DOI: 10.17725/rensit.2021.13.095

The problem of increasing the capacity of mobile communication channels and possible solutions

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Received November 30, 2020, peer-reviewed December 12, 2020, accepted December 27, 2020

Abstract: **In this paper the problem of the growing demand for increasing the capacity of communication channels is considered, using the example of real statistical data of the current mobile operator, and the search for possible ways to solve this issue. The analysis of the distribution of electromagnetic fields and SAR for a three-layer model of the human head when interacting with a cell phone is carried out. The results obtained allow us to conclude that it is impossible to significantly increase the capacity of mobile terminals. The increase in power is accompanied by a significant increase in the spatial peak SAR, which exceeds the value recommended by international standards. As an alternative, the main directions and developments for raising the energy potential in the fifth generation 5G cellular radio channels in the millimeter wavelength range have been identified.**

Keywords: **specific absorption rate, channel capacity, mobile phone antenna, electromagnetic effect**

PACS 07.57. −, 84.40.Ba

Acknowledgments: The reported study was funded by RFBR, project number 19-32-90038. The authors are grateful to the organization "KTK TELECOM", the official mobile operator in Crimea, for providing real statistical data presented in the article.

For citation: Andrey S. Tyutyunik., Alexey A. Badashev, Vladimmir S. Gurchenko. The problem of increasing the capacity of mobile communication channels and possible solutions. *RENSIT*, 2021, 13(1):95-103. DOI: 10.17725/rensit.2021.13.095.

Contents

1. INTRODUCTION

Communication technologies are one of the most actively developing areas in the field of science and technology. With the advent of new developments, such as cloud storage, smart home, smart city, automated systems for medical, financial, technical services, etc., the problem in the growth of data transmission speed is becoming more and more urgent [1-3]. Humanity has come close to the era of the Internet of

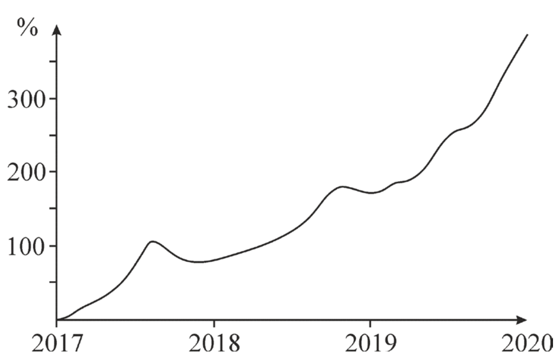
Things (IoT devices), when the automation of processes no longer requires human participation, which in turn leads to an unprecedented variety of requirements and scenarios for developed applications [4,5]. Along with this, the amount of data that is generated by a huge number of IoT devices continues to grow exponentially [6]. The number of devices connected to the IoT - smartphones, personal computers, urban and industrial sensors, etc., has already exceeded the population and reached 9 billion [7]. Thus, the upward trend in traffic and data transmission is a big problem for the functional operation of the network [8,9], and the gap between the rapidly growing requirements for data transmission speed and existing network infrastructures with limited bandwidth has become more and more noticeable [10]. Unfortunately, the modern 4G communication system can no longer provide effective support for the above technologies in terms of transmission speed, connection density, end-to-end latency, etc. [11]. A more efficient and reliable mobile communication system is needed to meet all the growing needs.

On the other hand, an increase in the number of transceiver devices leads to an increase in the effect of radio waves on the human body [12]. The Institute of Electrical and Electronic Engineering (IEEE) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) have established requirements for a peak absorption power standard to limit exposure to electromagnetic fields [13,14]. When exposed to electromagnetic radiation, biological tissues absorb it, as a result of which the absorbed energy is converted into heat, which leads to an increase in tissue temperature, which negatively affects the biological functions of the body [15].

Based on the foregoing, the purpose of this work is to study the problem of increasing the demand for the bandwidth of communication channels using the example of real statistical data and to find possible ways to solve this problem. In particular, the analysis of the impact of microwave electromagnetic radiation on the human biological system.

2. PROBLEMS OF INCREASING MOBILE TRAFFIC VOLUME

With the development of the economy and the growth of material and cultural needs of people, the subscriber base of mobile operators is increasing, which subsequently leads to an increase in the number of terminals (**Fig. 1***a*). The volume of mobile data transmission (voice and



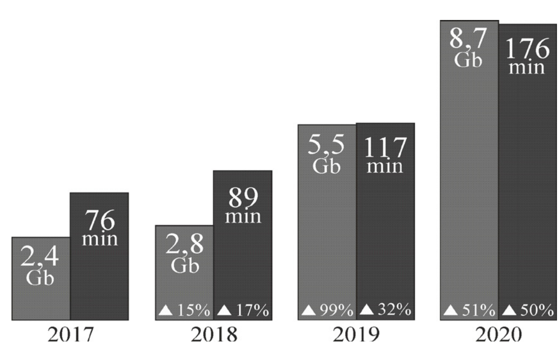


Fig. 1. *(a) - Growth of the subscriber base for the period from 2017 to 2020; (b) - an increase in voice and Internet traffic consumed on average by one subscriber per day.*

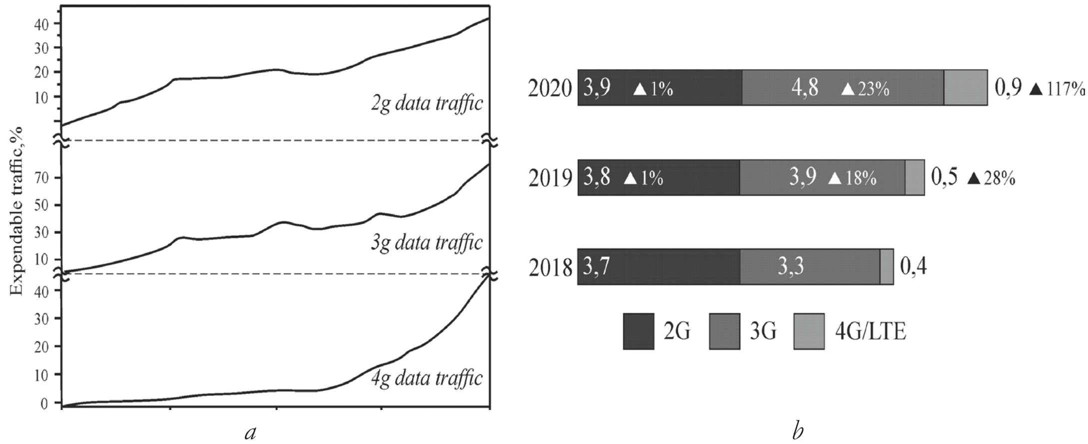


Fig. 2. *(a) - The trend of growth in the total consumption of 2G/3G/4G traffic for the period from 2016 to 2020 in percentage terms; (b) - an increase in the number of BS cells for the period from 2018 to 2020.*

traffic) is growing rapidly from year to year (Fig. 1*b*).

Over the past few years, the total consumption of mobile data has been increasing annually to a significant extent (**Fig. 2***a*). In order to cope with the growth in the volume of transmitted information and ensure a high level of system reliability, mobile operators annually increase the number of hundreds of base stations (Fig. 2*b*) and the total throughput of communication channels (**Fig. 3***a*). This has a positive effect on the increase in the average speed for subscribers (Fig. 3*b*).

Despite all the efforts being made to increase the number of base stations, improve coverage density, expand communication channels, the need for an increase in the speed of information transmission leads to the need to increase the bandwidth of communication lines. The classical theorem of K. Shannon [16,17] allows you to theoretically describe the capacity of a communication channel:

$$\tilde{N} = \Delta f \log_2\left(1+\frac{P_c}{N}\right) = \Delta f \log_2\left[1+\frac{E_\delta}{N_0}\left(\frac{C}{\Delta f}\right)\right], \quad (1)$$

where Δf – the frequency band occupied by the system, P_c – the average signal power, N – the average noise power, E_δ – the bit energy, N_0 – the spectral density of the noise power.

Based on expression (1), it follows that there are two possible ways to solve the problem of increasing the capacity of communication lines. The first solution is to increase the average signal power P_c in

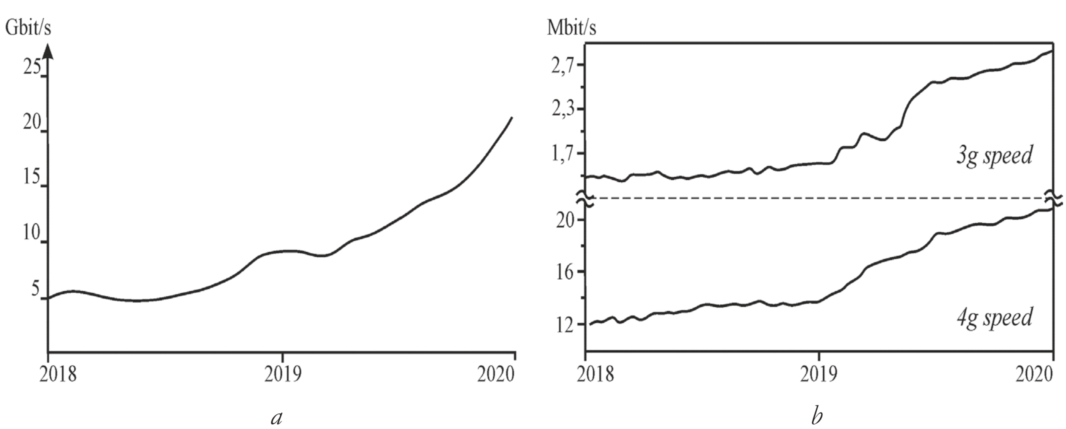


Fig. 3. *(a) - Increase in the throughput of communication channels for the period from 2018 to 2020; (b) - an increase in the average subscriber speed for the period from 2018 to 2020.*

relation to the total energy of noise and interference. The second is an increase in the capacity of the communication channel due to the expansion of the frequency band Δf occupied by the signal.

3. EFFECT OF ELECTROMAGNETIC RADIATION ON HUMAN BIOLOGICAL SYSTEM

To assess the interaction of electromagnetic radiation with a biological environment, it was decided to use SAR (Specific Absorption Rate) - specific absorbed power within the environment [18]. SAR (2) is defined as the ratio of the absorbed power in a given cell to the weight of biological tissue in it:

$$SAR = \frac{\sigma |E|^2}{\rho}, \tag{2}$$

where σ(S/m) - electrical conductivity, ρ (kg/m^3) - material density, $E(V/m)$ - electric field strength.

SAR is set by national and international standards. The SAR limit in the US is 1.6 W/kg, and in Europe it is 2.0 W/kg as set by the International Commission on Non-Ionizing Radiation Protection (ICNIPR) [19]. Analyzing the effect of electromagnetic radiation on the human body, the most interesting area is the head area, as it is the closest to the radiation source - a mobile phone.

The HFSS (High Frequency Structure Simulator) simulation software was used to calculate the SAR parameter based on the finite element method. A three-dimensional multilayer model consisting of skin (4 mm), skull (4.5 mm) and brain (50 mm) is considered as the initial model of the human head (**Fig. 4***a*). The total estimated area of human tissue was 200×200 mm.

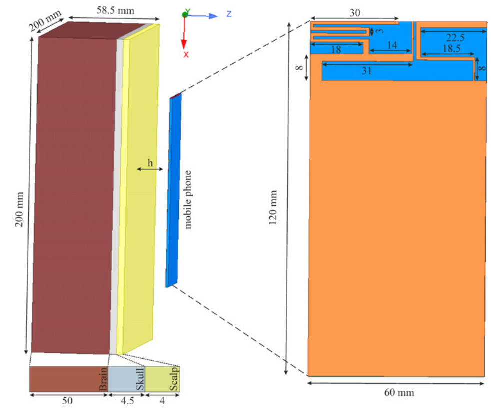


Fig. 4. *(a) Three-layer model; (b) Dimensions of antenna structure (unit: mm).*

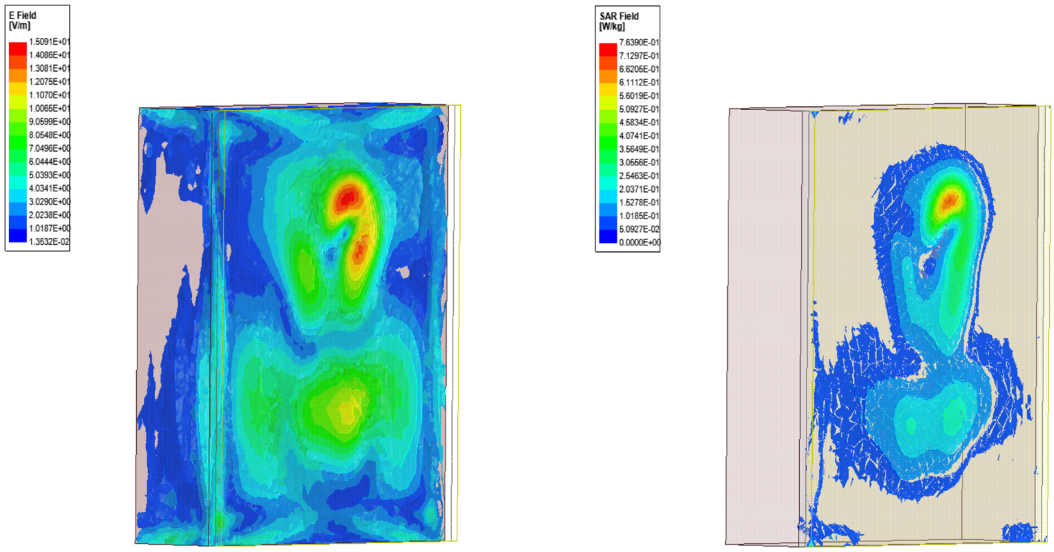
The radiation source was a designed flat monopole antenna, the type of which is quite common in the design of 2G 3G/4G mobile devices [20-22]. The advantage of such an antenna is its low weight, ease of installation and low manufacturing cost. The antenna is designed on an FR4 dielectric substrate with a relative permittivity (ε_r) of 4.4 and a loss tangent (δ) of 0.2. The thickness of the substrate used was 1.6 mm. The upper conductive copper coating was 0.036 mm thick. The dimensions and dimensions of the antenna are shown in Fig. 4*b*.

To calculate the electrical parameters of human tissues, as a rule, the fourth-order Cole-Cole model is used [23].

$$\varepsilon_r^* = \varepsilon_r' - j\varepsilon_r'' = \varepsilon_{r\infty} + \sum_{n=0}^{4} \frac{\Delta\varepsilon_{rn}}{1+(j\omega\tau_n)^{1-\alpha}} + \frac{\sigma_i}{j\omega\varepsilon_0}, \tag{3}$$

where ε_r^* – the complex relative permittivity; ε_r' – relative dielectric constant (real part of ε_r^*); ε_r'' – loss factor (imaginary part of ε_r^*); $\varepsilon_{r\infty}$ – dielectric constant at the field frequency; $\Delta\varepsilon_m$ – increment in the relative permittivity; α – relaxation distribution time; ε_0 – dielectric constant of vacuum; σ_i – ionic conductivity; ω – angular frequency.

In our case, the values of the electrical parameters of the head tissues given in [21]



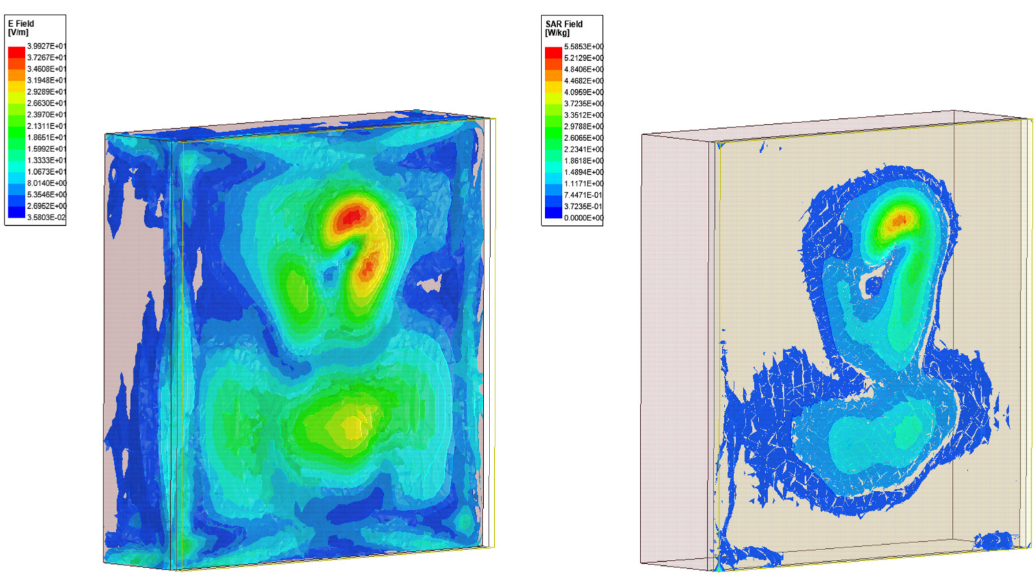
a b

Fig. 5. *Three-dimensional distribution of electromagnetic fields in the tissues of the head at a radiation power of 1 W, (a) the distribution of the electromagnetic field; (b) SAR distribution.*

for a frequency of 2600 MHz were taken as a basis. Fabric density values (kg/m^3): 1100 - for leather; 1850 - for the skull; 1030 - for the brain. The dielectric constant of the skin - 42.645, the skull - 11.293, the brain - 42.330. Conductivity (S/m) of skin - 1.684, skull - 0.424, brain - 1.603.

SAR distribution for the headform was calculated at 2600 MHz. As a comparative analysis, the antenna excitation power was 1 W (**Fig. 5**), which usually corresponds to the maximum usable power in the GSM standard, and 7 W (**Fig. 6**). The radiation source was located at a distance of 2 cm from the human head model.

At 1 Watt, the maximum SAR values do not exceed 0.763 W/kg for the skin, 0.53 W/kg for the skull and 0.33 W/kg for the brain (Fig. 5*b*). It should be noted that most of the incident energy is absorbed by the



a b

Fig. 6. *Three-dimensional distribution of electromagnetic fields in the tissues of the head at a radiation power of 7 W, (a) distribution of the electromagnetic field; (b) SAR distribution.*

scalp tissue. The closer the radiation source is to the head, the greater the harm from the electromagnetic effect of a mobile phone to the tissue of the human head. The highest values of the electric field strength (Fig. 5*a*) are observed on the surface of the human skin, in comparison with the brain and bone tissue, similar to SAR. The obtained values clearly demonstrate the possibility of using the simulated antenna as an element for a mobile phone device.

With an increase in the power of the emitter to 7 W, a sharp increase in the values of SAR (Fig. 6*a*) and electric field strength (Fig. 6*b*) is observed for all layers of the head tissue. The maximum SAR values for skin are 5.583 W/kg, for the skull - 3.23 W/kg, for the brain - 2.08 W/kg. The calculated data obtained indicate that the maximum permissible values of the specific absorbed power inside the human body are exceeded [19].

As can be seen from Figs 5 and 6, with an increase in the power of the radiation source by 7 times, the maximum SAR exceeds the allowable level according to the ICNIPR standard and is 2.08 W/kg for the human brain.

As an example, let us determine the bandwidth of the communication channel according to formula (1). To determine the signal-to-noise ratio (SNR), the useful signal power (P_c) values of 1 W and 7 W were selected, which translated into decibels is 30 dB and 38.45 dB, respectively. The noise power for both cases was N = 5 dB. The bandwidth of the communication channel was Δf = 10 MHz, which is standard for the territory of the Russian Federation, for the 4G/LTE frequency range (2500 - 2690 MHz). As a result of the calculation, the throughput of communication lines ($\tilde{N}$) was 83.093 Mbit/s and 111.125 Mbit/s, for a signal power of 1 W and 7 W, respectively. A 7-fold increase in power gave an increase of ~ 33%, which is not so significant. It follows from this that the method of increasing the throughput of communication channels by increasing the signal power of the receiving-transmitting device of the subscriber's terminal is unacceptable from the point of view of electromagnetic safety and insignificant in the context of the global problem of growing demand for expanding communication lines.

4. MODERN SOLUTIONS IN MOBILE COMMUNICATIONS SYSTEMS, 5G TECHNOLOGY

The solution to the problem of increasing the throughput of communication channels by increasing the signal power in relation to the total energy of noise and interference, by increasing the radiated power of the subscribers' terminals is not possible, due to the increase in the negative effect of electromagnetic radiation on the human body. Therefore, the best way to solve this problem is to expand the frequency band, in particular, the transition to 5*G* technology. 5*G* currently uses 160, 200, and 100 MHz bandwidths in the frequency range 2515 - 2675 MHz, 3.4 - 3.6 GHz and 4.8 - 4.9 GHz, respectively [24]. However, the frequency resources of these spectrum intervals are not unlimited and in the future there will be a number of problems associated with the limitations of the used frequency spectrum.

Currently, active work is underway to develop and conquer the millimeter wavelength range. The millimeter dimensions of the antennas and the frequency range of tens of gigahertz make it possible to significantly increase the energy potential in millimeter-wave radio channels [25]. Nokia has carried out a number of experiments with data transmission at 70 GHz and 80 GHz. The initial results demonstrated the ability of the 5*G* system to provide reliable coverage and high performance of an experimental mobile communication system [26]. Samsung and Huawei also have some success in the development and creation of equipment for a new generation of mobile systems, qualitatively not inferior to the developments of Nokia [27,28]. Ericsson was able to achieve a data transfer speed of 5 Gb/s [29], and Samsung even announced that it had reached a speed of 7.5 Gb/s [27], which gives hope for the possibility of a significant increase in the data transfer speed and the introduction of new technologies in the near future.

5. CONCLUSION

In this article, by means of numerical simulations, the SAR values and the distribution of the electromagnetic field for a three-layer human head model at a frequency of 2600 MHz, at various powers of the radiation source, have been obtained. Calculated results show that an increase in power up to 7 W, with a distance from the head to a mobile phone of 2 cm, significantly increases the SAR values and amounts to 5.583 W/kg for the skin, 3.23 W/kg for the skull, 2.08 W/kg for the brain. ... Considering the reference ICNIRP limit of 2 W/kg, the increase in power is unacceptable from the point of view of the negative impact on the human body. In addition, an increase in power to 7 W gave an increase in channel capacity by only ~ 33%, which is not significant in the context of the global problem of growing demand for expanding communication lines. The results thus obtained provide valuable information for designing devices and assessing the effects of an electromagnetic field.

The optimal solution to the problem of expanding the bandwidth of information transmission channels is the transition to the millimeter frequency range. This, in turn, will make it possible to use the existing spatial, frequency redundancy when receiving, and transmitting information, which will open up some ways to raise the energy potential in millimeter-wave radio channels.

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