Evaluation of LTE and Aeronautical Radionavigation Service Electromagnetic Compatibility in 694–790 MHz Frequency Band

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***Abstract*—In 2012 the 694-790 MHz (700 MHz) band was allocated to the International Telecommunication Union (ITU) Region 1 for mobile service (excluding aeronautical mobile), and was identified to the International Mobile Telecommunications (IMT). However, countries of Region 1 listed in Radio Regulations footnote No. 5.312 will also be able to continue using of these frequencies for their aeronautical radionavigation service (ARNS). This allocation comes into force immediately after the 2015 World Radiocommunication Conference (WRC-15). The objective of this article is to assess the electromagnetic compatibility of aeronautical radionavigation service and mobile service operating in 694 MHz–790 MHz. For interference analysis the Minimum Coupling Loss (MCL) method and Monte Carlo method simulation was used. The obtained results provide the minimum coupling distance required between ARNS and mobile service Long Term Evolution (LTE) stations to maintain the required performance level of the ARNS systems.**

***Index Terms*—ARNS; 4G mobile communication; electromagnetic compatibility; Monte Carlo method; radiocommunication; radiofrequency interference.**

I. INTRODUCTION

The 2012 World Radiocommunication Conference (WRC-12) adopted decision on the allocation of the frequency band 694 MHz-790 MHz (700 MHz) in ITU Region 1 to the mobile service, according to ITU Radio Regulations footnote 5.312A [1], [2]. The 700 MHz band has allocation to the mobile service also in Regions 2 and 3. The 700 MHz band is already being described as the *second digital dividend* following the allocation of frequencies in the 790 MHz–862 MHz (800 MHz) band – the *first digital dividend* – for mobile broadband services. This part of spectrum is valuable because it provides optimum coverage for mobile service. This study focuses on compatibility assessment between the aeronautical radionavigation service and the mobile service.

This study assumes that coexistence between mobile and broadcasting service might be unlikely in a co-channel situation due to large required separation distances between stations of the services therefore the combination of both services interfering with ARNS receiving ground stations at the same time can therefore be disregarded [3].

Manuscript received 21 December, 2015; accepted 14 October, 2016.

Authors found that studies on evaluation of compatibility of LTE (4G mobile communication) with aeronautical radionavigation service operating in the 700 MHz band were performed in the ITU-R study group JTG-4-5-6-7. According to the results of the Study#A.1 of [4] (based on implementation of coordination distances) the required coordination distance for rural environment for land path is 42 km for RSBN and RLS 2 Type 2. If only RSBN ground receivers of the ARNS system are concerned then coordination distance required is 13 km.

According to the results of the Study#A.2 of [4] (based on implementation of coordination distances) the required separation distance for rural environment for land path is 18 km for RSBN ground receivers of the ARNS system and 90 km for RLS 2 Type 2. Different parameters like antenna downtilt etc. were used, as well the tropospheric scattering effect was taken into account in the Study#A.2. Study#A.1 and Study#A.2 are based on protection criteria for ARNS as the permissible aggregate threshold field strength values from a mobile service base stations (BS) according to the Recommendation ITU-R M.1830 and the GE06 Agreement.

A third study is the one in [5], where analytical calculations (MCL) showed that the required protection distance for rural environment between RSBN ground receivers of the ARNS system and the mobile service BS is 132 km. The obtained results from SEAMCAT statistical simulations showed that separation distance should be above 100 km. In the study [5] $I/N = -6$dB interference criterion was used. Different parameters like e.i.r.p. of BS, channel bandwidth etc. were used in this study.

This article is organized as follows. The second chapter is devoted to the technical characteristics of systems. The third chapter describes the used protection criteria. The fourth chapter is devoted to the compatibility evaluation methodology. The fifth chapter represents the interference scenario. The sixth chapter is devoted to the compatibility analysis and results, and in the last one conclusions are derived.

II. TECHNICAL CHARACTERISTICS

A. Parameters of LTE

The LTE parameters used in this study are taken from

input documents to JTG 4-5-6-7 working group from WP5D [6]. General E-UTRA spectrum emission mask was simulated according to Table 6.6.2.1.1-1 of 3GPP TS 36.101 [7]. The spectrum emission mask characterizes the harmful interference level to ARNS operating in 700 MHz band. The Report ITU-R M.2292-0 [8] also was used for deriving LTE parameters. Mobile service (LTE) base stations basic parameters used in this study are provided in Table I.

TABLE I. CHARACTERISTICS OF LTE BASE STATION.

Parameter	Value
Tx frequency	743 MHz, 783 MHz
Rx frequency	728 MHz
Channel bandwidth	10 MHz
Signal bandwidth	9 MHz
Maximum output power	46 dBm
e.i.r.p.	58 dBm
Antenna height	30 m
Antenna gain	15 dBi
Feeder loss	3 dB
Base station (BS) antenna pattern	ITU-R F.1336 with k=0.7
Antenna downtilt	3°
Receiver noise figure	NF = 5 dB
Cell size/radius	8 km
Sectorization	3 sectors
Antenna polarization	± 45°
Reference sensitivity	-101.5 dBm
I/N	-6 dB
BS unwanted emission limits for 10 MHz channel bandwidth	Table 6.6.3.2.1-3 of 3GPP TS 36.104 (V11.2.0)

The main characteristics of LTE mobile station (MS) or user equipment (UE) are provided in Table II.

TABLE II. CHARACTERISTICS OF LTE USER EQUIPMENT.

Parameter	Value
Tx frequency	728 MHz
Rx frequency	743 MHz, 783 MHz
Channel bandwidth	10 MHz
Maximum output power, e.i.r.p	23 dBm
Antenna height	1.5 m
Antenna gain	-3 dB
Body loss	4 dB
Receiver noise figure	NF = 9 dB
Reference sensitivity	-95.5 dBm
Number of active LTE UE per BS cell	3

In this study the following frequency arrangement is assumed: 703 MHz–733 MHz (for uplink), 758 MHz–788 MHz (for downlink), and 738 MHz–758 MHz (for supplemental downlink -SDL) [9], [10]. The ARNS and possible mobile service frequency utilisation is presented in Fig. 1.

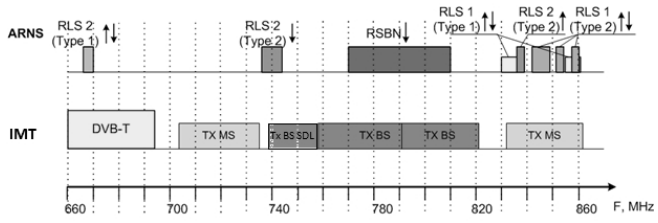

Fig. 1. ARNS and possible mobile service frequency utilisation.

B. Parameters of Aeronautical Radionavigation Service

The aeronautical radionavigation service (ARNS) parameters and technical characteristics used in this study are taken from Recommendation ITU-R M.1830 [11] and Recommendation ITU-R M.1461-1 [12]. The extract of basic parameters for the 694 MHz–790 MHz band is provided in Table III.

TABLE III. CHARACTERISTICS OF ARNS SYSTEMS OPERATING IN THE 694 MHz–790 MHz FREQUENCY BAND.

Parameter	ARNS system type	
	RSBN	RLS 2 Type 2
Transmitting station	Aircraft transmitter	Aircraft transponder transmitter
Receiving station	Ground radar receiver	Ground radar receiver
Rx frequency	784 MHz	740 MHz
Channel bandwidth	3 MHz	8 MHz
Receiver antenna height	10 m	10 m
Antenna gain (including loss)	22 dBi	28.4 dBi
ARNS station antenna pattern	3 dB beamwidth: vert. pl. = 50° hor. pl. = 4°–5°	3 dB beamwidth: vert. pl. = 50° hor. pl. = 4°–5°
Rx noise figure	5 dB	5 dB
Antenna polarization	Linear, horizontal	Linear, horizontal
I/N	-6 dB	-6 dB
Direction of antenna main beam	Azimuth: 0°–360°	Azimuth: 0°–360°
Predetermined aggregate trigger field strength values	42 dB (μV/m) at 10 m in a 3 MHz reference bandwidth	24 dB (μV/m) at 10 m in a 8 MHz reference bandwidth
Receiver blocking (filter) mask	Figure 1 of Recommendation ITU-R M.1830	Figure 1 of Reccomendation ITU-R M.1830

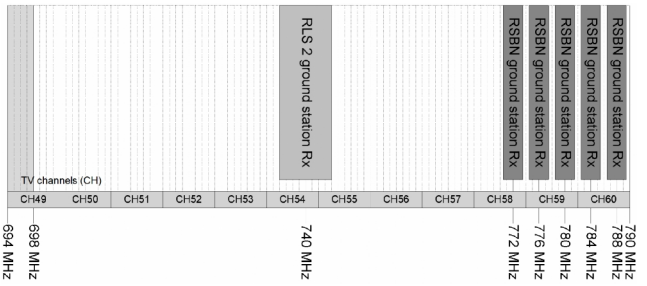

Fig. 2. Channel arrangement of the ARNS in the 700 MHz frequency band (in accordance with ITU-R M.1830).

As shown in Table III systems operating in the 694 MHz–790 MHz frequency band operate in *air-to-ground* direction. The channel arrangement of the ARNS in the 700 MHz frequency band in accordance with ITU-R M.1830 is presented in Fig. 2.

III. PROTECTION CRITERIA

In general four different types of coordination triggers can be discussed: coordination distances, single field strength triggers, aggregated field strength triggers, and coordination trigger based on I/N. Each of them has both benefits and drawbacks [4]. In this study were considered three types of coordination triggers i.e. coordination distance, coordination trigger based on I/N, and aggregated field strength triggers.

Three approaches were used in this paper to estimate the interference of LTE base stations operating in 738 MHz–

788 MHz (downlink) and 738 MHz–758 MHz (supplemental downlink) to ARNS operating in 694 MHz–790 MHz, namely Minimum Coupling Loss (MCL), Monte Carlo method simulation, and predetermined aggregate trigger field strength values for protection of ARNS. Therefore, three distant protection criteria were used to assess the interference from LTE BS to ARNS.

A. Protection Criteria Used in MCL Calculations

For calculation of interference to ARNS caused by mobile service, the interference to noise ratio (I/N) is used. The protection criteria used in MCL calculations: $I/N = -6$ dB [12].

B. Protection Criteria Used in Monte Carlo Simulations

In Monte Carlo simulations the protection criterion was derived from 3GPP TS 36.104, according to it the probability of interference (PoI) less than 5 % was considered to be a sufficient protection level. Second protection criterion used in Monte Carlo simulations of this study was $I/N = -6$ dB.

C. Predetermined Aggregate Trigger Field Strength Values

The protected field strength values are in accordance with Recommendation ITU-R M.1830 Annex 2 Table IV (see Table III of this article), which complay also with the protection criteria of ARNS against DVB-T interference. In the GE06 Agreement the protection of ARNS against DVB-T is defined and it ensures sufficient protection of ARNS. Due to similarity with DVB-T signals the protection of ARNS interfered by mobile service (LTE) can be considered with the same criteria.

IV. Compatibility Evaluation Methodology

A. Minimum Coupling Loss Method

The Minimum Coupling Loss (MCL) method is the worst case analysis and produces a boundary result for scenarios of statistical nature. This method evaluates the required path loss level according to minimum protection criteria.

B. Monte Carlo Method

The Monte Carlo method is used in order to assess the interference from LTE BS downlink to ARNS ground receivers. Monte Carlo method is applicable to simulate mainly all possible radio communication based scenarios. This flexibility is ensured by the manner of the characterization of input parameters inside the system. The input type of each variable parameter (as horizontal and vertical antenna pattern, e.i.r.p., propagation environment etc.) is modelled like statistical distribution function. The Monte Carlo modelling provides statistical elements of real life behaviour of BS network and interference, enabling a realistic estimate of the probable interference. In this study was used SEAMCAT software tool [13].

V. Interference Scenario

In this study considered LTE BS operation in 758 MHz–788 MHz (downlink) and 738 MHz–758 MHz (supplemental downlink) and its possible interference into ARNS operating in the 694 MHz–790 MHz frequency band. Two cases are considered: RSBN receiving ground station operating at 784 MHz and RLS2 Type 2 receiving ground station operating at 740 MHz (according to Recommendation ITU-R M.1830).

The interference scenario where LTE downlink interferes ARNS (receiver) station was evaluated in this study. The SEAMCAT simulation interference scenario is presented in Fig. 3.

While there are several possible scenarios for the interference between ARNS and mobile service, this contribution focuses only on a scenario that is mostly common as shown in figure above – mobile service BS interference into fixed ARNS ground receiver.

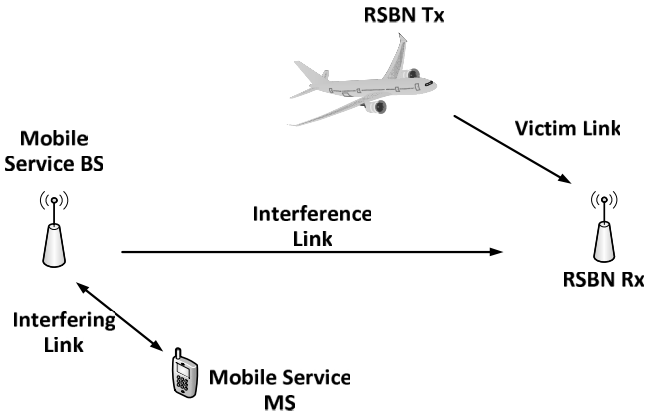

Fig. 3. SEAMCAT simulation interference scenario.

VI. Compatibility Analysis and Results

A. Minimum Coupling Loss Method Calculation Results

For initial assessment of compatibility was used MCL method. The required path loss or isolation (MCL), $L_{\mathrm{Re}quired\_path\_loss}$, between the interfering transmitter (I_t) and the victim receiver (V_t) to ensure that there is no harmful interference is obtained from

$$L_{\mathrm{Re}quired\_path\_loss} = \\ = P_{BS\_Tx} + G_{ARNS\_Rx} - P_{I\_ARNS\_Rx}, \quad (1)$$

where P_{BS_Tx} – e.i.r.p. of the interfering BS; G_{ARNS_Rx} – victim ARNS system antenna gain. The interference level at the ARNS ground station receiver, $P_{I\_ARNS\_Rx}$, due to operation of the mobile service, is obtained from

$$P_{I\_ARNS\_Rx} = P_{n\_ARNS\_Rx} + I / N, \quad (2)$$

where $P_{n\_ARNS\_Rx}$ – noise power at the ARNS receiver; I/N – interference to noise ratio. The required path loss between the LTE BS transmitter and the RSBN ground receiver of 1 MHz bandwidth is

$$L_{\mathrm{Re}quired\_path\_loss} = 48dBm/1MHz + 22dBi - \\ -(-110.6dBm/1MHz + (-6dB)) = 186.6\,[dB]. \quad (3)$$

The isolation figure is further converted into a separation distance using the Recommendation ITU-R P.1546-5. The

permissible interference level produced by interfering base station, $P_{I\_BS\_permissible\_ARNS\_Rx}$, at ARNS system ground receiver is obtained from

$$P_{I\_BS\_permissible\_ARNS\_Rx} = P_{BS\_Tx} - \\ -L_{\mathrm{Re}quired\_path\_loss}. \quad (4)$$

The maximum permissible interference level produced by interfering LTE BS, $P_{I\_BS\_\max permissible\_RSBN\_Rx}$, at RSBN ground receiver of 1 MHz bandwidth is

$$P_{I\_BS\_\max permissible\_RSBN\_Rx} = 48dBm/1MHz - \\ -186.6dB = -138.6\,[dBm]. \quad (5)$$

The calculated required protection (coupling) distance, $d_{sep\_req\_ARNS-BS}$, between LTE base station and the ARNS RSBN receiving ground station is about 132 km at 10 m receiving antenna height, i.e., longer than radio horizon.

B. Monte Carlo Method Calculation Results

SEAMCAT Monte Carlo simulation results show the required separation distance between the LTE BS (downlink) and ARNS ground receiver (only RSBN was considered). The Recommendation ITU-R P.1546-5 propagation model was used in this simulation. In this study the probability of interference (*PoI*) less than 5 % was considered to be a sufficient protection level. Results of SEAMCAT results are presented in Table IV in order to verify analytical calculations results obtained in previous chapter.

TABLE IV. SEAMCAT SIMULATIONS RESULTS.

Separation distance between LTE BS T_X and ARNS R_X, km	**Probability of interference (*PoI*), %**
130	4.25
112	4.93
105	5.30
95	6.00

The SEAMCAT simulation results present that the separation distance must be more than about 112 km.

C. Predetermined Aggregate Trigger Field Strength Values

TABLE V. CALCULATION RESULTS.

Parameter	**ARNS system type**	
	RSBN	**RLS 2 Type 2**
Transmitting station	Aircraft transmitter	Aircraft transponder transmitter
Receiving station	Ground radar receiver	Ground radar receiver
Rx frequency	784 MHz	740 MHz
Predetermined aggregate trigger field strength values	42 dB (μV/m) at 10 m in a 3 MHz reference bandwidth or 37.2 dB (μV/m) at 10 m in a 1 MHz	24 dB (μV/m) at 10 m in a 8 MHz reference bandwidth or 14.9 dB (μV/m) at 10 m in a 1 MHz
Separation distance between LTE BS Tx and ARNS Rx, km	15	45

The protected field strength values used in this study are in accordance with Recommendation ITU-R M.1830 Annex 2 Table IV (see Table III of this article). The Recommendation ITU-R P.1546-5 propagation model was used in this evaluation. The calculation results are presented in Table V.

The calculation results present that the required separation distance must be more than about15 km for RSBN ground receiver and about 45 km for RLS 2 Type 2 ground receiver.

VII. CONCLUSIONS

This study presents important results on the evaluation of coexistence requirements for LTE and ARNS use in the 694 MHz-790 MHz band. Electromagnetic compatibility between LTE BS downlink and ARNS ground receiver was assessed with three different methods: MCL calculations for worst case scenario and Monte Carlo method simulations for more realistic case (only RSBN ground receiver was considered), and predetermined aggregate trigger field strength values for protection of ARNS.

The minimum coupling distance required between LTE BS and RSBN ground receiver in the 700 MHz band to maintain the necessary performance level of the RSBN system is 132 km according to analytical MCL calculations. The Monte Carlo simulation results present that the required separation distance must be more than approximately 112 km with condition that the probability of interference (*PoI*) less than 5 % is considered to be a sufficient protection level using realistic ITU-R P.1546-5 propagation model. Using predetermined aggregate trigger field strength values of Recommendation ITU-R M.1830 the calculation results present that the required separation distance must be more than about15 km for RSBN ground receiver and about 45 km for RLS 2 Type 2 ground receiver. These three used calculation methods and obtained results identified that results could be verified by practical measurements.

The results of this study showed that using the selected frequency arrangement and assumptions the additional mitigation techniques, such as downtilting of antennas, antenna discrimination etc., for LTE network planning and deployment are required in order to assure the compatibility between these two services. Results of this study can be used by National Regulatory Authorities, mobile operators, equipment manufacturers when planning deployment of 700 MHz band for mobile service and ARNS in neighbouring countries.

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