Impact of Electromagnetic Radiation of 4G/5G Base Stations on Medical Short-Range Devices in Urban Area

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***Abstract*—The impact of electromagnetic radiation created by micro base stations of 4G/5G cellular networks on receivers of medical short-range devices of different systems (capsule endoscopy system, body area network system, and active implant system) located inside buildings is analyzed for urban area. The analysis is made by the use of computer simulation involving the multipath radiowave propagation model which takes into account outdoor-to-indoor propagation. To perform the simulation, a 3D model of a fragment of urban area containing buildings of a height from 6 m to 60 m is developed. The integrated interference margin is used as a criterion of electromagnetic compatibility. Results of the analysis show that 4G/5G base stations can create the interference to all considered types of medical short-range devices in cases when emitters are located outside buildings and receptors are located inside buildings. In order to achieve electromagnetic compatibility between these base stations and considered medical systems, recommendations on reducing of levels of electromagnetic interference are given. Results of this research can be used to ensure safe operation of 4G/5G base stations with respect to vital medical devices.**

Keywords—EMC, medical short-range device, 4G/5G cellular communications, base station

I. Introduction

Reliable operation of medical equipment is very important, especially for vital medical devices. In recent years, medical short-range devices (MD SRD) are used in modern hospitals for measuring and transmitting of vital health information (e.g., temperature, pulse, blood glucose level, blood pressure level, electrocardiogram, respiratory function readings) at short distances of several meters. Due to intensive expansion of 4G/5G mobile communications, its radiofrequency electromagnetic (EM) radiation may be dangerous for MD SRD operation. And taking into consideration essential asymmetry of downlink and uplink traffic volumes, EM fields created by base stations (BS) may be no less dangerous than EM fields created by 4G/5G user equipment operating in hospital buildings [1]. Terrestrial density of BS is increased in cities on areas with high density of subscribers; in many situations, BS of cellular communications can be located near hospital buildings. In these cases, the risk of interference created by BS to operation of MD SRD is increased, especially during business-hours of cellular communications. Therefore, the analysis of electromagnetic compatibility (EMC) between BS and MD SRD should be performed.

The objective of this paper is to analyze the impact of EM radiation of BS (LTE and 5G) located outdoor on MD SRD of different systems (medical body area network system, capsule endoscopy system, and active medical implant system) operating inside a hospital building.

II. Considered Base Stations and MD SRD

The following types of BS are considered in the analysis of EMC.

1) LTE BS operating in the frequency range of 2110-2170 MHz for downlink in frequency division duplex (FDD) mode [2].

2) LTE BS operating in the frequency range of 2570-2620 MHz in time division duplex (TDD) mode [2].

3) 5G BS (type 1-O) operating in the frequency range of 3400-3800 MHz [3].

The following types of MD SRD are considered in the analysis of EMC.

1) Peripheral (wearable) receiver of ultra low power wireless medical capsule endoscopy system operating in the frequency range of 430-440 MHz [4] (SRD 1).

2) Peripheral (wearable) receiver of medical body area network system operating in the frequency range of 2483.5-2500 MHz [5] (SRD 2).

3) Peripheral (fixed) receiver of low power active medical implant system operating in the frequency range of 2483.5-2500 MHz [6] (SRD 3).

4) Peripheral (fixed) receiver of ultra low power active medical implant system operating in the frequency range of 402-405 MHz [7] (SRD 4).

5) Peripheral (fixed) receiver of ultra low power medical data service system operating in the frequency range of 401-402 MHz [8] (SRD 5).

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III. INITIAL DATA

The following initial data and models are used.

1) The spectrum mask of the BS transmitter is constructed based on the requirements (main, out-of-band, spurious emission, etc.) given in [2], [3].

2) The mask of interference susceptibility characteristic of MD SRD receiver is constructed based on requirements (e.g., sensitivity, selectivity, carrier-to-interference ratio) given in [4], [5], [6], [7], [8].

3) Types of antennas of BS transmitters and MD SRD receivers are given in Table I and Table II. LTE BS and 5G BS antennas are directional. Types of MD SRD antennas may be different (e.g., either integral antenna or dedicated external antenna implemented in the form of skin patch or belt). In many situations, these antennas are specified as half-wave dipoles. If orientation of the antenna is fixed, this fixed orientation is used in the model intended for simulation. If orientation of the antenna can be changed during the system operation (e.g., due to change in position and orientation of the user of a wearable device), the worst-case orientation of the antenna is considered in the model as follows: the real antenna is replaced by an equivalent isotropic antenna with the same gain (ref. Table II).

TABLE I. ANTENNA TYPES OF BS TRANSMITTERS

Transmitter	Antenna in hardware	Antenna in model	Antenna gain in model, dB
LTE FDD BS (fixed)	Kathrein, Type No. 80010378	horizontal 3 dB beamwidth is 60°; vertical 3 dB beamwidth is 3.3°	21
LTE TDD BS (fixed)	Kathrein, Type No. 80010678	horizontal 3 dB beamwidth is 33°; vertical 3 dB beamwidth is 5.8°	20
5G BS (fixed)	Huawei, AAU5613	horizontal 3 dB beamwidth is 65°; vertical 3 dB beamwidth is 6°	16

TABLE II. ANTENNA TYPES OF MD SRD RECEIVERS

Receiver	Antenna in hardware	Antenna in model	Antenna gain in model, dB
SRD 1, 2: peripheral (wearable)	half-wave dipole	isotropic (worst case)	2.18
SRD 3, 4, 5: peripheral (fixed)	half-wave dipole	half-wave dipole	2.18

4) A three-dimensional computer model of a fragment of urban area containing buildings of height from 6 m to 60 m was developed (ref. Fig. 1).

5) The computer model of a wireless network fragment located in the city is given in Fig. 1 and Fig. 2. The model of wireless network contains micro BSs (intended for data transmission) with hexagonal arrangement. Service area radius of BSs is 200-500 m (the inter-site distance, i.e., BS to BS distance [9] is 350-750 m).

BSs are emitters of radiation. It is accepted that service areas of BS1, BS2, and BS3 contain subscribers with high terrestrial density, and service area of BS4 contains subscribers with lower terrestrial density. Therefore, the radius of service areas of BS1, BS2, and BS3 is selected to be 200 m; the radius of service area of BS4 is 500 m. Height of BS antenna is chosen equal to 30 m for 500 m cell radius and 25 m for 200 m cell radius. Tilt of the antennas is calculated in a way that the best conditions of receiving the signal by mobile stations at a border of the service area of BS are achieved. Antenna tilt is equal to 7 degree for 500 m cell radius and 3 degree for 200 m cell radius.

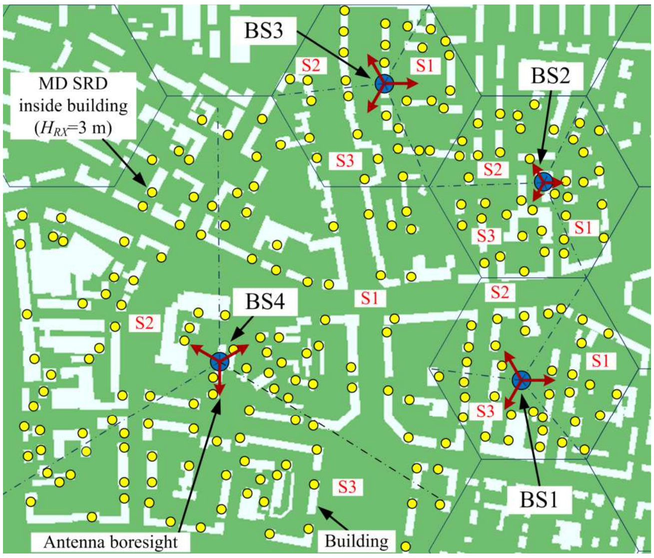

Fig. 1. The placement of the emitters and indoor receptors (at height of 3 m above ground) in the city plan (S1, S2, and S3 are sectors of BS)

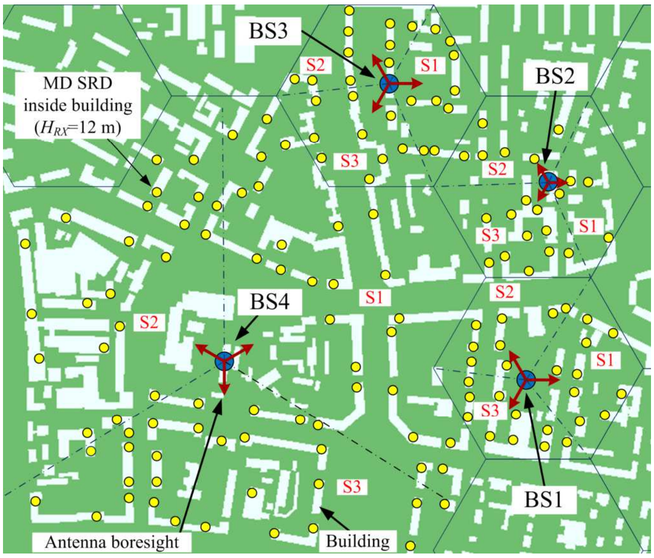

Fig. 2. The placement of the emitters and indoor receptors (at height of 12 m above ground) in the city plan (S1, S2, and S3 are sectors of BS)

MD SRD receivers are considered as receptors. The MD SRD receivers are located in buildings in observation points (OP) at different height H_{RX} above the ground: $H_{RX} = 3$ m that corresponds to the ground floor; $H_{RX} = 12$ m that corresponds to the third floor. The number of OPs in each sector of each BS is equal or more than the following value: 10 OPs for BS with the radius of service area $R = 200$ m; 40 OPs for BS with the radius of service area $R = 500$ m. OPs are located inside buildings at a distance of approximately 2-3 m from walls by the following algorithm: one OP is located in each building of the service area in a way that the level of the BS signal (which is the unwanted signal for the MD SRD receiver) in the OP is maximized, the maximization is performed heuristically (no calculations are made); if the number of OPs in the sector is less than values of 10 or 40, then additional OPs are located in long buildings in a way that the OPs are distributed over the building length approximately uniformly.

6) A three-dimensional multipath model of radiowave propagation is used. The model combines ray-tracing algorithm [10] (tested in [11] in frequency bands which are close to considered LTE and 5G frequency bands), methods of geometric optics and uniform theory of diffraction [12]-[14], and outdoor-to-indoor propagation model [15].

IV. Procedure of EMC analysis

The following steps are made in order to perform the EMC analysis.

1) The analyzed frequencies f_A are selected in order to consider different types of interaction (ref. Table III as an example) between the transmitter and the receiver. Transmitter's and receiver's frequencies are central frequencies of the considered frequency bands at which transmitters and receivers operate. Other analyzed frequencies are selected below and above the tuning frequencies of transmitters and receivers.

TABLE III. Characteristics of LTE BS transmitter emission and SRD 1 receiver susceptibility

LTE mode	Interaction type	f_A, MHz	Δf_i, MHz	P_e, dBm	S, dBm
TDD	M2S	2595	4.5	50.5	-44
TDD	O2S	2585	10	4.5	-44
TDD, FDD	S2S	3000	10	-3	-44
FDD	M2S	2140	4.5	50.5	-44
FDD	O2S	2130	10	5.6	-44
TDD, FDD	S2S	30	10	7	-44
TDD, FDD	S2D	435	10	7	-99
TDD, FDD	S2A	445	10	7	-67.5

Type M2S – the main emission falling into the spurious response of the receiver; type O2S – the out-of-band emission falling into the spurious response of the receiver; type S2D – the spurious emission falling into the desired-channel response of the receiver; type S2A – the spurious emission falling into the adjacent-channel response of the receiver; type S2S – the spurious emission falling into the spurious response of the receiver.

2) For each analyzed frequency f_A, the value of emission power P_e (ref. Table III) is calculated by integrating the transmitter power spectrum over the influence bandwidth

$$\Delta f_i = \begin{cases} \min(BW_T, BW_R), f_A = f_T \\ \min(10 \cdot BW_T, BW_R), f_A \neq f_T \end{cases}, \text{ Hz}, \quad (1)$$

where BW_T is the transmitter bandwidth, Hz; BW_R is the receiver bandwidth, Hz; f_T is the transmitter frequency, Hz.

3) For each analyzed frequency, the value of the receiver susceptibility S (ref. Table III) is defined.

4) The amplitude-frequency characteristic (AFC) of LTE BS antenna (given in Table I) is taken into account in process of the EMC analysis. No information on the out-of-band characteristics of LTE antennas is provided, therefore a mathematical model proposed in [16] and called system-level minimum phase (SLMP) model is involved. By using the SLMP model, the dependence of the realized gain on frequency is calculated for both LTE FDD BS antenna and LTE TDD BS antenna (ref. Table IV and Table V). The realized gain is defined for analyzed frequencies f_A which are out of frequency band of LTE BS antenna operation. Note: for 5G BS transmitters, over the air requirements defined at the radiated interface boundary are given [3], therefore AFC is not taken into account.

Radiation pattern of LTE BS antennas is changed depending on analyzed frequencies f_A as given in Table IV and Table V.

TABLE IV. Model of radiation pattern of LTE FDD BS antenna

f_A, MHz	Pattern shape	Horizontal 3dB beamwidth, degree	Vertical 3dB beamwidth, degree	Realized gain, dBi
25	isotropic	—	—	-69.0
30	isotropic	—	—	-64.6
401.5; 401.525	reference	100	12	-3.8
403.5; 403.525	reference	100	12	-3.6
435	reference	100	12	-1.8
445	reference	100	12	-1.3
2130; 2140; 2491.75; 2492.75; 2494.75	datasheet (Kathrein, Type No. 80010378)	ref. Table I	ref. Table I	ref. Table I
3000	reference	66	3.7	20.3
4000	reference	73	6	17.7
12500	isotropic	—	—	17.2

TABLE V. Model of radiation pattern of LTE TDD BS antenna

f_A, MHz	Pattern shape	Horizontal 3dB beamwidth, degree	Vertical 3dB beamwidth, degree	Realized gain, dBi
25	isotropic	—	—	-71.5
30	isotropic	—	—	-68.0
401.5; 401.525	reference	55	21	-5.3
403.5; 403.525	reference	55	21	-5.1
435	reference	55	21	-3.3
445	reference	55	21	-2.8
2491.75; 2492.75; 2494.75; 2585; 2595	datasheet (Kathrein, Type No. 80010678)	ref. Table I	ref. Table I	ref. Table I
3000	reference	34	5.8	19.7
4000	reference	39	7	18.3
12500	isotropic	—	—	15.8

The reference radiation pattern is calculated as follows [17]:

- The normalized horizontal pattern

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

where φ_{3dB} is the horizontal 3dB beamwidth, degree; A_m is the front-to-back ratio (dB) (it is assumed that A_m =15 dB for LTE BS antennas); φ is the azimuth angle, defined between -180° and 180°.

- The normalized vertical pattern

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

where θ_{3dB} is the vertical 3dB beamwidth, degree; SLA_v is the side-lobe level limit (dB) (it is assumed that SLA_v =15 dB for LTE BS antennas); θ is the elevation angle, defined between -180° and 180° (0° represents the direction that is perpendicular to the antenna aperture).

5) The simulation is performed in order to predict the level P_I of unwanted signal at analyzed frequency f_A from the emitter at the input of each MD SRD receiver by involving the three-dimensional model of the city plan and three-dimensional multipath model of radiowave propagation which takes into account outdoor-to-indoor propagation. The calculation algorithm is as follows:

a) Levels P_P of unwanted signal at the receptor input are predicted in OPs specified in Table VI (for service area of radius R=200 m) and Table VII (for service area of radius R=500 m).

TABLE VI. CALCULATION OF LEVELS OF UNWANTED SIGNAL AT THE INPUT OF RECEIVER IN OPS LOCATED IN SERVICE AREAS OF RADIUS 200 M

Step	Service area	Emitter	Receptor
1	1 (R=200 m)	BS1 (sector S1)	SRDs (in OPs of the sector)
2		BS1 (sector S2)	SRDs (in OPs of the sector)
3		BS1 (sector S3)	SRDs (in OPs of the sector)
4	2 (R=200 m)	BS2 (sector S1)	SRDs (in OPs of the sector)
5		BS2 (sector S2)	SRDs (in OPs of the sector)
6		BS2 (sector S3)	SRDs (in OPs of the sector)
7	3 (R=200 m)	BS3 (sector S1)	SRDs (in OPs of the sector)
8		BS3 (sector S2)	SRDs (in OPs of the sector)
9		BS3 (sector S3)	SRDs (in OPs of the sector)

TABLE VII. CALCULATION OF LEVELS OF UNWANTED SIGNAL AT THE INPUT OF RECEIVER IN OPS LOCATED IN SERVICE AREAS OF RADIUS 500 M

Step	Service area	Emitter	Receptor
1	4 (R=500 m)	BS4 (sector S1)	SRDs (in OPs of the sector)
2		BS4 (sector S2)	SRDs (in OPs of the sector)
3		BS4 (sector S3)	SRDs (in OPs of the sector)

b) In order to ensure that the energy conservation law is not violated (i.e., the received power must not exceed the transmitted power), levels of unwanted signal are calculated by the formula:

$$P_I = \min(P_P, K_{A-A} \cdot P_e)\ , \text{ W}, \qquad (4)$$

where P_P is the power of unwanted signal at the receptor obtained by simulation, W; P_e is the transmitter emission power, W; $K_{A\text{-}A}$ is the factor of the coupling between transmitter and receiver antennas, W/W ($K_{A\text{-}A}$ = 1, the maximum possible value is used).

The range of levels of unwanted signal is obtained taking into account P_I values calculated in each OP. The average level $P_{I\,\text{aver}}$ of unwanted signal is calculated using all computed values of P_I for the considered situation (i.e., for the considered combination of R, H_{RX}, f_A) as well as the maximum level $P_{I\,\text{max}}$ of unwanted signal is selected from the range of P_I values. Note: the averaging is made over the values expressed in W, then the result is converted to dBm.

6) The interference margin (IM) is used as EMC criterion (interference criterion) [18]:

$$IM = P_I / S\ , \text{ W/W}. \qquad (5)$$

The unwanted signal is considered to be tolerable if IM < 1, and interference happens if IM ≥1 (note that 1 W/W is equal to 0 dB).

The relative number RN_{OP} of OPs in which the interference is observed (the level P_I of unwanted signal is equal or more than the susceptibility S of MD SRD receiver) is calculated:

$$RN_{OP} = \frac{OP_I}{OP_{total}} \cdot 100\ , \%, \qquad (6)$$

where OP_I is the number of OPs in which the interference is observed; OP_{total} is the total number of OPs.

Then the integrated interference margin (IIM) is calculated using IM at each analyzed frequency f_A [18]:

$$IIM = \sum_{i=1}^{n} IM(f_{A_i})\ , \text{ W/W}, \qquad (7)$$

where n is the number of analyzed frequencies.

The IIM accounts for the simultaneous influence of all types of transmitter emissions on the receiver.

The dependence of IIM on slant distance between BS transmitter and MD SRD receiver is constructed with the use of two propagation models: the multipath propagation model and the free-space model. If the free-space model is involved, the calculation is performed as follows.

- The free-space attenuation between isotropic antennas (the free-space basic transmission loss L_{bf}) is calculated as follows [19]:

$$L_{bf} = -147.6 + 20 \cdot \log f + 20 \cdot \log d\ , \text{ dB}, \qquad (8)$$

where f is the frequency, Hz; d is the distance between the antennas, m.

- The level of unwanted signal at the receiver input is calculated as follows:

$$P_I = \min(P_e - L_{bf} + G_T + G_R ; K_{A-A} + P_e)\ , \text{ dBm}, \quad (9)$$

where G_T is the transmitter antenna gain which is accepted equal to the realized gain of BS antenna (when the maximum emission of the antenna is achieved in the direction to the OP), dBi; G_R is the receiver antenna gain, dBi; $K_{A\text{-}A}$ = 0 dB.

- The IM is calculated by substituting (9) into (5) taking into account (8):

$$IM(f,d) = \min(P_e + 147.6 - 20 \cdot \log f - 20 \cdot \log d + \qquad (10)$$

$$+ G_T + G_R ; K_{A-A} + P_e) - S\ , \text{ dB}.$$

- The IIM is calculated by (7) using the IM values calculated by (10).

7) Based on the value of IIM, the decision concerned the presence or absence of interference is made.

V. RESULTS OF EMC ANALYSIS

The IM is calculated at each analyzed frequency f_A. The result of the calculation of IM in case of influence of LTE BS transmitter radiation on SRD 1 receiver is provided in Tables VIII, IX, X, and XI as an example. The values of IM_{aver} ≥ 0 dB and IM_{max} ≥ 0 dB (interference happens) are marked by red color. The value of IM_{aver} (the average level of IM) is calculated using the $P_{I\,\text{aver}}$ value and the receiver susceptibility S value. The value of IM_{max} (the maximum level of IM) is calculated using the $P_{I\,\text{max}}$ value and the receiver susceptibility *S* value. Then, the IIM is calculated with the use of IM_{aver} and IM_{max} values.

TABLE VIII. THE IM AND IIM FOR CASE OF INFLUENCE OF LTE FDD BS (BS1, BS2, AND BS3; *R*=200 M) ON SRD 1 RECEIVER (H_{RX}=3 M) IN 105 OPS

f_A, MHz	P_I, dBm	$P_{I\ aver}$, dBm	$P_{I\ max}$, dBm	*S*, dBm	IM_{aver}, dB	IM_{max}, dB	RN_{OP}, %
30	-166.1…-93.2	-102.4	-93.2	-44	-58.4	-49.2	0.0
435	-102…-57.7	-70.1	-57.7	-99	28.9	41.3	98.1
445	-105.6…-61.3	-69.6	-61.3	-67.5	-2.1	6.2	21.0
2130	-111.8…-58	-69.3	-58.0	-44	-25.3	-14.0	0.0
2140	-71.4…-12.8	-24.7	-12.8	-44	19.3	31.2	89.5
3000	-132.6…-70	-80.0	-70.0	-44	-36.0	-26.0	0.0
IIM_{aver} = 29.4 dB; IIM_{max} = 41.7 dB							
Note: slant distance between emitter and receptor is 32.3…193.1 m							

TABLE IX. THE IM AND IIM FOR CASE OF INFLUENCE OF LTE FDD BS (BS1, BS2, AND BS3; *R*=200 M) ON SRD 1 RECEIVER (H_{RX}=12 M) IN 76 OPS

f_A, MHz	P_I, dBm	$P_{I\ aver}$, dBm	$P_{I\ max}$, dBm	*S*, dBm	IM_{aver}, dB	IM_{max}, dB	RN_{OP}, %
30	-146.3…-91.6	-99.9	-91.6	-44	-55.9	-47.6	0.0
435	-101.5…-58.8	-66.2	-58.8	-99	32.8	40.2	97.4
445	-102.4…-57.5	-66.3	-57.5	-67.5	1.2	10.0	44.7
2130	-111.3…-54.3	-64.2	-54.3	-44	-20.2	-10.3	0.0
2140	-67.8…-9.4	-19.2	-9.4	-44	24.8	34.6	86.8
3000	-123.6…-64.6	-73.4	-64.6	-44	-29.4	-20.6	0.0
IIM_{aver} = 33.5 dB; IIM_{max} = 41.2 dB							
Note: slant distance between emitter and receptor is 27…192.3 m							

TABLE X. THE IM AND IIM FOR CASE OF INFLUENCE OF LTE FDD BS (BS4; *R*=500 M) ON SRD 1 RECEIVER (H_{RX}=3 M) IN 127 OPS

f_A, MHz	P_I, dBm	$P_{I\ aver}$, dBm	$P_{I\ max}$, dBm	*S*, dBm	IM_{aver}, dB	IM_{max}, dB	RN_{OP}, %
30	-171.8…-94.5	-108.9	-94.5	-44	-64.9	-50.5	0.0
435	-123.7…-66.5	-77.2	-66.5	-99	21.8	32.5	85.8
445	-122…-66.4	-77.3	-66.4	-67.5	-9.8	1.1	0.8
2130	-123.1…-65	-77.8	-65.0	-44	-33.8	-21.0	0.0
2140	-76.3…-20.1	-32.8	-20.1	-44	11.2	23.9	63.8
3000	-146.1…-75.2	-87.5	-75.2	-44	-43.5	-31.2	0.0
IIM_{aver} = 22.2 dB; IIM_{max} = 33.1 dB							
Note: slant distance between emitter and receptor is 32.5…494.7 m							

TABLE XI. THE IM AND IIM IN CASE OF INFLUENCE OF LTE FDD BS (BS4; *R*=500 M) ON SRD 1 RECEIVER (H_{RX}=12 M) IN 74 OPS

f_A, MHz	P_I, dBm	$P_{I\ aver}$, dBm	$P_{I\ max}$, dBm	*S*, dBm	IM_{aver}, dB	IM_{max}, dB	RN_{OP}, %
30	-140.9…-96.4	-109.1	-96.4	-44	-65.1	-52.4	0.0
435	-109.8…-64	-73.8	-64.0	-99	25.2	35.0	95.9
445	-102.3…-63.7	-73.4	-63.7	-67.5	-5.9	3.8	6.8
2130	-109.3…-63.2	-71.3	-63.2	-44	-27.3	-19.2	0.0
2140	-62.5…-16.8	-25.8	-16.8	-44	18.2	27.2	81.1
3000	-121.9…-73.2	-81.5	-73.2	-44	-37.5	-29.2	0.0
IIM_{aver} = 26.0 dB; IIM_{max} = 35.7 dB							
Note: slant distance between emitter and receptor is 72.3…494.3 m							

The worst-case values of IIM_{max} are provided in Table XII. These values are obtained as follows: for a fixed combination of BS type and MD SRD type, the maximum value of IIM_{max} over the considered values of *R* and H_{RX} is chosen (ref. Tables VIII, IX, X, and XI). The most dangerous emitter, the most susceptible receptor, and the maximum value of IIM_{max} are marked by red color in Table XII. The least dangerous emitter, the least susceptible receiver, and the minimum value of IIM_{max} are marked by yellow color in Table XII.

The dependences of IIM on slant distance between LTE FDD BS and SRD 1 for H_{RX} = 12 m are given in Fig. 3 and Fig. 4 as examples. The following propagation models are involved: multipath propagation model (scatter plot), free space (line plot).

TABLE XII. WORST-CASE VALUES OF IIM_{MAX} (DB), TAKING INTO ACCOUNT THE INFLUENCE OF BS TRANSMITTER RADIATION ON MD SRD

Emitter	Receptor					Average IIM_{max}
	SRD 1	SRD 2	SRD 3	SRD 4	SRD 5	
LTE BS (FDD)	41.7	31.5	33.3	38.3	38.2	38.0
LTE BS (TDD)	40.9	30.2	32.2	36.4	36.6	36.8
5G BS	24.4	24.2	24.2	31.7	31.7	28.8
Average IIM_{max}	39.6	29.6	31.3	36.2	36.4	
Note 1: The averaging is made over values of IIM_{max} expressed in W/W, then the result is converted into dB. Note 2: as level of IIM_{max} increases, the risk of electromagnetic interference to the receiver is higher.						

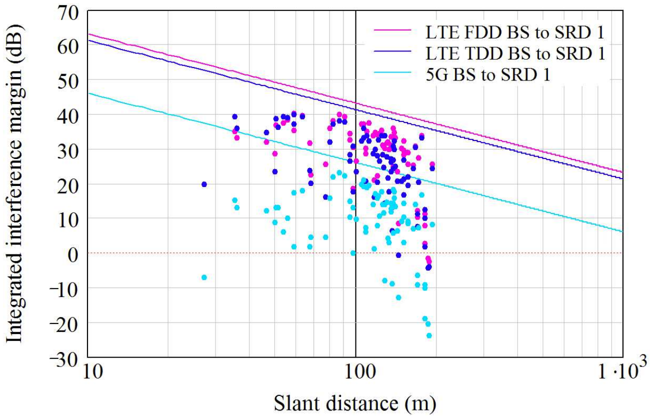

Fig. 3. Dependence of IIM on slant distance between BS transmitters and SRD 1 receivers (*R*=200 m; H_{RX} =12 m)

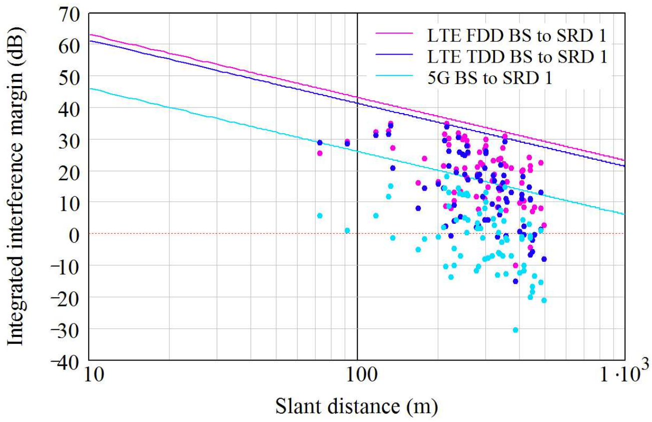

Fig. 4. Dependence of IIM on slant distance between BS transmitters and SRD 1 receivers (*R*=500 m; H_{RX} =12 m)

BS transmitters can create the interference to all considered types of MD SRD receivers because IIM_{max} > 0 dB in all cells of Table XII. The EMC criterion (IIM_{max}) can be equal to 24.2…41.7 dB, depending on the emitter type and receiver type.

Interference of type S2D is predominant in approximately 34% of the considered situations (totally, 60 situations are considered). In 97% of situations, S2D interference is observed. In 90% of situations, two types of interference are observed simultaneously: S2D and M2S.

Results of EMC analysis are impacted by the following effects of the radio wave propagation (these effects are taken into account by the multipath radiowave propagation model): reflections from on-site objects (the reflections may increase the disturbance levels), diffraction (the diffraction may decrease the disturbance levels), and penetration of radio waves through walls into buildings (the disturbance level is decreased due to attenuation in walls and in objects located inside buildings).

Since the minimum value of IIM_{max} given in Table XII is greater than 0 dB, the EM radiation from each considered emitter makes risk of interference to each considered receptor. This means that the interference will be observed in the worst case and in some amount of bad cases, but it may not be observed in some amount of good cases due to the following reasons.

1) Spurious emissions do not appear at all frequencies of spurious emission domain. Therefore, frequencies of spurious emissions of the transmitter can be not equal to the receiver frequency.

2) Levels of most of spurious emissions are lower than the spectrum envelope. If the frequency of a spurious emission of the transmitter is equal to the receiver tuning frequency, the level of the spurious emission may not be enough to create the interference for the receiver.

3) A real device may have better characteristics than those specified by spectrum and susceptibility envelopes given in standards.

4) Some types of MD SRD use different mechanisms of adaptation: automatic selection of frequency band and subcarriers, control of effectiveness of coding, retransmission of data, etc.

VI. Conclusions

As follows from the obtained results, LTE BS and 5G BS located outside buildings can potentially create interference to all considered types of MD SRDs located inside buildings. Compliance with the requirements of standards [2]-[8] does not guarantee the absence of interference to MD SRDs. Therefore, we advise the following measures to reduce the risk of interference to MD SRD operation: 1) to set more stringent requirements on susceptibility characteristics of the MD SRD receivers in frequency bands of BS operation, as well as on spurious emission of BS transmitters in frequency bands of MD SRD operation; 2) to use additional filters in order to decrease the level of spurious emissions of BS transmitters in MD SRD frequency bands; 3) to locate BS antennas in a way that ensures the absence of the line-of-sight irradiation of hospital buildings; 4) to locate MD SRD in rooms situated on the ground floor; 5) to locate MD SRD far from windows of the room.

In this work, the worst case models of emission spectra and susceptibility characteristics in the frequency domain are employed (the upper envelope of a spectrum and the lower envelope of a susceptibility characteristic). Therefore, the calculated values of the EMC criterion are pessimistic, i.e., these values concern the worst situation. The authors intend to verify the obtained results by experiments in order to define more precisely the restrictions needed to ensure the safe use of 4G/5G BS equipment.

The results of this work can be used in the field of standardization for improving standards intended to ensure the EMC between considered equipment, as well as in the field of design/upgrade/deployment of mobile communication systems for the diagnostics of intersystem EMC between 4G/5G BS and medical devices.

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