum perspective, we can see that 5G systems will need to be able to operate over wide range of frequencies from sub-1GHz up to and including mmWave frequencies (spanning 10-to-90GHz).

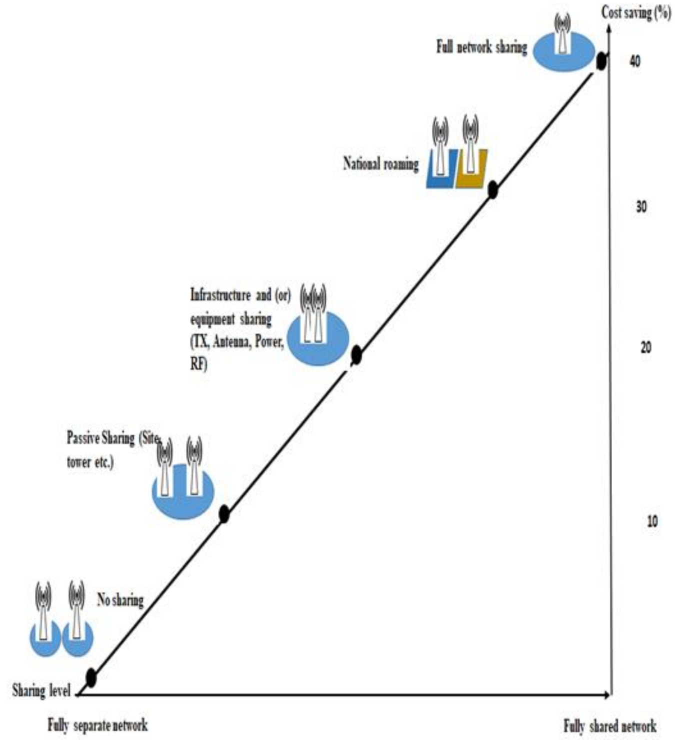

Figure 3 Network sharing models vs cost saving gains[9]

Since the 5G demands will require wider bandwidth of the spectrum frequency which is a limited resource then, the scenario of spectrum sharing will definitely be required to solve problem of scarcity of spectrum frequency. Further to that, the spectrum sharing will definitely help to save costs to the part players.

1.6. Our contributions and organization of the paper

In this paper, we provided brief understanding on the importance of spectrum sharing in the future of wireless communication (5G), we detailed the role of coordination techniques in implementation of spectrum sharing scenario in 5G networks, we illuminated the gaps in the existing coordination techniques, and we further suggested solutions (way forward) to the implementation of spectrum sharing in 5G networks.

The remaining part of this manuscript is structured as follows: Section two (2) describes related works done by other researchers; Section three (3) provides the proposed solutions (way forward) to the efficient employment of coordination techniques in spectrum sharing; Section four (4) gives conclusion about this paper by summarizing the authors' views on the significance of spectrum sharing, and how improved coordination techniques will efficient help the implementation of spectrum sharing.

2. RELATED WORK

2.1. A review of state of the art (SOTA) articles

Spectrum sharing concept has lately received considerable attention from regulatory bodies and governments in globally as it seemed to be a promising solution to the massive demand of spectrum frequency during the deployment of 5G wireless networks. It is observed that, the traffic growth in mobile wireless communications in the last decade which has recently been driven by popularity of numerous smart devices and Internet-based applications[1], has led to great capacity demand which in turn a require a solution since the spectrum frequency is a limited resource.

2.2. Sharing scenarios

So far there are various sharing scenarios which have been proposed and discussed including: Inter-operator RAN and Spectrum Sharing and, Spectrum sharing (no RAN sharing) as diagrammatically in Figure 4.

Different sharing scenarios with different technical and business concerns (e.g., mobility management, interference management, inter-operator coordination, security, charging, etc.) are identified[10]. However, due to the business concerns and lack of strong evidence in favor of sharing and associated gains, the sharing players have not shown willingness to proceed for the practical deployment so far[11],[12]. The existing proposed sharing schemes in the writings (which assimilate coordination techniques) are: a) Inter-operator RAN and Spectrum Sharing and, b) Spectrum sharing (no RAN sharing).

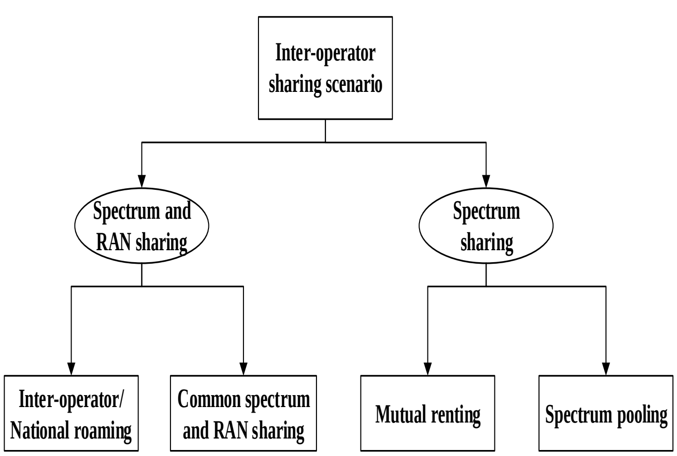

Figure 4 Inter-operator "Sharing Scenarios"

2.3. Spectrum and RAN sharing

This sharing model is categorized as: i) Inter-operator/National Roaming, when sharing players provide coverage in different geographical areas (i.e., exclusive RAN deployment), and ii) Common Spectrum and RAN Sharing, when two different sharing players cover the same geographical area.

2.4. Inter-operator/national roaming

The prospect for a UE to operate in a network other than its own home network is denoted as roaming (also known as inter-operator handover). This is normally executed by the UE, which measures the signal strength of the pilot signals (beacon signals) of the bordering BSs and subsequently will be connected to the BS with the strongest pilot signal. The term national roaming suggests that multiple sharing players, owning exclusive spectrum, radio access networks (RANs), and core network (CN) nodes, offer coverage in various parts of a country but together can offer coverage of the whole country. National roaming can be considered as both RAN and spectrum sharing in non-collocated areas (which may partially overlay), which is carried out based on agreements [13] among the sharing players. In the case of national roaming, interference and mobility management of the involved UEs are straightforward and less challenging, as UEs perform handover to the coverage area of the target sharing players, and thus, the target sharing player is responsible for resource allocation and management of the UEs. However, for the UEs, which are located in the partially overlapped coverage areas, additional consideration and negotiation among the sharing players are required[10].

2.5. Common Spectrum and RAN Sharing

In this sharing scenario, two/multiple operators share a common RAN (i.e., RNC and BS), in the same geographical area, which is connected to separate Core Network (CN) nodes belonging to the respective operators. This scenario is known as virtualized RAN and spectrum sharing, and enables the deployment of virtualization in cellular networks with subsequent support for Mobile Virtual Network Operator (MVNOs)[14]. One advantage of the RAN sharing is considerable cost saving.

2.6. Spectrum Sharing (Co-Primary Spectrum Sharing (CoPSS))

Spectrum sharing in general is the use of a frequency band by two or more parties in agreement basis. The sharing parties can be of the same nature (Homogeneous) or of different nature (Heterogeneous). The spectrum sharing scenario is an agenda given high priority as it seemed to be a solution which will address the problem of scarcity and underutilization of spectrum frequency[15][16][17][18].

It has been observed that, part of entirely allocated licensed bands remain significantly unutilized at some location or period of time. Based on the results from measurement campaigns in various locations across the world, the average spectrum usage percentage of some spectrum bands was found to be low in several deployment scenarios[19]. For instance, the measurements showed that 54% of the spectrum in the U.S., Germany, and Netherlands is rarely used in the 20MHz-6GHz band[20]. The spectrum occupancy in 20MHz-to-3GHz was found to be 32% for indoor scenarios and very low in 3-to-6GHz[21]. Such observation highlight the possibility which can allow co-existence of one/multiple sharing players with incumbent systems to dynamically exploit unutilized licensed spectrum in a shared manner[22].

2.7. Mutual ranting

In this access mode, licensed bands that have been already allocated to a sharing player on an exclusive basis can be rented to another sharing player(s) subject to the permission of the respective NRA. This provides sharing player with an additional source of revenue from its temporarily unutilized spectrum, and improves spectrum utilization efficiency. This scheme is advantageous for sharing player that faces temporal capacity shortage and requires more licensed spectrum to accommodate high data rate/capacity requirements with guaranteed QoS and cheaper license fee compared to the case of exclusive access. However, in this access method, the spectrum owner has anticipatory priority to access its own spectrum at any time, in contrast to the case of spectrum pooling. Therefore, this access scheme seems to be more beneficial when the spectrum is expected to remain unutilized over a long period of time[6],[23] or by the instantaneous spectrum opportunity detection, taking advantage of traffic diversity in time/location.

This type of spectrum sharing is similar to the interweave approach in CRNs, i.e., exclusive shared spectrum access where no interference is tolerable and almost always the actual owner of the spectrum (who is denoted as *host* operator) has the priority to access the band[24]. However, in contrast to the CRNs interweave approach, and based on the agreement among operators, access to the spectrum as well as QoS must be guaranteed for both sharing players. An exemplary case of this type is; when the host operator owns RAT-specific bands (e.g., 3G license) and shares this spectrum with other operators (denoted as *guest* operators), who do not own the bands.

2.8. Spectrum Pooling

The National Regulatory Authority (NRA), instead of dedicating allocation of the particular licensed bands to a sharing player, allocates them to a number of sharing players (limited number). This access mode provides an opportunity for the sharing players to attain additional licensed bands on a shared basis; where/when it is needed, and therefore improves spectrum utilization efficiency. Under bi/multi-lateral agreements among sharing players, specific rules can be set to achieve the fair/reasonable level of spectrum access guarantees, as well as preventing aggressive/un-coordinated re-use of spectrum. However, simultaneous access to the bands for all participating sharing players still proves insufficient to meet the capacity demand. This access scheme, as a complementary opportunity, seems to be beneficial for the sharing players to fulfill their QoS targets and capacity demands, with the considerably lower license fee (compared to auction-based license fees), together with their own dedicated licensed spectrum[6],[25].

However, in licensed sharing schemes, a set of rules and regulations should be defined and agreed prior to the use of shared spectrum to secure spectrum access for sharing players and also protect against potential interference. For example, parameters such as the level of prioritization, i.e., the right of access in terms of temporal, spatial, and spectral granularities, the maximum allowed transmit power, out-of-band transmitted power limits, and protection radii[26], etc., are taken into account.

2.9. Coordination Techniques

In spectrum sharing manna, there has to be coordination between sharing players when sharing the spectrum frequency. However, Coordination between sharing players can be carried out through various methods which are realized as “coordination” or “spectrum access” techniques/protocols. Coordination techniques are categorized under centralized and decentralized as shown in Figure 5 [26],[27],[28].

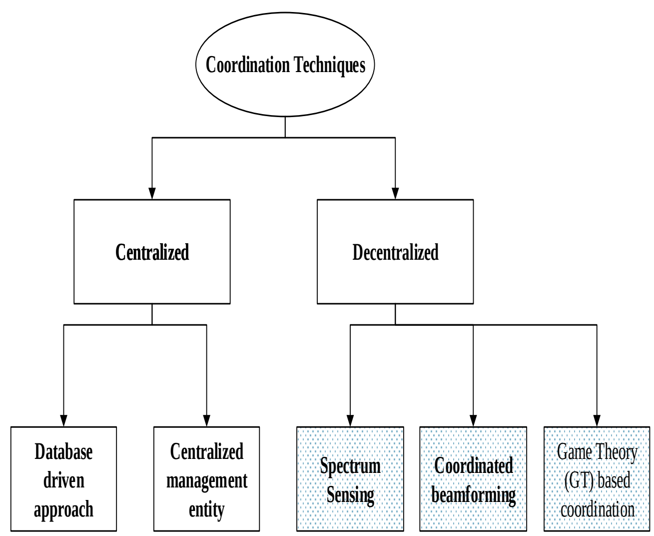

Figure 5 Coordination Techniques

2.10. Centralized based coordination techniques

In the centralized based coordination techniques, sharing players coordinate via a central entity, so that they do not directly interact with each other[6]. The centralized techniques, which have been applied to the licensed spectrum sharing so far, are:

1) Database-driven approaches: One example of this is geo-location database; it can obtain, process, and store the geo-localized spectrum availability information of a service provider, which can be sharing player or an incumbent. In a robust, but more complex type of geo-location database, interference between users is calculated based on offline (none real-time) theoretical propagation models, which allows promising interference protection[11]. This technique is widely applied in the case of Television White Spaces (TVWS) sharing, and also in the License Shared Access (LSA) reference system architecture.

2) Centralized management entity: The techniques such as super resource scheduler, meta-operator, and spectrum broker, and also shared Radio Network Controller (RNC) have been widely applied in the literature in the case of inter-operator spectrum sharing for reliable management of spectrum sharing[11].

Although the centralized has advantages (like: they provide accurate information regarding spectrum availability across the network, they provide interference protection for sharing players and, can be an unbiased entity for fair spectrum allocation among sharing players) but the implementation of such centralized technique have got shortcomings including; requiring additional infrastructure such as backhaul for deployment, requires third party to manage the sharing procedure, imposes excess signaling overhead to the network and, is vulnerable to jamming attack[11],[15].

2.11. Decentralized coordination techniques

In decentralized coordination, sharing players cooperate in a distributed manner. The decentralized techniques, which have been applied to licensed spectrum sharing so far, are: *Spectrum sensing, Game Theory (GT) based coordination* and, *Coordinated beamforming*

2.12. Spectrum sensing

By the aid of sensing techniques, devices (e.g., BS or UE) can detect the presence of other devices operating on shared bands, prior to transmission to avoid interference. A wide range of sensing techniques are available, ranging from; energy detection, feature detection of co-existence beacons etc.[23],[11],[15],[29],[30].

Although the spectrum sensing technique has number of achievements (including; capable for on-demand and real-time spectrum opportunity detection, no additional infrastructure is required and, only target user equipment (UE) is involved to perform sensing, thus lower signaling is imposed to the network) however, it has got number of challenges /shortcomings including; vulnerable to some issues such as hidden node, false alarm and detection and, is not reliable to QoS sensitive service when sensing is performed by UE[11],[29],[30]. Moreover, some factors such as reduced energy consumption form UEs while performing sensing, reduced sensing time duration will be the representative targets of this spectrum sharing scheme coordination

2.13. Game Theory (GT) based coordination

GT is a well-defined technique for studying distributed decision-making in multi-user systems. Game-theoretic frameworks have been applied to the problems such as power control, spectrum allocation, call admission control, and routing. In the case of co-existence of multiple service providers, the resource/spectrum sharing problem can also be explored from a game theoretic perspective. Dependent on whether players collaborate or not, a game can be cooperative or non-cooperative. Without coordination among users/systems, the existence of stable outcomes is analyzed through the so-called Nash Equilibria (NE). To achieve better payoffs, cooperation between users may be carried out. Subject to sharing some information, players can define whether there are hypothetically extra utilities for everyone if they work together. Suppose there are such extra utilities, players may bargain Nash Bargaining (NB) with each other to decide how to share the information. The NB solution, in fact, is a specific game which depends on the manner of cooperation. However, the success of GT-based solutions in the case of resource/spectrum sharing and allocation in mobile communication systems, requires robust solutions to the open challenges such as implementation complexities, uniqueness complexities, efficiency and fairness[31],[17],[32].

Game-Theory based coordination technique has a number of advantages and (or) achievements including; Low to no, information sharing between sharing players during sharing procedure, low to no overhead is imposed to the network and, experiments shows that no need for real-time inter-operator information sharing. Despite the advantages depicted above, the Game-Theory coordination technique has got number of challenges including; implementation complexities, low fairness and guarantees between sharing players and, experiments has explored that efficiencies and fairness policies are complex to implement[31],[7],[8],[33].

2.14. Coordinated beam forming

Beam forming techniques enable the mobile cellular networks to adjust size of the cells to better serve users. This is achieved by flexibly modifying the phase and amplitude of the signals to shape and steer the direction of the radiated beam vertically and horizontally to create constructive or destructive interference [34],[17].

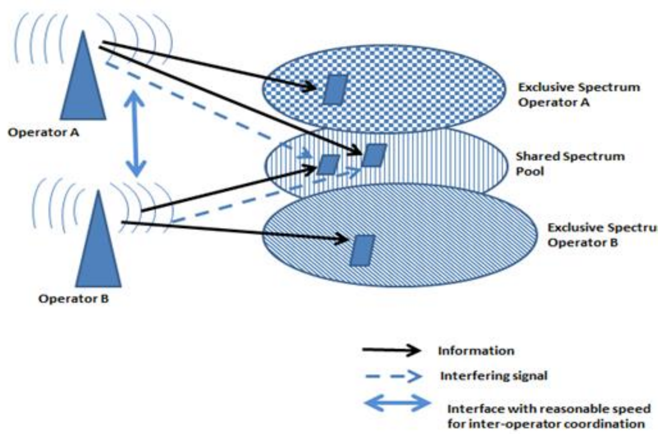

Figure 6 Multiple operator spectrum pooling beamforming techniques

Although beamforming technique, has a number of advantages or achievements (including; simultaneous utilization of spectrum by multiple service providers and, increased spectrum utilization efficiency) but there are number of shortcomings need to be addressed including; the requirement of Channel State Information (CSI) and User data sharing between sharing players, requirement of interface (such as backhaul, X2) between sharing players and, and also experiments has shown that currently the system is only beneficial to users with high SINR, close to their serving BSs[34],[19][33].

It was studied that, when two Mobile Network Operator (MNOs) simultaneously operate on shared spectrum in the same area (i.e. Inter operator spectrum sharing) the Channel State Information (CSI) need to be shared among corresponding base stations (BSs) of different Licensee(s) as well as interfering CSI of one operator and user equipment (UEs) of the other operator. Such information exchange needs to be carried out in a reasonable time scale (i.e., smaller time scale than the channel coherence time, which refers to the duration on that the band is available[27],[28][11][15][29][30][34], through an interface with reasonable capacity/speed. Similarly to the case of inter-operator ICIC (Inter Cell Interference Coordination), the point-to-point coordination and exchange are subject to additional cost as well as the satisfaction of participating MNOs. Enhanced coordinated beam forming techniques with minimum to no sharing of information between MNOs, is required to solve the stated problem.

Coordination techniques	Reviewed paper titles	Drawbacks (gaps)
Spectrum sensing	“A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications”[12] “Radar, TV and Cellular Bands: Which Spectrum Access Techniques for Which Bands?”[14] “A Comparison Between the Centralized and Distributed Approaches for Spectrum Management”[13]	I)- LACK OF CERTAINTY -The technique is vulnerable to some issues such as hidden node, false alarm and detection -The technique is also not reliable for quality of service (QoS) sensitive services when sensing is performed by UE by UE
Game Theory based coordination	“A Secure Radio Environment Map Database to Share Spectrum”[7] “Ofcom Gives Green Light for ‘TV White Space’ Wireless Technology”[8] “IEEE 802.11af: A Standard for TV White Space Spectrum Sharing”[19]	I)- EFFICIENT AND FAIRNESS POLICIES COMPLEXITIES -The technique have implementation complexities -Also has low fairness guarantee between sharing players
Coordinated beamforming	“Coordination Protocol for Inter-Operator Spectrum Sharing in	I)-The technique requires Channel State Information (CSI) and user information sharing between sharing players

	Co-Primary 5G Small Cell Networks"[17] "A survey on game theory applications in wireless networks"[32]	II)-Also requires interface (such as backhaul,X2, etc) between sharing players which lead to additional costs

Table 1 Summarized drawbacks (gaps) of the coordination techniques (Spectrum sensing, Game Theory (GT) based coordination and, Coordinated beamforming)

Summarily, each coordination scheme is applicable to the scenarios characterized by different demands. The centralized approaches, typically without the need for UE involvement, are simpler to be controlled, and provide more reliable and fair allocation of spectrum. However, there is a need for additional network infrastructure and result in considerable amount of signaling overhead for coordination between sharing contributors, especially the ones with dynamic varying traffic load, and therefore dynamic spectrum usage. Besides, the latency in such schemes matters, when the real-time traffic is transmitted due to the fact that coordination with the central entity requires additional time. On the other hand, in distributed schemes, the adoption of an efficient, accurate and reliable technique is a challenge although they may not need additional infrastructure.

3. PROPOSED SOLUTIONS (WAY FORWARD)

In the previous sections we briefly discussed spectrum sharing in general paradigms and decentralized coordination techniques including; spectrum sensing, Game Theory based coordination and, Coordinated beamforming along with their potential drawbacks. However, the future mobile cellular systems (namely 5G) is expected to have much higher spectrum sharing gains. This in turn will demand efficient sharing approaches which will obvious require the discussed drawbacks to be attended.

In this part, we present a brief overview of how the sharing coordination techniques should be addressed and we depict important open issues that have to be solved for the real deployment of this technique in inter-operator spectrum sharing. The overview and depicted open issues of each scenario are briefly described and also summarized in Table 2.

3.1. Spectrum sensing

In the previous section, we briefly presented the shortcomings of this technique such as lack of certainty. However, in the licensed spectrum sharing, sensing techniques will play a significant role as balancing trends in combination with other techniques. Therefore, improved sensing techniques will be needed that can capture spectrum availabilities across the network in a more reliable modus. Some factors such as reduced energy consumption for UEs while performing sensing, reduced sensing time duration, will be the representative targets of spectrum sharing schemes.

3.2. Game Theory based Coordination

As previewed in the previous sections, despite of the advantages Game-Theory coordination technique holds (including; Low to no information sharing between sharing players during sharing procedure, low to no overhead is imposed to the network and, experiments shows that no need for real-time inter-operator information sharing), the technique have a number of challenges including; implementation complexities, low fairness and guarantees between sharing players and, experiments has explored that efficient and fairness policies are complex to implement.

However, in this case one of the main obstacles is efficient and fairness policies, of which in this context is implementation complexities. Therefore, Regulatory Authorities need to revert and revise policies that brings low fairness guarantee and implementation complexities.

Coordination techniques	Drawbacks (gaps)	Proposed Solution (Way forward)
Spectrum sensing	I)- LACK OF CERTAINTY -The technique is vulnerable to some issues such as hidden node, false alarm and detection -The technique is also not reliable for quality of service (QoS) sensitive services when sensing is performed by UE	I)- Improved sensing techniques will be needed that can capture spectrum availabilities across the network in a more reliable modus
	I)- EFFICIENT AND FAIRNESS POLICIES COMPLEXITIES -The technique have implementation complexities	I) - Regulatory Authorities need to revert and revise policies that brings low fairness guarantee and implementation

Game Theory based coordination	-Also has low fairness guarantee between sharing players	complexities. That means, policies which suites some of the coordination techniques (in specific: Game Theory based coordination
Coordinated beamforming	I)-The technique requires Channel State Information (CSI) and user information sharing between sharing players II)-Also requires interface (such as backhaul,X2, etc) between sharing players which lead to additional costs	I)- Such information exchange needs to be carried out in a reasonable time scale (i.e., smaller time scale than the channel coherence time, which refers to the duration on that the band is available), through an interface with reasonable capacity/speed and very high security (i.e. encryptions) II) Enhanced coordinated beamforming techniques with minimum to no sharing of information between Mobile Network Operators (MNOs), are highly required.

Table 2 Summary of the proposed solutions (way forward)

3.3. Coordinated beamforming

The utilization of beamforming as a prominent coordination technique, when MNOs instantaneously operate on shared spectrum in the same area, was briefly presented in the introduction. However, there are significant open disputes that have to be resolved for the real utilization of this technique in inter-operator spectrum sharing.

As previewed in the previous section, the channel state information (CSI) needs to be shared among the corresponding BSs of different Licensee(s) as well as interfering CSI among BSs of one operator and user equipment (UEs) of the other operator. Therefore, such information exchange needs to be carried out in a reasonable time scale (i.e., smaller time scale than the channel coherence time, which refers to the duration on that the band is available), through an interface with reasonable capacity/speed and, with very high security (encryptions).

Likewise, for the case of "requirement of interface between sharing players", the point-to-point coordination and information exchange are subject to additional cost as well as the satisfaction of participating MNOs. So, in this case, enhanced coordinated beamforming techniques with minimum to no sharing of information between Mobile Network Operators (MNOs), are highly required.

4. CONCLUSION

In this paper, we provided an overview on spectrum sharing scenario in 5G networks, and we also provided a review on coordination techniques for licensed spectrum sharing in 5G networks. Specifically; a brief overview on spectrum sharing was provided also three coordination techniques namely; *spectrum sensing, Game Theory based coordination* and, *coordinated beamforming* were presented in detail.

The main objectives of this paper are; to give more understanding on the importance of spectrum sharing in the future of wireless communication (5G), to detail the role of coordination techniques in implementation of spectrum sharing scenario in 5G networks, to illuminate the gaps in the existing coordination techniques, and to suggest solutions (way forward) towards the implementation of spectrum sharing in 5G networks.

Thus, we presented our observations from the mentioned existing coordination techniques, we enlighten the gaps on the existing coordination techniques and we provided solution (way forward) to the efficient employment of the coordination techniques in implementation of spectrum sharing issue in 5G networks. In summary, we have seen that spectrum sharing is very important in 5G networks, and accordingly the improved coordination techniques will significantly help to improve the implementation of spectrum sharing in 5G networks.

REFERENCES

[1] C. Yang, J. Li, M. Guizani, A. Anpalagan, and M. Elkashlan, "Advanced spectrum sharing in 5G cognitive heterogeneous networks," *IEEE Wirel. Commun.*, vol. 23, no. 2, pp. 94–101, 2016.
[2] Delloitte, "The Impact of Licensed Shared Use of Spectrum," 2014.
[3] J. Khun-Jush, P. Bender, B. Deschamps, and M. Gundlach, "Licensed

shared access as complementary approach to meet spectrum demands: Benefits for next generation cellular systems," *ETSI Work. reconfigurable radio Syst.*, no. December, pp. 1–7, 2012.

[4] T. Report, "TR 122 951 - V12.0.0 - Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Service aspects and requirements for network sharing (3GPP TR 22.951 version 12.0.0 Release 12)," vol. 0, pp. 0–20, 2014.

[5] J. G. J. G. Andrews *et al.*, "What will 5G be?," *IEEE J. Sel. Areas Commun.*, vol. 32, no. 6, pp. 1065–1082, 2014.

[6] M. R. Hassan, G. Karmakar, J. Kamruzzaman, and B. Srinivasan, "Exclusive Use Spectrum Access Trading Models in Cognitive Radio Networks: A Survey," *IEEE Commun. Surv. Tutorials*, vol. XX, no. X, pp. 1–41, 2017.

[7] S. Sodagari and S. Member, "A Secure Radio Environment Map Database to Share Spectrum," vol. 9, no. 7, pp. 1298–1305, 2015.

[8] S. Publication, "Implementing TV White Spaces," no. February, 2015.

[9] BEREC, "BEREC-RSPG report on infrastructure and spectrum sharing in mobile/ wireless networks," *Spectrum*, no. June, pp. 1–23, 2011.

[10] L. Cui, M. Gomez, and M. B. H. Weiss, "Dimensions of cooperative spectrum sharing: Rights\r\nand enforcement," *New Front. Dyn. Spectr. Access Networks*, pp. 416–426, 2014.

[11] H. D. Schotten and M. a. Uusitalo, "Deliverable D5.1 - Intermediate description of the spectrum needs and usage principles," p. 62, 2013.

[12] V. M. Patil and S. R. Patil, "A survey on spectrum sensing algorithms for cognitive radio," *2016 Int. Conf. Adv. Hum. Mach. Interact. HMI 2016*, vol. 11, no. 1, pp. 149–153, 2016.

[13] G. Salami, O. Durowoju, A. Attar, O. Holland, R. Tafazolli, and H. Aghvami, "A comparison between the centralized and distributed approaches for spectrum management," *IEEE Commun. Surv. Tutorials*, vol. 13, no. 2, pp. 274–290, 2011.

[14] F. Paisana, N. Marchetti, and L. A. Dasilva, "Radar, TV and cellular bands: Which spectrum access techniques for which bands?," *IEEE Commun. Surv. Tutorials*, vol. 16, no. 3, pp. 1193–1220, 2014.

[15] T. Irnich, J. Kronander, Y. Selen, and G. Li, "Spectrum sharing scenarios and resulting technical requirements for 5G systems," *IEEE Int. Symp. Pers. Indoor Mob. Radio Commun. PIMRC*, pp. 127–132, 2013.

[16] J. M. Park, J. H. Reed, A. A. Beex, T. C. Clancy, V. Kumar, and B. Bahrak, "Security and enforcement in spectrum sharing," *Proc. IEEE*, vol. 102, no. 3, pp. 270–281, 2014.

[17] B. Singh *et al.*, "Coordination protocol for inter-operator spectrum sharing in co-primary 5G small cell networks," *IEEE Commun. Mag.*, vol. 53, no. 7, pp. 34–40, 2015.

[18] O. Aydin, D. Aziz, and E. Jorswieck, "Radio resource sharing among operators through MIMO based spatial multiplexing in 5G systems," *2014 IEEE Globecom Work. GC Wkshps 2014*, pp. 1063–1068, 2014.

[19] A. B. Flores, R. E. Guerra, E. W. Knightly, P. Ecclesine, and S. Pandey, "IEEE 802.11af: A standard for TV white space spectrum sharing," *IEEE Commun. Mag.*, vol. 51, no. 10, pp. 92–100, 2013.

[20] M. Bennis, M. Debbah, S. Lasaulce, and A. Anpalagan, "A hierarchical game approach to inter-operator spectrum sharing," *GLOBECOM - IEEE Glob. Telecommun. Conf.*, no. 1, 2009.

[21] B. Wang, Y. Wu, and K. J. R. Liu, "Game theory for cognitive radio networks: An overview," *Comput. Networks*, vol. 54, no. 14, pp. 2537–2561, 2010.

[22] V. T. Conference, "Final Programme 2 – 5 June 2013 Dresden, Germany," no. June, 2013.

[23] M. Matinmikko *et al.*, "Overview and comparison of recent spectrum sharing approaches in regulation and research: From opportunistic unlicensed access towards licensed shared access," *2014 IEEE Int. Symp. Dyn. Spectr. Access Networks, DYSPAN 2014*, pp. 92–102, 2014.

[24] Y. Saleem and K. A. Yau, "Joint Channel Selection and Cluster-based Routing Scheme based on Reinforcement Learning for Cognitive Radio Networks," no. I4ct, pp. 21–25, 2015.

[25] Y. Chen and H. S. Oh, "A survey of measurement-based spectrum occupancy modeling for cognitive radios," *IEEE Commun. Surv. Tutorials*, vol. 18, no. 1, pp. 848–859, 2016.

[26] M. Matinmikko, H. Okkonen, M. Palola, S. Yrj??l??, P. Ahokangas, and M. Mustonen, "Spectrum sharing using licensed shared access: The concept and its workflow for LTE-Advanced networks," *IEEE Wirel. Commun.*, vol. 21, no. 2, pp. 72–79, 2014.

[27] F. Beltrán, "Accelerating the introduction of spectrum sharing using market-based mechanisms," *Proc. 2016 ITU Kaleidosc. Acad. Conf. ICTs a Sustain. World, ITU WT 2016*, no. September, pp. 66–72, 2017.

[28] E. Karipidis *et al.*, "Transmit beamforming for inter-operator spectrum sharing," *2011 Futur. Netw. Mob. Summit*, pp. 1–8, 2011.

[29] F. R. K. J. Ondral and U. N. K. Arlsruhe, "Spectrum Pooling : An Innovative Strategy for the Enhancement of," no. March, pp. 8–14, 2004.

[30] I. F. Akyildiz, W. Lee, M. C. Vuran, and S. Mohanty, "AND N ETWORKS A Survey on Spectrum Management in Cognitive Radio Networks," no. April, pp. 40–48, 2008.

[31] R. Litjens, H. Zhang, and K. Börner, "System-level Assessment of Non-Orthogonal Spectrum Sharing via Transmit Beamforming," 2013.

[32] D. E. Charilas and A. D. Panagopoulos, "A survey on game theory applications in wireless networks," *Comput. Networks*, vol. 54, no. 18, pp. 3421–3430, 2010.

[33] S. Lasaulce *et al.*, "Inter-Operator Spectrum Sharing from a Game Theoretical Perspective To cite this version : HAL Id : hal-00446284 Inter-Operator Spectrum Sharing from a Game Theoretical Perspective," 2010.

[34] F. Guidolin, L. Badia, and M. Zorzi, "A Study on the Coexistence of Fixed Satellite Service and Cellular Networks in a mmWave Scenario," pp. 2444–2449, 2015.

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