Heliyon 7 (2021) e07412

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Evaluation of adjacent channel interference from land-earth station in motion to 5G radio access network in the Ka-frequency band

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A R T I C L E I N F O

Keywords:
Compatibility
Land-mobile earth station in motion
Adjacent channel interference
5G radio access network
Minimum coupling loss

A B S T R A C T

As the fifth-generation (5G) mobile communication service is expected to operate in one of the 11 candidate frequency bands of 24.25–27.5 GHz, compatibility and coexistence with other adjacent wireless applications must be evaluated. In this paper, the adjacent channel interference (ACI) between Land-Earth Station in Motion (L-ESIM), 5G base station (BS), and user equipment (UE) operating in the adjacent frequency bands is assessed. The minimum coupling loss (MCL) method is used by considering the worst-case scenario to evaluate the effect of geostationary orbit-fixed satellite service's (GSO-FSS) frequency band of 27.5–29.5 GHz on the 5G radio access network (BS and UE) from L-ESIM. From the numerical simulations, minimum separation distances of 35 km and 12 km were recorded for the BS and UE to meet the maximum acceptable interference of -147 dBW/MHz. The obtained results will protect the 5G RAN from harmful interference by ensuring adjacent channel compatibility and coexistence with L-ESIM in their future deployment.

1. Introduction

Earth Stations in Motion (ESIM) communicating with the Geostationary Orbit (GSO) Fixed Satellite Service (FSS) systems in the Ka-spectrum band is one of the satellite communications technology requirements needed for reliable and seamless broadband connectivity. ESIM will satisfy users' demands for worldwide internet, voice, applications, and other multimedia connectivity through the harmonious integration and compatibility of satellite and terrestrial communications systems [1].

ESIM is a recent advanced satellite mobile earth station technology installed on vehicles, ships/vessels, and aircraft. It provides high-power multiple-beam coverage with small-sized, highly directive, and high precision tracking antenna capabilities. At World Radiocommunication Conference-2015 (WRC-15), WRC-19 agenda item 1.5 was adopted for ESIM to operate in 17.7–19.7GHz (downlink) and 27.5–29.5GHz (uplink) with GSO-FSS. The operation of ESIM is classified into Land-ESIM (L-ESIM), Aeronautical-ESIM (A-ESIM), and Maritime-ESIM (M-ESIM) with an expected transmission data rate of approximately 100 Mbps [2].

The fifth-generation (5G) of mobile technologies is expected to connect things, data, people, applications, cities, and transport systems in smart grid communication environments [1]. The 5G is also expected to be commercialized in 2020 with a peak data rate of 20Gbps, enhanced mobile broadband (eMBB), massive machine-type communications (mMTC), and ultra-reliable low latency communications (URLCC) [3]. Moreover, 5G requires more spectrum due to the increased capacity and data rates promised and vastly more spectrally efficient technologies beyond what is currently used in 3G and 4G systems. Among the 11 candidates' band set for 5G technologies set by ITU [1], 24.25–27.5GHz is contiguous to the ESIM's uplink transmission band of 27.5–29.5GHz. This makes it necessary to study the coexistence and compatibility between these two systems using the adjacent channel interference scenario.

S. K. Menanor et al. [4] analyzed the compatibility of co-channel interference scenario between L-ESIM, and fixed service (FS) station operating in the 28 GHz frequency. A separation distance of 33 km was recorded to meet the maximum allowable interference of -139.52 dB/MHz using MCL method between the systems for tolerable coexistence. In [5], the ACI from M-ESIM to 5G was studied, and numerical simulation result showed a minimum separation distance of 27 km that was required between these systems considering the worst-case scenario. Also, authors in [6] considered the effect of ACI on 5G BS and UE from an A-ESIM using the MCL method. In their study, two simulation cases were considered: A-ESIM with fuselage loss and without fuselage loss. The separation altitude of 670m and 380m with fuselage loss for BS and UE,

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https://doi.org/10.1016/j.heliyon.2021.e07412
Received 7 April 2021; Received in revised form 6 May 2021; Accepted 23 June 2021

and 1150m and 3180m without fuselage loss for BS and UE, respectively, were recorded when the elevation angle was set at 5°.

This paper aims to investigate the effects of adjacent channel interference (ACI) from L-ESIM's uplink communications with GSO-FSS to 5G RAN (BS/UE) in the Ka-band using the minimum coupling loss (MCL) method. The MCL method analyses interference effects between a single transmitting interferer and a single victim receiver assuming the worst-case scenario. The MCL method provides a minimum separation distance for compatibility and tolerable coexistence. The recent beamforming antenna pattern of 5G is also analyzed to obtain the BS and UE peak gains used for the ACI analyses.

The remainder of this paper is arranged as follows: the interference methodology analyses are presented in section 2, while section 3 presents the parameters used in the analyses. Simulation results are provided in section 4, and section 5 gives the conclusion of the studies.

2. Methodology analyses

2.1. Interference scenario analyses between L-ESIM and 5G RAN

The system model configuration for interference assessment between L-ESIM and 5G RAN is shown in Figure 1 below. The interference scenario model of ESIM with 5G RAN is dependent on the type of ESIM, which is specified according to the environment of operation. For this case, the L-ESIM terminal applies the propagation loss modeled by the International Telecommunication Union Radiocommunication Sector (ITU-R) [7]. This model works from the assumption that the L-ESIM interfering transmitter and 5G RAN interfered-with receiver operate within the surface layer of the atmosphere., The propagation model has been tested and recommended for radio stations operating in the frequency range from 0.1 GHz to 50 GHz. The L-ESIM antenna points to a fixed satellite service (FSS) in the Geostationary Orbit (GSO). This direction is defined as the uplink direction, which forms an elevation angle θ_{ele} with the L-ESIM horizontal direction. The L-ESIM's effective isotropic radiated power (EIRP) is determined by the off-axis angle, φ_{off}, and the interference is transmitted along the interfering path from the L-ESIM to 5G RAN.

2.2. Minimum coupling loss (MCL)

The MCL method is used in this research to compute the isolation required between ESIM, and 5G RAN to ensure that no interference hinders the performance of the 5G service by maintaining the desired throughput. The MCL method allows rough simulation for the worst-case interference scenario where the coupling loss between the two systems is the smallest. It is used to deal with a one-to-one interference analysis: a single transmitter and a single receiver. The MCL analysis is made where a single micro-BS or a single UE receives interference from a single L-ESIM transmitter. The MCL between an interfering transmitter (Tx) and a victim receiver (Rx) is described in [8].

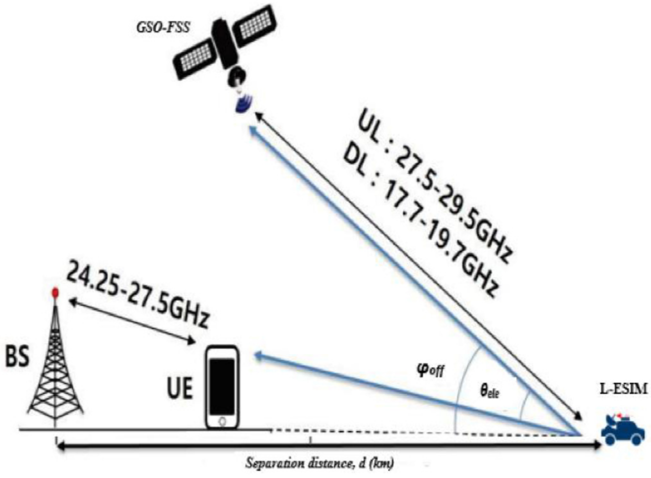

Figure 1. Interference scenario between L-ESIM and 5G RAN.

2.3. Protection criteria/ratio (I/N)

The protection ratio concept was used as a generic interference management methodology and criterion, defined by a minimum ratio of relative levels of wanted and unwanted signals at the victim input. The victim sets the protection ratio as the criterion for maximum acceptable interference to limit harmful interference levels. Coexistence and compatibility are only possible when the interference power level is less than the maximum acceptable interference level. The maximum acceptable interference level at the receiver input of 5G victim is defined as [9]:

$$I_{max} = {}^{I}\!/_{N} + N \tag{1}$$

where I_{max} is the maximum acceptable interference level, I is the received interference power level the 5G system can tolerate. N is the 5G RAN noise power level, and it is the amount of noise power added by the electronic circuitry of the 5G consisting of the thermal noise power. The victim receiver's noise power is defined below as in [10]:

$$N = -174 + 10\log_{10}(B_R) + NF \tag{2}$$

where B_R is the bandwidth of victim receiver in MHz and NF is its noise figure in dB, which measures the degradation of the signal-to-noise ratio (SNR) of the 5G RAN victim receiver.

2.4. Adjacent channel interference (ACI)

ACI results from signals that are adjacent in frequency to the desired signal and is due to imperfect receiver filters, which allow nearby frequencies to move into the passband and nonlinearity of the amplifiers. Unwanted emissions cause radio wave interference between two systems operating in adjacent bands at the transmitting end. Unwanted emission is unwanted radio wave radiations in unwanted bands other than the designed frequency band of the transmitter. Due to this, the radio system operating in the adjacent frequency band is subjected to interference, which can be expressed as [6]:

$$I_{ACI}\ (dBW) = E_{ESIM} + G_r - L_p - L_A - L_{ACIR} \tag{3}$$

where E_{ESIM} is the effective isotropic radiated power in dBW/40 KHz, G_r is the receiver gain of 5G, L_A is additional loss of 5G such as Ohmic loss and body loss. Ohmic loss is due to a drop in voltage across 5G cells during the passing of current due to the cells' internal resistance. Body loss indicates loss due to signal absorption and blocking when a terminal is close to the body affecting UEs. L_P is the transmission loss due to free space propagation, and L_{ACIR} is loss due to adjacent interference ratio between systems in adjacent band.

The received interference power at the input of the receiver victim can also be computed for radiocommunication services considering gains and losses between the systems to determine the signal strength at the victim receiver. The received interference power from L-ESIM to the input of the 5G RAN victim is also expressed as in [11]:

$$I_{ACI}\ (dBW) = P_t + G_t + G_r - L_p - L_A - FDR(\Delta f) \tag{4}$$

where P_t is interfering L-ESIM's transmit power density in dBW/Hz, G_t is antenna gain of the interferer in dBi, and the other parameters as defined in (3) above. For interference analysis in adjacent bands, FDR(Δf) is replaced with L_{ACIR} and expressed as:

$$I_{ACI}\ (dBW) = P_t + G_t + G_r - L_p - L_A - L_{ACIR} \tag{5}$$

To guarantee coexistence between these two systems, I_{ACI} must be less than or equal to I_{max} (i.e., $I_{ACI} \leq I_{max}$).

2.5. Propagation loss model

For separation or protection distance which is the minimum physical geographical separation between L-ESIM and 5G RAN, the basic transmission loss due to free space propagation considering the worst-case scenario between the systems is expressed below as described in [7]:

$$L_p = 92.45 + 20\log_{10}(f) + 20\log_{10}(d) \tag{6}$$

where *f* is the frequency of operation of L-ESIM and d is the separation distance between the L-ESIM and 5G RAN. A complementary model of Eq. (6) considers extra attenuation due to diffraction loss, atmospheric gas attenuation, and clutter loss to predict the interference on 5G BS/UE and is expressed as:

$$L_p = 92.45 + 20\log_{10}(f) + 20\log_{10}(d) + L_d + A_h + A_g \tag{7}$$

where L_d is diffraction loss, A_g is attenuation due to atmospheric gaseous absorption, and A_h is clutter loss which is additional loss of ground scattering (buildings, vegetation, etc.).

The loss due to diffraction L_d considered, assumed a knife-edge located obstacle centered in the middle between the interferer and victim systems and is defined by [12]:

$$L_d = 6.9 + 20\log_{10}\sqrt{\left((v-0.1)^2+1\right)} + v - 0.1 \tag{8}$$

$$v = \theta\sqrt{\frac{d \times 10^3}{2\lambda}} \tag{9}$$

where θ is the angle of diffraction with a value of 0.01 radians is used in this analysis.

A clutter loss of 18.5 dB is taken for dense urban areas as specified in [13].

The attenuation, Ag due to atmospheric gaseous absorption comprises attenuation due to oxygen and water vapor for frequencies less than 57 GHz as defined in [14]:

$$A_g = (\gamma_o + \gamma_w)d \tag{10}$$

where γ_o, γ_w are the attenuations due to oxygen and water vapor, respectively, and *d* is the path length between interferer and victim systems in km.

2.6. Adjacent channel interference ratio

ACIR refers to the ratio of the output power from the transmission channel band of the L-ESIM transmitter to the power received in the adjacent band of the 5G RAN victim receiver. ACIR is a measure of the interference effect between two radio systems in adjacent bands [5] and is expressed as:

$$L_{ACIR} = 10\log_{10}\left(\left(\frac{1}{10^{\frac{ACLR}{10}}} + \frac{1}{10^{\frac{ACS}{10}}}\right)^{-1}\right) \tag{11}$$

where L_{ACLR} is loss due to the adjacent channel leakage ratio (ACLR) of the L-ESIM interferer and is the ratio between power in a transmission channel band and power leakage into an adjacent band. This ACLR concept is helpful for the analysis of compatibility between two systems operating in adjacent frequencies. ACS is an adjacent channel selectivity (ACS) of the 5G victim receiver, defining the ability to suppress the signal from the adjacent channel of the interferer. The ACLR and ACS parameters, when combined, determine the total leakage between two transmissions on adjacent channels.

2.7. Effective isotropic radiated power (EIRP)

EIRP is the sum of the output transmitted power and antenna gain of the L-ESIM interferer. The EIRP level of L-ESIM is determined according to where the antenna is directed and the off-axis angle (φ_{off}) formed. Some discontinuous patterns may appear since this pattern is to limit the output of the satellite earth station.

Generally, L-ESIM will make an elevation angle as it communicates with the GSO-FSS where off-axis emission to the horizon will cause radio interference to the 5G network. The off-axis e.i.r.p spectral density (ESD) mask in 40 kHz has been specified in [15] as a transmitting characteristic for compatibility and coexistence studies between ESIM and incumbent services.

$$E_{ESIM}(\varphi_{off})\left[\frac{\text{dBw}}{\text{40KHz}}\right] = \begin{cases} 19 - 25\log_{10}\varphi_{off} & \text{if} \quad 2^\circ \le \varphi_{off} \le 7^\circ \\ -2 & \text{if} \quad 7^\circ < \varphi_{off} \le 9.2^\circ \\ 22 - \log_{10}\varphi_{off} & \text{if} \quad 9.2^\circ < \varphi_{off} \le 48^\circ \\ -10 & \text{if} \quad 48^\circ < \varphi_{off} \le 180 \end{cases} \tag{12}$$

Eq. (12) above is the off-axis e.i.r.p. density mask as specified in [15]. The off-axis e.i.r.p density levels are determined by the sidelobe gain, transmitter output power level, and the spectral distribution of that power. Figure 2 below shows the off-axis e.i.r.p density levels from an ESIM, which is determined according to the point where the antenna is directed, known as its elevation angle (θ_{ele}) and the off-axis angle (φ_{off}) formed. It is observed that the ESD is constant at -10 dBW/40 KHz for off-axis angles above 48°, as illustrated in Figure 2 below.

2.8. Antenna pattern modeling of 5G BS/UE

The receive antenna pattern of 5G is specified by the sum of the element pattern and array pattern. The array pattern implements 3D beamforming, and the gain is determined by the antenna array after the UEs and BSs are connected. The beamforming of 5G is applicable to compensate for high path loss which is a disadvantage of millimeter-wave frequency bands. Figure 3 below illustrates the parameters defining the beamforming antenna pattern based on an antenna array. The antenna array consists of several identical radiating elements located in the YZ-plane with a fixed separation distance of λ/2. All elements have identical radiation patterns with maximum directivity along the x-axis. The azimuth and elevation angles of the signal direction are defined as phi (φ) and theta (θ) respectively, with φ ranging from -180° to 180° and θ from 0° to 180°. The beamforming antenna gain between 5G BSs and UEs is defined by the horizontal and vertical radiation patterns that combinedly form the single element pattern, which is added to create the composite antenna pattern. The composite antenna pattern is used to serve one or more UEs with one or more beams indicated by the parameter 'i', as defined in [3]. Below are described the 5G beamforming antenna model:

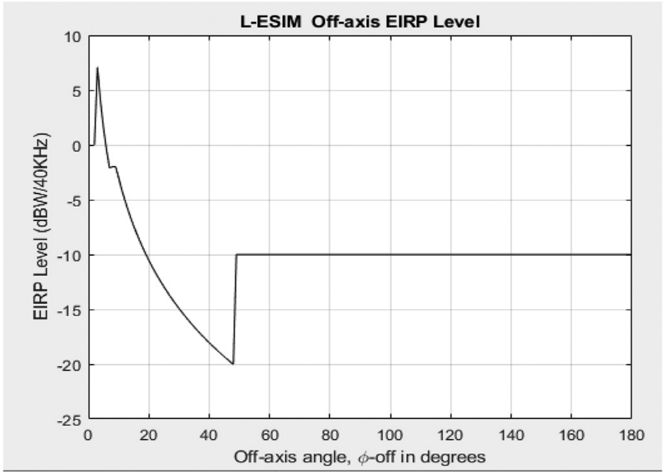

Figure 2. L-ESIM Off-Axis EIRP Levels at 40 kHz.

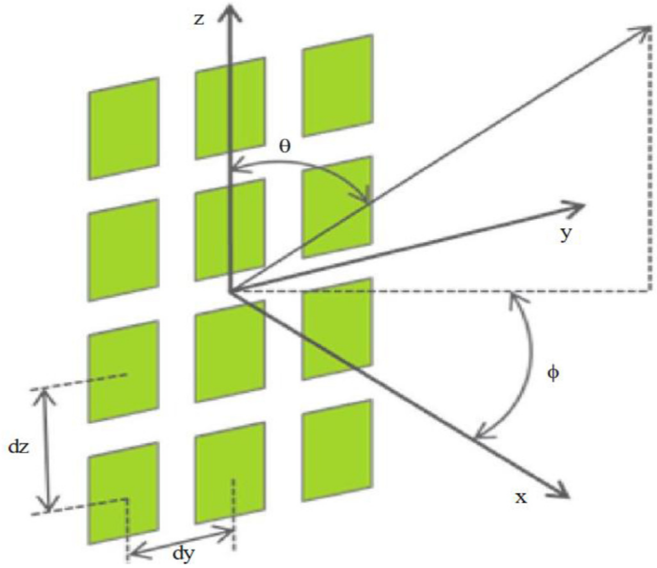

Figure 3. 5G antenna model geometry [3].

$$A_{E,H}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, \quad A_m\right] dB \qquad (13)$$

$$A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta - 90^\circ}{\theta_{3dB}}\right)^2, \quad SLA_v\right] dB \qquad (14)$$

$$A_E(\varphi,\theta) = G_{E,max} - \min\{-|A_{E,H}(\varphi) + A_{E,V}(\theta)|, A_m\} \qquad (15)$$

$$A_{A,Beami}(\theta,\varphi) = A_E(\varphi,\theta) + 10\log_{10}\left(\left|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} W_{i,n,m}\cdot V_{n,m}\right|^2\right) \qquad (16)$$

where $A_{E,\,H}(\varphi)$ is horizontal radiation pattern, $A_{E,\,V}(\theta)$ is vertical radiation pattern, $A_E(\varphi,\theta)$ is single element radiation pattern. A_m is the front-to-back ratio of power radiated in the main radiation lobe and the power radiated in the opposite direction (180° from the main lobe). SLA_v is the maximum sidelobe attenuation, $A_{A,\,Beami}$ is the composite antenna pattern that forms the logarithmic sum of the array gain and the single element gain as shown above. The parameters $V_{n,\,m}$ and $W_{i,\,n,\,m}$ are respectively the superposition vector and weighting function to steer the beam in various directions as described below in [3]. N_H and N_V are the total numbers of horizontal and vertical elements (represent the antenna elements' configuration), n is the number of horizontal elements (n = 1, 2…, N_H), and m the number of vertical elements (n = 1, 2, …, N_V).

$$V_{n,m} = \exp\left(\sqrt{-1}\,.2\pi(n-1).\frac{d_V}{\lambda}.\cos(\theta) + (m-1).\frac{d_H}{\lambda}\sin(\theta).\sin(\varphi)\right) \qquad (17)$$

$$W_{i,n,m} = \frac{1}{\sqrt{N_H N_V}}\exp\left(\sqrt{-1}.2\pi(n-1).\frac{d_V}{\lambda}.\sin(\theta_{i,etilt}) - (m-1).\frac{d_H}{\lambda}.\cos(\theta_{i,etilt}).\sin\left(\varphi_{i,escan}\right)\right) \qquad (18)$$

3. Simulation parameters

Tables 1 and 2 below give details of the simulation parameters used in the generation of the result.

Figures 4 and 5 show the beamforming antenna radiation patterns produced by the 4 × 4 and 8 × 8 antenna array configurations used to generate the maximum antenna gains of 17 dB and 23 dB for the 5G UE and BS, respectively, as defined in section (2.8).

4. Results and discussion

The ACI was analyzed considering a single base station (BS) and user equipment (UE) of the 5G system from a single L-ESIM using the

Table 1. 5G RAN parameters [3, 16].

No	Parameter	5G RAN	
		Base Station (BS)	User Equipment (UE)
1	Frequency of Operation (GHz)	24.25–27.5	
2	Duplex	TDD	
3	Channel Bandwidth-BW (MHz)	200	
4	Signal Bandwidth (MHz)	>90% of BW	
5	Noise Figure-NF (dB)	10	
6	ACLR (dB)	22.6	21.8
7	ACS (dB)	23.5	22.5
8	Antenna Height-h1 & h2 (m)	6	1.5
9	Peak Antenna/Element gain (dBi)	5	
10	Protection Criterion-I/N (dB)	-6	
11	Body loss (dB)	0	4
12	Ohmic loss (dB)	3	
13	Antenna Array-Row x Column (N_H N_V)	8 × 8	4 × 4
14	Distribution density (/km2)	30 BSs	100 UEs
15	Antenna Pattern	ITU-R M.2101 [3]	
16	Horizontal 3dB BW-ϕ_{3dB} (°)	65	90
17	Vertical 3dB BW- θ_{3dB} (°)	65	90
18	Front-to-Back ratio, Am (dB)	30	25
19	Max. Side Lobe Attenuation, SLA_V (dB)	30	25
20	Polarization loss (dB)	3	
21	Down tilt (°)	10	
22	Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V	
23	Noise Temperature (K)	290	
24	Antenna Gain (dBi)	23	17

Table 2. L-ESIM parameters [17].

No.	Parameters	Value
1	Frequency of operation (GHz)	27.5–29.5
2	Bandwidth (MHz)	180
3	Antenna Height (m)	2
4	Maximum Transmit Power Density (dBW/Hz)	-46.3 to -56
5	Maximum Antenna Gain (dBi)	40–45
6	ACLR (dB)	25–30
7	Elevation angle (degrees)	5°, 15°, 20°, 30°, 50°
8	Transmitting power (dBm)	37
9	Transmission Protocol	TDMA

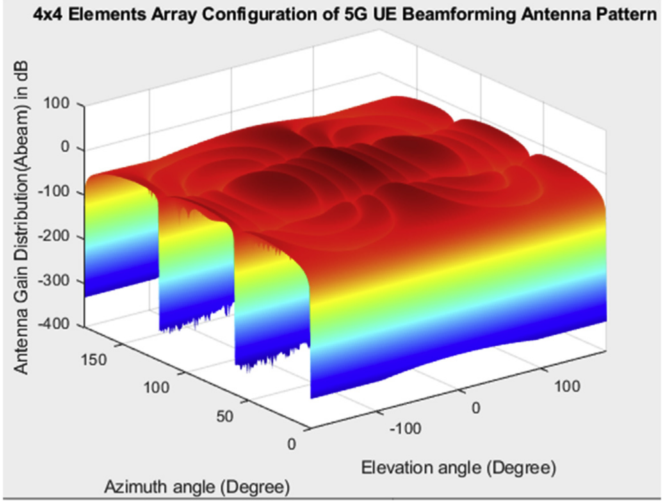

Figure 4. Beamforming pattern of 5G UE (4 × 4).

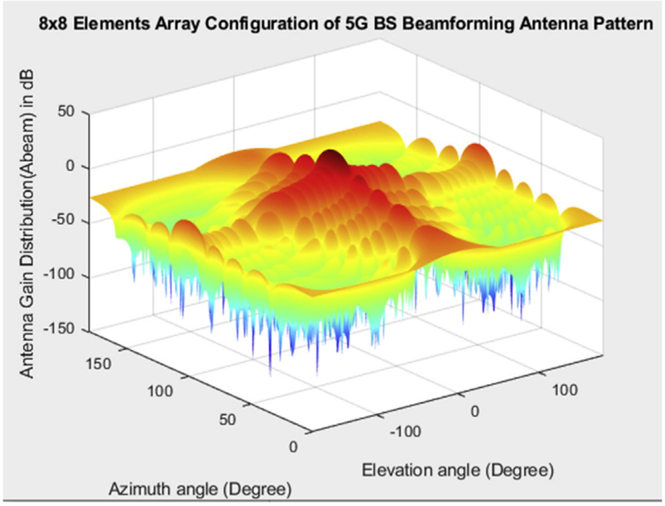

Figure 5. Beamforming pattern of 5G BS (8 × 8).

minimum coupling loss (MCL) method. The minimum elevation angle of L-ESIM of 5° was set in the simulation result, which set the highest interference power of -130.3 dBW/MHz and -139.5 dBW/MHz received by 5G BS and UE, respectively. Varying the elevation angle changes only the angle of the antenna and does not change the physical position of the L-ESIM, and as a result, a difference in interference power occurs due to the EIRP level of L-ESIM.

Tables 1 and 2 respectively show the technical parameters of 5G RAN and L-ESIM used in the simulation process to generate the interference resulting graphs below. The minimum separation distances required to protect 5G RAN from L-ESIM's harmful interference using the MCL method were recorded from the graphs to meet the maximum acceptable interference of -147dBW/MHz in all the scenarios. Figures 6, 7, 8, and 9 show graphs of the received ACI based on the off-axis e.i.r.p level at elevation angles of 5°, 15°, 20°, 30°, and 50° from L-ESIM to 5G RAN victims (BS and UE). Figures 10 and 11 show the received ACI from L-ESIM based on its maximum transmitting power and antenna gain. The results also show both the worst-case scenario of the transmission loss due to free space propagational and a complementary model which considers the basic transmission loss model that led to extra attenuation of the ITU-R P. 452-16 model [6]. Considering the worst-case scenario of the propagation loss and the L-ESIM transmitter at an elevation angle of 5°, the minimum separation distances recorded for compatibility is 35 km for the victim BS and 12 km for the victim UE as shown in Figures 6 and 7. It is observed that as the elevation angle increases, the interference on the 5G victim decreases, consequently reducing the separation distance. The reason for this is shown in Figure 2 above, where the e.i.r.p level from the L-ESIM terminal decreases as the elevation angle increases. At the same time, the e.i.r.p level becomes constant with a maximum value of -10dBW/40 kHz at angles of 48° and above.

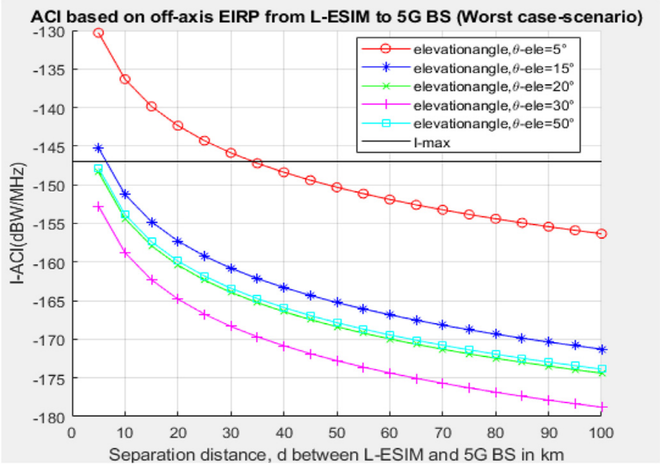

Figure 6. ACI from L-ESIM to 5G BS (worst case-scenario).

Simulations were also done considering the extra attenuation caused by the complementary propagational loss model. With all other parameters held constant, no interference on 5G BS and UE was detected at a 5° elevation angle, as shown in Figures 8 and 9.

Simulations were also done using the constant operational parameter values of the maximum transmitter output power of -46.3 dBW/Hz and the maximum antenna gain of 45 dBi of L-ESIM considering the worst-case scenario. Holding all other 5G RAN constant, the separation distance recorded for the BS victim is 12.5 km, as shown in Figure 10. No interference level was recorded for the UE victim, as displayed in Figure 11. This is because the 5G BS has a higher antenna gain of 23 dBi

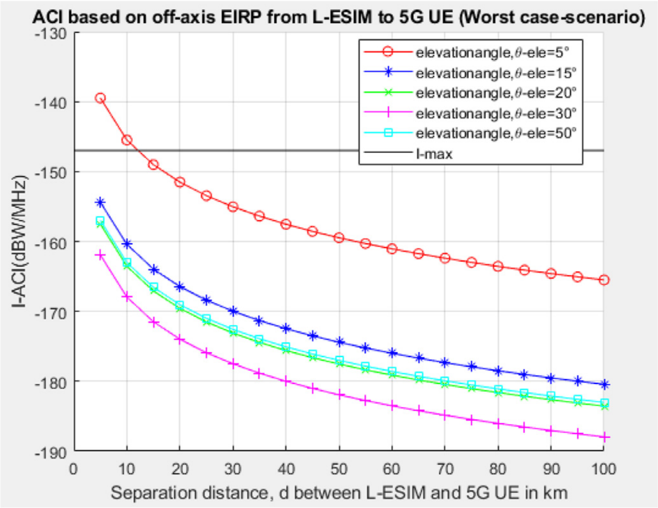

Figure 7. ACI from L-ESIM to 5G UE (worst case-scenario).

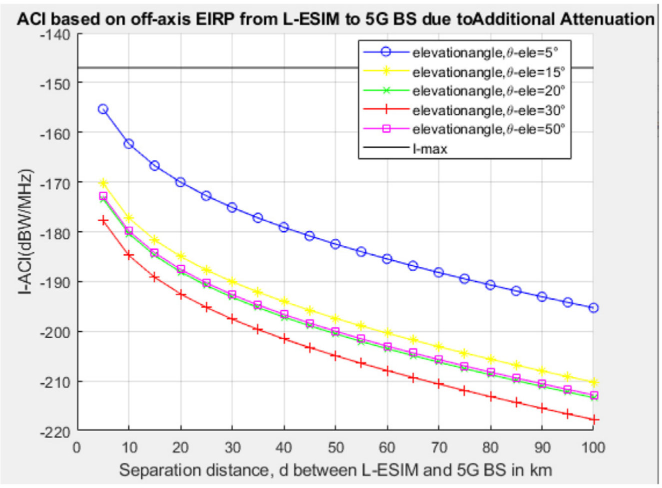

Figure 8. ACI from L-ESIM to 5G BS (additional attenuation).

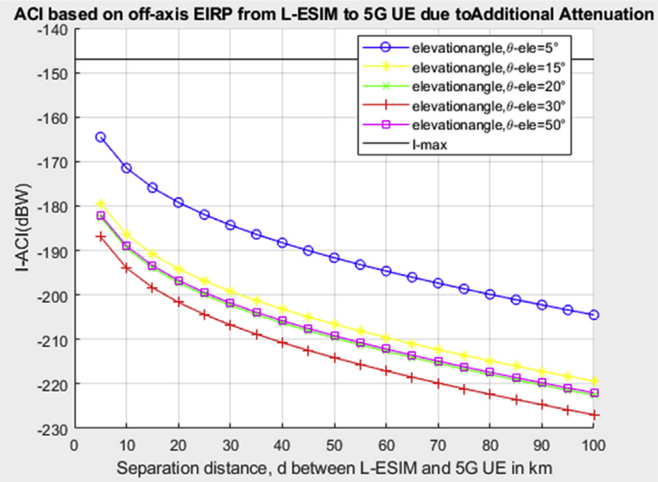

Figure 9. ACI from L-ESIM to 5G UE (additional attenuation).

and lower additional loss (only Ohmic) of 3 dB compared to the UE, having an antenna gain of 17 dBi and additional loss (Body plus Ohmic) of 7 dB. The lower antenna gain and additional loss of the UE led to extra attenuation and lower interference power levels that did not cause harmful interference.

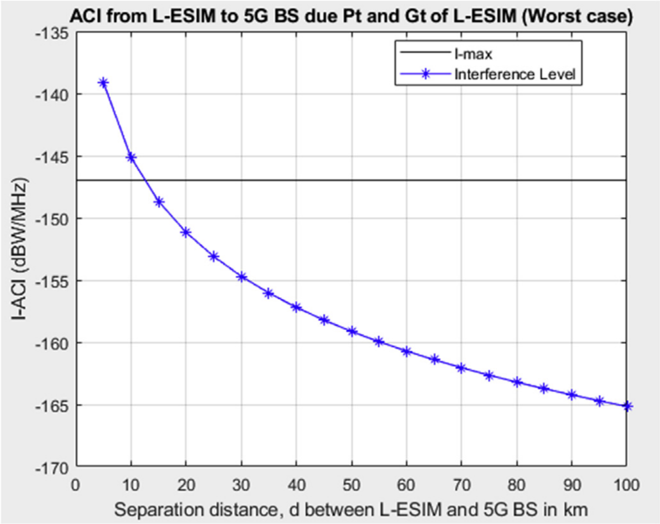

Figure 10. ACI from L-ESIM to 5G BS.

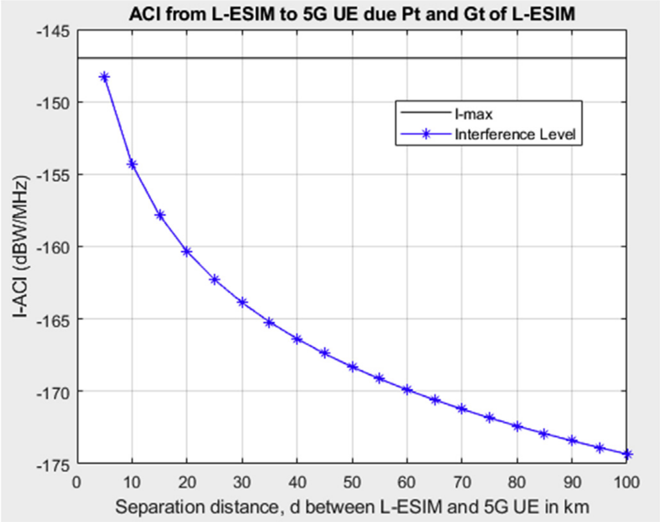

Figure 11. ACI from L-ESIM to 5G UE.

5. Conclusion

Analysis between L-ESIM and 5G RAN operating in the adjacent frequency band was conducted using the MCL method to determine the separation distance (s) between the two services for tolerable compatibility and coexistence. Two interference analyses were considered: interference based on the off-axis e.i.r.p density levels from L-ESIM on 5G RAN, and interference based on the maximum transmit power density and the antenna gain of the L-ESIM terminal. The first scenario recorded a protection distance of 35 km for the 5G victim base station (BS) and 12 km for the user equipment (UE) victim when the minimum elevation angle was set at 5° considering the worst-case scenario. It was observed that the interference levels decreased when the elevation angles increased, yielding a reduction of the protection distance. The second scenario recorded a protection distance of 12.5 km for the 5G BS and no interference recorded for the UE when the maximum antenna gain and maximum transmit power of L-ESIM were used to meet the maximum acceptable interference power level -147 dBW/MHz. The simulation results also observed that the interference levels on the 5G RAN service decreased when the transmit power and antenna gain was reduced. The level of unwanted emissions on 5G RAN increases considering the lowest path loss of the basic transmission due to propagation loss and vice versa. Simulations were also done by considering extra attenuations on the propagation loss model, such as the diffraction loss, attenuation due to gaseous absorption, and clutter loss. As a result, no interference was detected on the 5G RAN. Therefore, coexistence and compatibility between these two services in the adjacent bands are possible when L-ESIM operates outside the recorded minimum separation distances.

Declarations

Author contribution statement

Sajor Barrie: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dominic D. B. O. Konditi: Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by the African Union through its Commission of Human Resources, Science and Technology (Pan African Institute for Basic Sciences, Technology and Innovation-PAUSTI), hosted in Kenya.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] https://www.itu.int/en/mediacentre/backgrounders/Pages/5G-fifth-generation-of-mobile-technologies.aspx. (Accessed 22 December 2020).

[2] ITU-R S.2464-0, Operation of Earth Stations in Motion Communicating with Geostationary Space Stations in the Fixed-Satellite Service Allocations at 17.7-19.7 GHz and 27.5-29.5 GHz, July 2019.

[3] ITU-R Recommendation M.2101-0, Modelling and Simulation of IMT Networks and Systems for Use in Sharing and Compatibility Studies, February 2017.

[4] S.K. Menanor, E. Mwangi, G. Kamucha, Assessment of the interference effect from Land earth stations in motion to fixed service stations, in: IEEE AFRICON, September 2019.

[5] H.K. Kim, Y. Cho, E.E. Ahiagbe, H.S. Jo, adjacent channel interference from Maritime earth station in motion to 5G mobile service, in: International Conference on Information and Communication Technology Convergence (ICTC), 2018.

[6] H.K. Kim, Y. Cho, H.S. Jo, Interference analysis for compatibility evaluation between aeronautical earth station in motion and 5G mobile communications, J. Kor. Inst. Electromagn. Sci. (JKIES) (2019). (Accessed 25 December 2020).

[7] ITU-R Recommendation P.452-16, Prediction Procedure for the Evaluation of Interference between Stations on the Surface of the Earth at Frequencies above about 0.1GHz, July 2015.

[8] ITU-R Recommendation M.2041, Sharing and Adjacent Band Compatibility in the 2.5 GHz Band between the Terrestrial and Satellite Components of IMT-2000, 2003.

[9] H.K. Son, Y.J. Chong, Analysis of the interference effects from Maritime earth station in motion to 5G mobile service, in: International Conference on Information and Communication Technology Convergence (ICTC), 2017 transmitting in the 6 GHz, 13 GHz, 14 GHz, and 30 GHz frequency bands," 2006.

[10] H.K. Kim, Y. Cho, D.K. Tettey, H.S. Jo, adjacent channel compatibility between OFDM based earth station in motion and 5G, in: 2019 IEEE Globecom Workshops (GC Wkshps), 2020.

[11] ITU-R Recommendation SM.337-4, Frequency and Distance Separations, 2008.

[12] Recommendation ITU-R P.526-14, Propagation by Diffraction, January 2018.

[13] ITU-R Recommendation SF.1486, Sharing Methodology between Fixed Wireless Access Systems in the Fixed Service and Very Small Aperture Terminals in the Fixed-Satellite Service in the 3400-3700 MHz Band, May 2000.

[14] ITU-R Recommendation P.676-10, Attenuation by Atmospheric Gases, September 2013.

[15] ITU-R Recommendation S.524-9, Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz, and 30 GHz frequency bands, 2006.

[16] Revision 3 to Document 5D/TEMP/265-E, Characteristics of Terrestrial IMT Systems for Frequency Sharing/Interference Analyses in the Frequency Range between 24.25 GHz and 86 GHz, February 2017.

[17] ITU-R WP4A Contribution 479, Studies on the protection of FS Links in EACO Countries, International Telecommunication Union, October 2017.