Assessment of the Impact of Intra-System Interference on the Throughput of a 5G-Based Telemedicine Network

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Abstract: The article is devoted to the use of 5G networks in the field of telemedicine, namely for the deployment of telemonitoring clusters with a high density of telemedicine sensors and detectors. As part of the study, the possibility of fifth-generation technology for organizing a telemonitoring system was assessed, provided that a guaranteed data transfer rate is ensured, considering the simultaneous connection of many devices and sensors. The assessment was carried out considering that any device within the cluster is a potential source of additional electromagnetic interference and affects other devices. The telemonitoring system based on fifth-generation networks was modeled for different initial conditions (distance to the base station, interference power, etc.) under the influence of intra-system interference. The distribution of intra-system interference sources and their distance to the object of study is realized as a random process based on the Monte Carlo method. The results obtained show that the actual throughput of a telemedicine network based on 5G technology largely depends on the number of sources of intra-system interference, which in turn affects the capacity of the telemonitoring cluster (number of endpoints) and the actual density of endpoints is several times less than stated by the technology developers.

1 INTRODUCTION

Today, thanks to information technology and network development, many different areas are undergoing a paradigm shift, and the medical field is no exception. The integration of information technology into the healthcare industry has contributed to the development of telemedicine. Telemedicine is a healthcare area that involves information technology to increase the availability of medical services and facilitate communication between patients and doctors in cases where distance is a critical factor, i.e., personal communication is not possible at the current time [1, 2]. The development of telemedicine has contributed to creating a wide range of services and applications to facilitate the exchange of data in various forms and volumes within the provision of medical services. In accordance with the Sustainable Development Goals [3] and national healthcare development programs, the priority areas of healthcare development are both increasing the availability of medical services and timely monitoring of the health of citizens. Within the framework of telemedicine, this direction is realized through such a service as telemonitoring.

Modern telemonitoring is developing through the convergence of information technology and the concept of the Internet of Things (IoT)/Internet of Medical Things (IoMT). The importance of telemedicine in general, and telemonitoring in particular, became apparent during the outbreak of the COVID-19 pandemic. The pandemic has demonstrated the critical importance of telemonitoring systems, which made it possible to monitor patients' vital signs in real-time remotely and, at the same time, ensure doctors' health. Today, the demand for telemonitoring systems continues to grow. This is because the likelihood of a recurrence of the pandemic remains very high, as well as the growing number of military conflicts and wars. This situation requires creating large-scale, functional, and efficient telemedicine monitoring systems to monitor critical vital signs and inform doctors about them in real-time. All of this suggests, however, that telemonitoring systems will become more complex in their architecture and increase in scale, and while today's telemonitoring systems contain hundreds of sensors, shortly telemonitoring systems will include thousands of such sensors and sensors. To create such systems, it is necessary to use new information and communication technologies capable of providing the required density of devices within the telemonitoring system, the required bandwidth, etc. One of these technologies is the fifth-generation technology and network 5G.

This paper aims to analyze the possibilities of implementing 5G networks in developing and improving telemonitoring systems, taking into account possible intra-system interference.

2 TELEMONITORING SYSTEMS

Telemonitoring is one of the essential services of telemedicine [2], which makes it possible to control vital signs and reduce the risks of developing and complicating chronic diseases, such as heart disease and diabetes, by continuously monitoring patients using data analytics and decision support systems. A modern telemonitoring system (Fig. 1) is an information and communication system for collecting and transmitting indicators.

From an architectural point of view, the monitoring system consists of three components [4,5]:

1) The level of actuators. It is represented by sensors and transducers that collect various physiological data of the patient in real time.
2) Data transmission level. It is represented by gateways and an information network that transmits the collected data from sensors to storage and analysis systems.
3) Analytical processing level. This level is represented by various local and/or cloud storage, analytics, and decision support systems that provide storage, processing, and analysis of data received from the system's sensors and detectors.

The system is based on actuators - sensors and detectors. A sensor is a device that directly measures a particular physiological parameter (e.g., temperature, pressure, etc.) and converts it into a signal suitable for transmission over a network. A sensor cannot display and analyze data [6]. A detector is a more complex device containing several sensors and additional components for displaying and analyzing data. Sensors and detectors are divided into electrical, optical, mechanical, and chemical according to the principle of operation. According to how they are used, they are divided into wearable and implantable, and according to how the collected data is transmitted, sensors and detectors are divided into wired and wireless. It is obvious that, in most cases, flexible and scalable telemonitoring systems can be created based on wearable wireless sensors and detectors. Such devices are connected to a data transmission network using appropriate radio technology [6].

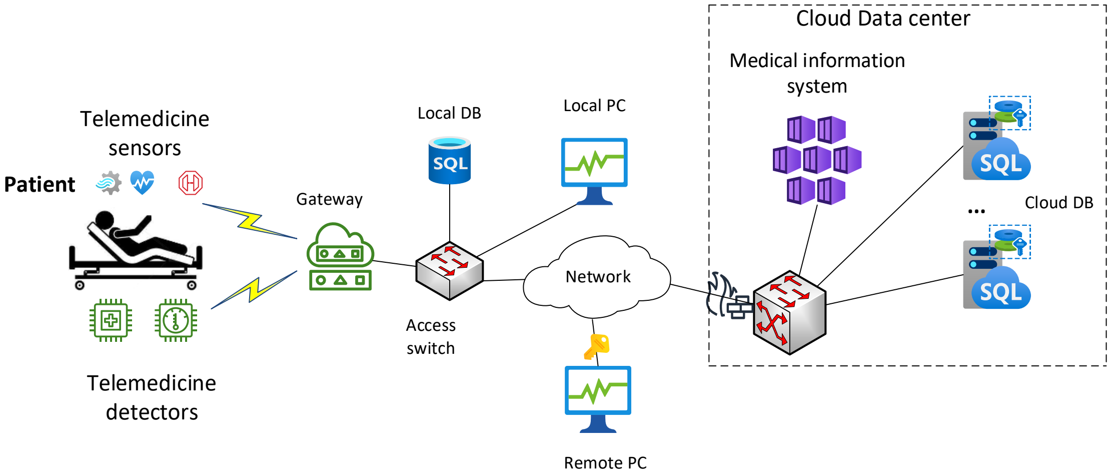


Figure 1: Basic architecture of the telemonitoring system.

To create a reliable telemonitoring system, the data transmission layer must be based on radio technologies that provide high-speed data transmission, low latency, and high density of devices per unit area. Existing technologies, such as 4G, are not able to fully meet the current and future needs of the telemonitoring system (telemonitoring systems require a high density of devices per unit area), so it is advisable to use 5G technologies, which have several advantages over 4G technology, to create a data transmission layer [7]. An alternative to 5G technology is to create a system based on WI-FI 7 technology or on ZigBee with a gateway to a wired Ethernet network. However, such solutions have certain limitations. 5G technology provides greater mobility, better bandwidth, lower latency, and greater scalability. Scalability and mobility play an important role in cases where it is necessary to serve thousands of devices in a small area and provide connection to the system for mobile medical teams [11]. WI-FI 7 or ZigBee should be considered as a solution for creating a local telemonitoring system only inside the building, while a solution based on 5G technology is universal and allows you to create large-scale telemonitoring systems.

The primary data source within the telemonitoring service is sensors and sensors that collect medical data and transmit it for further processing over the network. Channels with a bandwidth of 0.1 – 1 Mbps are sufficient for telemonitoring data transmission [8]. Providing such bandwidth is not a problem for existing technologies, but a high density of sensors and sensors per unit area characterizes modern telemonitoring systems.

It is known that the maximum network capacity for a MIMO channel is determined by the following (1):

$$C = M \cdot \left(\frac{BW}{n}\right) \log_2 \left(1 + \frac{P_s}{N}\right), \tag{1}$$

where M is the number of MIMO levels, BW is the channel bandwidth, n is the number of subscribers, P_s and N is the power of the useful signal and interference, respectively.

The signal strength at the receiver input depends on many factors: operating frequency, terrain, weather conditions, etc. Various radio wave propagation models are used to estimate the signal strength at the receiver input. The telemonitoring cluster can operate in different areas, and it is recommended to use radio wave propagation models for various types of terrain to model the loss level (Rural, Urban Macro, Urban Micro) [9, 10] using (2), (3) and (4). These models are part of the 3GPP recommendation and are widely used in real-world applications as basic models.

$$\begin{gathered} PL_{Rural} = 20\lg\left(40\pi d_{3d}\ f/3\right) + \min(0.03h^{1.72},10)\lg(d_{3d}) - \\ - \min(0.044h^{1.72},14.77) + 0.002\lg(h)d_{3d}; \end{gathered} \tag{2}$$

$$PL_{Urban\,Macro} = 28 + 22\log\left(d_{3D}\right) + 20\log\left(f\right), \tag{3}$$

$$PL_{Urban\,Micro} = 32{,}4 + 21\log\left(d_{3D}\right) + 20\log\left(f\right). \tag{4}$$

The following (5) determines the minimum noise level of the receiver:

$$N = -174 + 10\log\left(BW\right) + N_f, \tag{5}$$

N_f is receiver noise level equal to 0.3 dB.

It is possible to determine the maximum range of the telemonitoring service as a function of the 5G channel bandwidth and signal strength under different radio wave propagation conditions and to assess how this indicator is affected by such a factor as the number of connected devices (sensors) using (1)-(5).

Table 2 shows how the radius of telemonitoring service provision, the density of connected devices (sensors), and the technical parameters of the 5G network are interrelated [8].

The table shows that in the base case, the service radius, the number of devices, and the MIMO configuration (M) are directly proportional to all three components. 5G technology allows scalable telemonitoring systems with different configurations, but the service coverage radius is relatively small. For example, you can create a system for 1000 devices, but the maximum range is only 28 meters, with the maximum MIMO configuration (M = 8).

Table 2: The Dependence of the distance of the remote monitoring service on the number of connected devices and 5G network parameters.

Environment	Number of devices					
	100		500		1000	
	$M = 2$	$M = 8$	$M = 2$	$M = 8$	$M = 2$	$M = 8$
Rural	60	115	27	54	17,5	38
Urban Macro	53	110	22	47	13,5	32
Urban Micro	45	88	19	40	12	28

3 ASSESSMENT OF THE IMPACT OF INTRA-SYSTEM INTERFERENCE ON TELEMEDICINE NETWORK THROUGHPUT

The studies in [8] were carried out for a system with one base station without considering intra-system interference in the cluster. In real conditions, the telemonitoring cluster, like any other cluster of the IoT concept, contains many different radio devices (base stations, various sensors and sensors, gateways, smartphones), which are a source of intra-system interference. In conditions of low density of end devices within a cluster, intra-system interference can be ignored. Clusters created based on 5G technology have hundreds of times higher density of end devices. Accordingly, intra-system interference will significantly impact network capacity, which in turn may lead to a change in the radius of service provision and a reduction in the number of devices in the cluster. In such circumstances, the model described by (1)-(5) needs to be adapted to function in the face of intra-system interference.

The communication channel capacity is determined by the Shannon-Hartley theorem:

$$\mathrm{C} = \Delta f \, log_2 \, (1 + SINR), \tag{6}$$

where Δf is is the bandwidth, SINR is the signal-to-noise ratio.

In order to determine the SINR value, it is necessary to determine the signal power at the receiver input P_s, the noise spectral density P_n and the level of total interference from other devices $P_{\Sigma i}$. To find the useful signal power, use the formula:

$$P_s(d) = P_t + G_t + G_r - PL(d), \tag{7}$$

where P_t is the power of the transmitter (base station), G_t and G_r are the gain of the transmitting and receiving antennas, respectively, $PL(d)$ is the path loss, which depends on the operating frequency, distance, and propagation medium.

The power level of other devices was estimated using a similar (8):

$$P_i = P_d + G_d + G_r - PL(d_i), \tag{8}$$

where P_d is the power of the interfering transmitter, G_d and G_r are the gain of the interfering antenna and the device under study, $PL(d_i)$ is the path loss, d_i is the vector distance between the devices.

After determining the power of each individual interference, the total interference level is calculated:

$$P_{\Sigma i} = \sum_{j=1}^{N} P_i, \tag{9}$$

The minimum noise level of the receiver P_n is determined as follows:

$$P_n = -174 + 10\log(\Delta f) + N_f, \tag{10}$$

N_f is the receiver noise level of 0.3 dB.

The Urban Macro model was chosen as the radio wave propagation medium. According to the ETSI recommendation, the interference level can be determined by the following (11) [9].

$$PL(d) = 28 + 22\log(d) + 20\log(f), \tag{11}$$

where f is the working frequency, GHz.

The analysis of the formalized model allows us to conclude that the number of devices and the cluster radius depend on two parameters:

- the number of additional sources of interference acting on the object of study;
- the distance between the interference source and the object of study.

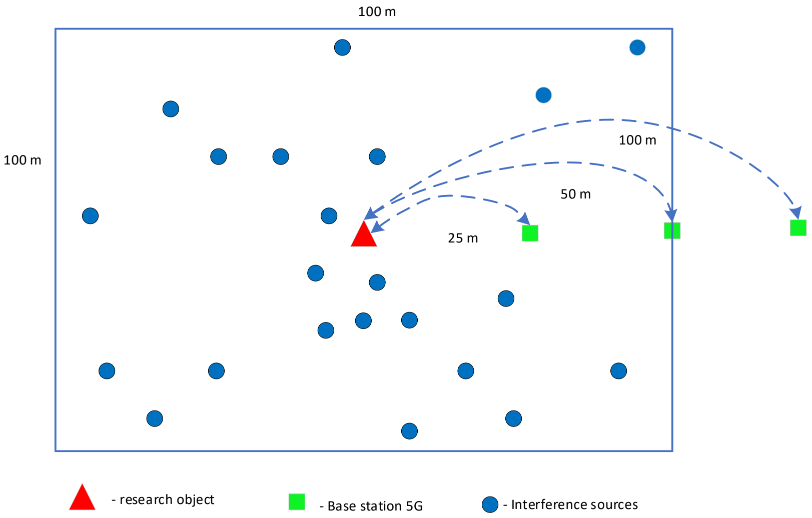
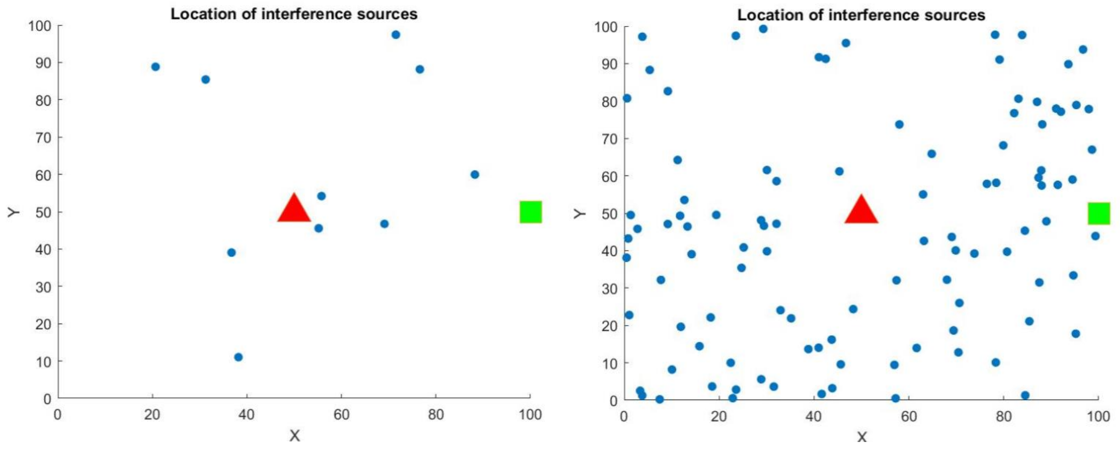


Figure 2: Geometric model of a telemedicine cluster.



(a) (b)

Figure 3: Location of devices in the selected area with n = 10 (a) and 100 (b).

To assess the impact of such interference sources on such important indicators as the density of devices and the radius of the telemedicine cluster, we will conduct a simulation in Matlab based on a formalized model (described by formulas 6-11).

A computer model for estimating the maximum throughput was created to determine the maximum number of simultaneously connected devices to the 5G telemetry network, which ensures the required data transmission rate of 1 Mbps. The modeling was performed for the following initial data: the area under consideration S is 100 m2, the number of devices N is from 2 to 1000, and the distance to the base station is 25, 50, and 100 m. The general modeling scheme is shown in Figure 2.

Since the territorial distribution of subscribers is random, the Monte Carlo method was used to place telemetry devices [10]. The network space is modeled as a two-dimensional plane in which interference sources (other devices) are randomly placed. For each source, the location coordinates and power of the generated interference are determined, taking into account the vector distance between the devices, the propagation medium, and equipment parameters.

This allows us to calculate the total interference level as the sum of the power from all interference sources and to estimate the throughput for each scenario using the (1).

To obtain more accurate estimates, the described experiments were repeated 10 times. After that, the throughput is averaged over all experiments, and its dependence on the number of active interferers is estimated.

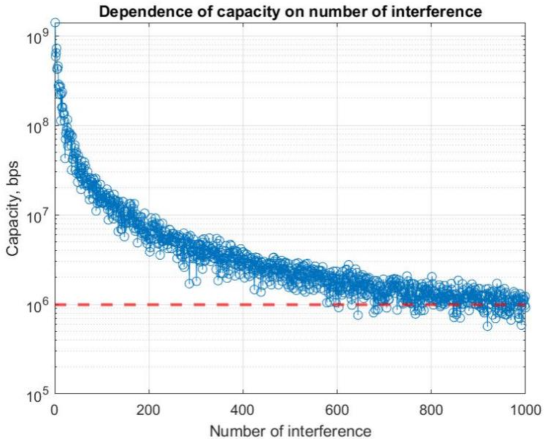


Figure 4: Dependence of bandwidth on the number of devices at 25 meters to the BS.

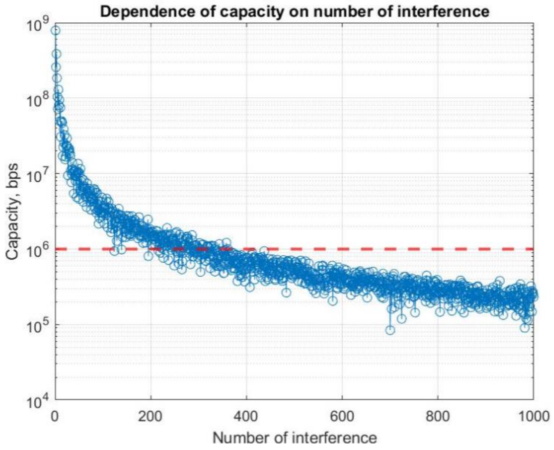


Figure 5: Dependence of bandwidth on the number of devices at 50 meters to the BS.

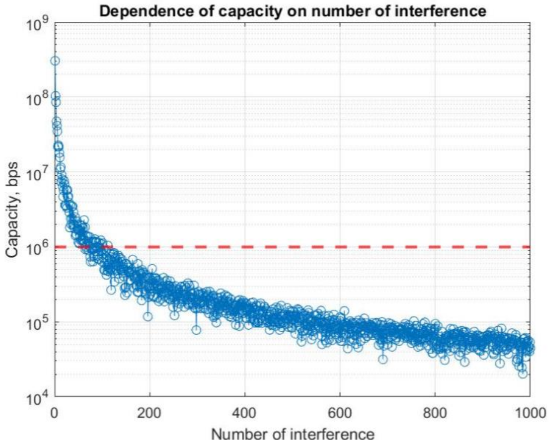


Figure 6: Dependence of bandwidth on the number of devices at 100 meters to the BS.

The described model for the example of 10 and 100 devices is shown in Figs. 3a and 3b.

Figures 4-6 show the dependence of the maximum bandwidth of the device on the number of other devices at a fixed distance to the base station.

The presented dependencies allow you to estimate the maximum number of simultaneously functioning devices at different distances to the base station. For example, at a distance of 25 meters, you can provide a guaranteed data rate for 640 devices, while at a distance of 100 meters to the BS - for only 80 devices.

4 CONCLUSIONS

The high density of devices per unit area declared in fifth-generation networks creates a potential problem - it forms a set of sources of intra-system interference, the power of which is almost equal to the network capacity. This poses a significant problem for systems and networks with a high density of devices deployed on the basis of 5G, such as telemedicine telemonitoring networks. To meet the requirements for the density of connected devices specified in the requirements for telemonitoring networks, it is necessary to take into account the mutual influence of all telemonitoring devices operating simultaneously, since the mutual influence leads to a significant reduction in network quality indicators, such as network speed and reliability.

The proposed method of assessing mutual influence based on the Monte Carlo method allows us to estimate the level of influence of intra-system interference on network efficiency and predict optimal conditions for telemedicine systems.

Reducing the mutual influence of devices is possible due to parametric optimization of system characteristics, such as frequency range, transmitter power, configuration of MIMO and beamforming technologies.

The results of this study can be the basis for further design and optimization of telemedicine networks based on 5G. In particular, the proposed method can be implemented to form a strategy for effective management of radio frequency resources in conditions of high density of devices and scenarios requiring high reliability of data transmission. This will ensure a high level of quality of service (QoS) and minimize the risk of loss of communication during data transmission, which is critical for the successful functioning of telemedicine services based on 5G technology.

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