

6G Access Network Performance Based on Dynamic Spectrum Sharing

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Abstract— The allocation of frequencies to new generations of mobile networks is becoming an issue for the responsible organizations, as frequencies are scarce resources in telecommunications. The irregular use of frequencies by mobile telecom terminals creates free channel time slots, known as "holes," during periods of terminal inactivity on these frequencies. Frequency resources are limited and costly, so they require effective management.

Radio resource management is a key control strategy for wireless communication systems. This mechanism involves strategies and algorithms for controlling parameters such as frequency planning, link budgeting, modulation techniques, access methods, and frequency reuse.

In this paper, the performance limitations of 6G secondary users accessing the network using dynamic spectrum sharing solutions are investigated. Three different approaches are considered. The simulation results highlight the trade-off in reducing the frequency band allocation while increasing the number of 6G access nodes.

Keywords— Access network, dynamic spectrum, primary user, secondary user, cognitive radio.

I. INTRODUCTION

The radio frequency spectrum is a national resource managed by the government of each country, delegated to a regulatory body that is responsible for assigning frequency bands and for allocating them to mobile network operators and broadcasting services [1]. The use of a frequency band by a communication operator requires a license, issued by the national regulatory body, following a series of regulatory steps.

Mobile wireless networks have experienced unprecedented growth in recent years. Radio networks have become ubiquitous, with prominent standards such as 4G, 5G and 6G accompanying the deployment of successive generations of mobile telecommunication networks [2-10]. Each generation of mobile networks utilizes specific frequency bands tailored to the services they provide.

Numerous research studies have shown that these generations of mobile digital communication networks do not fully utilize the frequency band allocated to them, because frequencies are not in continuous use; this current static allocation of frequency resources leads to inefficiencies and scarcity. The sixth generation is facing high frequency demand, with allocation challenges exacerbated by limited availability. The advent of the fifth-generation mobile network is expected to improve throughput, latency, and connectivity for numerous

users, as well as the Internet of Things (IoT) and other applications [3]. This will require dynamic frequency access in this type of network, which in turn calls for dynamic and optimal management of the frequency spectrum. This need has driven the search for innovative frequency spectrum management techniques. The solution for this optimal utilization of the frequency spectrum would be the application of cognitive radio (CR) technology, enabling more efficient utilization of the frequency spectrum [4].

The rest of this article is structured as follows. Section II delves into cognitive radio, covering its architecture and functions. In Section III, we describe our spectrum sharing scenarios. Simulation outcomes and the rationale behind our selected architectures are depicted in Section IV. Finally, Section V summarizes our findings and directions for future research.

II. COGNITIVE RADIO

The recent and rapid evolution of mobile networks up to 6G is placing heavy demands on spectrum resources. Overcoming this problem requires more efficient management of the spectrum. That is the guiding context of the studies conducted in the field of cognitive radio [11].

Cognitive radio (CR) is a system that enables a terminal to interact with its environment [12]. This means that it can perceive its environment, model it and adapt to it. It can detect free frequencies and use them, thus contributing to greater spectral efficiency. It is also a form of wireless communication in which a transceiver can intelligently detect which communication channels are in use and move to unused channels [13]. This technology optimizes the use of available radio frequencies in the spectrum while minimizing interference with other users.

CR allows the use of temporarily unused space in the spectrum, referred to as a spectrum hole or white space. If a band is used by an authorized user, CR offers the ability to switch to another white space, changing its transmission power or modulation level to avoid interference. From this point of view, two types of users are omnipresent in cognitive radio communication [14]:

- Primary users (PUs, or so-called licensed users)
- Secondary users (SUs, or unlicensed users who access the spectrum opportunistically)

Indeed, at a given time and in a specific geographic location, a primary user may not be using their frequency band, so other users (secondary users) can exploit these frequencies, thanks to

spectrum holes, without disrupting primary users' communications.

A. Cognitive radio architecture

Mitola has defined CR as a software-defined radio system characterized by a consistent set of rules and design, whereby specific components achieve a range of functions and services [15]. The simplest CR architecture is the minimalist set of functional components shown in Figure 1 [16].

- The user's sensory perception interface includes visual and acoustic sensing and perception functions, which collect data on the environment.
- Local environment sensors (position, temperature, acceleration, etc.). enable the radio to understand the environment around it and adapt its parameters accordingly, which is essential for selecting the optimum frequencies.
- System applications consist of independent media services such as a network game, which can benefit from dynamic spectrum adaptation.
- Software-defined radio (SDR) functions handle radio frequency (RF) detection and SDR radio applications, allowing transmission parameters to be adapted to the spectrum available.
- Cognitive functions cover control, planning and learning, which are at the core of spectrum management and decision making in CR.
- Local effector functions include speech synthesis, text, graphics, multimedia displays, user interfaces and outputs for the radio.

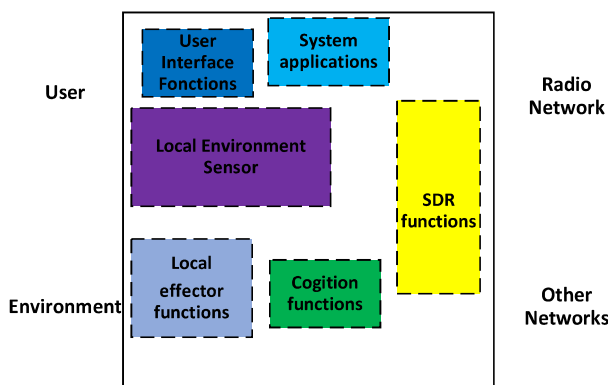


Figure 1. Minimal Cognitive radio Node architecture [16]

B. Cognitive radio functions

The main functions of CR are as follows [4], [17]:

1) **Spectrum detection:** Detecting available spectrum areas for use, by identifying "holes" in the spectrum that can be accessed without interfering with primary users.

2) **Spectrum management:** Several processes are applied to capture the best available frequencies to meet users' communication needs. These include assessing frequency availability and prioritizing spectrum space for secondary users in line with changing demand.

3) **Spectrum analysis:** Spectrum sensing results are analysed to estimate spectrum quality, ensuring that the CR system selects high-quality channels for optimum communication.

4) **Spectrum decision:** This decision is based on a model and user behaviour, as follows:

- Decision model required for spectrum access, capable of analysing the spectrum to consider multiple needs of secondary users.
- Competition and cooperation in a multi-user environment, as each user maximizes their own objectives. In a cooperative environment (see Figure 3), users collaborate to achieve a common goal, with possible coordination by a central controller.

C. Distributed Implementation of Spectrum Access Control

In a distributed multi-user environment, for non-cooperative spectrum access, each user can reach an optimal decision independently by observing the behaviours (history of actions) of other system users. Consequently, a distributed algorithm is needed for a secondary user to make the spectrum access decision autonomously [18].

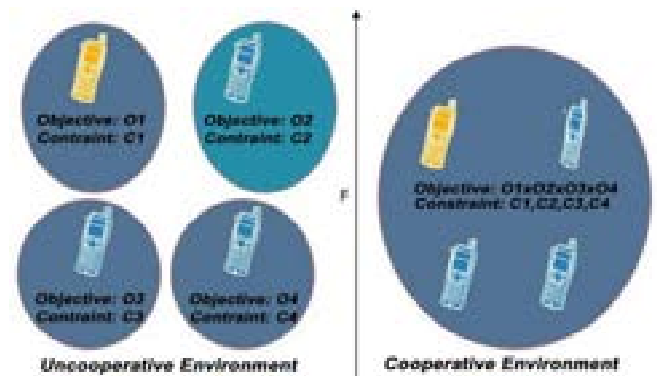


Figure 2. Access to the cooperative and non-cooperative spectrum

D. Spectrum Mobility

Spectrum mobility refers to the process of allowing the CR user to change their operating frequency. CR networks attempt to use spectrum space dynamically, allowing radio terminals to operate in the best available frequency band, while keeping communication requirements transparent during the transition to a better frequency [19]. This step requires:

1) **Finding the best frequency bands:** The CR system needs to keep track of the available frequency bands, so that it can switch immediately to other frequency bands as needed. When a secondary user transmits, the status of the frequency band must be respected.

2) **Auto-coexistence and synchronization:** When a secondary user performs a spectrum transfer, two issues must be considered. The target channel must not be currently used by another secondary user (the self-coexistence requirement), and the corresponding secondary link receiver must be informed of the spectrum non-interference (the synchronization requirement).

E. Adaptive Learning in Cognitive Radios

CR systems must have the ability to learn and adapt their wireless transmissions according to the ambient radio environment. Intelligent algorithms such as those based on machine learning, genetic algorithms and fuzzy logic are therefore essential for the implementation of CR technology. In general, these algorithms are used to observe the status of the wireless environment and to construct knowledge about the environment [20].

III. SPECTRUM SHARING SCENARIOS

Each generation of mobile networks uses a frequency band. We are now moving towards a new generation of mobile 6G networks, some of the applications of which need a large amount of bandwidth to transmit large amounts of data at high speed.

Other applications require only a small bandwidth from long-range frequencies. But the shortage of frequencies in the band reserved for mobile network deployment means that frequencies are not available for new needs.

Studies carried out by the Federal Communications Commission (FCC) have shown that frequencies are not used continuously in mobile networks. Rather, there are dead times in the use of frequencies, referred to as “frequency gaps” or “free channels”. Also, between two neighbouring cells, one is overloaded while the other is underloaded. To overcome these problems, we need to consider dynamic and optimal frequency management. This could be done by CR in a well-defined network architecture.

We consider three scenarios, each different from the other in terms of the number of primary and secondary stations.

Each scenario consists of a given number of PUs and SUs. A secondary station detects the availability of free channels or gaps in the frequency of a neighbouring primary station, in order to pass on its user's communications.

A primary base station serves the PU. In the following discussion, a node or base station will be referred to as a BS. On radio frequency links, the frequency is divided into 8 channels (time slots). The SU maintains permanent contact with the secondary base station via a beacon frequency on an unlicensed frequency band.

A. 2PU1SU scenario

An architecture (Figure 3) with two neighbouring primary stations, each operating on a licensed frequency, and a secondary station adjacent to both primary stations is considered in this scenario. In this setup, the secondary base station (SB) opportunistically uses the available frequency gaps (holes) from each of the primary SBs to transmit its SU's communications. This configuration gains one frequency of the three that would otherwise be required in architecture comprising three SBs.

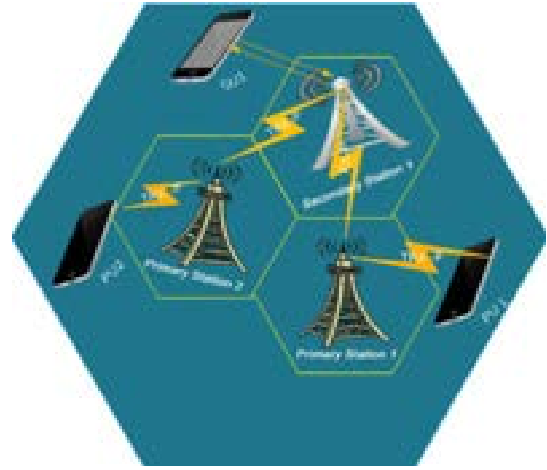


Figure 3. Architecture using two primary BSs and one secondary SB

The secondary user network access failure rate function, AR_I , was developed as follows:

$$AR_I = \frac{1}{(1+x)^2} \quad (1)$$

where AR_I depends on the number x of available frequency holes.

B. 1PU2SU scenario

In the second scenario, architecture (Figure 4) with a primary BS operating on a licensed frequency and two SBs adjacent to the primary BS are considered. The two SBs use the frequency gaps (holes available) on the primary BS's frequency to transmit their SU's communications. This saves two of the three frequencies that would be necessary if the architecture consisted solely of three primary BSs.

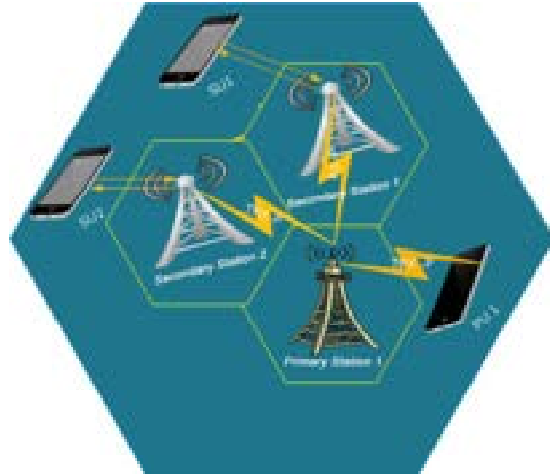


Figure 4. Architecture using a primary BS and two secondary SBs

According to this scenario, the secondary user network access failure rate function is given by

$$AR_2(x) = \begin{cases} 1, & x \leq 1 \\ \frac{2}{(1+x)} & x > 1 \end{cases} \quad (2)$$

where AR_2 is the access rate failure and x corresponds to the number of available holes while there is availability on the licensed frequency channel.

C. 2PU2SU scenario

The third scenario (Figure 5) involves an architecture comprising two adjacent primary BSs, each operating on a licensed frequency, and two SBs adjacent to the two primary stations.

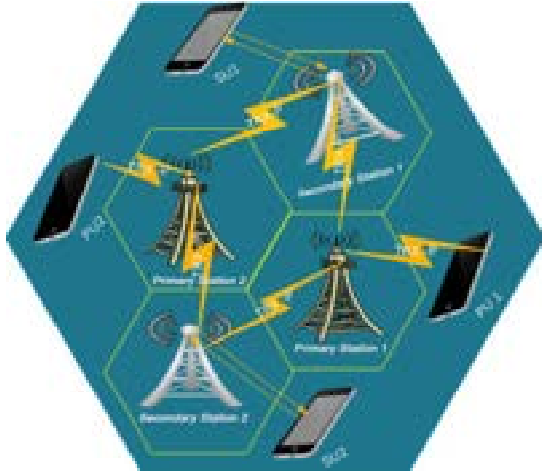


Figure 5. Architecture using two primary BSs and two secondary SBs

The two SBs use the frequency gaps (holes) available on each of the two primary BSs' frequencies to transmit their SU's communications. This architecture saves two frequencies of the four that would be used if the architecture consisted solely of four primary SBs. In accordance with this scenario, the secondary user network access failure rate function could be expressed as:

$$AR_3(x) = \begin{cases} 1, & x = 0 \\ \frac{3}{(1+x)^2} & x > 0 \end{cases} \quad (3)$$

where AR_3 is the access rate failure and x is the number of available holes while there is availability on the licensed frequency channels.

IV. SECONDARY USERS ACCESS NETWORK PERFORMANCE

A. First scenario (2PU1SU)

When both frequencies of the two primary stations are fully occupied, the access failure rate (Figure 6) of the secondary BS is 1 (100%), meaning that no SU communication can be transmitted. The rate then drops from 1 to 0.25 when there is at least one hole available in one of the frequencies of each primary BS, giving the SB at least one hole to transmit its SU's communication on the network. This rate drops to 0.11 when at

least two holes are available on the frequencies of at least one of the primary BSs. The secondary station has at least two channels and transmits the SU's communications. The decrease in the failure rate (Figure 6) depends on the availability of holes offered by the two primary BSs.

B. Second scenario (1PU2SU)

The failure rate in Figure 7 reaches a maximum value equal to 1 and remains constant even when there is one hole available, because the single hole is not sufficient for the communication by both SUs. So the two SBs will transmit their SU's communication one at a time on the only available hole. The access failure rate decreases from 1 to 0.66 when at least two holes are available on the primary BS's frequency, enabling the two SBs to transmit their SUs' communications. As more holes become available on the primary BS's frequency, the failure rate continues to decrease, reaching 0.49 with the availability of three gaps (holes).

C. Third scenario (2PU2SU)

When both primary BSs are simultaneously occupied, the failure rate is 1. This means that all channels are occupied. The two secondary BSs will therefore be unable to transmit their SU's communications. In Figure 8, the rate drops from 1 to 0.75 when at least one hole is available in each of the primary BSs' frequencies. Both SUs have at least one channel by which to communicate. This rate drops to 0.33 when at least two holes are available in either of the two primary BSs' frequencies. In this way, the two SBs each have at least two holes for transmitting their SU's communications. The rate decreases from 0.33 to 0.18 when at least three holes are available. The rate decreases according to the availability of holes in each frequency of the two primary BSs up to the zero-value following the increase in the number of available holes.

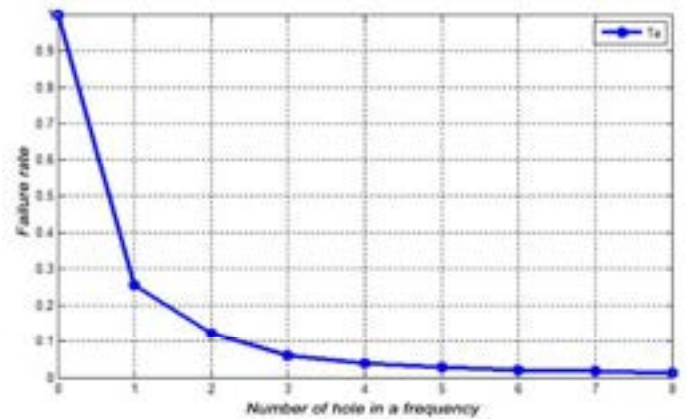


Figure 6. Hole availability failure rate on two frequencies of two primary BSs for one SB following the increase in hole availability in the primary station until it is zero for an availability of 8 holes.

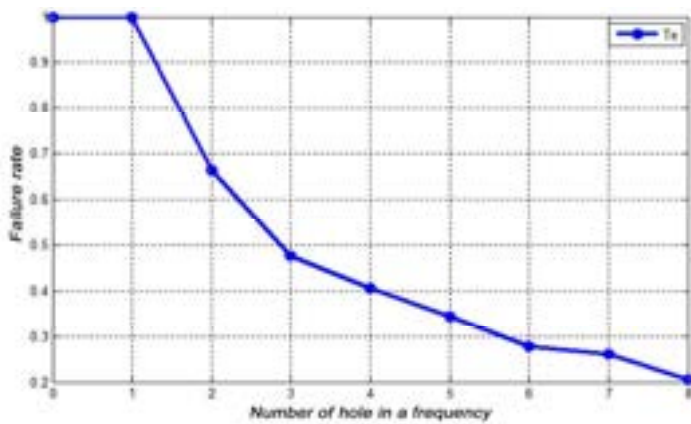


Figure 7. Access failure rate with a primary BS and two secondary SBs

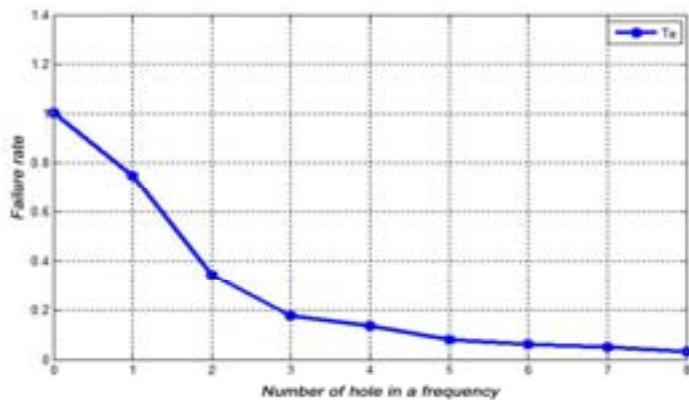


Figure 8. Hole availability failure rate in two primary BS frequencies for two secondary SBs frequencies

V. CONCLUSIONS AND FUTURE WORK

The radio spectrum is an essential resource for telecommunications, particularly mobile networks. This resource, employed by mobile network operators, normally utilized only on a temporary basis. Some frequency channels are thus intermittently unoccupied due to the inactivity of mobile terminals on specific channels. The static frequency allocation method used by operators leads to spectrum scarcity and congestion. Several research projects have focused on improving spectrum utilization. The solution identified here is cognitive radio, an emerging technology that aims to address spectrum congestion and the intermittent usage patterns of primary users. CR enables dynamic and opportunistic access to the spectrum, which will be especially beneficial for 6G, as it requires a broader frequency band than current networks. Given the services that 6G is anticipated to provide, it is the network the world has awaited since around 2020, promising to transform users' interactions with their devices and impact their daily lives.

The proposed dynamic frequency sharing investigation has shown the possibility, during network engineering, to consider secondary users' base stations or nodes at the cost of a given access failure rate. This solution will guide operators in

selecting appropriate architectures for implementing CR technology without requiring changes to existing network infrastructures, thus reducing costs associated with spectrum acquisition. CR will be integrated both into the equipment that operates on the 6G network, allowing access to any available frequency band, and into the next-generation Node Bs (gNBs) of 6G base stations.

Future research could explore the integration of software-defined networks (SDN), network function virtualization (NFV) and management and orchestration (MANO) with open-source platforms like srsRAN and Open5GS to optimize dynamic spectrum sharing and enhance adaptability in 6G networks.

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