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Interference Analysis of 5G in Coexistence Scenario with Short Range Devices (SRD)

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Abstract
The rapid growth of mobile data traffic and demand of faster broadband services set the target of 5G for mobile and broadband services. For the 5G cellular mobile communication, lower (below 1GHz) and mid (1 to 6 GHz) 5G candidate band are more promising due to coverage and capacity. Government of Nepal is planning to test 5G for cellular and commercial use in near future. Based on Nepal Telecom Authority (NTA) study plan and current frequency allocation data for cellular system in Nepal, this paper presents an interference analysis of 5G in co-existence scenario with Short Range Devices (SRD) in the 850 MHz band considering 868 MHz as 5G reference frequency and SRD's operating in (863 – 870) MHz licensed exempted band. Monte-Carlo based SEAMCAT simulation has been used to exploit the interference probability on victim system from interfering system while operating in same or adjacent frequency in coexistence scenario. Several elements, such as separation distance, number of interferers, and propagation scenario, are studied using this methodology for their impact and tendencies on the chance of interference on victim systems (e.g. indoor and outdoor). Based on the result of probability of interference/bitrate degradation, required minimum distance between interfering transmitter and victim receiver are recommended to ensure victim system service availability greater than 95%. This paper also highlights some future research directions to minimize the probability of interference to ensure the compatible operation 5G and SRD's in coexistence scenario.

Keywords
Electromagnetic Interference, 5G, Spectrum, Short Range Device (SRD), Co-existence, SEAMCAT

1. Introduction

The rapid growth of mobile data traffic and demand of faster broadband services set the target of 5G for mobile and broadband services. 5G is expected as high capacity system, so more spectrum resources is needed to address this expectation. Frequency band below 1 GHz is highly occupied and above 1GHz is less occupied compare to the first due to less systems are operating in this range. While using 5G at lower band, there exists a coexistence scenario of 5G with existing incumbents so main challenge is the interference between the system while operating in co-channel by frequency sharing or operating in adjacent band. Before deployment of 5G system in any 5G candidate band, it's compulsive to assess interference between the systems sharing same frequency spectrum resources or operating in adjacent band known as compatibility analysis. By exploiting the potential interference scenario between the system and analyzing interference probability, we can conclude that system is compatible to operate in given scenario or further mitigation technique have to use with specific contract between system under regulatory rules.

1.1 Theortical Background

1.1.1 5G System Basic

The 3GPP's 5G New Radio specification includes various bands that are designed for 5G. The full capabilities of 5G are best realized through the widest channel sizes. Frequency band allocation for 5G networks comes in 3 sets.

- Frequency range 1 (FR1)
  Below 1 GHz (lower band)
- Frequency range 2 (FR2)
  Above 1 GHz up to 6 GHz (Mid-band)
- Frequency range 3 (FR3)
  Above 24 GHz (Higher mmWave band)

1.1.2 Short Range Devices (SRD)

The term "short-range device" (SRD) refers to radio transmitters that are capable of providing either unidirectional or bidirectional communication while posing low risk of interfering with other radio equipment. Tele-control for home or other systems, building automation systems, wireless sensor systems, alarms, automobile systems including remote keyless entry and remote car-starting, wireless speech and video, and so on are all common uses for SRDs.

The Short Range devices in band of (862- 870)MHz has been given in table 1[1].

Table 1: SRD Annex's from CEPT/ERC/REC 70-03 (ERC 2017) in band of (863- 870) MHz)

Application category	Sub-band	Frequency low [MHz]	Frequency high [MHz]	Power [mW]	Band width [KHz]	Duty cycle [%]
Non – specific Short Range Devices						
Annex 1	f	868	868.6	25	na	1
	g	868.7	869.2	25	na	0.1
	h	869.3	869.4	10	25	100
	i	869.4	869.65	500	25	10
	k	869.7	870	5	na	100
Alarms						
Annex 7	a	868.6	868.7	10	100	0.1
	b	869.25	869.3	10	25	0.1
	c	869.65	869.7	25	25	10
	d	869.2	869.25	10	25	0.1
Radio microphones						
Annex 10	c	863	865	10	200	100
Wireless Audio Application						
Annex 13	a	863	865	10	300/600	100
	b	864.8	865	10	50	100

1.1.3 Current frequency allocation plan for cellular system in Nepal

Table 2: Cellular frequency allocation in Nepal (Source: NTA)

Frequency Band	800 MHz	850 MHz	900 MHz	1800 MHz	2100 MHz	2300 MHz	Total
Frequency range	852-862 MHz paired with 811-821 MHz	824-834 MHz paired with 869-879 MHz	880-915 MHz paired with 925-960 MHz	1710-1785 MHz paired with 1805-1880 MHz	1920-1980 MHz paired with 2110-2170 MHz	2300 - 2400 MHz	
Available system B/W	2 × 10 MHz (FDD)	2 × 10 MHz (FDD)	2 × 35 MHz (FDD)	2 × 75 MHz (FDD)	2 × 60 MHz (FDD)	100 MHz (TDD)	2 × 190 MHz (FDD) 100 MHz (TDD)
1 Nepal Telecom	2 × 10	2 × 6	2 × 9.6	2 × 20	2 × 10	30	2 × 55.6 MHz (FDD) 30 MHz (TDD)
2 Ncell/Axiata Ltd.			2 × 8	2 × 20	2 × 10		2 × 38 MHz (FDD)
3 United Telecom Ltd.		2 × 2.5	2 × 5	2 × 12			2 × 19.5 MHz (FDD)
4 Nepal Satellite Pvt. Ltd.			2 × 4.4	2 × 9			2 × 13.4 MHz (FDD)
5 Smart Telecom Pvt. Ltd.			2 × 5	2 × 12			2 × 17 MHz (FDD)
Total assigned frequency(MHz)	2 × 10	2 × 8.5	2 × 32	2 × 73	2 × 20	30	2 × 143.5 MHz (FDD) 30 MHz (TDD)
Remaining freq. (MHz)		2 × 1.5	2 × 3	2 × 2	2 × 40	70	2 × 46.5 MHz (FDD) 70 MHz (TDD)

Table 2 shows the current cellular frequency allocation plan in Nepal. Where lower 5G candidate band (below 1 GHz) frequency allocation for cellular system is almost full. Where's in mid-5G candidate band (1-6 GHz), 2100 MHz band has 2 × 40 MHz (Frequency Division Duplexing) and in 2400 MHz band has 70 MHz (Time Division Duplexing) remaining frequency resources for cellular use.

1.2 Problem Statement

World is digitizing in every aspects, so numbers of SRD (operates in licensed exempted band) are rapidly growing day by day. FR1 and FR2 5G candidate bands cellular allocated frequency are highly occupied, 5G especially while operating in FR1 and FR2 candidate band have to co-exist with SRD in same frequency or in adjacent frequency band to achieve larger bandwidth. Since, every system are vulnerable to interference for their proper operation, Interference is the main challenge we have to face in coexistence scenario of 5G and SRD. Before deployment of 5G system, there should have a proper interference analysis for compatibility between the system by exploiting possible probability of interference and corresponding impact analysis in coexistence scenario.

1.3 Objective

The prime objectives of this research work on interference analysis of 5G coexistence with short range devices (SRD) is:

• Interference analysis of 5G on SRD and SRD to 5G system in coexistence scenario while sharing same frequency or operating in adjacent frequency band.

1.4 Literature Review

5G being emerging technology in cellular and commercial use, researchers are continuously working on its compatibility with incumbents in all 5G candidate band to identify and minimize possible potential interference in future 5G implementation.

Zaid A. Shamsan, S. K. Syed-Yusof & Tharek Abd. Rahman [2] discussed and analyzed interference in Coexistence between IMT-Advanced and Existing Fixed Systems operating in co-channel and adjacent channel taking co-sited and and non co-sited base station varying the separation distance and off-set frequency between two system.

Weidong Wang, Fei Zhou, Wei Huang, Ben Wang and Yinghai Zhang [3] studied the co-existence of two systems in 3400 3600 MHz based on the fixed satellite service (FSS) parameters in China. The analysis result suggested that LTE frequency offset from edge of fixed satellite service (FSS) channel should be above 10MHz for downlink and above 5 MHz for uplink in China.

W. Li, J. Chen, H. Long and B. Wu [4] analyzed the interference from the broadcasting system to the long term evolution (LTE) system with different distances between the two systems and suggested to locate broadcasting TV antenna system at the edge of the cell to ensure throughput loss of LTE below 5%.

F. Guidolin and M. Nekovee [5] In a scenario where both systems operate co-channel in the large spectrum bandwidth available around 28 GHz, the impact of interference caused by FSS radiation on the achievable capacity and throughput of 5G small cells was investigated using various multiple antenna configurations at base stations (BSs).

J. Kim, L. Xian and A. S. Sadri [6] studied the impact of the co-existence between a fixed service (FS) system and 5G small cell networks at 28 GHz, 38 GHz, and 60 GHz millimeter-wave (mmWave) frequency bands. Simulation result of this study determined that how much interference rejection is required to protect the operation of fixed service (FS).

STANKEVIČIUS [7] the possibility of LTE UL out of band emission at (852-862) MHz and its interference with Short Range Devices (SRD) operating in the nearby (863–879) MHz license exemption band were explored. The filter bank multicarrier approach (FBMC) has been proposed for out of band emission reduction, and the probability of interference with and without FBMC has been studied.

S. Kim, E. Visotsky, P. Moorut, K. Bechta, A. Ghosh and C. Dietrich [8] paper provides an extensive study of the co-channel coexistence of 5G in 28 GHz and 70 GHz band with Fixed Service (FS) and Fixed Satellite Service (FSS). Result sugested that interference from 5G into the FSS space stations can be kept below the FSS interference protection criterion at 28 GHz. Whereas in 70 GHz, interference found critical and suggested some mitigation technique to suppress interference to tolarable limit.

W. A. Hassan, H. Jo and A. R. Tharek [9] suggested that there is possibility to share spectrum between BS-BS but a lot of precaution should be taken such as separation distance of 182 Km in rural and 82 Km separation in urban environment based on Monte-Carlo (MC) approach. This study also has been recommended mm Wave band for 5G operation in near future.

Ancans, Guntis, et al. [10] briefly discussed about its investigation of future 5G potential band in the world and Europe as well as listed some 5G use case scenario. It also highlighted the interference analysis methodology, evaluation method and future research direction about interference mitigation.

Suzan Bayhan, Gürkan Gür, Anatolij Zubow [11] described about spectrum sharing in 5G and present key coexistence solutions, mostly in the context of WiFi.

Meng, Xi and Zhong, Liyuan and Zhou, Dong and Yang, Dacheng [12] investigated the intelligent co-channel coexistence between the 5G IoT system and the fixed-satellite service (FSS) system at 40 GHz. The key issue was identified, and different deployment scenario tested to minimize interference considering parameters such as antenna patterns, height of Earth station (ES), and separation distance.

Ekawibowo, Septi Andi and Haryadi, Sigit [13] the low band spectrum sharing between 5G and analog TV on the 700 MHz band could not be done, according to simulation results, because it required a 20-kilometer protective distance. The elevation angle of the ES 20° antenna demands a protective distance of 10 kilometers in the middle band 3.5 GHz sharing spectrum between 5G BS and ES FSS. In the high band 28 GHz, 5G AP with FSS can share spectrum without a protection distance for the antenna elevation angle ES 20° and a protection distance of 5 Km for the antenna elevation angle ES 0° and 10°.

R. Dionísio, T. Lolić and P. Torres [14] using an appropriate propagation model, offered an agnostic methodology for assessing radio interferences between different industrial IoT equipment on the manufacturing floor. As a result of the findings, legacy systems appear to be more susceptible to interference from other legacy systems. With Wifi as an interferer, legacy systems create a higher degradation in the UE Uplink channel at 5G band n53 and bitralte loss of up to 12

António Morgado, Kazi Mohammed Saidul Huq, Shahid Mumtaz, Jonathan Rodriguez [15], describes the requirements, regulatory frameworks, technologies and standardization efforts in a single document about 5G.

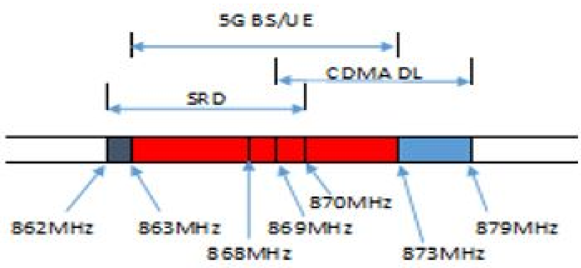


Figure 2: Proposed frequency allocation after 5G (Test purpose) in 868MHz (10MHz B/W)

Artist studied 3GPP release 15 and 16 which is related to 5G NR (UE and BS) technical specifications [9][10] for 5G. Whereas Release 16 of 3GPP provides guidance for NR-based access to unlicensed spectrum. Report ITU-R M.2292-0 "Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses", ITU-Recommendation [16] and other related topic has been studies as a standard and guidance materials.

From these literature revies, co-channel and adjacent channel coexistence system interference between the system can be done in different way at different frequency band. So based on the literature, Monte-carlo algorithm give more realistic result in interferene and compatibility study. So, in this thesis work, Monte-Carlo algorithm in the form of SEAMCAT simulator is used for interference analysis of 5G in coexistence scenario with Short Range Devices (SRD) in 850 MHz band.

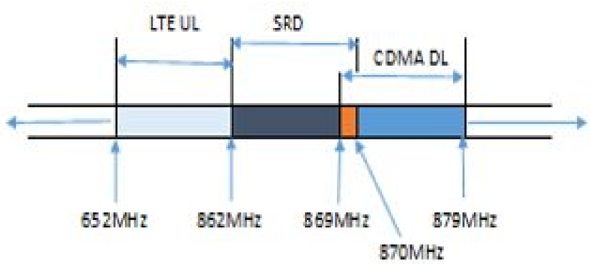


Figure 1: Current frequency occupancy at 850MHz band in Nepal

In context of Nepal, Government planning for deployment of 5G. Accordingly, Nepal Telecom Authority (NTA) studying and planning to test of 5G in lower 5G candidate band (below 1 GHz) and in mid-band (1-6 GHz). Almost frequency assigned for cellular system in lower band are occupied and very small spectrum 2×1.5 MHz (frequency division duplexing) at 850 MHz band and 2×3 MHz (frequency division duplexing) at 900 MHz band is remaining as per table 3. CDMA operating in band n5 i.e. 850 MHz band (824-834) MHz UL and (869-879) MHz DL is almost absolute. For the test purpose, it's better to choose frequency that uses some part of CDMA DL as well as license exempted band (862-870) MHz frequency. So, as per source of NTA 5G study team, 868 MHz frequency was assumed for 5G test purpose in this study. So interference analysis has been focused on coexistence scenario of 5G and SRD only in this study using Morte-carlo algorithm. Current frequency occupation and possible 5G test plan frequency allocation has been dipicted in fugure 1 and 2 respectively.

2. Methodology

2.1 Statistical Interference Analysis methodology

For the statistical analysis of 5G interference in a short-range device coexistence (SRD) scenario, a popular model in the field of co-channel and adjacent channel interference analysis was developed within the framework of the European Conference. by the postal and telecommunications regulator (CEPT) called MonteCarlo in simulation (SEAMCAT)[17] was used to analyze the interference of one system to another in co-existence scenario of 5G and SRD in 850 MHz band, we considered the 5G operational frequency at 868 MHz band with 10 MHz bandwidth, whereas SRD's operates in licensed exempted (863 – 870) MHz band. There are two main potential interference scenarios, 5G to SRD interference and SRD to 5G interference. SRD's operates mostly in indoor operation with low power, so most probable coexistence exists between 5G UE and SRD's in indoor environment i.e. within same room or close proximity. So, interference over SRD's from UE as well as over user equipment (UE) from SRD's are considered for analysis in this work.

The requirement for interference to occur over SRDs from 5G is a carrier to interference plus noise ratio (C/(N+I)) less than the minimum permitted value of 8dBm. To calculate the C/(N+I) of the SRD receiver, we must first determine the desired signal from the SRD transmitter, which corresponds to the C, the signal produced by the interfering transmitter, which corresponds to the I, and the thermal noise, which corresponds to the N. Similarly, for interference from SRDs over 5G UE, an interference to noise ratio (I/N)

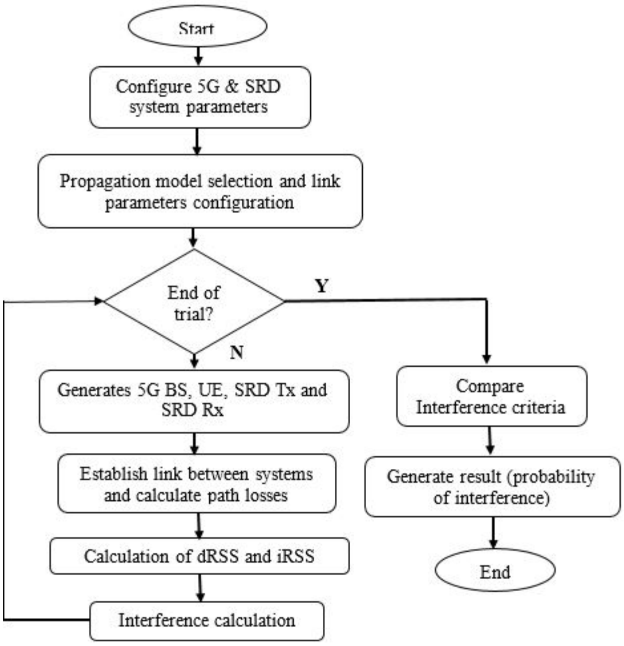


Figure 3: Flow chart for statistical interference analysis approach

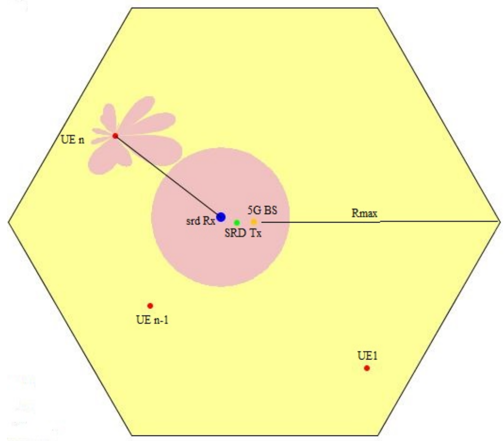


Figure 4: 5G and SRD system generation and link establishment

of less than -6dBm is required for interference to occur.

This is done defining technical parameters for each system; this includes the receiver and transmitter specifications, the propagation model associated with the medium of communication and a measure of the quality of service required. The position of the SRD transmitter and the SRD receiver is identified and a link budget is computed. The same process occurs for the interfering system. Having knowledge of both the desired signal and the interfering signal allows the I/N and C/(N+I) to be computed for 5G UE and SRD receiver respectively while operating as victim system, using a Monte-Carlo technique.

For the statistical approach of interference analysis, the main components of general methodology are as shown in figure 3. The methodology used in this work is based on the Recommendation ITU-R M.2101 [16] to assess the statistical distribution of interference over victim system.

2.2 Overview of methodology Flow Chart

All the parameters such as antenna pointing (azimuth and elevation), antenna height, radiation pattern, antenna Gain, transmitter emission characteristics such as power distribution, emission mask, transmitting power, power control factor, operating frequency, operating bandwidth, receiver characteristics such as noise floor, blocking mode, blocking mask, reception bandwidth, sensitivity etc. of both interfering system and victim system was defined in this work based on 3rd generation partnership program (3GPP) released technical specifications of 5G BS and user equipment. For the operation of 5G and SRD in 850MHz band, Extended Hata and Extended Hata SRD are used for path loss calculation of 5G system link and SRD system link respectively Before run the simulation, simulator checks consistency of all defined parameters related to 5G, SRD and link systems. Based on defined system and link parameters, 5G base station, user equipment, short range devices transmitter/receiver are generated and system establish link between 5G BS and UE, SRD Tx and Rx as well as interference link between 5G and SRD too as shown in figure 4.

The SEAMCAT simulation (Event Generation) uses the relevant radio system as well as link parameters from a proposed simulation interference scenario and parameters definition that generates samples (snapshot) from the relevant data. For N number of trials defined as simulation parameter control, N snapshot are generated which includes different simulation parameters from given range of input defined. The generated samples are processed to calculate the desired (wanted) received signal strength (dRSS) and all interfering (unwanted) signal strengths (iRSS).

General formula to calculate desired received signal strength (iRSS) used in our simulation,

dRSS=P(Vt)+G(Vt)-PL(Vt→Vr)+G(Vr)–A(Vr)

Where, P(Vt)= maximum power of victim (desired) transmitter antenna

G(Vt)= gain of the victim transmitter(Vt) (includes GVLT→VLR=GVLT(max)*Pattern(VLT)(θVLT→VLR, φVLT→VLR)

G(Vr) = gain of victim receiver (Vr) (includes GVLR→VLT=GVLR(max) * Pattern(VLR)(θVLR→VLT, φVLR→VLT)

PL(Vt → Vr)= path loss between the victim transmitter (Vt) and the victim receiver (Vr) (propagation loss, slow fading and clutter losses taken in account)

A(Vr)= attenuation by Victim receiver (Vr)

The unwanted signal strength on victim system receiver from interfering system transmitter either they may use same frequency band or adjacent frequency band generates iRSS.

General formula to calculate Interference received signal strength (iRSS) used in our simulation,

iRSS=(PIt+GIt+GVr+GItPC-PL(It→Vr)-AVr)

Where, PIt= maximum power of interfering transmitter antenna

GIt= Interfering transmitter (It) Gain (Includes GILT→VLR=GILT(max) * Pattern(ILT)(θILT→VLR,φILT→VLR)

GVr= Victim receiver (Vr) Gain (includes GVLR→ILT=GVLR(max) * Pattern(VLR)(θVLR→ILT,φVLR→ILT)

GItPC = Power control of interfering transmitter

PL(It→Vr)= path loss between the interfering transmitter (It) and the victim receiver(Vr) (propagation loss, slow fading and clutter losses taken in account)

AVr= attenuation by victim receiver (Vr)

For the interference analysis of SRD victim receiver from 5G system, we used C/(N+I) criteria in our work. Whereas for interference analysis of 5G system from SRD, we used I/N criteria.

3. Scenario and Simulation setup

All the simulation scenario use in statistical interference analysis consists of one victim link and one or more interfering links and networks that operates in same or in adjacent frequency band. Typical coexistence scenario consists of urban 5G micro base station and randomly distribution of 5G UE within the coverage of BS. Short range devices mostly operates in indoor environment e.g. within same room, same building or different buildings but within coverage area of 5G system

Possible coexistence of 5G UE and SRD in indoor environments are:

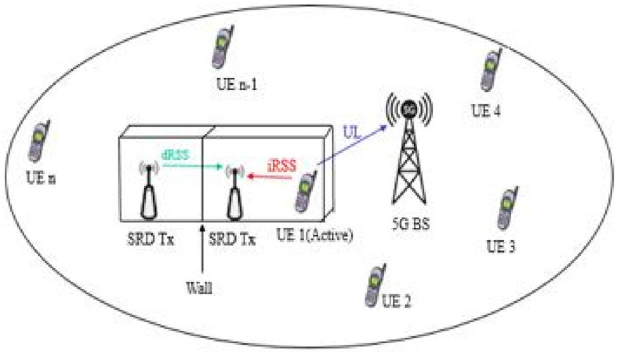
i. Interfering transmitters and victim receiver within same room.

ii. Interfering transmitters and victim receiver in different room within same building.

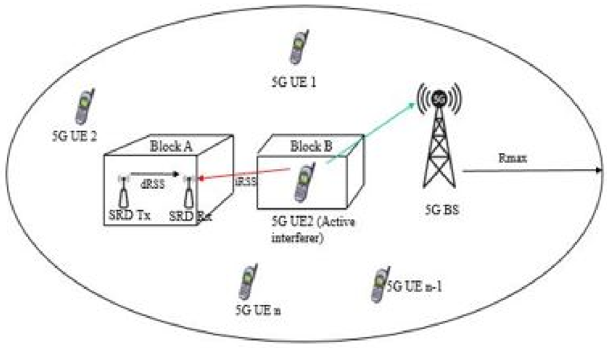
iii. Interfering transmitters and victim receiver in different buildings.

Potential interference scenario in co-existence of 5G and SRD in indoor environment are given in figure 5 and 6.

5G and SRD's system related simulation parameters and propagation model used has been given in table 3 and 4 respectively. Other general assumptions are Indoor room size 4 ×4×3 m3 , wall assumed to be concrete and wall loss = 5dB ± 3dB, adjacent floor



(a) Indoor scenario for SRD Tx and Rx in in same building but within same or different room



(b) Scenario for interfering Tx and Victim Rx in different buildings

Figure 5: Scenario and Simulation setup

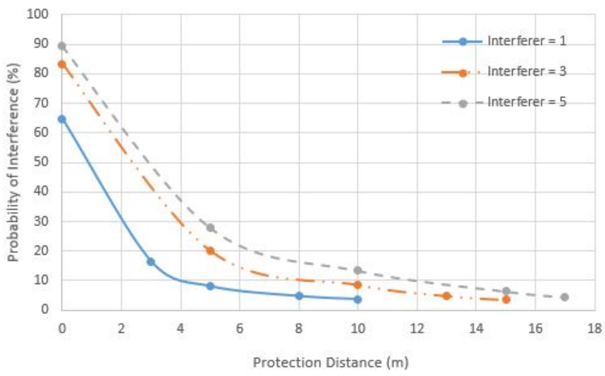


Figure 6: Probability of interference over SRD Annex 1 from 5G UE for interference criteria C/(N+I) = 8dBm

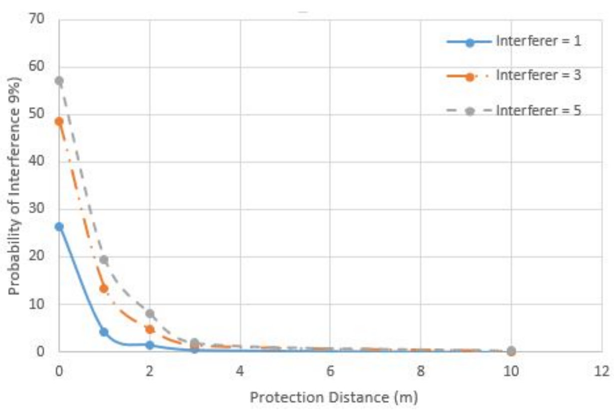


Figure 7: Probability of interference over SRD Annex 7 from 5G UE for interference criteria C/(N+I) = 8dBm

loss = 10 dB, Minimum coupling loss of 5G = 70 dBm.

4. Result, Discussion and Analysis

4.1 Interference over SRD's from 5G UE

For each case, 20000 simulation trials have was performed to calculate the probability of interference over SRD's from 5G user equipment's (UE) as a function of separation/protection distance (PD) between interfering transmitter and victim receiver as well cases of single and multiple interferers (1, 3 and 5) present around the victim receiver. The simulation result thus obtained for predefined victim receiver interference criteria C/(N+I) = 8 dBm has been shown below for each SRD victim receiver operating in (863 – 870) MHz frequency band.

Result discussion and analysis of 5G UE to SRD interference:

Table 3: Simulation Parameters

(a) 5G systems simulation parameters

Parameters	Values	Remarks/References
Frequency	868MHz (863 – 873) MHz	Given for test purpose from 5G FR1 (lower band)
System Bandwidth	10MHz	
No. of Resource block per Base station	52	
Sub carrier Spacing (SCS)	15/30/60/120	
Resource block Bandwidth	180 KHz	
BS Receiver Noise figure	5/10/15 dB (wide/medium/local area)	
BS trans receiver sensitivity	-101.7 dBm (wide area) -96.7 dBm (medium) -93.7dBm (low area)	
Emission mask	5G NR 10MHz UE below 1GHz	
Base station height	30m (outdoor)	
Mobile station height	1.5m	70 % indoor, 30% outdoor
Base station antenna pattern	3GPP tri-sector (60deg)/ Beam forming (8×8)	
Base station antenna gain	15dBi	
Base station antenna tilt	-3 degree	
Max. allowable MS Tx power	23dBm (min. -40dBm)	
Mobile station antenna pattern	Omni-directional/sectoral/ Beam forming (4×4)	Rec. ITU-R M.2101-0 (wide area coverage / Small area coverage)
MS antenna gain	0 dBi	
MS receiver Noise Figure	7dB	
Cell	Single Omni/3GPP trisector Cell	
Propagation model	Extended Hata	(Rural / Suburban / Urban) (Indoor/outdoor)

(b) SRD systems simulation parameters

Parameters	Values				Remarks
	SRD Annex 10	SRD Annex 1	SRD Annex 7	SRD Annex 13	
Frequency	864.25 MHz	868.1 MHz	869.65 MHz	864.975 MHz	ETSI TS 300 220 1 v3.1.1/ECC report 207 CEPT/ERC/REC 70-03[15],
Reception Bandwidth	200 KHz	100 KHz	25 KHz	50 KHz	[15]
Blocking mask	SRD cat 2 Blocking mask	SRD cat2 blocking mask	SRD cat2 blocking mask	SRD cat2 blocking mask	Design depends on system bandwidth of SRD
Noise figure	6.5 dBm	6.5 dBm	6.5 dBm	6.5 dBm	
Noise floor	-114.5 dBm	-117.5 dBm	-123.5 dBm	-120.5 dBm	
Sensitivity	-90.0 dBm	-101.0 dBm	-107.0 dBm	-104.0 dBm	
Max. radiated peak power	25mWatt (14dBm)	25mWatt (14dBm)	25 mWatt (14dBm)	10 dBm	
Antenna height	1.5m (indoor)	1.5m (indoor)	1.5m (indoor)	1.5m (indoor)	
Coverage	30m	30m	30m	30m	
C/(N+I) criteria	8 dBm (digital microphone/ 17dBm analog)	8 dBm	8 dBm	8 dBm	
Emission mask	Wireless microphone digital	SRD Annex 1	SRD Annex 7	SRD Annex 13	EN 300 422.1
Antenna pattern	Omni-directional antenna	Omni-directional antenna	Omni-directional antenna	Omni-directional antenna	
Propagation model	Extended Hata SRD	Extended Hata SRD	Extended Hata SRD	Extended Hata SRD	

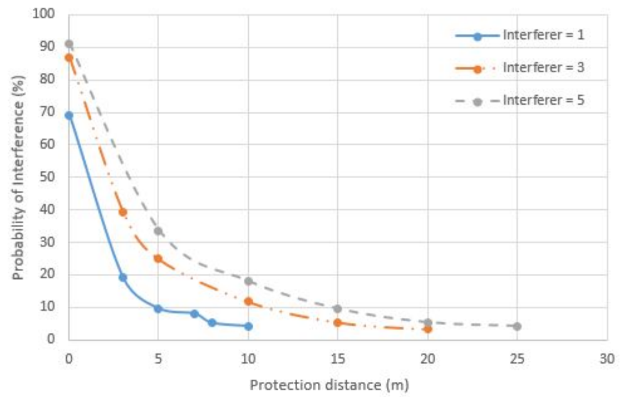


Figure 8: Probability of interference over SRD Annex 10 from 5G UE for interference criteria C/(N+I) = 8dBm

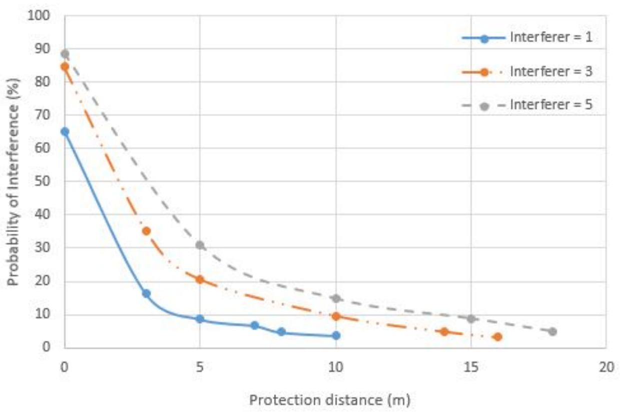


Figure 9: Probability of interference over SRD Annex 13 from 5G UE for interference criteria C/(N+I) = 8dBm

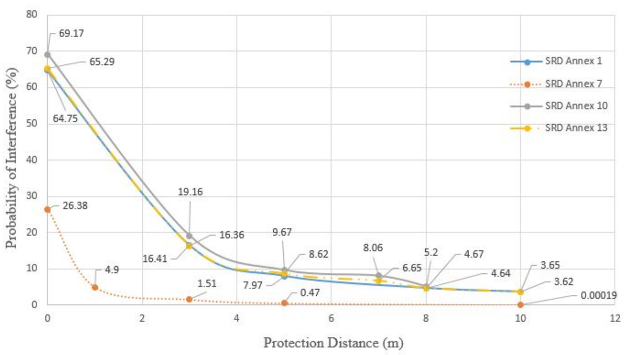


Figure 10: Comparison of probability of interference from UE to SRD's for single interferer case, interference criteria C/(N+I) = 8 dBm

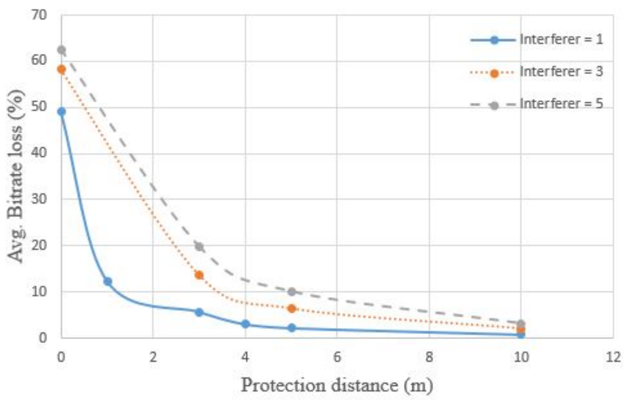


Figure 11: Bitrate degradation of 5G downlink network due to interference from SRD Annex 1, Interference criteria I/N = -6dB for UE

Results shows that probability of interference are severs when 5G UE and SRD's co-located within indoor environment and gradually decreses as distance between interfering transmitter and victim receiver increases as shown in figure 5, 6, 7 and 8 for each SRD Annex. In other hand, while increasing the number of interferers, aggregate probability of interference over victim receiver increases as shown in same results. Whereas result in figure 9 compare the probability of interference overs different SRD's from UE for the same simulation scenarios. Based on the result, interference over SRD Annex 7 found minimum and interfering transmitter and victim receiver can run in coexistence indoor scenario maintaining at least 3m separation distance between then that ensures the probability of interference below 5%. Whereas for remaining SRD's operation, separation distance have to at least 8m to ensure the reliable operation of victim receiver.

4.2 Interference over 5G UE from SRD

Assuming the same system parameters and scenario, simulation results provides the interference interm of bitrate degradation of 5G downlink network where 5G UE was assumed a victim receiver.

Result discussion and analysis of SRD to 5G UE interference:

Results in figure 10, 11 ,12 and 13 shows that bitrate degradation of 5G downlink network is sever when interfering transmitter and victim receiver co-located in indoor environment. As protection distance between interfering transmitter and victim receiver increases, average bitrate loss gradually decreases at first and then slowly decreasing while moving away to

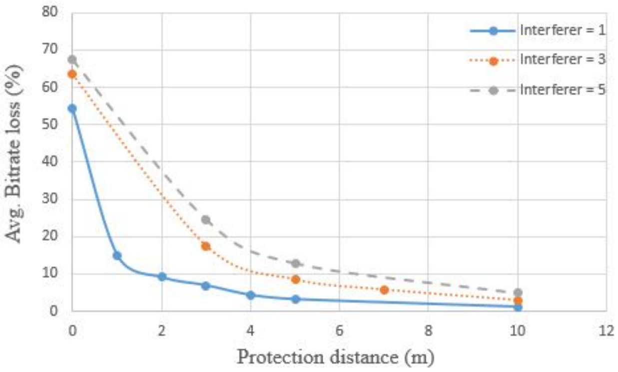


Figure 12: Bitrate degradation of 5G downlink network due to interference from SRD Annex 7, Interference criteria I/N = -6dB for UE

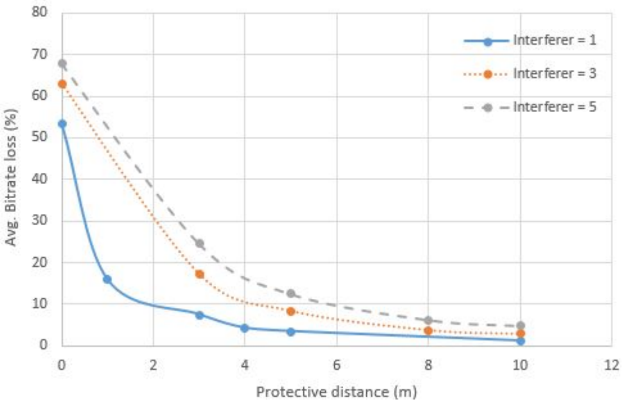


Figure 13: Bitrate degradation of 5G downlink network due to interference from SRD Annex 10, Interference criteria I/N = -6dB for UE

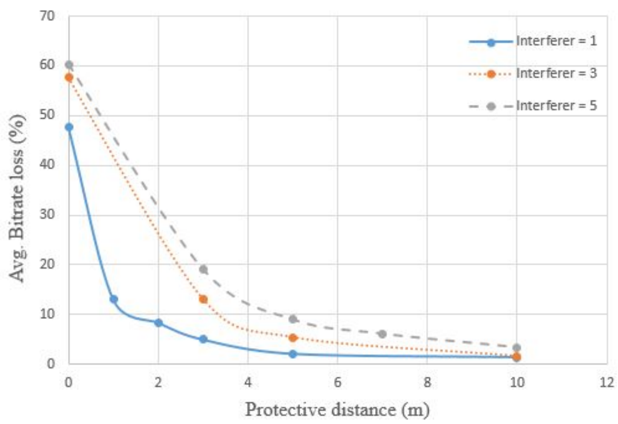


Figure 14: Bitrate degradation of 5G downlink network due to interference from SRD Annex 13, Interference criteria I/N = -6dB for UE

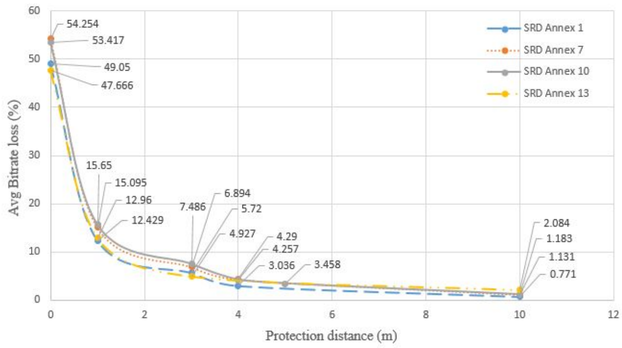


Figure 15: Comparison of average bitrate loss for 5G network BS downlink received by UE due to interference from SRD Annex 1, 7, 10 and 13, considering interference criteria I/N = -6 dB in single interferer case

each other. As number of interferers around victim receiver increases, bitrate degradation increases accordingly as shown in entioned figure. Figure 14 is comparison of interference over 5G downlink network interms of bitrate degradation from different SRD's considering single interferer case. Result shows that keeping protection distance between interfering transmitter and victime receiver at least 3 m only ensures the bitrate degradation of 5G downlink network below 5% at the UE end.

5. Conclusion, Recommendation and Future Research Direction

SEAMCAT was used an agnostic simulation tool to perform a detail interference analysis of 5G system and Short Range Devices in indoor co-existence operating both in 850 MHz band as a function of separation distance, number of interferers and interference criteria. From simulation results, we concluded that in indoor operation of 5G UE and SRD's, interference over SRD's from 5G UE is more severe than interference from SRD to UE for the same interference scenario. Based on the simulation result in figure 11, single 5G UE and SRD Annex 7 can co-exists within distance of 1m ensuring the probability of interference below 5%, whereas others SRD's of Annex 1, 10 and 10 required minimum protection distance of 8m. Whereas from simulation in figure 16, to ensure the bitrate loss below 5% of 5G downlink system due to SRD interferences, minimum required separation distance is 3m. Finally, to ensure the reliable system operation of both 5G and SRD system keeping interference level below 5%, Without any further mitigation technique implies, mandatorily recommended that to maintain protection distance at least 3m for the coexistence of 5G and SRD Annex 7 whereas, 8m for coexistence of 5G with other SRD Annexes (1, 10 and 13) in indoor environment other than in case of any further mitigation technique implies.

Notably, this type of coexistence analysis is not only essential but also mandatory before 5G system deployment to confirm whether 5G system operation is compatible or not in frequency sharing or operating in adjacent band scenario. This study expressed for instances in term of probability of interference or bitrate loss, so, future research direction may have an evaluation, definition and validation of rules and conditions under which new or evolved technologies that design proper framework for spectrum sharing and minimizes probability of interference allowing the compatible co-existence of 5G and SRD's not only in this band but also on mid and higher 5G candidate band .

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