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Analytical review of schemes models for wireless multiservice networks under shared access frameworks

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The modern development of infocommunication technologies is closely connected with the problem of rapid growth of the transmitted data volume in the conditions of limited radio frequency range of mobile networks. The shortage of radio resources leads to a decrease in the bit rate in mobile communication networks, and, consequently, degrades the level of quality of user service, the requirements for which are defined in the telecommunication standards.

One possible solution of this problem is the use of the licensed frequency sharing system (Licensed Shared Access, LSA) proposed by the European Telecommunication Standardization Institute (ETSI). This system is an example of effective use of the frequency spectrum, taken by the mobile operator for rent from the owner, who uses this spectrum periodically. The owner has absolute priority in using this spectrum of frequencies. Setting priority is possible with the help of various scenarios, differently influencing to the level of quality of user service. In these conditions fundamental researches in the field of development of the most effective scenarios of realization of a priority of the owner – mathematical modelling for shared use schemes of radio frequencies are actual.

The second technology that solves the problem of radio resources lack is LAA - Licensed Assisted Access. LAA is a technology that allows to increase the connection bit rate and the bandwidth of the communication channel. LAA uses small cells for its work. By installing small base stations with an integrated LAA system, operators can increase the transmission rate in congested areas, for example, indoors.

Researching of such systems is aimed at the development and analysis performance measures of Markov models describing wireless multiservice networks. Researches of such models and current technologies used in wireless multiservice networks are carried out by the using mathematical apparatus of the queueing theory, the teletraffic theory, and also the methods of stochastic geometry. This will make it possible to calculate and evaluate the quality of service (QoS) for users in wireless networks of future generations, as well as to plan various options for the development of networks to keep previous users and attract new ones. The paper presents an analytical review of the existing models using the considered systems and the conducted research.

Key words and phrases: LSA, LAA, multiservice network, radio resource management, shared frequency, frequency sharing technologies, streaming traffic, queuing system, performance measures.

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1. Introduction

In the modern world, portable mobile devices have become an integral part of almost every person. Most everyone has a smartphone, tablet, laptop or other device that has an Internet connection and uses broadband mobile services, generating more and more traffic [1, 2]. Advanced mobile devices and connections are not only getting smarter in their computing opportunities but are also developing due to higher-generation network connectivity (3G, 3.5G, and 4G or LTE). Such combining device opportunities with faster, higher bandwidth and more intelligent networks leads to wide adoption of progressive multimedia applications that contribute to increased mobile and Wi-Fi traffic. The increase in the number of users of mobile services leads to problems related to the shortage of radio resources necessary to support the required level of quality of service (QoS) and quality of experience (QoE).

Since it is expected that the amount of global traffic generated by mobile and wireless devices will soon exceed the traffic generated by wired equipment, more efficient use of the existing frequency spectrum is not enough to improve the situation globally. The solution of this problem is impossible without additional frequency resources that will be required for a number of different technologies suffering from a lack of frequency spectrum from conventional mobile to device-to-device and multi-hop connections. Consequently, there is an urgent need for searching and using additional resources.

To solve this problem, the largest companies such as IEEE, 3GPP and Cisco Mobile are developing systems that can attract additional resources, or that can improve the efficiency of using existing radio resources. The solutions offered by the companies include, for example, the use of extremely high frequencies, the so-called millimeter waves (mmWaves) [3], the temporary use of the band of licensed frequencies (Licensed Shared Access system, LSA) [4], and the use system of Licensed Assisted Access (LAA) [5].

LSA technology is currently the most researched, so in this article we will consider a description of the LSA system concept and a literary review of previous research about this topic. A brief overview of LAA technology will also be offered.

2. Frequency resource sharing technologies

The mobile sector is developing the new generation of mobile wireless communications networks based on cellular technologies. In a limited frequency range, the purpose of these developments is to find solutions for more efficient, economical and rational radio resource management. Even if the traffic growth forecasting are adjusted for the benefits provided by the new technologies, the availability of licensed radio resources spectrum may not be sufficient to satisfy the increased demand for mobile bandwidth until the decade's end.

Simplifying the use of the spectrum of unlicensed frequencies is an attempt to satisfy the demands of the communications services market in the context of traffic growth. An example of using an unlicensed frequency band are ubiquitous Wi-Fi networks. The unlicensed spectrum can be an supplement to the licensed spectrum for cellular operators to help eliminate the explosion of traffic in some scenarios, such as hotspot areas (physical location where people may obtain Internet access, typically using Wi-Fi technology). Technology Licensed Assisted Access offers an alternative to the operator to use unlicensed spectrum using one radio network, thereby LAA offers new opportunities for optimizing network efficiency.

An unlicensed spectrum can never replace the need for a more licensed spectrum because of its inability to be used in macroelements that provide wide-area coverage and its overall inability to provide highly reliable quality of service due to unmonitored interference. The unlicensed spectrum has an unpredictable and rapidly changing electromagnetic environment due to the free access of many users to it, which cannot guarantee the high quality of transmissions. In addition, for this reason, special measures are needed to reduce conflict situations. Thus, the unlicensed spectrum is better used as a "licensed access" integrated into LTE, where it is considered as the carrier of the secondary component in the carrier aggregation scenario.

For the first time, LAA technology is introduced in 3GPP TR.36.889 Release 13 as part of LTE Advanced (LTE-A) technology [6]. The LAA technology provides for the aggregation of the frequency spectrum of Wi-Fi in the 5 GHz band by connecting it to the licensed LTE spectrum. The efficiency of the Wi-Fi spectrum in busy conditions is low, and LTE technology is able to more effectively manage resources and control errors. The main task of LAA is to ensure efficient, uninterrupted and fair coexistence with Wi-Fi technology. The advantage of this system is its use in any place, since the frequency in 5 GHz is available in almost any zone. The listen-before-talk (LBT) operating procedure, proposed 3GPP in Release 13 for LAA, is defined as a mechanism by which an equipment makes a clear channel assessment (CCA) test before using the channel.The CCA identifies the presence or absence of other signals on a channel in order to determine if a channel is occupied or clear, respectively. LBT usage is one way for fair sharing of the unlicensed spectrum and therefore it is considered to be a key element for fair operation in the unlicensed spectrum in a single global solution framework.

However, it is clear that the unlicensed spectrum can never match the quality of the licensed spectrum. Therefore, the most popular ways to solve the shortage of the frequency range are methods that allow the maximum use of licensed frequencies. A preliminary analysis of related papers on the subject of more efficient using of the resource spectrum showed that one of the most studied solutions to this problem in 4th generation networks (4G) and subsequent generations is the use of the LSA-system. Licensed Shared Access, as a new additional regulatory framework, is another measure that can improve the effectiveness use of spectrum and thus help to ease spectrum deficit in areas where LSA may be relevant. The LSA framework enables agreed shared access to spectrum that would otherwise be unavailable for using by mobile connection.

The LSA framework provides controlled access to the radio spectrum used by several participants (see Fig. 1): the current owner of the resources and a limited number of licensees (for example, cellular operators). The owner of the LSA band (shared band) has absolute priority when deciding whether to provide access to the radio resources of this LSA band to licensees. Licensees can access the spectrum only if the owner's QoS level is not disturbed. The rules governing the use of the LSA band are based on dedicated agreement, taking into account the necessary requirements for the QoS level. The implementation of these rules is possible using various scenarios that affect the users QoS level served in the shared band.

Since in the LSA system the owner and the LSA licensee use the same frequency spectrum, it is necessary to take measures to control the resulting interference between the participants, because the absence of such phenomenon as interference has a positive effect on the levels of QoS and QoE. Studies have shown that limiting interference on the shared band created by licensee users is typically accomplished through two basic scenarios – limiting the base station (BS) signal power transmitting data to devices or interrupting service (Fig. 2). Within limit power scenario, LSA band is available, but it is used with reduced power. All the BSs of licensee are forced to reduce the corresponding uplink power whenever instructed. In the interruption or shutdown scenario, LSA band is fully unavailable to the licensee. All the BSs which are have a chance to cause interference on LSA bands are "powered off". The shutdown scenario is to limit the power of users to zero, i.e. there is a full confiscation of the LSA band for licensee.

Within each of these scenarios, various policies for the allocation of time or power resource can be applied to improve the system efficiency using shared access (Fig. 3). There are two types policies: simple policies that allow to distribute the frequency spectrum to one type of resource and flexible policies (combinations of simple policies) that allow to distribute several types of resource. The application of these policies makes it possible to take into account the spatial position of network users, which becomes a decisive factor in determining the system performance.

In addition, the achievable bit rate is the important indicator of the connection quality and the network as a whole, as already mentioned, so should be paying special attention to the main parameters that affect the data transmission. Therefore notice,

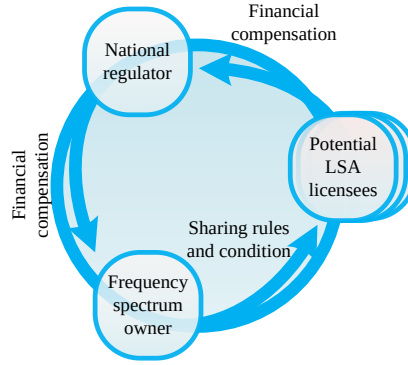

Figure 1. LSA regulatory framework: Key participants

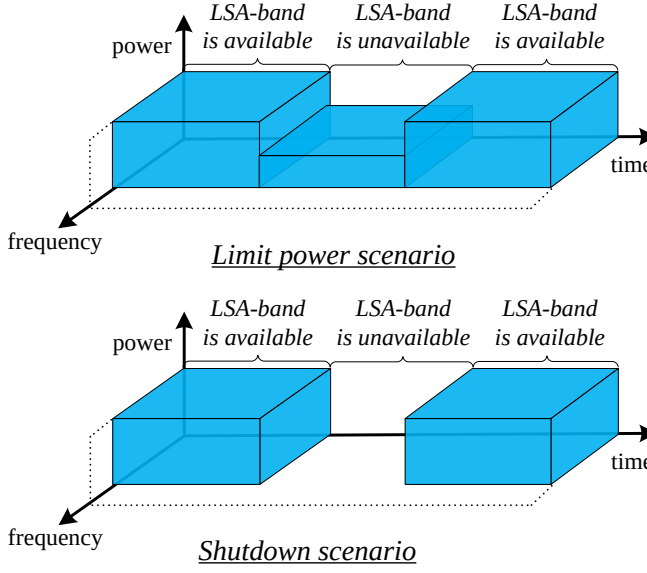

Figure 2. Scenarios of interference limitation

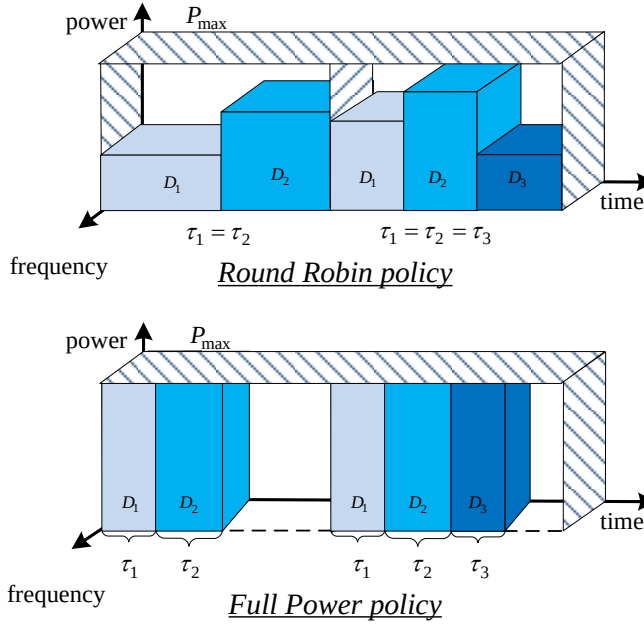

Figure 3. Radio resource allocation policies

that the achievable bit rate depends on the bandwidth ω, transmit power p, time resource allocated for servicing in accordance with its location relative to BS d, noise power N_0, propagation exponent κ and is defined, according to the Shannon formula, as follows (1):

$$r\left(d,p\right)=\omega\ln\left(1+\frac{Gp}{dN_0}\right) \tag{1}$$

Depending on the selected scenario of interference limitation and radio resource allocation policy, these parameters may vary and thus achievable bit rate can take different values (can be seen in the Fig. 2, 3).

For a better understanding of the LSA system functioning and the interaction of its elements, the Fig. 4 shows an example of the technical implementation of the LSA concept. The main components of this system are repository, controller and network OA&M (Operations, Administration and Maintenance):

- LSA-Repository: This database includes the actual information on frequency spectrum use by the owner and information about the availability of the LSA band and the conditions of its use by the licensee.
- LSA-Controller: The LSA-Controller determine LSA spectrum availability based on rules LSA of use and information on the owner's use provided by the LSA-Repository.
- Network OA&M: The OA&M translates into radio resource management commands the availability of frequency spectrum information received from the LSA-Controller.

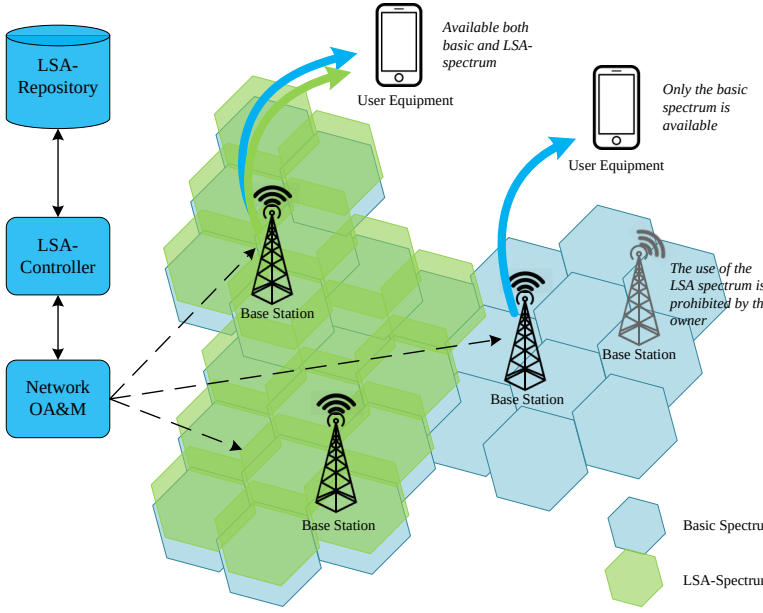

Figure 4. An example of the LSA system architecture

Then these commands are transmitted to BSs in the LSA licensee's network. Based on this information, BSs enable user devices to access the LSA spectrum.

Such an implementation is not the only possible and true, but represents one of the possible options.

3. Analysis of the current state of research LSA and LAA system

Currently, the implementation in wireless multiservice network systems shared use of a licensed frequency spectrum LSA is still under development, therefore this subject attracted the attention of many researchers. The literature review showed that the number of articles devoted to simulation modeling of the LSA system is quite large, while the analytical side of the issue is insufficiently studied.

For example, the paper [7] deals with various scenarios of network resource management that will allow meeting the requirements of the services and applications being developed. Special attention is paid to the issue of resource allocation for service devices machine-to-machine interaction (M2M), which is expected to be one of the key drivers for using shared network resources. The main idea of the work is that, unlike the currently used frequency spectrum, most of the new spectra (about 80%) will become shared spectra, and therefore either the models of sharing the licensed frequency spectrum LSA or the models of opportunistic spectrum access (OSA) will be applicable to them. This

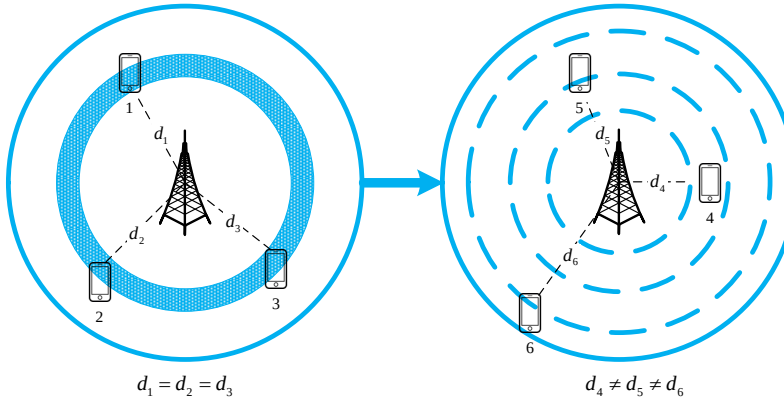

Figure 5. Accounting for the spatial position of users

once again underlines the study relevance of the proposed ETSI system LSA. However, this paper are proposed only theoretical considerations about different scenarios of network resource management, but actual analytical models are not provided.

The authors [8] give a detailed description of the LSA system with two separate BS: primary and secondary. Users of the secondary BS can be served only when the data transfer of the secondary BS does not degrade the quality of service of users of the primary BS below a certain level, otherwise the secondary BS goes into standby mode. To achieve this, both BS must be fully synchronized. This model provides shared planning for only two base stations. The authors [9, 10] propose a mechanism for the distribution of the LSA frequency spectrum among several LSA licensees using a joint auction with a mixed graph mechanism. This scheme provides unhindered access to the licensed sharing spectrum for various commercial operators that are not connected to each other, and the BS are coordinated by the management organization.

The paper [11] presents a solution that uses cognitive radio technology to solve the problem of frequency spectrum lacks providing dynamic access to the spectrum. The model was evaluated both analytically and by means of simulation. Also in the literature, three scenarios of limiting interference in the shared band are described in some detail: ignoring the owner's requests, interrupting user service [12], limiting the signal power of the BS [13]. The analysis of two simple radio resource allocation policies, such as policy of equal allocation of a temporary resource (Round Robin policy) and policy of maximum employment of a bandwidth (Full Power policy) [14, 15], allows to take into account the position of users on the plane (see Fig. 5). A combined approach using Queuing theory and stochastic geometry was used to investigate models with simple radio resource allocation policies, but the structure of the LSA system was not taken into account.

In the study of technical documentation, as well as scientific articles on LAA technology, it was found that most sources have only a descriptive part and propose simulation models for this technology, but no mathematical models were considered. In article [16], a new theoretical structure was proposed to quantify the performance of LAA with QoS restrictions, and various probabilistic characteristics were derived.

4. Conclusions

Currently, rapid increasing of transmitted data volume in the cellular networks is an important moment in the development of wireless communication technology. In recent years, the deficit of available radio frequency spectrum has become a major obstruction in developing today's wireless communications technology. For provision services with a high QoS and QoE to users is necessary the large volume of frequency resources. Accordingly, deficit of system resources leads to degraded of bit rate in mobile networks, and consequently reduction of QoS and QoE levels. Due to this, various methods of using the frequency range, both licensed and unlicensed, are being actively studied.

Licensed Shared Access, as a new additional regulatory framework, is another measure that can improve the effectiveness use of spectrum and thus help to ease spectrum deficit in areas where LSA may be relevant. According to the literature analysis at the moment there are no standardized solutions to choose the most effective scenarios for sharing LSA band resources, flexible radio resource allocation policies, as well as the impact of the spatial distribution of users on the system performance have not been studied at all.The usage of unlicensed range resources has been studied much less. As the literature review showed, research in this area is aimed at the implementation of LAA technology. However, now there are no mathematical models that would allow to implement this technology.As a task for further research, it is planned to compare performance measures of mobile network models considering within LSA and LAA technologies depending on various scenarios of limitation interference and different allocation policies of radio resource.

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