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COMPARATIVE ANALYSIS OF INTERFERENCE, NOISE AND LOSSES IN THE MOBILE COMMUNICATION SYSTEMS IN MILLIMETER WAVE RANGE

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Abstract: The article analyzes the approaches to the mathematical modeling of mobile systems in the millimeter wave range. The architecture of a mobile network using Radio over Fiber (RoF) technology is considered which is proposed for forming and transmitting the millimeter-wave signals via fiber-optic communication lines. The noise of the optical heterodyne used for the formation of radio signals is analyzed. The mathematical analysis of the components of the energy budget of the radio link in the millimeter wave range is carried out on the basis of a study of the fundamental physical aspects that affect the value of noise, losses and signal gains. The comparative analysis of the signal-to-interference ratio and the signal-to-noise ratio, the probability of transmitting information radio signals through the reflected paths is carried out. A quasi-optical model of the narrow-beam antenna radiation is proposed for calculating noise interference and signal loss in multipath propagation models taking into account multiple reflections and diffractions, as well as absorption in various media. The analysis of the energy budget components of the radio link in the millimeter wave range shows that it is necessary to take into account both interference and noise associated with the method of signal generation and emission, for example, in phased antenna arrays, as well as the effects of molecular absorption (repeated radiation) in the atmosphere and the effects of the reflection of signals in urban scenario.

Key words: millimeter wave range, wireless communication, noise regime, directional antennas, interference, radio link energy budget, RoF technology, signal to interference ratio, signal to noise ratio.

1. Introduction

In order to increase the capacity of telecommunication systems serving 5G mobile networks and other wireless technologies, including nano-networks, the use of a millimeter-wave range (MMR) is expected in the near future. However, the use of such a range significantly differs from, for example, the decimeter range in terms of the physical characteristics of propagation, methods of forming signals and the characteristics of generating devices. As noted in [1], the problem of simulating a 5G channel consists in providing a fundamental physical basis which would be flexible and accurate, especially in the millimeter range.

It is well known that the main factor influencing the choice of modulation methods, coding and achieving the maximum data transfer rate is the SINR value (signal-to-noise ratio plus noise). For MMR, propagation mechanisms are atmospheric absorption, reflections and, to a lesser extent, diffraction. Therefore, approaches to modeling radio channels, interference and noise for MMR may differ significantly from approaches to modeling channels at lower frequencies. For example, in the range from 100 MHz to 6 GHz, the main factor for calculating the energy coverage of the urban scenario is wave diffraction. For solving this problem, channel models taking into account different diffraction depending on the geometry (typicality) of urban building were created [2].

In MMR, absorption and scarse diffraction features of MMW lead to the use of small cells – for 60 GHz (MMR absorption window) with a radius of up to 10 meters, for mobile systems (28, 73 GHz) up to 150–200 m, for nano-networks (MMR including terahertz range) – a few tens of millimeters [1, 3, 4]. Also, MMR waves are characterized by the possibility of a narrowly directed energy transfer – from several degrees to fractions of one degree, which makes it possible to increase the energy efficiency of such systems and compensate high absorption in the atmosphere.

Methods of forming signals in MMR are still being investigated [5, 6]. At a small wavelength of the MMR, the noise and dynamic characteristics of the radiation devices are important. Optical heterodyning methods are quite promising for generating the MMW, as, for example, the conversion of optical domains into millimeter-wave electrical signals in a photodiode [5, 6]. Such a method is considered promising both for generating MMR signals and for modulation, as well as for converting millimeter signals into optical signals, multiplexing, transmission over fiber optic communication lines over long distances, for example, for combining base stations and data centers. Optoelectronic methods are also used to form directional diagrams of phased antenna arrays (PAA) [5, 7].

The study of noise, losses and delay of the signal is fundamental for MMR. In contrast to the classical approach for systems operating in the decimeter range, where only thermal noise is considered as noise, it is necessary to take into account the dependence of the output power on noise and the dynamic range of interference. Also a classic relationship between the directivity of the antenna D and its effective area A_{eff} and wavelength λ $Dl^2 = 4pA_{\text{eff}}$ is correct for narrow-band systems. It may be necessary to take into account that both the directivity D and the effective area A_{eff} depend on the frequency (wavelength) of the carrier signal itself and, therefore, using the above expression will be narrowband approximation. For example, in [8], the impulse response of the antenna at the transmission and reception of a terahertz range signal is studied.

In addition, it is possible that the molecular absorption noise [4] and scattering due to reflections (both diffuse and specular) [9, 10] can be significant in terms of the energy budget components of the MMR radio channel.

Many papers are devoted to mathematical modeling of interference and the probability of blocking in the millimeter-wave channels for mobile systems based on stochastic geometry (e.g., see [11, 12]). However, they do not take into account the noise associated with the method of signal generation, molecular absorption noise, noise or signal amplification associated with the phenomena of reflections, diffraction, scattering of the MMR signal. In this paper, the authors analyze the values of the enumerated noise (amplifications) of the signal, their contribution to the signal-to-interference ratio (SIR) and signal-to-noise ratio (SNR).

2. Quasi-optical model of the millimeter-wave radio channel

The energy potential of a line-of-sight radio link in radio engineering is usually described by the classical Friis equation $P_{\text{RX}}/P_{\text{TX}} = G_{\text{TX}}G_{\text{RX}}(l/4pd)^2$, where P_{TX}, P_{RX} is the power of a transmitting and receiving antenna respectively, G_{TX} and G_{RX} is the gain of the transmitting and receiving antenna respectively, λ is the transmitted signal wavelength, d is the distance between the transmitter and the receiver, $(l/4pd)^2$ is the loss in "free space".

Mathematical empirical models of radio channels close to the Friis equation are currently used by various research groups (5GCM, mm MAGIC, METIS, 3GPPTR 38.901, etc.) to implement mobile telecommunications in the 0.5 to 100 GHz band [1]. In deriving the Friis equation, a frequency-dependent expression was used for the effective antenna area, where the directional gain of the antenna occurs.

Narrow-directional radiation in MMR is formed using a phased antenna array (PAA) with a large number of radiating elements. The directional coefficient of the PAA (gain) depends on the number of radiating elements ($D \approx 2Nd/\lambda$). In [10] it was noted that expressing the dependence of values is difficult, since it is associated with a large number of variables, the complex geometry of the radiating elements of the HEADLIGHTS, which are used as horn TEM antennas. In addition, 5G systems assume adaptive beamforming in power, direction, aperture angle, and dr. [1]. For mobile systems, communication in MMR is initially assumed only from the base station to the user, i.e. in the live channel.

Therefore, a quasi-optical model of the cone-shaped antenna radiation, which is typical for the calculation of optical open systems (Fig. 1), may be preferable for the analysis of the energy budget of MMR radio systems (Fig. 1):

$$P_{\text{TX}} = P_{\text{RX}}\frac{4pd^2L_{\text{atm}}(f_{\text{c}},d)}{D_{\text{TX}}A_{\text{RX}}}, \qquad (1)$$

where $L_{\text{atm}}(f_{\text{c}},d)$ is the attenuation coefficient of the signal in the atmosphere depending on the carrier frequency f_{c}, D_{TX} is the directional coefficient of the radiating antenna $\left(D_{\text{TX}} = 4p/\Omega = 2\big/\left(1-\cos\left(a/2\right)\right)\right.$, α is the aperture angle of the antenna, A_{RX} is the effective area of the receiving antenna.

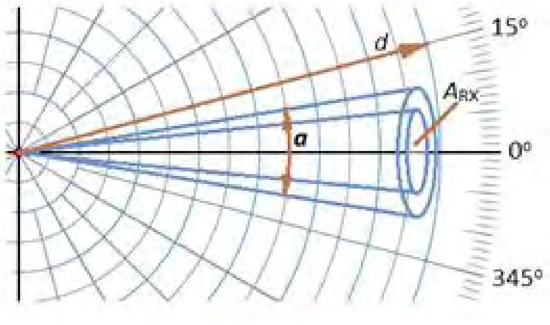

Fig. 1. Quasi-optical model of the cone-shaped antenna radiation

For highly targeted radiation and transmission over small distances, for example, for nano-networks, it is possible to express formula (1) in terms of the surface density of the radiation energy flux:

$$E_{\text{TX}} = E_{\text{RX}}\frac{4pd^2L_{\text{atm}}(f_{\text{c}},d)}{D_{\text{TX}}}, \qquad (2)$$

The side lobes of the antenna pattern can also be taken into account by a quasi-optical model (1) or (2), as well as attenuation in various media.

Quasi-optical models (1) and (2) in which the frequency-dependent parameter “free-space path loss” $(\lambda/4\pi d)^2$ is not used may be more acceptable for calculating interference and signal losses in multipath propagation models, especially taking into account the building geometry [14].

3. Noises and losses in the millimeter-wave channel

In the energy budget of the channel the losses and noise affecting the choice of coding methods, modulation, etc. should be taken into account. Terms “losses” and “noise” are often considered as similar, since their influence on the system is the same [15].

To analyze the budget of radio systems, it is necessary to determine the minimum signal power in the receiver, i.e. receiver sensitivity:

$$P_{\text{RX-sens}} = P_{\text{S}}\left(N_{\text{int}} + N_{\text{TX}} + N_{\text{RX}}\right)/N\,, \qquad (3)$$

where: P_{S}/N denotes the ratio of carrier power to noise power required for demodulation; N_{TX} is the noise power of a signal source which includes not only thermal noise, but also other components associated with the method of signal generation; a N_{RX} is the loss of signal power in the receiver; N_{int} is interference power, which includes $N_{\text{int}} = N_{\text{K}} + N_{\text{M}} + N_{\text{NLOS}}$, where N_{K} is the interference from other communication channels; N_{M} is the noise of molecular absorption; N_{NLOS} are changes in the signal level associated with diffraction and reflections from urban objects. It may also be necessary to take into account scattering due to diffuse (or multiple) reflections, molecular scattering, and scattering caused by atmospheric turbulences. Noise sources N_{M} and N_{NLOS} can be both inside the analyzed channel and in other communication channels. The signal can be restored properly if its power at a distance *d* from the transmitting antenna exceeds the sensitivity of the receiver, that is, when $P_{\text{RX}} - P_{\text{RX-sens}} \geq 0$. The signal/interference ratio plus noise (SINR), which determines the quality of the received signal, takes the form:

$$SINR = \frac{P_{\text{RX}}}{\left(N_{\text{int}} + N_{\text{TX}} + N_{\text{RX}}\right)}\,, \qquad (4)$$

or using (1)

$$SINR = \frac{P_{\text{TX}} D_{\text{TX}} A_{\text{RX}}}{4\pi d^2 \left(N_{\text{int}} + N_{\text{TX}} + N_{\text{RX}}\right) L_{\text{atm}}}\,. \qquad (5)$$

4. Molecular absorption noise

The emissivity of the medium in which the MMR radio waves propagate is considered as a source of noise [4]. In approximation to the Beer–Lambert–Bouguer law, the formula for the power of molecular absorption noise can be written as follows:

$$N_{\text{M}}(f_{\text{c}}, d) = P_{\text{TX}} \frac{D_{\text{TX}} A_{\text{RX}}}{4\pi d^2} \left(1 - e^{-K(f)d}\right), \qquad (6)$$

where: *K*(*f*) is the generalized absorption coefficient of the medium, whose value can be found, for example, from the Hitran database [16].

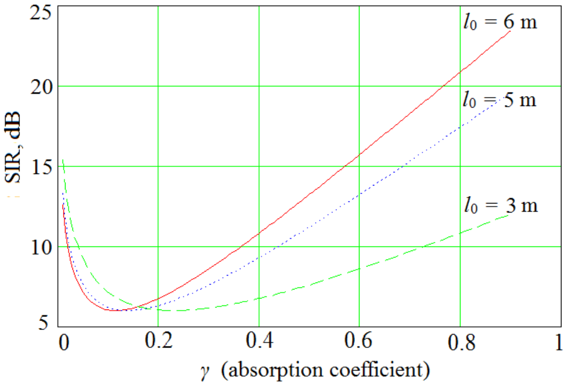

Fig. 2. Calculated value of the signal-to-noise ratio of molecular absorption depending on the coefficient of absorption γ and the distance l_0 from the transmitter to receiver.

Electromagnetic radiation absorbed by molecules in the medium, as shown in [17], is re-emitted out of phase at frequencies similar to those at which it was absorbed. However, in [18] it was shown that absorption of terahertz radiation by molecules of water vapor introduces color noise. At the moment, the nature of the molecular absorption noise is still being studied. It is possible that the basis of absorption/radiation is the combination of various physical phenomena, for example, stimulated, spontaneous or repeated radiation. The authors of papers [17, 18] suggest that molecular noise absorption is the main factor determining the SNR for terahertz transparency windows, and thus the main factor of remote limitation, especially for dense networks. However, the relaxation time of molecular noise, the delay time associated with reemission of energy, the spectral composition etc. being temporal characteristics (properties) of absorption / emission ultimately determine the amount of energy received by the receiver. Therefore, for the THz range, pulsed methods for coding and modulation are proposed [18].

5. Gain and noise of millimeter-wave signal associated with the phenomena of reflection and diffraction

For 5G MMR telecommunications, small cell sizes (10–150 m and less) are assumed due to the need for fast exchange of multimedia data, for example, between D2D communications, strong MMR absorption, MMR propagation in the line of sight LOS, narrow-beam signal transmission. Also, for MMR systems, the effect of reflections and diffractions on the signal gain for the LOS and NLOS regions is analyzed. Measuring the coefficients of reflection from building materials at a frequency of 28 GHz [19] shows values up to 0.896.

Consider the multipath model of the energy potential in urban development formed as a result of reflection, diffraction, absorption of rays, for the aperture angle a of the transmitting antenna and the effective area A_{RX} of the receiving antenna (not depending on the carrier frequency), the signal power at the input of the receiving antenna [10] is:

$$P_{\mathrm{RX}} = \frac{P_{\mathrm{TX}} D_{\mathrm{TX}}(a) A_{\mathrm{RX}}}{4\pi r^2} \times \sum_j \left(\prod_m p_m(q_j) \frac{\left|\Gamma_m(q_{mj})\right|^2}{r_m} \times \right. \tag{7}$$

$$\left. \times \prod_n p_n(q_j) \left|\mathrm{T}_n(q_{nj})\right|^2 \prod_l p_l(q_j) \frac{\left|D(q_{lj})\right|^2}{r_l} \right),$$

where P_{TX} is the power of transmitting antenna; $r_m, r_l > 1$ are coefficients determining the excess path of the rays q_j under the conditions of reflection and diffraction; $p(q_j)$ is the probability of the corresponding process for certain conditions; $D_{\mathrm{TX}}(a) = 2/(1-\cos(a/2))$; Γ, T, D are reflection, transmission and diffraction coefficients, respectively.

Due to the beam radiation of the MMR antennas and the short transmission distance (for mobile systems), *m*, *n* and *l* must assume certain values, depending on the geometry of the building.

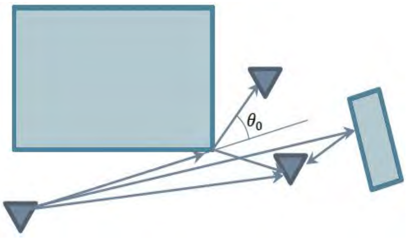

Fig. 3. Example of channel gain due to reflection and diffraction at right angles.

6. Photon methods for generating signals and sources of noise

To implement the concepts of wireless communications in MMR, it is proposed to use photon methods of generating and transmitting MMR signals via optical lines. Photographic methods for generating millimeter signals are more fundamentally studied in comparison with electronic methods and also have better noise and dynamic characteristics [5]. Photon methods of forming and transmitting signals using Radio over Fiber (RoF) technology, you can: tune the frequency in a specific step; operate in a very wide frequency band, for example, 10 GHz; transmit radio signals through an optical fiber over long distances (kilometers) to a remote base station or data center (Fig. 4, 5), as well as multiplex channels using wavelength-division multiplexing (WDM) technology.

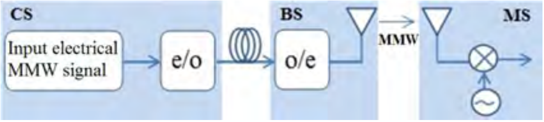

Fig. 4. Channel structure for the MMR mobile system using RoF technology; CS – central station, BS – base station, MS – mobile station.

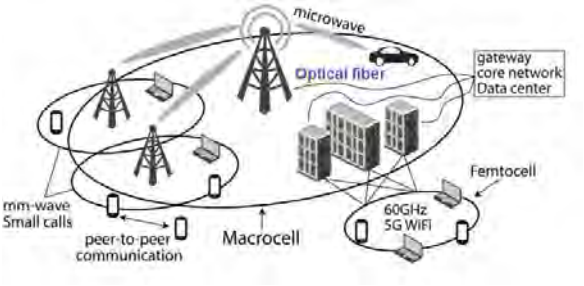

Fig. 5. Mobile network architecture using RoF technology.

Sources of noise generated using RoF technology are considered as Gaussian random processes with zero mean, which can be summed up as current sources, since they are formed during optoelectronic conversion in a photodiode (PD) [5]:

$$s^2_{\text{noise}} = s^2_{\text{thermal}} + s^2_{\text{shot}} + s^2_{\text{RIN}} + \\ + s^2_{\text{sig-ASE}} + s^2_{\text{ASE-ASE}}, \tag{8}$$

where s_{thermal} is thermal noise caused by random motion of carriers in the conductor leading to random fluctuations of the generated current; s_{shot} is shot noise representing random fluctuations of the signal caused by the discreteness of the charge; s_{RIN} represents fluctuations in the optical intensity of a laser; $s_{\text{sig-ASE}}$ is the noise of the amplified signal in the optical amplifier,

$s_{\text{ASE-ASE}}$ is the amplified noise of spontaneous emission (ASE) generated inside the amplifier.

Therefore, the signal-to-noise ratio at the output of the photodiode can be written as follows:

$$SNR_{\text{PD,out}} = \frac{S}{s_{\text{noise}}^{2}} = \frac{P_{\text{opt}}^{2} R_L}{B_{\text{el}} W},$$

$$W = \frac{4k_{\text{B}}T}{R_L \Re^2} + 2q\frac{P_{\text{opt}}}{\Re} + 10^{\frac{RIN^{dB}}{10}} P_{opt}^{2} + \tag{9}$$

$$+ 2G_{\text{opt}}^{2} P_{\text{opt}} NF_{\text{opt}} hn_{\text{opt}} + \left(G_{\text{opt}} NF_{\text{opt}} hn_{\text{opt}}\right)^2 B_{\text{opt}},$$

where k_{B} is the Boltzmann constant, T is absolute temperature, B_{el} is the noise equivalent electrical bandwidth obtained after converting the optical signal into electrical one in the PD, q is the charge of the electron, P_{opt} is average optical input power, R_L is load resistance, $\Re$ is photodiode sensitivity, G_{opt} is the gain of an optical amplifier, NF_{opt} is the noise factor of the optical amplifier, B_{opt} is the band of the optical amplifier, hv_{opt} represents photon energy, RIN is the relative noise of laser intensity.

Passive optical and electrical components (optical fibers, electrical cables, connectors, etc.) do not create current fluctuations, so their contribution to the total noise can be ignored. Optical modulators can also be considered as passive components without interference, since their main element is an optical waveguide, which does not create noise. Experimental results [20] show that when the spectral line width of the optical source is within 50 MHz and the transmission range up to 50 km, the chromatic dispersion of SSMF fiber leads to insignificant increase in phase noise. The results of calculations of the SNR value according to the formula (9) are shown in Fig. 6.

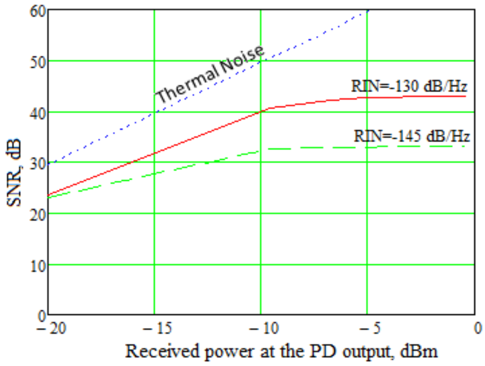

Fig. 6. Results of calculations of SNR values.

After the photodiode, the system passes through a set of low noise amplifiers (LNA) and medium power amplifiers (MPA), so the cascade noise level of the amplifiers in accordance with the Friis formula becomes the following [5]:

$$NF_{\text{amp}} = NF_{\text{LNA}} + \left(NF_{\text{MPA}} - 1\right)/G_{\text{LNA}}, \tag{10}$$

NF_{amp} being the total noise figure of amplifiers, NF_{amp} NF_{LNA} representing the noise figure of the amplifier, NF_{MPA} being the noise ratio of the power amplifier, G_{LNA} being the noise gain in the amplifier.

7. Simulation of interference in cellular millimeter-wave networks based on stochastic geometry

The power of interference from other communication channels in a randomly located reference receiver in accordance with [21] can be expressed as:

$$N_{\text{K}} = \sum_{i=1}^{K} g_i h_i G(q_i, y_i) l_i^{-a}, \tag{11}$$

where g_i is the transmitted power, h_i is the attenuation coefficient in the channel (the Nakagami variable is used to simulate small-scale fading), l_i is the distance between the transmitter and receiver in the i-th interfering channel, respectively, K is the number of active interference sources.

For the millimeter range, the analysis is mainly carried out in a circular sector, the channel losses are taken into account according to the law $l(r) = r^{-a}$, the usually chosen coefficient value is a = 3, 3.5, ... 5 for NLOS systems.

Then the signal/noise ratio + interference noise is:

$$SINR = \frac{g_0 G_0 l_0^{-a}}{\sum_{i=1}^{K} g_i h_i G(q_i, y_i) l_i^{-a} + s^2}, \tag{12}$$

where index 0 corresponds to the reference receiver and transmitter, $s^2 = N_{\text{TX}} + N_{\text{RX}}$.

Signal/interference noise value, respectively, is:

$$SIR = \frac{G_0 l_0^{-a}}{\sum_{i=1}^{K} h_i G(q_i, y_i) l_i^{-a}}. \tag{13}$$

Losses in the MMR radio channel are also taken into account by the CI model:

$$\begin{aligned} L^{\text{CI}}\left(f_c, d_{3\text{D}}\right)[\text{dB}] &= \text{FSPL}\left(f_c, 1\text{m}\right) + \\ &+ 10n\log_{10}\left(d_{3\text{D}}\right) + c_s^{\text{CI}}, \end{aligned} \tag{14}$$

where c_s^{CI} is a shading loss, which is modeled as a zero mean Gaussian random variable with a standard deviation in dB, n is a path loss indicator found by minimizing the error of the measured data to (2), $d_{3D} > 1 \cdot \mathrm{m}$, $FSPL(f_c, 1\mathrm{m})$ are losses in free space at 1 m distance.

To study interference noise, stochastic geometry is often used. In particular, it could be the model of the spatial Poisson point process. Then, the probability of finding interfering nodes within region A is found by the expression [22]:

$$P\{N \in R\} = \frac{(l\,A)^N}{N!} e^{-l\,A}, \quad N \geq 0, \tag{15}$$

where λ is the density of interfering nodes N.

For the calculations, the spectral efficiency parameters for the ALOHA or TDMA system (access methods proposed for mobile systems in MMR) are input, namely, the density of potential sources of interference per unit area, transmitters (links) per unit area, the density of interference per unit area, etc.

Let us consider a transmitter-receiver control pair in the presence of the number N of interfering access points in a circular region A with radius R (Fig. 7).

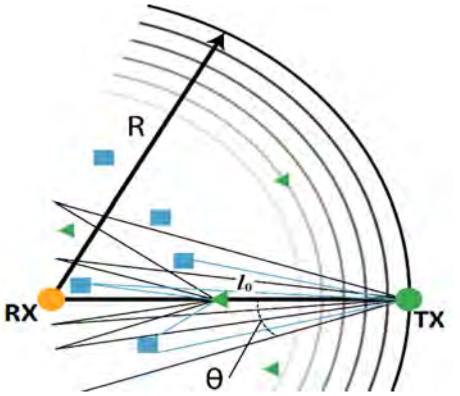

Fig. 7. Example of the Poisson point distribution: squares – blocking, triangles – interfering nodes, circles – receiver-transmitter under investigation.

Interfering nodes are distributed according to the spatial Poisson point process. The total received interference signal at a particular point in the network is the sum of the received signals from each node. Let us assume that the interfering sources are in line of sight (LOS) and their transmit power is constant. It has also been accepted that the reference transmitter-receiver pair with the distance l_0 between them is not involved in the Poisson point process and is not blocked. Effects associated with NLOS (for example, with reflection effects and, to a lesser degree, with diffraction) require separate study. The authors assume that the blocking probability for interfering nodes does not depend on the aperture angle of the antenna, but only on the distance and linear dimension of the block.

The total value of the interference from other communication channels in the receiver can be expressed as:

$$\begin{aligned} N_{\mathrm{int}} &= P_{\mathrm{TX}} \frac{D_{\mathrm{TX}} A_{\mathrm{RX}}}{4p} \sum_{i=1}^{N} l_i^{-2} e^{-g(f) l_i} = \\ &= P_{\mathrm{TX}} \frac{2/(1-\cos(q/2))\, A_{\mathrm{RX}}}{4p} \sum_{i=1}^{N} l_i^{-2} e^{-g(f) l_i}, \end{aligned} \tag{16}$$

where N is the number of interfering nodes affecting the receiver, l_i is a distance from the interfering node to the receiver, $r(f)$ is the absorption coefficient depending on the carrier frequency.

For a two-dimensional model, the probability of blocking a signal from interfering nodes of a circular shape with a radius r_b can be considered as a function of the distance from a particular node as follows [3] :

$$p_b = \exp\left(-l_b\,(l - r_b)\,r_b\right), \tag{17}$$

where l_b is blocking density.

The probability that the receiver is inside the main lobe θ of the active transmitter is:

$$p_l = 1 - \exp\left(-l^2 tg\left(q/2\right)\right). \tag{18}$$

The average value of the interference in the receiver $E[N_{\mathrm{int}}]$ can be calculated in accordance with (1), (16)–(18) as follows:

$$\begin{aligned} E[N_{\mathrm{int}}] &= P_{\mathrm{TX}} \frac{A_{\mathrm{RX}}}{2p\,(1-\cos(q/2))} \times \\ &\times \int_0^R l^{-2} \exp(-g\,l) p_l\,(1 - p_b)\, 2\,l\,p\,l dl = \\ &= P_{\mathrm{TX}} \frac{A_{\mathrm{RX}}}{2p\,(1-\cos(q/2))} \times \\ &\times \int_0^R l^{-2} \exp(-g\,l) \left[1 - \exp(-l^2 \mathrm{tg}(q/2))\right] \times \\ &\times \left[1 - \exp(-l_b\,(l - r_b) r_b)\right] 2\,l\,p\,l dl = \\ &= \left|q \leq 10^{\circ}\right| = P_{\mathrm{TX}} \frac{4A_{\mathrm{RX}}}{p q^2} \times \\ &\times \left[E_i(r_b, g, l, l_b, q) - E_i(R, g, l, l_b, q)\right], \end{aligned} \tag{19}$$

where $Ei(x)$ is an integral exponential function.

Signal/interference ratio:

$$SIR = \frac{P_{\mathrm{RX}}}{N_{\mathrm{int}}} = \frac{l_0^{-2} e^{l_0 g(f)}}{\left[E_i(r_b, g, l, l_b, q) - E_i(R, g, l, l_b, q)\right]}. \tag{20}$$

For $\gamma = 0.1$, $\lambda = 0.01$, $\lambda_b = 0.01$, $r_b = 0.3$ m, the calculated SIR value is presented in Fig. 8 for different θ and l_0.

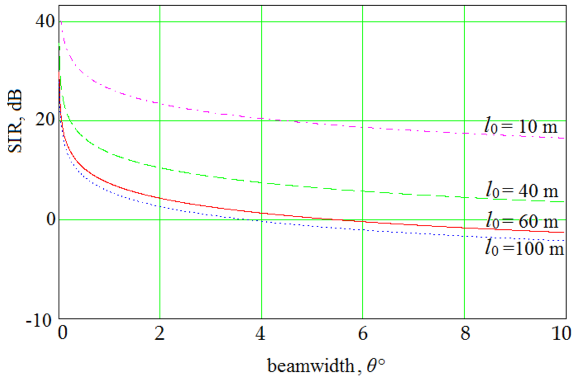

Fig. 8. Results of calculations of SIR values.

8. Analysis of SIR and SNR values for millimeter-wave communication systems

In the scientific literature devoted to mobile MMR systems attention is mainly focused on the study of interference noise and losses and, to a lesser extent, the study of amplification of signals due to reflections, molecular absorption noise and noise associated with the method of generating radio signals. However, the values of the listed kinds of noise can be comparable. In Fig. 2, 6, 8 the results of calculating the noise of MMR mobile systems are given for the comparison: molecular absorption associated with the method of optical heterodyning and interference, respectively.

After comparing the graphs, it can be concluded that the influence of interference noise on the simulation of MMR network coverage can be comparable to the values of noise, the sources of which can be generating devices. It is also necessary to take into account the effects of reflections which can also be used to calculate the gain zones of the useful signal.

9. Conclusions

Currently, mathematical channel models for 5G wireless technologies (and next generations) are only being developed. An important challenge for accurate 5G channel models using the MMR is to provide a fundamental physical basis. From the analysis of the energy budget components of the MMR radio link, it can be concluded that it is necessary to take into account both interference noise and noise associated with the method of generation and emission of PAA lights, as well as the effects of molecular absorption (re-radiation) in the atmosphere and signal reflections in urban scenarios.

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ПОРІВНЯЛЬНИЙ АНАЛІЗ ІНТЕРФЕРЕНЦІЇ, ШУМУ І ВТРАТ В МОБІЛЬНИХ СИСТЕМАХ ЗВ’ЯЗКУ МІЛІМЕТРОВОГО ДІАПАЗОНУ ХВИЛЬ

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Проаналізовано підходи до математичного моделювання мобільних систем у міліметровому діапазоні хвиль. Розглянуто архітектуру мобільної мережі з використанням технології Radio over Fiber (радіо по волокну), запропоновану для формування і передавання сигналів міліметрового діапазону через волоконно-оптичні лінії. Проаналізовано шуми оптичного гетеродинування, що застосовують для формування радіосигналів. Проведено математичний аналіз складових енергетичного бюджету радіолінії в міліметровому діапазоні на основі дослідження фундаментальних фізичних аспектів, що впливають на значення шумів, втрат і підсилень сигналу. Виконано порівняльний аналіз показників співвідношень сигнал/інтерференція та сигнал/шум. Запропоновано квазіоптичну модель конусоподібного випромінювання антени для розрахунків шумових завад і втрат сигналу в багатопроменевих моделях поширення з урахуванням множинних відображень і дифракцій, а також поглинання у різних середовищах. З аналізу складових енергетичного бюджету радіолінії в міліметровому діапазоні випливає, що необхідно в моделях покриття мобільних систем враховувати як залежність від інтерференційних завад, так і шуми, пов’язані з методом генерації, випромінювання сигналів, а також ефекти молекулярного поглинання (повторного випромінювання) в атмосфері й ефекти відображення сигналів у міській забудові.

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