Aeronautical Communication Systems as Potential Primary Users in Secondary Spectrum Access

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***Abstract*—Secondary spectrum access emerges as a means to increase spectrum utilization significantly in a near future. However, the technical availability and the economic value of the secondary access have not been fully investigated. Particularly, the impact of the secondary access on the real-life primary systems remains mostly unaddressed. Among the primary systems of interest are aeronautical communication systems operating in the radio frequencies under 6 GHz. In this paper, we present an overview of various aeronautical communication systems as the potential primary users. We describe the purposes, characteristics, and operational facts of not only existing but also future aeronautical systems. We also discuss the opportunities and challenges of secondary access to aeronautical spectrum and suggest a secondary use case suitable for the aeronautical spectrum.**

***Index Terms*—Secondary spectrum access, aeronautical communication systems, distance measuring equipment (DME), L-band digital aeronautical communication system (L-DACS), microwave landing system (MLS), airport surface communications**

I. INTRODUCTION

Spectrum scarcity has become one of the major issues in wireless and mobile networks with the dramatic increase in the demand for mobile broadband services. It is an irony that most of the spectrum resource is under-utilized according to the results of measurement campaigns [1], [2]. It suggests that the spectrum scarcity comes from the inefficient utilization of the spectrum. It is widely accepted that the discrepancy between the apparent spectrum shortage and the actual usage is mainly due to the current regime of static spectrum regulation and licensing that prohibits the flexible use of spectrum. This brought a new paradigm of dynamic spectrum access (DSA), which includes various implementation approaches. Taxonomy of DSA can be found in [3].

Secondary spectrum access (or opportunistic spectrum access) is considered to be the most feasible approach of realizing the DSA because it is the most compatible with the current spectrum allocation and existing radio systems. The secondary access is envisioned by the concept of cognitive radio [4], [5][1]. The basic idea of the secondary spectrum access is allowing secondary users to share the spectrum allocated to primary (legacy) users provided that the secondary users do not cause harmful interference to the primary users.

There have been extensive studies on the secondary spectrum access. Achievable rate region for secondary users was analyzed in [6], [7]. In [8], the impact of spectrum sharing techniques was evaluated. Temporal aspect of the secondary access was studied in [9]–[11]. Compared to the abundance of theoretical work, little research has been done to assess the practical availability and real-life benefit of the secondary access as pointed out in European FP7 project QUASAR [12]. Moreover, most of the practical assessment efforts have been focused on TV white spaces in 470-790 MHz. For example, quantification of the usable TV spectrum in the UK and the USA was addressed in [13] and [14], respectively. Similar results are presented for five European countries in [15]. In [16], opportunity of indoor usage was studied considering adjacent channel interference to TV receivers. International frequency allocation chart indicates that substantial amount of useful spectrum is allocated to various systems such as radars, satellites, maritime navigation, and aeronautical communications [17]. Thus, it is needed to investigate the secondary access to these spectrum bands in order to fully understand the technical requirements and economic value of secondary spectrum access.

In this paper, we present an overview of aeronautical communication systems as potential primary systems. The objective of this paper is to describe the purposes, characteristics, and operational facts of the aeronautical systems in order to assist future studies on the secondary access in aeronautical spectrum. We neither advocate nor oppose the idea of secondary access to aeronautical spectrum because its technical feasibility and economic worth has not been investigated enough. It is important to perform extensive and unbiased studies in order to make proper regulatory decisions. We believe that the overview of candidate primary systems is the first step of the investigation.

We consider not only existing systems but also planned future systems in the overview. Particular attention will be paid to the two frequency bands: 960-1215 MHz and 5030-5150 MHz. In 960-1215 MHz, we review two systems: distance measuring equipment (DME) which has been in use for more than 50 years and L-band digital aeronautical communication system (L-DACS) which is planned to be in place around

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[1] The term cognitive radio is often abused as the synonym of secondary spectrum access. Cognitive radio denotes a capability of a radio node that it recognizes changes in environment and adapts itself to them, whereas secondary spectrum access is a spectrum management regime that can be implemented by technologies such as cognitive radio.

the year 2020. We also introduce two systems in 5030-5150 MHz band: microwave landing system (MLS) which was developed in the year 1978 and future airport surface communication systems that are currently under discussion. Moreover, we discuss the opportunities and challenges of secondary access to aeronautical spectrum, and then suggest a secondary use scenario that is thought to be suitable for the use of aeronautical spectrum.

The rest of the paper is organized as follows: In Section II, a general description of the secondary access to aeronautical spectrum is depicted. Selected aeronautical systems in 960-1215 MHz and 5030-5150 MHz are presented in III and IV, respectively. Concluding remarks are provided in Section V.

II. GENERAL DESCRIPTION OF SECONDARY ACCESS TO AERONAUTICAL SPECTRUM

A. Spectrum allocation to aeronautical systems

Large portion of useful spectrum is allocated primarily to aeronautical usage. Examples of spectrum bands, primary purposes, and current and future systems are summarized in Table I. Detailed descriptions of the systems can be found in [18]–[24]. The frequency band 108-137 MHz is considered too low for mobile broadband services. 2700-2900 MHz is mainly occupied by ground-based air traffic control radars. This spectrum is also is shared by meteorological radars on a basis of equal priority. Thus, it can be categorized into radar spectrum rather than aeronautical band. We focus on 960-1215 MHz and 5030-5150 MHz in this overview.

B. Opportunities and challenges in aeronautical spectrum

Aeronautical spectrum has distinct merits as well as strong disadvantages as a potential primary frequency band. A major advantage is the global coordination that it has achieved. If a secondary service in aeronautical spectrum is feasible in an area, it will also be feasible in the rest of the world because the frequency usage and system characteristics of aeronautical equipments are well coordinated worldwide. This gives an opportunity of achieving economy of scale for the secondary system manufacturers and service providers. On the other hand, aeronautical systems have stringent protection requirements because they perform safety-of-life operations. This makes the control of interference from the secondary system difficult task. Discussions from regulatory perspective will be even more difficult. Reliable and sufficient protection of primary users is a key challenge to realize the secondary access to aeronautical spectrum. Thorough technical investigations should precede regulatory discussions.

C. Secondary system model

It should be emphasized that the availability of secondary spectrum access hugely depends on the features of the secondary system such as transmit power, link distance, and interference control scheme. Thus, it is important to consider the most suitable secondary system in the investigation of secondary access. We identify three elements that are needed for a potential secondary system in aeronautical spectrum: low power, indoor, and central interference control. Low transmit power is desirable due to the high interference susceptibility of primary systems to interference. Indoor usage is encouraged by several reasons. First, low power transmission is usually useful in indoor environments where short range communications prevail. Second, it will give more protection to primary systems by means of wall penetration loss. Finally, it is expected that most of the traffic will be generated indoors in a near future [25]. Indoor secondary use of aeronautical spectrum will help relieve congestion of macro cellular spectrum. The indoor networks should be controlled in a centralized manner in order to ensure the reliable protection to the primary users.

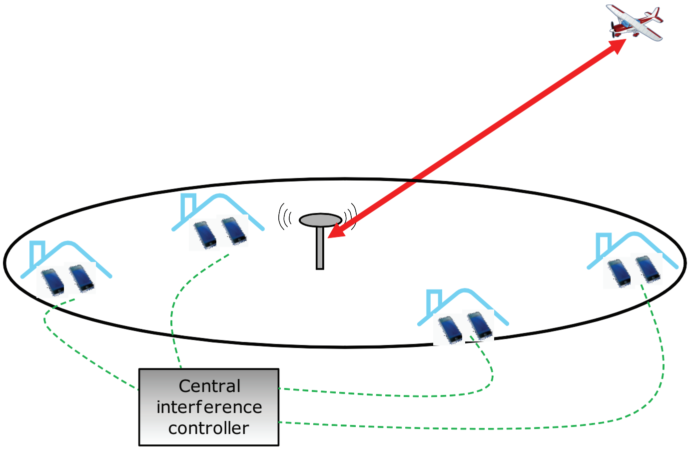

Fig. 1: Orthogonality between primary and secondary systems in spatial domain

From the above reasoning, we propose indoor femtocells connected to a central interference controller as the secondary system of further discussion. This model benefits from an orthogonality between the primary and secondary systems in spatial domain. The concept of spatial orthogonality is illustrated in Fig. 1. Aeronautical systems typically have a link between a ground station near airport and an airplane with large transmission range and high transmit powers. On the contrary, secondary communication is performed over distances around 10 m with the isolation provided by walls. It is expected this contrast between primary and secondary systems usage can be exploited to achieve efficient spectrum sharing.

III. AERONAUTICAL COMMUNICATION SYSTEMS IN 960-1215 MHZ

The frequency band of 960-1215 MHz has been in active use for several decades. Several aeronautical systems coexist in this spectrum as described in [26]. In some countries, the band is also used by military systems. However, we consider civil systems only in this study. Current spectrum allocation to civil aeronautical systems is depicted in Fig. 2. The figure shows this frequency is mostly occupied by the DME system. Upper part of the spectrum (1164-1215 MHz) is planned to be shared by the European radio navigation satellite system (RNSS) Galileo. Due to the ubiquitous locations of RNSS

TABLE I: Aeronautical systems and frequency allocation

Frequency	Purposes	Systems
108 – 137 MHz	mid-range navigation, landing aid	VOR, ILS
960 – 1215 MHz	navigation aid, collision avoidance, data link	DME, SSR, UAT, L-DACS
2700 – 2900 MHz	air traffic control	ATC ground radar
5030 – 5150 MHz	precision landing aid, airport surface communication	MLS, Airport WLAN

receivers and their low receiver sensitivity, this spectrum is considered to be infeasible for the secondary access. Universal access transceiver (UAT) and secondary surveillance radar (SSR) account for less than 25 MHz bandwidth. Secondary spectrum sharing with UAT and SSR is not interesting from the business perspective because the bandwidth is not enough for broadband services. Thus, spectrum of research interest is that allocated soly to the DME system, which is about 180 MHz out of 252 MHz in the frequency band. Although not shown in Fig. 2, this spectrum is also planned to be used by L-DACS which is a future data link system. In this section, we introduce the DME and the L-DACS more in detail.

A. DME

DME is a type of secondary radar for measuring the distance between an airborne equipment (interrogator) and a ground station (transponder). It has been used as the navigation aids of aircrafts for several decades. The airborne equipment sends an interrogation signal to the ground. Then, the transponser responds on a frequency of ±63 MHz from the interrogation frequency after a delay of 50 micro seconds (μs). The airborne interrogator can determine the slant distance between the transponder and itself based on the round trip delay of the signal. The interrogator and the transponder burst short Gaussian pulses with the duration of 3.6 μs. Their transmit powers reach up to 300 W for the interrogator and up to 2 kW for the transponder [19]. The operation of DME is depicted in [18], [19].

The channel bandwidth of DME is 1 MHz. This means that there are 252 channels in total because the frequency band allocated for DME operation is 962-1213 MHz as shown in Fig. 2. Interrogators and transponders are allotted 126 channels each. A 1 MHz channel is allocated to each transponder. A ground transponder can serve up to around 100 airplanes simultaneously. If it receives too many interrogations, the transponder decreases its sensitivity so that the weakest interrogations get disregarded. Theoretically, the communication range of DME system can reach 250 nautical miles.

Interference tolerance of the airborne interrogator is specified as -99 dBm/MHz [26]. It is obtained from the carrier to interference ratio (CIR) threshold of 16 dB under the receiver sensitivity of -83 dBm [27]. Receiver sensitivity of the transponder is known to be about 8 dB better (lower) than that of the interrogator. In [28], the requirements of secondary access to DME spectrum was investigated. To our best knowledge, it is the first work addressing the secondary spectrum access issues in 960-1215 MHz band. The DME protection threshold used in [28] appears in Table II.

TABLE II: Protection threshold of DME

Parameter	Value
Receiver sensitivity of airborne interrogator	-83 dBm/MHz
Receiver sensitivity of ground transponder	-91 dBm/MHz
Minimum required CIR	16 dB
Safety margin	6 dB
Apportionment of secondary interference	6 dB
A_{thr} for airborne interrogator	-111 dBm/MHz
A_{thr} for ground transponder	-119 dBm/MHz

B. L-DACS

High speed air-to-air and air-to-ground data link that supports continental airspace environment is one of key requirements for future aeronautical communications infrastructure (FCI). European organisation for the safety of air navigation (Eurocontrol) and federal aviation administration (FAA) jointly evaluated various candidate technologies for new data link in L-band, and identified two most promising options, namely L-DACS1 [20] and L-DACS2 [21].

L-DACS1 has a FDD configuration employing OFDM technique. It is intended to operate in 960-1164 MHz frequencies. It has a channel bandwidth of 500 kHz which is deployed with inlay between two DME channels in order to prevent interference to the DME. Its traget data rate is 480 kbps. L-DACS2 employs GMSK modulation scheme and operates in a TDD mode. It utilizes 960-975 MHz band which is not actively used by DME equipments. It is to offer 270 kbps per channel data rate with 200 kHz channelization. Both specifications adopt frequency reuse scheme similar to conventional cellular systems. Cell radius has a range between 40 nautical miles (75 km) and 200 nautical miles (370 km) with the expected frequency reuse factor of 7 or 12. Comparison of two specifications are summarized on page 15 of [29]. The technical details of the L-DACS system has not been fixed yet. It is expected that one of the candidates will be selected and be deployed around the year 2020.

IV. AERONAUTICAL COMMUNICATION SYSTEMS IN 5030-5150 MHZ

According to the international spectrum regulation, 5030-5150 MHz is primarily allocated to the MLS for precision approach and landing. Communications on the airport surface is also under discussion in this frequency band. These two systems are described in detail in this section.

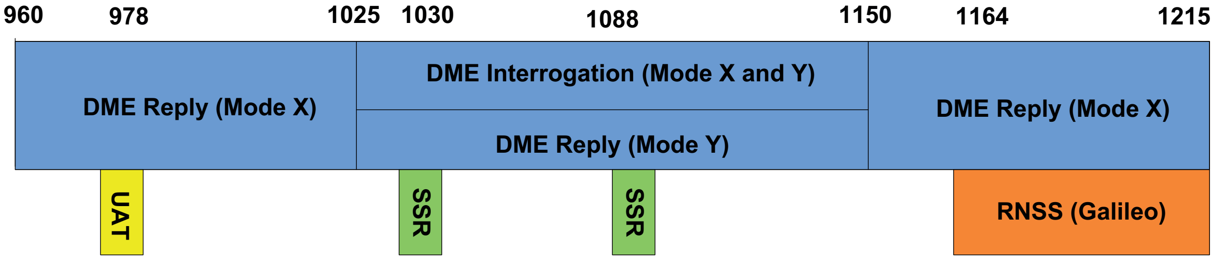

Fig. 2: Frequency allocation to civil aeronautical systems in 960-1215 MHz

A. *MLS*

For landing aids of aircrafts, instrumental landing system (ILS) operating in 108-112 MHz band has been used since 1940's. The MLS was introduced in 1978 to overcome problems and limitations of ILS. It was planned to replace ILS in a long term basis. The reference [18], [22] contains more information of the MLS.

The basic principle of MLS is the scanning of time-reference beams. Two directional sweeping beams are used for azimuth and elevation guidance. In horizonal domain, the time-referenced azimuth beam sweeps from left to right (called TO) and from right to left (called FRO) after a certain pause. An aircraft receiver detects pulses and determines its horizonal location based on the time difference between the 'TO' and 'FRO' pulses. The same principle applies to determine the elevation level. The spectrum for MLS spans from 5030 to 5090 MHz. It is divided into 200 channels with 300kHz of channel bandwidth. The in-band interference susceptibility of MLS receiver is considered to be -130 dBm/150 kHz [30]. Although the MLS was introduced in 1978, it has not gained a worldwide usage for commercial aircrafts. For example, the USA decided not to continue the operation of MLS in favor of satellite-based navigation systems [31]. Therefore, an investigation of the current spectrum usage as well as future plan for 5030-5090 MHz is needed in some countries for more reliable study on the secondary spectrum access.

B. *Airport surface communications*

The frequency spectrum of 5091-5150 MHz is called MLS extension band, and is currently unused for the aeronautical purpose. This spectrum is expected to be occupied by high speed communication systems at the airport surface. Eurocontrol and FAA jointly considered the use of Mobile WiMAX technology based on IEEE 802.16e standard for the airport surface communication. The considered system profile can be found in [23]. From the technical point of view, 5091-5150 MHz looks promising for the secondary spectrum access because the locations of primary users are limited to the airport surface. In contrast to other aeronautical systems employing short pulses or narrow band signals, the airport surface communication system will adopt wide band technology whose operational characteristics are almost same as the candidate secondary systems. Thus, it may be possible to apply advanced interference suppression techniques to both primary and secondary systems. Since the specification of the surface communication system has not been fixed, a higher level of coordination between primary and secondary systems can also be considered.

V. CONCLUDING REMARKS

We presented an overview of existing and future aeronautical communication systems as a potential candidates of primary systems for secondary spectrum access. In 960-1215 MHz spectrum, two aeronautical systems were presented: DME for navigation aid that has been used for more than 50 years and L-DACS which is a future data link system planned to be deployed in 2020. Another spectrum of interest was 5030-5150 MHz band where a part of spectrum (5030-5090 MHz) is used for MLS, precision landing aid, and the other part (5091-5150 MHz) is planned to be used for M-WiMAX based airport surface communications. We described the purposes, characteristics, and operational facts of these systems.

Feasibility of secondary access to aeronautical spectrum remains mostly unaddressed. Aeronautical spectrum accounts for large chunks of interesting radio frequencies which have achieved a good global coordination. On the other hand, it cannot be overestimated that aeronautical communication systems perform operations regarding safety-of-life. These systems are also highly susceptible to interference in general. Thus, it is challenging to provide reliable protection to aeronautical systems from aggregate interference generated by multiple secondary transmitters. It is too early to conclude whether the secondary access to aeronautical spectrum is viable due to the lack of study. It is important to have thorough investigations on the technical feasibility of secondary spectrum access and the quantification of availability in each frequency spectrum in geographical areas in order to provide an appropriate input to policy and regulatory discussions. In this regard, the overview presented in this paper and references herein will be a useful starting point of the further research.

ACKNOWLEDGMENT

The authors would like to thank the European Union for providing partial funding of this work through the EU FP7 project INFSO-ICT-248303 QUASAR.

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