Analysis of EMC between Equipment of Wireless Systems and Medical NB IoT Devices

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***Abstract*—The analysis of EMC between equipment of wireless systems (4G/5G user equipment of cellular communications as well as access points of radio local area network) and medical narrowband Internet-of-things (NB IoT) devices (utilizing LTE carrier in 452.5–457.5 MHz range for uplink and 462.5–467.5 MHz range for downlink) operating inside a hospital building is made. Computer simulation with the use of multipath radiowave propagation model and a 3D model of hospital premises is performed. The integrated interference margin involved as a criterion of EMC is calculated as a result of the analysis. It was concluded that the equipment of considered wireless systems can interfere with medical NB IoT devices (as well as NB IoT devices can interfere with receivers of these wireless systems) if emitters and receptors are located within the same room or in contiguous rooms. In order to reduce the levels of electromagnetic interference, recommendations are given.**

Keywords—EMC, medical narrowband Internet of things, 4G/5G cellular communications, radio local area network

I. Introduction

Narrowband Internet-of-things (NB IoT) is a low-power wide area network technology for wireless communications. This technology is widely used to provide different services (smart metering, smart cities, smart buildings, agriculture) as well as for medical applications [1], [2], [3]. In the case of medical purpose, NB IoT is aimed to use for remote monitoring of patients' health parameters (e.g., blood pressure, heart beat, respiratory rate, glucose level), for elderly healthcare services (e.g., to automatically communicate the occurrence of a fall of a patient outside the patient's home in order to make treatment earlier [4]). NB IoT can also be useful to improve healthcare service during pandemic in smart hospitals especially for high-risk patients [5]. During operation of medical NB IoT system, the data (health information) is transmitted by NB IoT device to a base station of cellular communications and then can be accessible to medical staff for making decisions and treatment, as well as the patient's NB IoT device receives the data from the base station for remote adjustment and controlling of the user device.

According to [1], [6], [7], NB IoT technology is more suitable for healthcare applications (in respect to licensing policy, long-range data transmission, and energy-efficiency) than other wireless technologies. Taking into account the other advantages of NB IoT technology (ability to operate within current LTE network, supporting up 100000 IoT devices per a base station, high quality of service, high reliability [1], [4], [8]), this technology is promising for healthcare industry in the future. According to forecast [10], IoT connections will grow rapidly in near 10 years.

Mass use of 4G/5G wireless systems in hospitals can create a challenge of electromagnetic compatibility (EMC) between NB IoT and equipment of wireless systems, because medical staff and patients can use mobile devices of 4G/5G cellular communications and radio local area network (RLAN) near to NB IoT devices operating in active mode. Previous researches of EMC between NB IoT systems and wireless systems gave the alarming results: medical short-range devices can interfere with receivers of NB IoT devices (because the standards do not guarantee the absence of interference) [11], LTE signal creates a strong interference to the receiver of NB IoT user equipment [12], NB IoT cell coverage is affected due to radar interference [13].

The objective of this paper is to analyze EMC between wireless equipment (user equipment of LTE and 5G cellular communications and RLAN access points) and medical NB IoT devices used inside buildings of medical facilities.

II. Description of Equipment

A. Considered NB IoT devices

NB IoT devices [14] utilizing LTE carrier in 452.5–457.5 MHz frequency range for uplink and 462.5–467.5 MHz frequency range for downlink [15] (band 31) is considered in EMC analysis. According to [16], band 31 can be used for NB IoT operating. The decision [17] introduced the use of LTE land mobile system in this frequency band in frequency division duplex (FDD) mode.

B. Equipment of wireless systems under consideration

Equipment of wireless systems involved in EMC analysis is as follows.

1) LTE mobile station which operates in the following frequency ranges: 1920–1980 MHz for uplink and 2110–2170 MHz for downlink in FDD mode, and 2570–2620 MHz in time division duplex (TDD) mode [15].

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2) 5G mobile station which operates in 3400–3800 MHz frequency range [18].

3) RLAN access point which operates in 5150–5250 MHz frequency range [19].

III. INITIAL DATA

Initial data and models used for performing of EMC analysis are as follows.

1) The spectrum mask (i.e., the upper envelope of a spectrum) of the transmitter is constructed taking into account requirements to various types of emission [14], [15], [18], [19]: main, out-of-band, and spurious. The spectrum mask of transmitter of 5G mobile station is given in Fig. 1 as example (where PSD is the power spectral density).

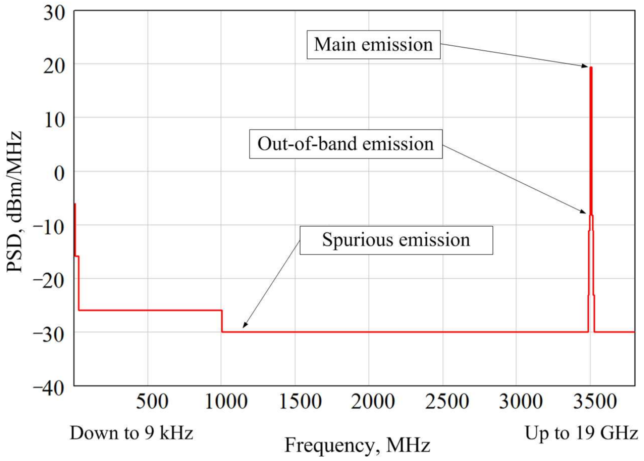

Fig. 1. Spectrum mask of 5G mobile station transmitter

2) The receiver susceptibility to interference (i.e., the lower envelope of the susceptibility characteristic) is constructed taking into account requirements (reference sensitivity, carrier-to-interference ratio, adjacent channel selectivity, blocking, etc.) according to standards [14], [15], [18], [19]. The NB IoT receiver susceptibility mask is given as example in Fig. 2.

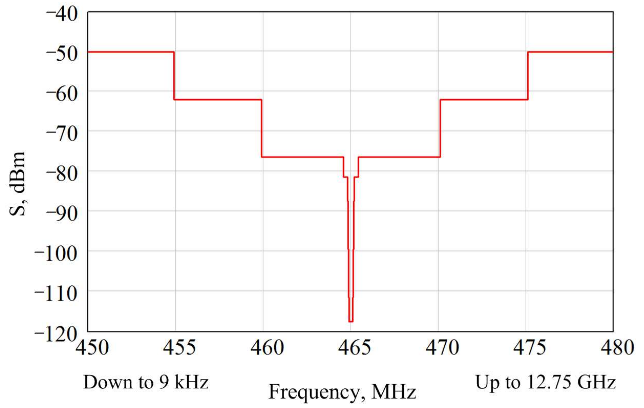

Fig. 2. Susceptibility mask of NB IoT user equipment receiver

3) The antennas of LTE mobile station, 5G mobile station, and NB IoT device are considered as isotropic [14], [15], [18] (ref. Tables I and II). For RLAN access point, the antenna is omnidirectional [20] (ref. Tables I and II). This antenna was modeled as follows: instead of the transmitter power, the equivalent isotropically radiated power (EIRP) is employed; real pattern of the antenna is taken into account; and gain of the antenna is equal to 0 dB [11].

TABLE I. PARAMETERS OF TRANSMITTER ANTENNAS

Transmitter	Antenna in hardware	Antenna in model	Antenna gain in model, dB
LTE mobile station (wearable)	Unknown	Isotropic	0
5G mobile station (wearable)	Unknown	Isotropic	0
RLAN access point (fixed)	Built-in omni-directional	Real antenna pattern	0 (EIRP is used)
NB IoT device (wearable)	Unknown	Isotropic	0

TABLE II. PARAMETERS OF RECEIVER ANTENNAS

Receiver	Antenna in hardware	Antenna in model	Antenna gain in model, dB
LTE mobile station (wearable)	Unknown	Isotropic	0
5G mobile station (wearable)	Unknown	Isotropic	0
RLAN access point (fixed)	Built-in omni-directional	Real antenna pattern	2.8
NB IoT device (wearable)	Unknown	Isotropic	0

4) The 3D fragment of typical plan of hospital premises [21] considered in the EMC analysis is developed [11] (ref. Fig. 3). This fragment contains several rooms including the treatment room and the corridor. Parameters of walls are as follows: the height is 3 m, the thickness of internal walls is 0.12 m; the material is brick. The following material is set for other elements of the hospital premises model: concrete is the material of floor and ceiling, and wood is the material of doors.

5) Allocation of emitters and receptors is given in Fig. 3 and Fig. 4. Potential sources of interference (transmitters) and potential sources of interference (receivers) are placed at close distance (in the same room or in contiguous rooms) in order to consider the worst-case positions of transmitters and receivers. "Tx" designation means the transmitter and "Rx" designation means the receiver.

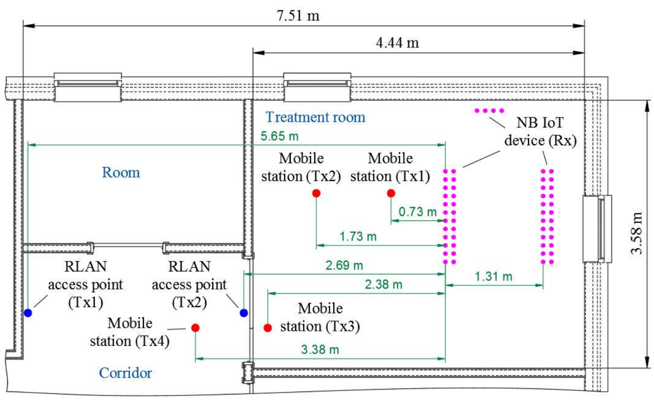

Fig. 3. The allocation of mobile stations and RLAN access points as emitters and NB IoT devices as receptors

a) Mobile stations (emitters) of LTE and 5G cellular communications are placed in four points of the premises plan at height above the floor of 1.5 m (it is assumed that hospital nurse or patients can use mobile phones at these positions) (ref. Fig. 3). Mobile stations as receptors are placed uniformly above the bed of a patient and close to the door in the treatment room and corridor (ref. Fig. 4).

b) RLAN access points are placed on the wall in the corridor (close to the treatment room containing medical NB IoT devices) at height of 2.8 m [11] from the floor.

c) Medical NB IoT devices are placed near the bed of a patient at height of 1.5 m from the floor [11]. The infusion monitoring system (for monitoring of the real-time drop rate and the volume of remaining drug during the intravenous infusion [3]) was considered as application of NB IoT for medical purpose.

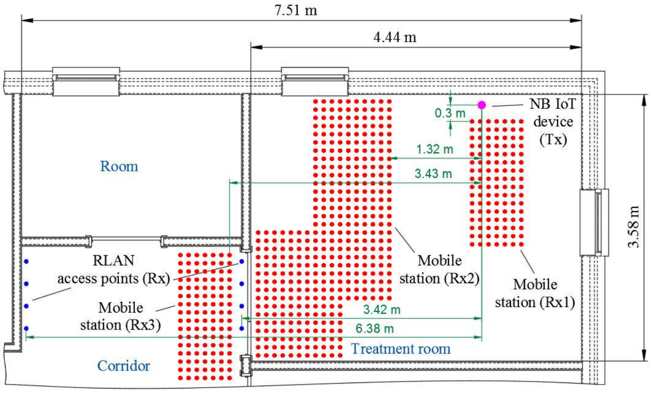

Fig. 4. The allocation of NB IoT device as emitter and mobile stations and RLAN access points as receptors

6) For the simulation, a 3D multipath model of radiowave propagation is employed. The model uses ray-tracing algorithm [22] (tested at frequencies close to LTE and 5G frequency bands under consideration [23]) as well as geometric optics and uniform theory of diffraction methods [24], [25], [26].

IV. Procedure of EMC Analysis

Procedure of the EMC analysis includes the following steps.

1) The analyzed frequencies f_A are chosen in order to take into account different types of interaction between the transmitter and the receiver [11] (ref. an example given in Table III and Table IV). Types of interaction are as follows: the main emission of the transmitter falls into the spurious response of the receiver (M2S); the out-of-band emission of the transmitter falls into the spurious response of the receiver (O2S); the spurious emission of the transmitter falls into the desired-channel response of the receiver (S2D); the spurious emission of the transmitter falls into the adjacent-channel response of the receiver (S2A); the spurious emission of the transmitter falls into the spurious response of the receiver (S2S) [11].

TABLE III. Characteristics of Emission of 5G Mobile Station Transmitter and Susceptibility of NB IoT Receiver

Interaction type	f_A, MHz	Δf_i, MHz	P_e, dBm	S, dBm
M2S	3500	0.18	11.8	-50
O2S	3490	0.18	-19.4	-50
S2S	12750	0.18	-37.4	-50
S2S	0.099	0.18	-14.4	-50
S2D	465	0.18	-33.4	-117.5
S2A	465.2	0.18	-33.4	-81.5

Note:
BW_T = 9.375 MHz for 5G mobile station transmitter [18];
BW_R = 0.18 MHz for NB IoT device receiver [14].

Tuning frequencies of transmitters and receivers are central frequencies of frequency bands under consideration (ref. Subsections II.A and II.B). Other analyzed frequencies f_A are chosen below and above the tuning frequencies [11].

TABLE IV. Characteristics of Emission of NB IoT Transmitter and Susceptibility of 5G Mobile Station Receiver

Interaction type	f_A, MHz	Δf_i, MHz	P_e, dBm	S, dBm
M2S	455	0.18	33.8	-50
O2S	456	1.8	22.7	-50
S2S	1	1.8	-12.5	-50
S2D	3500	1.8	-27.4	-110
S2A	3490	1.8	-27.4	-66.2
S2S	12749.1	1.8	-27.4	-50

Note:
BW_T = 0.18 MHz for NB IoT device transmitter [14];
BW_R = 9.375 MHz for 5G mobile station receiver [18].

2) The value of transmitter emission power P_e (ref. Table III and Table IV) is calculated for each analyzed frequency f_A with the use of integrating the power of transmitter spectrum over the influence bandwidth [11]

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

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

3) The value of the receiver susceptibility S is defined for each analyzed frequency f_A (ref. Table III and Table IV).

4) For each analyzed frequency f_A, the level P_P of unwanted signal from each emitter at the input of each receiver is predicted with the use of simulation by involving the 3D model of the premises plan (ref. Fig. 3 and Fig. 4) and multipath model of radiowave propagation. Then levels P_I of unwanted signal are calculated in order to ensure that the energy conservation law is conserved [11]:

$$P_I = \min(P_P, K_{A-A} \cdot P_e), \text{ W}, \quad (2)$$

where K_{A-A} is the factor of the coupling between antennas of the transmitter and the receiver, W/W (K_{A-A}=1, the maximum possible value is involved).

5) The maximum level $P_{I\max}$ of unwanted signal is selected from P_I values calculated for each observation point (possible position of the receiver; ref. Fig. 3 and Fig. 4).

6) The interference margin (IM) involved as EMC criterion (interference criterion) is calculated:

$$IM = P_I / S, \text{ W/W}. \quad (3)$$

The value P_I of unwanted signal is suitable if IM < 1, and interference occurs at the input of the receiver if IM ≥1 (note: 1 W/W = 0 dB).

The IM is calculated with the use of $P_{I\max}$ value.

7) The integrated interference margin (IIM) is calculated with the use of IM value at analyzed frequency f_A [27]:

$$IIM = \sum_{i=1}^{n} IM(f_{A_i}), \text{ W/W}, \quad (4)$$

where n is the number of analyzed frequencies.

The IIM takes into account the simultaneous interaction of all considered types between the transmitter and the receiver.

8) The IIM depending on slant distance between the transmitter and the receiver is calculated with the use of the multipath propagation model as well as using the free-space model. The calculation with the use of the free-space model is performed as follows.

- The free-space attenuation between isotropic antennas (the free-space basic transmission loss) is calculated according to [28]:

$$L_{bf} = -147.6 + 20 \cdot \log f + 20 \cdot \log d \text{ , dB,} \qquad (5)$$

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:

$$P_I = \min(P_e - L_{bf} + G_T + G_R; K_{A-A} + P_e) \text{ , dBm,} \qquad (6)$$

where G_T is the gain of transmitter antenna, dBi; G_R is the gain of receiver antenna, dBi; $K_{A\text{-}A} = 0$ dB.

- The IM is calculated by substituting (6) into (3) taking into account (5):

$$IM(f,d) = \min(P_e + 147.6 - 20 \cdot \log f - 20 \cdot \log d + \qquad (7)$$

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

- The IIM is calculated by (4) with the use of the IM values calculated by (7).

9) The decision on the presence or absence of the interference to the receiver is made on the basis of the IIM value.

V. Results of EMC Analysis

The IM was calculated at each analyzed frequency (ref. Table V and Table VI as example). The values of IM ≥ 0 dB (interference is created to the receiver) are marked by red color. The interference can be created to the receiver during M2S and S2D interaction simultaneously (IM > 0 dB at tuning frequencies of the transmitter and the receiver). The highest level of IM is calculated at tuning frequency of the receiver. Dependence of IM on slant distance between 5G mobile station (emitter) and NB IoT device (receptor) at each analyzed frequency is given in Fig. 5–Fig. 7 as example.

Values of IIM are given in Table VII and Table VIII for all cases of EMC analysis. These values are calculated for short distances between the transmitter and the receiver. The maximum value of IIM is marked by red color and the minimum value of IIM is marked by yellow color. Transmitters of 4G/5G wireless system can interfere with NB IoT receivers, as well as NB IoT devices can interfere with receivers of considered wireless systems since IIM > 0 dB in Table VII and Table VIII. The dependence of IIM on slant distance between wireless system equipment as emitter and NB IoT devices (receptor) as well as between NB IoT device as emitter and wireless system equipment as receptor is given as examples in Fig. 8 and Fig. 9.

Reflections from on-site objects as well as penetration of radio waves through the internal walls of the building are effects affecting the results of EMC analysis with the use of multipath model.

TABLE V. Results of Calculation of IM (5G Mobile Station is Tranmitter; NB IoT Device is Receiver)

Interaction type	f_A, MHz	$P_{I\,max}$, dBm	S, dBm	IM, dB
S2S	0.099	1) -14.4	-50	1) 35.6
		2) -14.4		2) 35.6
		3) -14.4		3) 35.6
		4) -14.4		4) 35.6
S2D	465	1) -54.6	-117.5	1) 62.9
		2) -57.8		2) 59.7
		3) -54.4		3) 63.1
		4) -63.8		4) 53.7
S2A	465.2	1) -54.7	-81.5	1) 26.8
		2) -58.0		2) 23.5
		3) -54.4		3) 27.1
		4) -63.9		4) 17.6
O2S	3490	1) -58.7	-50	1) -8.7
		2) -61.3		2) -11.3
		3) -61.4		3) -11.4
		4) -66.3		4) -16.3
M2S	3500	1) -27.1	-50	1) 22.9
		2) -31.2		2) 18.8
		3) -31.1		3) 18.9
		4) -36.0		4) 14.0
S2S	12750	1) -86.4	-50	1) -36.4
		2) -90.1		2) -40.1
		3) -90.8		3) -40.8
		4) -95.3		4) -45.3

Note 1:
1) Emitter is Mobile station Tx1 (ref. Fig. 3).
2) Emitter is Mobile station Tx2 (ref. Fig. 3).
3) Emitter is Mobile station Tx3 (ref. Fig. 3).
4) Emitter is Mobile station Tx4 (ref. Fig. 3).
Note 2:
1. Slant distance between Mobile station Tx1 and NB IoT Rx is 0.7-2.3 m.
2. Slant distance between Mobile station Tx2 and NB IoT Rx is 1.7-3.3 m.
3. Slant distance between Mobile station Tx3 and NB IoT Rx is 2.5-4.3 m.
4. Slant distance between Mobile station Tx4 and NB IoT Rx is 3.5-5.2 m.

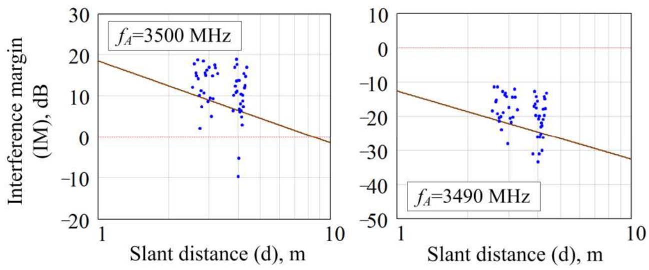

Fig. 5. Interference margin at frequencies of desired and adjacent channels of the transmitter (5G mobile station is the transmitter, NB IoT device is the receiver): frequency of desired channel is 3500 MHz and frequency of adjacent channel is 3490 MHz. Models of radiowave propagation involved: multipath model (scatter plot) and free space model (line plot)

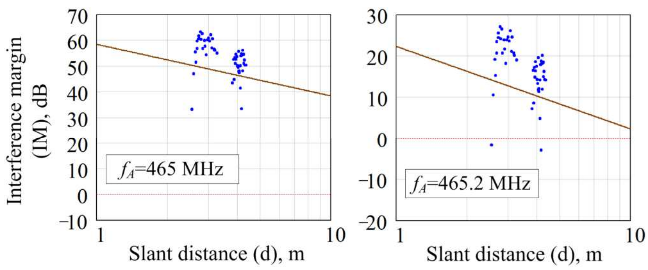

Fig. 6. Interference margin at frequency of desired and adjacent channel of the receiver (5G mobile station is the transmitter, NB IoT device is the receiver) frequency of desired channel is 465 MHz and frequency of adjacent channel is 465.2 MHz. Models of radiowave propagation involved: multipath model (scatter plot) and free space model (line plot)

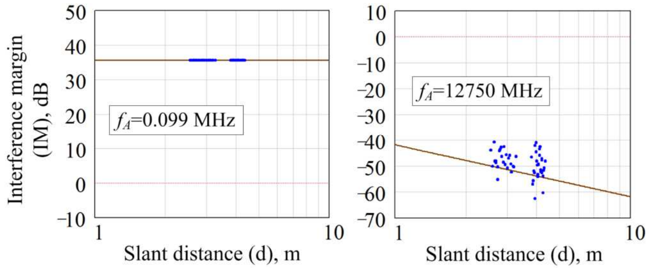

Fig. 7. Interference margin at low and high frequencies (5G mobile station is the transmitter, NB IoT device is the receiver). Models of radiowave propagation involved: multipath model (scatter plot) and free space model (line plot)

TABLE VI. RESULTS OF CALCULATION OF IM (NB IOT DEVICE IS TRANMITTER; 5G MOBILE STATION IS RECEIVER)

Interaction type	f_A, MHz	$P_{I\,max}$, dBm	*S*, dBm	IM, dB
S2S	1	1) -12.5	-50	1) 37.5
		2) -12.5		2) 37.5
		3) -12.5		3) 37.5
M2S	455	1) 16.4	-50	1) 66.4
		2) 12.3		2) 62.3
		3) 4.4		3) 54.4
O2S	456	1) 5.2	-50	1) 55.2
		2) 1.2		2) 51.2
		3) -6.6		3) 43.4
S2A	3490	1) -64.2	-66.2	1) 2.0
		2) -65.0		2) 1.2
		3) -76.4		3) -10.2
S2M	3500	1) -64.9	-110	1) 45.1
		2) -65.2		2) 44.8
		3) -79.3		3) 30.7
S2S	12749.1	1) -75.4	-50	1) -25.4
		2) -78.4		2) -28.4
		3) -88.2		3) -38.2

Note 1:
1) Receptor is Mobile station Rx1 (ref. Fig. 4).
2) Receptor is Mobile station Rx2 (ref. Fig. 4).
3) Receptor is Mobile station Rx3 (ref. Fig. 4).
Note 2:
1. Slant distance between NB IoT Tx and Mobile station Rx1 is 0.6-2.0 m.
2. Slant distance between NB IoT Tx and Mobile station Rx2 is 1.3-4.3 m.
3. Slant distance between NB IoT Tx and Mobile station Rx3 is 4.0-7.5 m.

TABLE VII. RESULTS OF CALCULATION OF IIM (WIRELESS SYSTEMS EQUIPMENT IS TRANSMITTER; NB IOT DEVICE IS RECEIVER)

Emitter	Slant distance, m	Receptor is NB IoT IIM, dB
LTE TDD mobile station (EIRP = 28 dBm)	2.77	63.1
LTE FDD mobile station (EIRP = 25 dBm)	2.77	63.1
5G mobile station (EIRP = 29 dBm)	2.77	63.1
RLAN access point (EIRP = 23 dBm)	3.48	52.1

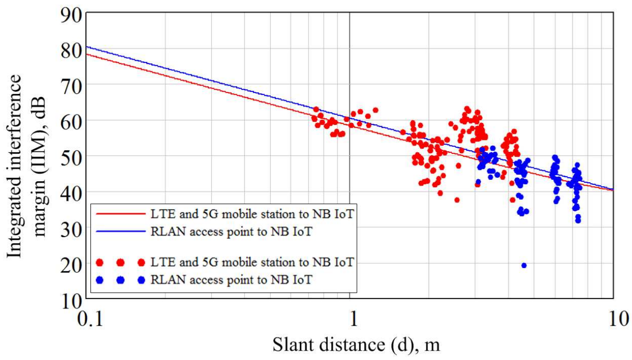

Fig. 8. Integrated interference margin: wireless systems equipment is the transmitter, NB IoT device is the receiver. Radiowave propagation models involved: multipath (scatter plot) model and free space model (line plot)

TABLE VIII. RESULTS OF CALCULATION OF IIM (NB IOT DEVICE IS TRANSMITTER; WIRELESS SYSTEMS EQUIPMENT IS RECEIVER)

Emitter	Receptor	Slant distance, m	IIM, dB
NB IoT device (EIRP = 23 dBm)	LTE TDD mobile station	0.59	66.8
	LTE FDD mobile station	0.59	67.1
	5G mobile station	0.59	66.7
	RLAN access point	4.22	63.4

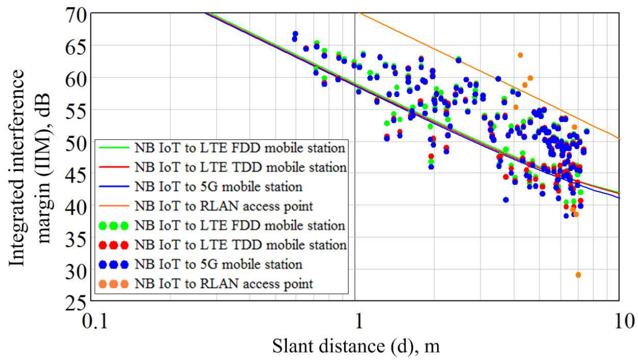

Fig. 9. Integrated interference margin: NB IoT device is the transmitter, wireless systems equipment is the receiver. Radiowave propagation models involved: multipath (scatter plot) model and free space model (line plot)

VI. ASSESSMENT OF DAMAGE DUE TO INTERFERENCE

The level of damage to the receiver determines the danger of the created interference.

The maximum possible damage due to an interference created to NB IoT device receiver is errors in data received by the NB IoT device from a base station. The errors can lead to untimely and incorrect controlling and adjustment of NB IoT devices. This damage is unacceptable especially for vital medical NB IoT devices and high-risk patients. In addition, NB IoT interface is characterized by high latency (up to 10 s [29]). In low-latency applications more interference-resistant radio interface can be used.

The interference created by NB IoT device to 4G/5G mobile stations and RLAN access points can be considered harmless in a majority cases. Data rate reduction or a short-time loss of communications is maximum possible damage due to the interference.

VII. CONCLUSIONS

The considered equipment of 4G/5G wireless systems can interfere with NB IoT devices when emitters and receptors are located within the same room or in contiguous rooms of a hospital building; as well as NB IoT devices can interfere with receivers of wireless systems in similar case (i.e., within the same room or in contiguous rooms). The absence of interference to receivers of NB IoT devices and 4G/5G equipment is not guaranteed even in case of compliance with requirements of standards [14], [15], [18], [19]. Such problem is detected in [11], [30], [31] for other medical equipment.

In order to reduce the risk of interference to medical NB IoT devices, the following measures could be applied: 1) to tighten requirements to susceptibility characteristics of NB IoT receivers in frequency bands assigned for considered wireless systems, as well as requirements to spurious emission of transmitters of wireless systems in frequency bands assigned for NB IoT; 2) to forbid the use of 4G/5G mobile phones during operation of NB IoT devices used especially by high-risk patients inside the same room; 3) to use medical NB IoT equipment in separate rooms located far from 4G/5G equipment operating in health facilities.

In this research, calculated values of the integrated interference margin (EMC criterion) concern the worst situation, because the worst-case models of emission spectra and susceptibility characteristic constructed with the use of [14], [15], [18], [19] are employed. Therefore, authors intend to perform experimental validation of the obtained results for determining more precise restrictions in order to ensure the safe use (as well as to determine capability of the safe use) of 4G/5G wireless systems equipment regarding to medical NB IoT user devices.

The results of this research can be used in case of designing and upgrading of communication systems for diagnostics of intersystem EMC between 4G/5G equipment and wireless medical devices as well as in the field of standardization in order to improve standards intended to ensure the EMC between 4G/5G wireless equipment and medical NB IoT devices.

REFERENCES

[1] N. Sultana, F. Huq, Md. A. Razzaque, and Md. M. Rahman, “User Utility Maximization in Narrowband Internet of Things for Prioritized Healthcare Applications,” Sensors (Basel), Vol. 22 (3), 2022, p. 1192.

[2] K. T. Kadhim, Ali M. Alsahlany, S. M. Wadi, and H. T. Kadhum, “An Overview of Patient’s Health Status Monitoring System Based on Internet of Things (IoT),” Wireless Personal Communications, Vol. 114, 2020, pp. 2235–2262.

[3] H. Zhang, J. Li, B. Wen, Y. Xun, and J. Liu, “Connecting Intelligent Things in Smart Hospitals Using NB-IoT,” IEEE Internet of Things Journal, Vol. 5, No. 3, 2018, pp. 1550–1560.

[4] W. Manatarinat, S. Poomrittigul, and P. Tantatsanawong, “Narrowband-Internet of Things (NB-IoT) System for Elderly Healthcare Services,” 2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 02-05 July, Luang Prabang, 2019, pp.1–4.

[5] R. P. Singh, M. Javaid, A. Haleem, and R. Suman, “Internet of things (IoT) applications to fight against COVID-19 pandemic,” Diabetes & Metabolic Syndrome: Clinical Research & Reviews, Vol. 14, 2020, pp. 521–524.

[6] S. Chen, X.Jin, L.Zhang, and J. Wan, “A comprehensive review of IoT technologies and applications for healthcare,” In International Conference on Artificial Intelligence and Security; Springer: Berlin/Heidelberg, 2021, pp. 358–367.

[7] Y. Cheng, X. Zhao, and J. Wu, “Research on the Smart Medical System Based on NB-IoT Technology,” J. Mob. Inf. Syst. 2021, 2021, 7801365, 10 p.

[8] R. S. Sinha, Y. Wei, and S. Hwang, “A survey on LPWA technology: LoRa and NB-IoT”, ICT Express, Vol. 3, Issue 1, 2017, pp. 14–21.

[9] M. Chen, Y. Miao, Y. Hao, and K. Hwang, “Narrow Band Internet of Things,” IEEE Access, Vol.5, 2017, pp. 20557–20577.

[10] I. Kasujee. IoT forecast: connections, revenue and technology trends 2022–2031, Analysis mason, Feb. 2023. [Online]. Available: https://www.analysysmason.com/research/content/regional-forecasts-/iot-worldwide-forecast-rdme0.html.

[11] A.Svistunou, V.Mordachev, E.Sinkevich, Ming Ye, and A. Dubovik, “Analysis of EMC between Medical Short-Range Devices and Equipment of Wireless Systems,” Proc. of the 2021 Joint IEEE Virtual Int. Symp. "EMC-SIPI and EMC Europe", July 26 - Aug. 20, Glasgow, 2021, pp. 214–219.

[12] G. J. Gonzalez, F. H. Gregorio, and J. Cousseau, “Interference Analysis in the LTE and NB-IoT Uplink Multiple Access with RF impairments,” 2018 IEEE 23rd International Conference on Digital Signal Processing (DSP), 19-21 November, Shanghai, 2018, pp. 1–4.

[13] S, Bhattarai, P. R. Vaka, and Jung-Min Park, “Co-Existence of NB-IoT and Radar in Shared Spectrum: An Experimental Study,” GLOBECOM 2017 - 2017 IEEE Global Communications Conference, 04-08 December, Singapore, 2017, pp. 1–6.

[14] 3GPP TR 36.802 V13.0.0 (2016-06); 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); NB-IOT; Technical Report for BS and UE radio transmission and reception.

[15] ETSI TS 136 101 V15.10.0 (2020-04). LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception.

[16] GSMA. NB-IoT Deployment Guide to Basic Feature set Requirements. April 2018.

[17] ECC Decision (19)02. Land mobile systems in the frequency ranges 68-87.5 MHz, 146-174 MHz, 406.1-410 MHz, 410-430 MHz, 440-450 MHz and 450-470 MHz, March 2019.

[18] ETSI EN 301 908-25. IMT cellular networks; Harmonised Standard for access to radio spectrum; Part 25: New Radio (NR) User Equipment (UE).

[19] ETSI EN 301 893 V2.1.1 (2017-05). 5 GHz RLAN Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU.

[20] Huawei AP7052DN& AP7152DN Access Points. Datasheet, 2017. [Online]. Available: https://www.router-switch.com/media/upload/product-pdf/huawei-ap7052dn-ap7152dn-access-point-datasheet.pdf

[21] Hospital layout design CAD drawing, CADBLOCKSfree, Sept. 2015. [Online]. Available: https://www.cadblocksfree.com/en/hospital-layout-design.html

[22] J. Schuster and R. Luebbers, “Hybrid sbr/gtd radio propagation model for site specific predictions in an urban environment,” 12th Annual Rev. of Progress in Applied Computational Electromagnetics, vol. 1, 1996, pp. 84–92.

[23] J. Schuster and R. Luebbers, “Comparison of site-specific radio propagation path loss predictions to measurements in an urban area,” IEEE AP-S International Symposium and URSI Radio Science Meeting, vol. 1, July 1996, pp. 1210–1213.

[24] C. Balanis, Advanced Engineering Electromagnetics. New York: Wiley, 1989.

[25] J. B. Keller, “Geometrical theory of diffraction,” Journal of the Optical Society of America, vol. 52, February 1962, pp. 116–130.

[26] R. G. Kouyoumijian, P. H. Pathak, “A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface,” Proceedings of the IEEE, vol. 62, 1974, pp. 1448–1461.

[27] R. A. Pearlman, “Physical interpretation of the IEMCAP integrated EMI margin,” IEEE International Symposium on Electromagnetic Compatibility, 1978, pp. 310–315.

[28] Rec. ITU-R P.525-4. Calculation of free-space attenuation.

[29] 3GPP TR 45.820 V13.1.0 (2015-11). Cellular system support for ultra-low complexity and low throughput Internet of Things.

[30] M. Das, R. Vogt-Ardatjew, B. van den Berg, F. Leferink, “Risk-based EMC Approach in Hospital Environment,” 2020 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI), 28 July-28 Aug., Reno, NV, USA, 2020, pp.676–680.

[31] A. Svistunou, V. Mordachev, E. Sinkevich, Ming Ye, A. Dubovik, and I. Shakinka, “Impact of Electromagnetic Radiation of 4G/5G Base Stations on Medical Short-Range Devices in Urban Area,” 2022 International Symposium on Electromagnetic Compatibility – EMC Europe, 05-08 September, Gothenburg, 2022, pp. 537–542.