Intersystem Interference Study between Medical Capsule Camera Endoscopy and Other Systems in Co-Channel and Adjacent Bands

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Abstract—**The Ultra-High Frequency (UHF) band occupies a very vital region in the spectrum and is becoming very congested because many applications use it. The capsule camera (CapCam), an ultra-low power wireless device, is a Short Range Device (SRD) application that utilizes the UHF spectrum for medical endoscopy and it is designed to operate at the 430-440MHz frequency band range. This study will focus on the interference between the CapCam and other systems operating in the frequency of 435MHz and adjacent bands. Other systems that can operate in this band include non-specific SRD and radiolocation services such as airborne radar and ground radar stations. The Minimum Coupling Loss (MCL) method is implemented in this study. The findings showed that restricted distances between the CapCam and other services must be considered when the CapCam is in use. This should be done to avoid harmful interference from the CapCam especially in the case of radiolocation services.**

Keywords-CapCam; airborne radar; ground radar; interference; MCL method

I. INTRODUCTION

Wireless Medical Capsule Endoscopy (WMCE) is a new generation of medical Short Range Device (SRD) applications, which are characterized by operating in ultra-low power and short distance applications. The capsule camera (CapCam) is a main component of the ultra-low power WMCE application. The CapCam endoscopy is a practice recommended by doctors that uses a miniature wireless camera to take images of a patient's digestive tract as it passes through it. The endoscopy camera is placed within a small capsule (approximately the same size as a vitamin pill) that the patient swallows. The camera takes pictures as the capsule passes through the patient's digestive system and transfers them wirelessly to a recorder carried by the patient [1]. The CapCam is a medical diagnostic tool designed to operate in the UHF range including the frequency band of 430-440MHz [2]. This frequency band is occupied by several services such as radiolocation services, amateur radio services, non-specific SRDs (NSRDs), land mobile services, and earth exploration-satellite services.

Therefore, the possibility of interference occurring between these systems and the CapCam service is something that needs to be investigated. As a result of the interference, system performance deterioration may occur.

Depending on the properties of various WMCE systems and the method of treatment, many contraindications are set by manufacturers. Such a contraindication is the electromagnetic radiation represented by the interference of the CapCam with other wireless devices (or intersystem interference). Based on previous studies and the manufacturers' recommendations, these contraindications include the effect on the cardiac pacemakers or other implanted electro-medical devices, creating strong electromagnetic fields on devices such as Magnetic Resonance Imaging (MRI), etc. [3, 4]. More broadly, in this paper, the intersystem interference between the CapCam service and other systems is controlled in a primary-secondary operating basis, where the CapCam service is a secondary service and the other systems are considered the primary services [5]. Comprehensively, when the SRDs (as a secondary service) operate in shared bands, they are not permitted to cause harmful interference to radio services (primary). So, in general, SRD cannot claim protection from interference caused by radio communication services as defined by the International Telecommunication Union Radio Regulations (ITU-RR) [6]. Further, this means that the CapCam must not cause interference to the other primary services. Therefore, this paper will study the effect of the CapCam service on other services. Both co-channel interference and adjacent channel interference will be examined in Line of Sight (LOS) and non-LOS (NLOS) environments.

II. INTERSYSTEM INTERFERENCE SCENARIOS

This section provides a summary of the proposed interference scenario between the CapCam and other systems that share the same frequency band of 430-440MHz. The services/systems involved in this study are described in detail.

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A. Interference Scenario

The interference scenario is shown in Figure 1. The CapCam service is assumed to be operating in the 430-440MHz frequency band and shares it with other services (radiolocation and NSRD) according to the ITU-RR's Article 5 [5] and the European Common Allocations (ECA) [7]. The frequency allocation for the 430-440MHz band regarding radiolocations services (airborne and ground radars) and SRD are shown in Table I. It can be realized that the proposed use of the CapCam application operating in the frequency band of 430-440MHz would lead to affecting both radiolocation and NSRD systems. This study will investigate this impact in order to coordinate the use of the CapCam with radiolocation and NSRD systems.

TABLE I.   THE ITU-R SPECTRUM ALLOCATION FOR THE CAPCAM, RADIOLOCATION, AND NSRD SERVICES IN THE 430-440MHz BAND

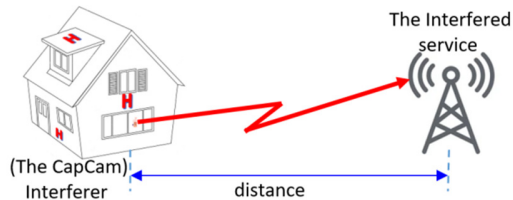| Frequency band (MHz)	ITU RR allocation
430-433.05	RADIOLOCATION
433.05-434.79	RADIOLOCATION, NSRD
434.79-440	RADIOLOCATION

Fig. 1.   The interference scenario of CapCam with other services.
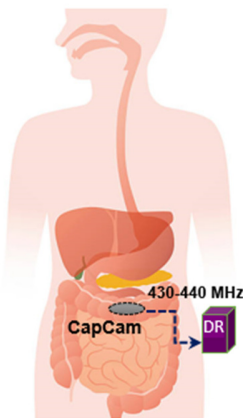

Fig. 2.   The scenario of CapCam and DR as a WMCE application.

It is assumed that the CapCam service (the interferer) is utilized inside a medical building such as a hospital and causes interference to three discrete outdoor wireless systems (airborne radar, ground radar, and NSRD), which can be termed as interfered services (Figure 1). In the following subsections, a brief description of these systems, as well as the CapCam service are presented.

B. The CapCam Service

It is a relatively new application of medical SRDs that can perform medical tests of patients with specific digestive conditions without causing bleeding or sedation hazard involved by traditional endoscopy [2]. The crucial part of the new application is a disposable tiny optical imaging camera imbedded in a capsule. The CapCam is given to the patient to swallow and while it moves through the patient's digestive tract it sends images to a receiver (Data Recorder-DR) outside the patient's body as shown in Figure 2.

C. Non-specific SRDs

NSRDs are devices for wireless telegraphy including telemetry, tele-command, alarms, and data transmission. Telemetry services use radio communication for automatically indicating or recording measurements at a distance from the measuring instrument. Tele-command services use radio communication for the transmission of signals to create, modify or dismiss functions of equipment at a distance; and the alarms are devices used for alarm systems, including social, security, and safety alarms [8].

D. Radiolocation

Radiolocation services are defined as radio-determination services for the purpose of position determination. Radio-determination is defined as the determination of the position, velocity, and/or other characteristics of an object by the propagation properties of radio waves [9, 10]. The airborne radar [11], is a radar on a plane used to detect objects moving at very low speeds whereas ground radar is used for fixed, mobile, or transportable operations.

III.   INTERFERENCE CALCULATION METHODOOLGY

The method proposed to calculate the intersystem interference from the CapCam and other systems is the standard Minimum Coupling Loss (MCL) which consists of attaining the critical minimum propagation losses required to avoid interference. Once the total losses are obtained, it is straightforward to determine a matching minimum separation distance depending on a given propagation model. The propagation model used for the assessment of the separation distance is the free space model as well as indoor penetration losses due to the natural work of the CapCam from the indoor environment and emitting power into the outdoor environment. The free space wave propagation model is given by [12]:

$$I = \frac{P_t G_t G_r}{L_{f+p}} \times I_{cf} \quad (1)$$

where I denotes the received interference power at the interfered system (radiolocation or NSRD systems), P_t denotes the transmit power from the interferer system (the CapCam service), G_t and G_r are the gain of the transmitter and receiver antenna respectively, I_{cf} denotes the correction factor of bandwidth between the CapCam and the interfered system, and L_{f+p} is the channel propagation loss due to the free space (outdoor) environment and the indoor penetration loss. The expression in (1) can be represented using the decibel scale as follows [13]:

$$I = P_t + G_t + G_r + I_{cf} + L_{f+p} \quad (2)$$

where L_{f+p} is the free space loss due to the free space environment (L_f) and the indoor penetration loss L_p. The L_f

loss mainly depends on the wavelength of the traveling signal, λ, either in LOS or NLOS environments, and the distance between the transmitter and receiver d. L_p is based on the material type used to construct the hospital building. Therefore, the L_{f+p} factor can be defined for the LOS and NLOS as follows:

$$L_{f+p} = L_f + L_p \quad (3)$$

When the signal travels in a LOS outdoor environment, the loss L_{f+p} is given by (4) for true urban propagation prediction [14, 15]:

$$L_{f+p(LOS)} = 32.45 + 20\log(fd) + L_p \quad (4)$$

If the signal travels in an NLOS outdoor environment, the loss L_{f+p} is given by:

$$L_{f+p(NLOS)} = 32.45 + 20\log(f) + 35\log(d) + L_p \quad (5)$$

where the frequency f is in MHz and the distance d is in km.

In this study, both interference situations (co-channel and adjacent channel interferences) will be considered in both propagation environments.

IV. SYSTEM PARAMETERS

The main parameters for the considered systems for the CapCam, NSRD, airborne radar, and ground radar are shown in Tables II and III. It is worth mentioning that the radiations from the CapCam may not be highly uniform throughout the whole channel bandwidth except within the co-channel frequency (at around 10MHz). Also, 10dB is assumed as the body loss which is applied to distinguish the power levels inside/outside the body.

TABLE II.   MAIN PARAMETERS OF THE INTERFERER SYSTEM (THE CAPCAM)

Parameters	Value
Frequency of operation	430-440MHz
Single channel RF bandwidth	10MHz
Maximum ERP of the transmitter	-30dBm
Antenna gain	2.15dB
ERP outside patient's body	-40dBm
Maximum ERP density outside patient's body	-50dBm/100kHz
Single use of activity cycle	8-12h
Building penetration loss	10dB

TABLE III.   MAIN PARAMETERS OF INTERFERED SYSTEMS

Parameters	NSRD	Airborne radar	Ground radar
Channel bandwidth, MHz	0.250	1	1
Rx antenna gain, dB	-2.85	22	38
Rx interference threshold, dBm	-110	-114.9	-115.9
Rx protection criteria, dB	$C/I = 8$	$I/N = -6$	$I/N = -6$
Height above ground level, m	3	>9000	8

V. RESULTS AND DISCUSSION

This section of the paper analyzes and discusses the results of the coordination between the CapCam and the considered systems that share the frequency band of 430-440MHz.

A. The CapCam and NSRD Systems

Since the NSRD is set to run in the frequency band 433.05-434.79MHz, the operating carrier frequency is assumed as 433.91MHz. The channel propagation will be affected by the penetration loss of 10dB as well as the loss in the LOS and NLOS environments. The values of interference levels from the CapCam service into the NSRD service versus the separation distances using co-channel frequency are shown in Figure 3. This Figure illustrates that the minimum distance in the LOS environment is about 322m whereas it is 27.6m in the NLOS dense urban areas. At these distances, minimum power will be detected according to the NSRD receiver sensitivity which is -110dBm/25kHz. Figure 3 shows that as the distance increases the interference level from the CapCam into the NSRD receiver decreases due to the propagation effect for both LOS and NLOS. However, the interference level drastically decreases in NLOS compared to the LOS environment. To allow for proper coordination between the CapCam system and the NSRD system the required margin in the co-channel frequency band is depicted in Figure 4. It can be seen from Figure 4 that as the distance increases, the required margin decreases linearly in the log scale. In Figure 4, we can notice that the required margin is 0dB at the separation distances of 322m and 27.6m for LOS and NLOS respectively. The reason is that at these distances the received power is equal to the NSRD receiver sensitivity of -110dBm. Before reaching the aforementioned distances, the interference power is high and can cause deterioration in NSRD receiver performance. Therefore, it is required to keep that distance in consideration regarding the operation of the CapCam and NSRDs services.
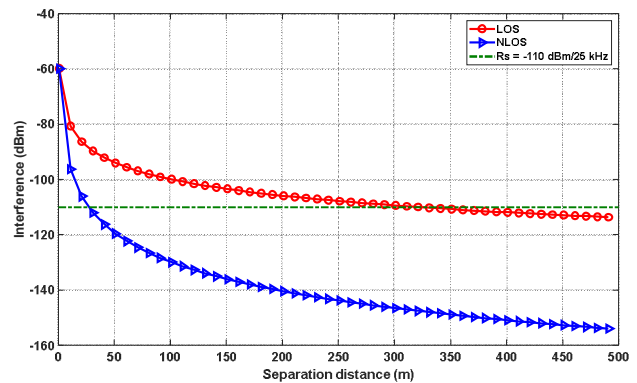
Fig. 3.   The interference from the CapCam into the NSRD in the co-channel frequency band.

On the other hand, by shifting the CapCam carrier frequency by 10MHz the two systems will operate under the adjacent channel band scenario. This is illustrated in Figures 5 and 6. In Figure 5, the interference level from the CapCam service is 102m in LOS areas, while the distance in NLOS dense urban areas is only 15m and lower than that of LOS environment. These findings are confirmed in Figure 6, which shows the power margin in both areas. This shows that the power margin is 0dB at the above mentioned distances due to the received power being equivalent to the NSRD receiver sensitivity. From the findings of the operation of the CapCam and NSRD services, it can be concluded that the interference

power in NLOS is less than in the LOS environment. This variation in interference power is due to the environment in the NLOS blocking the interference power from the CapCam from reaching the interfered system receiver in its entire strength. The LOS environment allows the interference signal power to travel with no obstacles in its path. Moreover, the minimum distance required to operate the CapCam and NSRD services simultaneously in the same area with no harmful interference using the co-channel frequency band is higher compared to the distance using the adjacent channel. This occurs due to the fact that the emitted power from the CapCam service in the case of the adjacent channel frequency band is less than the power emitted in the case of the co-channel band by 10dB. Thus, the decrease in the interference emission power is transferred into decreasing the distance that enough harmful interference signal can reach the affected receiver of the NSRD. This finding is consistent with the findings of [16].
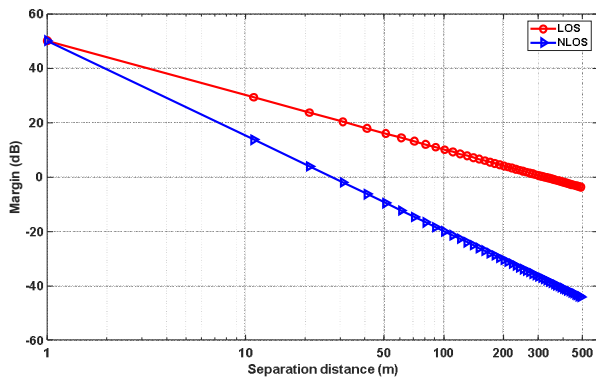
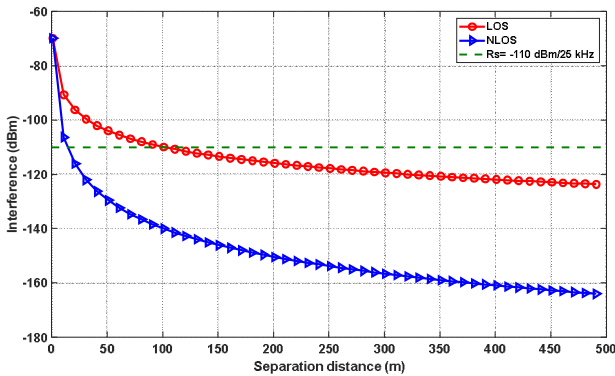Fig. 4.   The required margin for coordination of the CapCam and the NSRD in the co-channel frequency band.

Fig. 5.   The interference from the CapCam to the NSRD in the adjacent channel frequency band.

B. The CapCam and Airborne Radar Systems

Here, the affected service is the airborne radar while the interferer is the CapCam service. The airborne radar receiver has an interference threshold of −114.9dBm. Figures 7 and 8 illustrate the interference power level with the distance increasing between the two systems in co-channel and adjacent channel frequency bands respectively. Both Figures show that the distance required in LOS is higher than that required in

NLOS areas. In addition, the minimum distance in the co-channel band is higher than that in the adjacent channel band. In the co-channel scenario the distance is 1563m and 67.5m, while in the adjacent channel scenario it is 494.5m and 36m for LOS and NLOS respectively. Also, in Figures 9 and 10, the power margin is depicted for the same scenarios, in which 0dB is the margin at the abovementioned distance. At greater distances, the power margin is negative which means it allows the airborne radar to run with no interference acting on it from the CapCam.
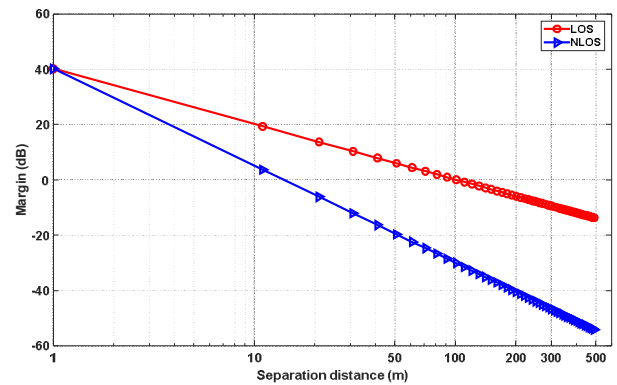

Fig. 6.   The required margin for the coordination of the CapCam and the NSRD in the adjacent channel frequency band.
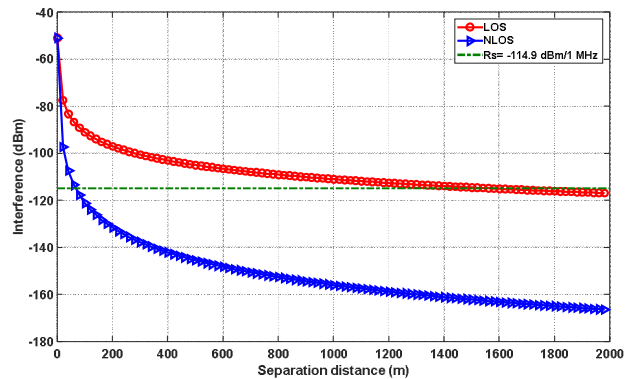

Fig. 7.   The interference from the CapCam to the airborne radar in the co-channel frequency band.
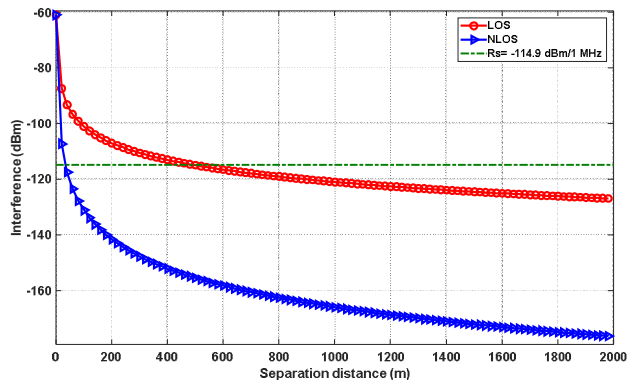

Fig. 8.   The interference from the CapCam to the airborne radar in the adjacent channel frequency band.

C. The CapCam and Ground Radar Systems

For this scenario, the receiver has an interference threshold that is lower than that of the airborne radar, which is −115.9dBm. The findings shown in Figures 11 and 12 present the interference levels with the distance between the CapCam and ground radar services. It is found that the minimum distance at which the two systems can operate together with no harmful interference is 1754m and 72m for the co-channel frequency band in the LOS and NLOS environments respectively. The minimum distance decreases using the adjacent channel band are 555m and 39m in the LOS and NLOS environments respectively. Moreover, Figures 13 and 14 show the required power margin between the received interference from the CapCam service and the maximum interference threshold. Therefore, at the abovementioned distances, this margin is 0dB, and before the ground radar cannot work. For instance, in distances less than 1754m and 555m the ground radar may not operate properly if the CapCam service operates at the same time.

compared with many other SRD applications, distance should be taken into account. Another important point in this study is that it assumes that the patient treated by the CapCam is separated by only one wall from the considered devices/services. In practical situations there may be many walls or partitions, which can contribute to more propagation loss that may allow the operation of the CapCam with other services without interferences.
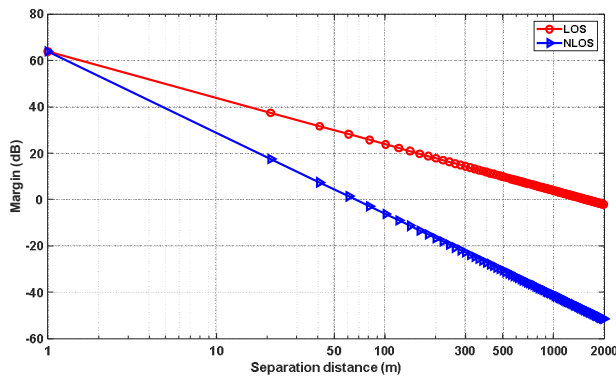
Fig. 9.   The required margin for the coordination of the CapCam and the airborne radar in the co-channel frequency band.
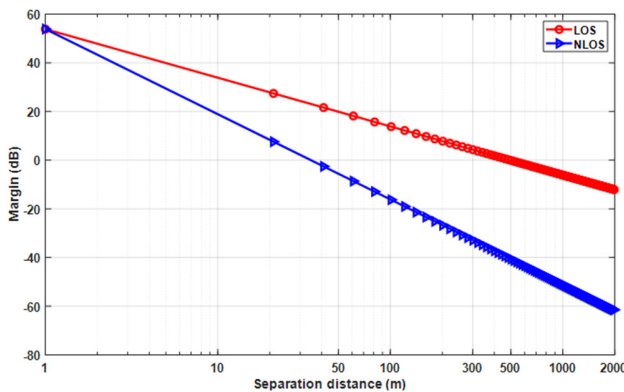
Fig. 10.   The required margin for the coordination of the CapCam and the airborne radar in the adjacent channel frequency band.

Table IV summarizes the results from the presented scenarios. It shows that the ground radar service is the most affected among other services due to the maximum interference threshold and its higher antenna gain. Although, the exceptionally low deployment density of the CapCam services and the short time period of single-use of the CapCam devices,
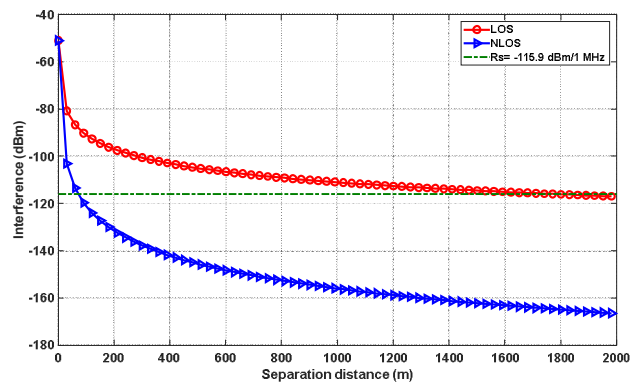
Fig. 11.   The interference from the CapCam to the ground radar in the co-channel frequency band.
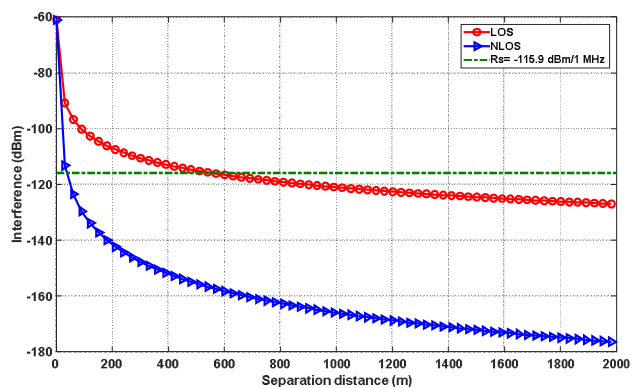
Fig. 12.   The interference from the CapCam to the ground radar in the adjacent channel frequency band.
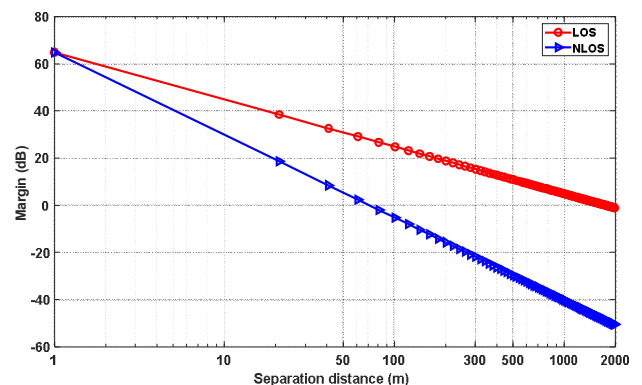
Fig. 13.   The required margin for the coordination of the CapCam and the ground radar in the co-channel frequency band.
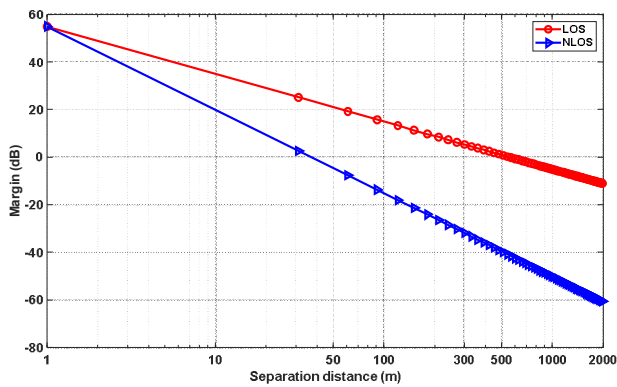
Fig. 14.   The required margin for the coordination of the CapCam and the ground radar in the adjacent channel frequency band

This paper illustrates new findings on the coordination of operating a CapCam system with radiolocation and NSRD services, which are investigated in order to eliminate possible interferences to those services. This study considered the effect of building penetration loss, adjacent channel interference, and long coverage distance which makes this study more technically sound compared to the work in [2]. Ultimately, the findings of this paper aim to decrease the required restrictions that should be taken into account for the CapCam service to run harmlessly besides other wireless services.

TABLE IV.   MINIMUM PHYSICAL SEPARATION BETWEEN THE CAPCAM AND OTHER SYSTEMS IIN LOS AND NLOS ENVIRONMENTS

Channel type	Environment	Physical separation (m)		
		With NSRD	With airborne radar	With ground radar
Co-channel	LOS	322	1563	1754
	NLOS	27.6	67.5	72
Adjacent channel	LOS	102	494.5	555
	NLOS	15	36	39

VI. CONCLUSION

This paper presents a study of the medical capsule camera endoscopy (CapCam) and other systems in the 430-440MHz band using the MCL approach. The study covered LOS and NLOS areas using co-channel and adjacent channel frequency bands. It has been found that 1754m is the maximum distance for the three systems as a conservative protection distance in the case of the co-channel frequency band. The minimum distance for the three services is 555m in the adjacent channel scenario within a LOS environment. In the case of NLOS, the physical separation distances decrease dramatically. More studies may be recommended to investigate and analyze the effect of different practical situations with different building construction materials, stories, and designs.

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