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INVESTIGATION OF A MILLIMETER-WAVE RADIO LINK CHARACTERISTICS OF IEEE 802.11AD STANDARD IN URBAN AREAS

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Background. The explosive growth in the use of mobile broadband is significantly increasing the bandwidth requirements. Millimeter-wave spectrum is necessary for 5G networks to achieve data transfer rates of the order of Gb/s, in particular, for the provision of 3D video services, and the use radio modules for millimeter-wave frequencies as picocells in the streets will expand the capabilities of existing cellular networks and provide an increase in bandwidth. Therefore, the study of the characteristics of this spectrum is an urgent task today.

Objective. The purpose of the paper is to present the results of studying the characteristics of a millimeter-wave radio link to ensure high-speed user access to IP data transmission networks and the possibility of using the IEEE 802.11ad standard in open areas.

Methods. Structural and functional methods of constructing a millimeter-wave wireless network in urban areas based on IEEE 802.11ad standard hardware are investigated.

Results. The studies were carried out using a test bench with a point-to-point topology deployed in an urban environment (Kiev) with the line of sight without significant obstacles. The studies tested the possibility of using for millimeter-wave hardware technologies of the IEEE 802.11ad standard, which is used indoors, for applications in urban areas.

The use of a narrow beam antenna based on an antenna array allows adaptive control of the radiation pattern to bypass small obstacles blocking direct transmission, which allows reducing interference and receive/transmit a signal.

Conclusions. Experimental testing of the hardware capabilities of the IEEE 802.11ad standard has been carried out. Scenarios for constructing a millimeter-wave radio link under various weather conditions have been worked out.

Keywords: millimeter-wave; bandwidth; IEEE 802.11ad standard; 5G networks

I. INTRODUCTION

The explosive growth in the use of mobile broadband is significantly increasing the bandwidth requirements. Current methods for increasing capacity have reached their limits: spectral efficiency is slowly approaching the Shannon limit, and acquiring more spectrum satisfies only a limited increase in capacity and is expensive. Thus, to provide increased throughput for mobile applications, new approaches to delivering wireless content need to be considered [1-3].

To minimize additional deployment costs, cellular operators are exploring methods to deploy smaller, denser cells for higher capacity, such as LTE picocells on lampposts or Wi-Fi hotspots that complement existing LTE macrocells.[7-9] The development of the millimeter-wave range is a promising direction for the developed high-speed mobile broadband radio access systems. The use of narrow beams in the millimeter-wave bands can significantly reduce the interference that is inherent in these frequencies. The 60 GHz band provides 7 GHz of unlicensed spectrum for bandwidth-intensive mobile applications and is supported by the IEEE 802.11ad standard (currently targeting multi-gigabit wireless networks indoors), which defines multiple data rates from 385 Mbps to 6.76 Gbps. Because 60 GHz has a carrier wavelength of about 5 mm, this allows large antenna arrays to be packaged in relatively small form factors. For example, an array of 100 elements fits into an area of no more than 6.5 cm^2, which is easily integrated into modern mobile devices [10-18].

The main advantage of the millimeter-wave range (mmWave) is the possibility of using a wide frequency band, but there are also serious drawbacks that hindered the development of telecommunications in this range: strong attenuation of mmWave during propagation; the level of the received signal significantly depends on the influence of hydrometeors (raindrops, snow, hail, fog) and on the presence of solid irregularities in the atmosphere (foliage of trees, flocks of birds, dust); a high degree of influence on the level of the received signal by obstacles covering the track; the presence of zones of strong signal attenuation at some frequencies due to attenuation of millimeter-wave signals by oxygen molecules and water vapour.[19-23]

In [23-26], it is shown that the path loss increases sharply in the transition to frequencies of the millimeter range only when it is assumed that the antenna gain is constant in frequency. If the physical size of the antenna is kept constant in frequency at both ends of the link and the weather is clear, then free-space path loss actually decreases quadratically as the frequency increases. Higher antenna amplification at higher frequencies requires adaptive beam control on base station and user equipment. Beam-steered antenna technologies adaptively switch the directional diagrams to compensate for the losses on the track caused by the blocking due to dynamic obstacles and to capture the signal [27-30].

The article's main purpose is to present the results of the study of the characteristics of the millimeter-range radio line to provide high-speed user access to IP data networks and the possibility of using the IEEE 802.11ad standard in the open.

II. EXPERIMENTAL STUDY OF THE CHARACTERISTICS OF THE MILLIMETER RANGE

The study is conducted using a test bench with a topology "point-to-point", deployed in an urban environment (Kyiv) in the presence of direct visibility without obstacles (trees and buildings are serious obstacles to normal operation). The IEEE 802.11ad channel consists of a pair of radio modules (wireless access points). The radio module can operate in the modes of the client control point (CP-control point) or access point (AP-access point) [5].

On the roofs of buildings located on the campus of the "Igor Sikorsky Kyiv Polytechnic Institute", two radio modules were installed. One radio module operates in client mode (STA-Station), and a similar one operates in AP access point mode. The distance of radio signal propagation between access points is approximately 250 m (Fig.1).

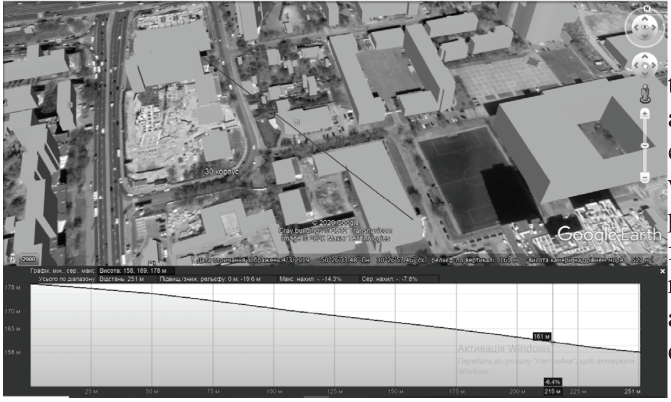


Fig. 1. Profile of the signal propagation path

The height of the antenna suspension for the construction of the route is approximately 12 m and 22 m, respectively. The scheme of the investigated radio line is presented in Fig. 2.

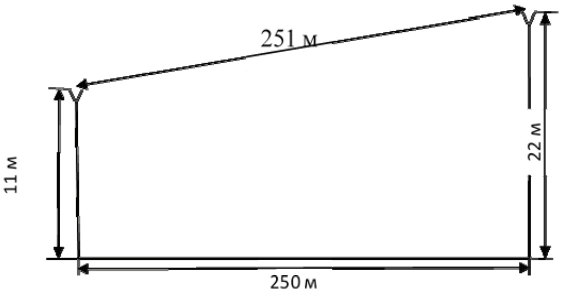


Fig. 2. Scheme of the radioline

Both set of equipment include a wireless access point of millimeter-wave range, a wireless access point 5 GHz for WiFi bridge in case of an emergency shutdown of bridge, switch, IP camera, laptop, passive adapter 24V/0.5A with gigabit port for power supply via Ethernet, as well as the corresponding software. On the subscriber side is also installed a traffic generator and a router.

Characteristics of the wireless access point

The International Telecommunication Union (ITU-R) guidelines define a global channel allocation and a corresponding spectral mask for the 802.11ad signal, which contains four 2.16 GHz wide channels with 58.32 GHz, 60.48 GHz, 62.64 GHz center frequencies and 64, 80 GHz, respectively (Table 1).

Table 1

List of channels of the IEEE 802.11ad standard

Channel	Center (GHz)	Min. (GHz)	Max. (GHz))	Bandwidrh (GHz))
1	58.32	57.24	59.4	2.16
2	60.48	59.4	61.56	2.16
3	62.64	61.56	63.72	2.16
4	64.8	63.72	65.88	2.16

The radio consists of a narrow- spot-beam antenna that uses millimeter-wave range as the main channel and a built-in antenna with a range of 5 GHz for emergency operation. Thus, in case of bad weather, which has the most significant impact on the propagation of millimeter radio waves of all destructive factors, backup radio communication of 5 GHz with a maximum modulation frequency of 866 Mbps is available. Also, the device supports wireless communication in the 2.4 GHz band, which is designed to control (make settings by the administrator) and 5 GHz bandwidth.

The block diagram of wireless access points is shown in Fig. 3. This point-to-point wireless radio is used for connections with a low level of interference and high bandwidth at a distance of up to 250 meters.

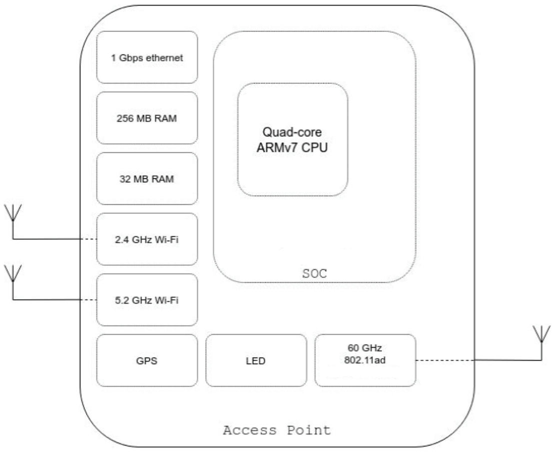


Fig. 3- Block diagram of the access point

The antenna consists of 64 patch antennas arranged in an antenna array with a controlled 60° pattern (Fig. 4). Beam control can be used to avoid small obstacles blocking direct transmission.

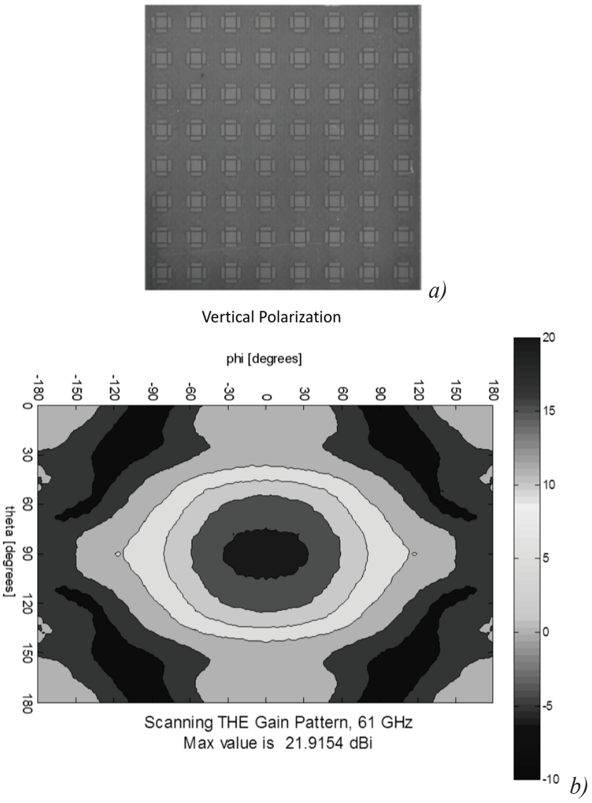


Fig. 4 - Characteristics of the mmWave radio module: a) antenna phased array with 64 patch elements; b) antenna beam diagram

Specifications of the wireless access point for radio bridges are shown in Table 2.

Table 2

Wireless access point characteristics

Dimensions	140 x 140 x 44 mm
Weight	376 g
Antenna gain	5 GHz — 10 dBi 60 GHz — 17.2 dBi
Networking interface	1x 10/100/1000 Mbit Ethernet-port Wi-Fi –for Management
Maximum power consumption	11 W

Each radio module is connected to server machine, which includes auxiliary drivers and monitoring utilities. The studied IEEE 802.11ad radio module uses the main beamwidth of 10 ° - 30 ° on a 250m route. The radio module contains a single-carrier physical implementation that supports nine data rates (MCS indices 1 to 9). Basic information and theoretical level of physical MCS are presented in Table 3.

Table 3

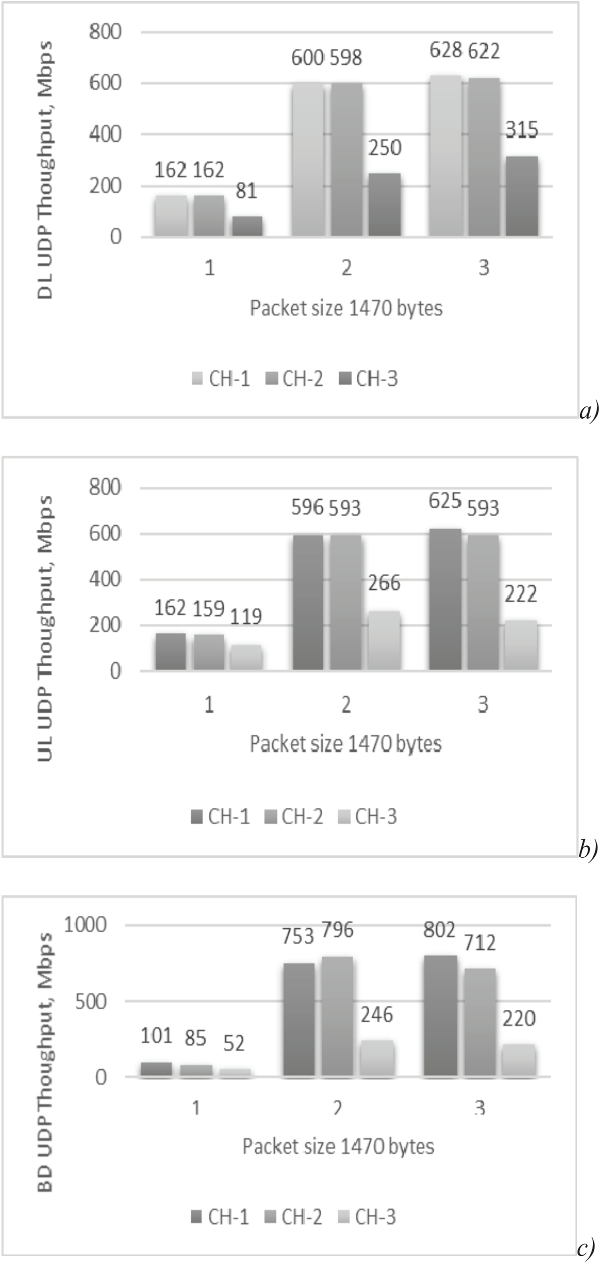
Radio module specification

Output power	14 dBm - 60 GHz
Operating frequency range	5180-5875 MHz 57000–66000 MHz 2412–2472 MHz (optional Wi-Fi control module)
Channel Bandwidth	20/40/80 MHz - 5 GHz 2160 MHz - 60 GHz
Transmission speed	866 Mbit / s— 5 GHz 4600 Mbps - 60 GHz

Performance study of IEEE 802.11ad for external use

The study begins with checking the signal quality of the IEEE 802.11ad channel (i.e the ranges of RSSI values) in our environment. To determine the RSSI range, we record the RSSI value every 0.1 seconds. We found that the IEEE 801.11ad channel can exchange data in the signal range (-63 dBm, -69 dBm) at a distance of 250m. Then we investigate the TCP and UDP bandwidth of the IEEE 802.11ad channel and analyse supported MCS and channel quality scenarios. We also consider different MTU sizes because they greatly affect bandwidth. Choose the value of MTU

1470 bytes, which is typical for Wi-Fi and the Internet. The evaluation results are performed for 3 channels (Ch-1 -58320MHz, Ch-2 - 60480 MHz, Ch-3- 62640 MHz) for uplink (UL), downlink (DL), and bidirectional (BD) links of communication. and show the behaviour of throughput for UDP, TCP and MCS traffic. Fig. 5, Fig.6, Fig.7 and Fig.8 show the measurement results.



a)

b)

c)

Fig.5- UDP traffic bandwidth for channels 58320MHz, 60480 MHz, and 62640 MHz, respectively for downlink (DL), b) uplink (UL), c) bidirectional (BD) link

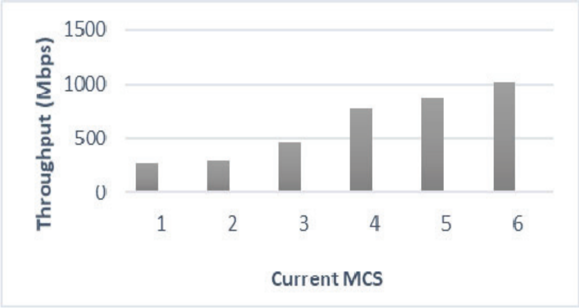
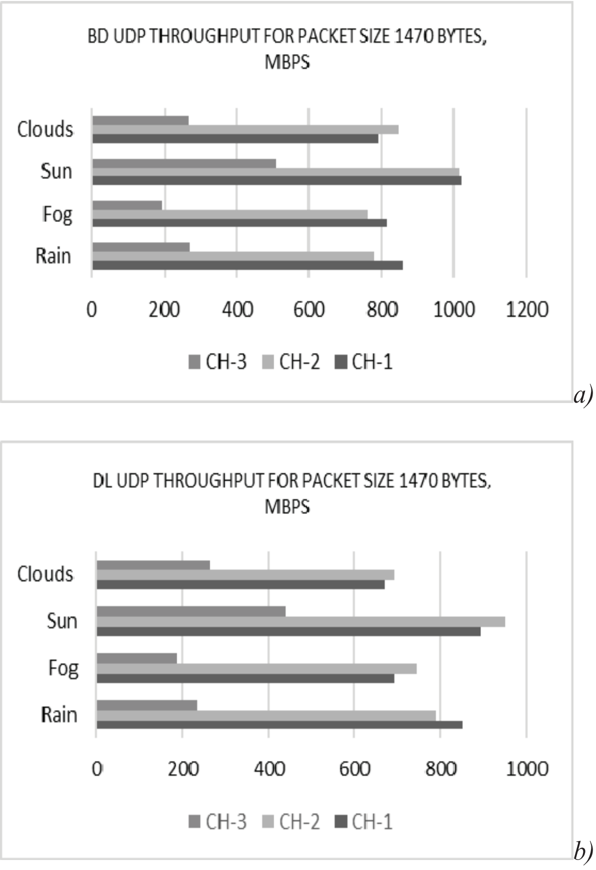


Fig.6 - Achievable bandwidth with the appropriate MCS

By comparing UDP throughput in the graphs, we can conclude that UDP throughput is the highest for 60480 MHz and 62640 MHz channels. UDP throughput reaches about 1 Gbps with MCS 6, MCS 7-9 at distances of about 250 m were not reached. Obviously, an IEEE 802.11ad link cannot provide multi-Gbps performance with a 1470 byte MTU.



a)

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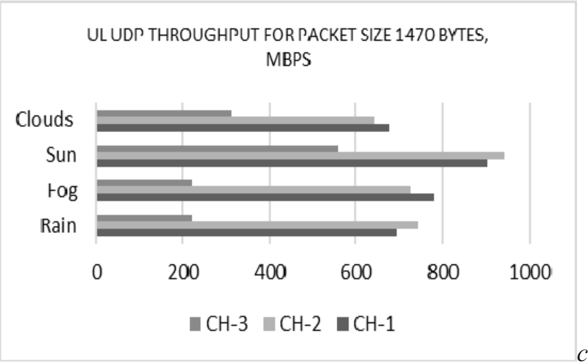

Fig.7- UDP traffic bandwidth for channels 58320MHz, 60480 MHz, and 62640 MHz under different weather conditions: a) for bidirectional (BD), b) downlink (DL), c) uplink (UL)

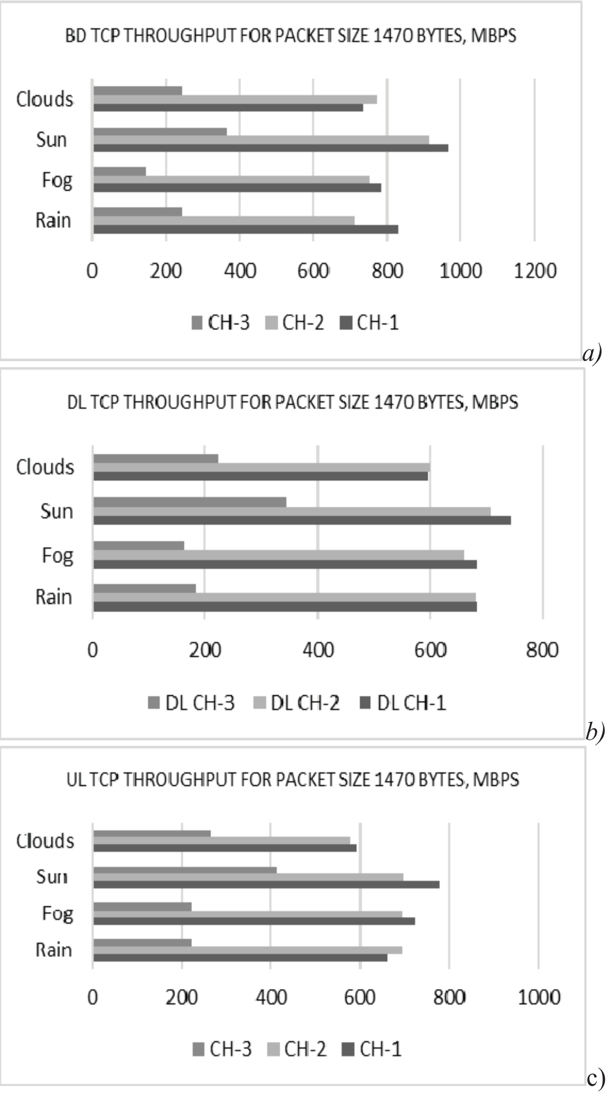

Fig.8.- TCP traffic bandwidth for channels 58320MHz, 60480 MHz, and 62640 MHz under different weather conditions: a) for bidirectional (BD), b) downlink (DL), c) uplink (UL)

The throughput of the TCP and UDP traffic channel was investigated under various weather conditions, namely, sunny (with an average relative humidity of about 42% and a pressure of 743 mmHg), Cloudy (with an average relative humidity of about 76% and a pressure of 752 mmHg), foggy (with an average relative humidity of about 82% and a pressure of 747 mmHg) and rain (with an average relative humidity of about 94% and a pressure of 750 mmHg). Under various weather conditions, continuous TCP throughput of 600+ Mbps and UDP throughput of 700+ Mbps are provided for a long time for 60480 MHz and 62640 MHz channels. Minor speed fluctuations are randomly distributed over the measurement period and may be the result of random interference caused by wind gusts. Also, there is no significant difference in throughput between clear weather and heavy rain, confirming that the 60 GHz band is weather resistant up to 250 m.

III. CONCLUSIONS

The research was carried out using a point-to-point test bench deployed in an urban environment (Kiev) with unobstructed line of sight (trees and buildings are major obstacles to normal operation). The channel consists of a pair of radio modules (wireless access points), which can operate in the client control point (CP-control point) or access point (AP-access point) modes. To overcome the attenuation and reduce the interference of the 60 GHz radio link, a radio station based on 8x8 antenna arrays was used to form the beam and concentrate the transmission energy in the desired direction. Array radios performed directional transmission using electronic beam steering using baseband signal processing to control beam directions with minimal delay.

The research examined the possibility of using mmWave hardware technologies of the IEEE 802.11ad standard, which is used indoors, for applications in urban development. It was found that the effective data rate during sunny weather and precipitation (in the form of rain) corresponds to about 700 Mbit/s at a communication range of 250m. This confirms that at distances of about 100+ m radio line 60 GHz is quite stable to weather conditions. It was found experimentally that in rain with an intensity of about 3 mm/h, the loss of the RSSI signal level of approximately 1.5 dBm, which does not lead to a significant deterioration of the connection. Thus, it is concluded that access points based on antenna arrays of size 8 × 8 can support a range of distances of 100+ m at a speed of 700 Mbps, even in heavy rain.

The IEEE 802.11ad standard for mmWave defines some modulation and coding schemes for adaptation to different baud rates. Given the need to adapt to a much more dynamic environment than internal networks, for which the 802.11ad standard is currently designed, it was determined that UDP traffic bandwidth reaches values of about 800 Mbps with MCS4 and MCS6 for channels 62640 MHz and 60480 MHz at RSSI -64 dBm and -65dBm respectively.

The measurements showed the possibility of using millimeter wave radio modules of the IEEE 802.11ad standard in 5G networks. The use of millimeter wave radio modules as a picot cell on the streets, will expand the capabilities of existing cellular networks and increase bandwidth. However, the mmWave radio link can be easily blocked by the human body, given that the loss is about 20-50 dB.

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Дослідження характеристик радіолінії міліметрового діапазону стандарту IEEE 802.11ad в міській забудові

Проблематика. Стрімке зростання використання мобільного широкосмугового доступу значно збільшує вимоги до пропускної здатності. Спектр міліметрового діапазону необхідний мережам 5G для досягнення швидкості передачі даних порядку Гбіт/с, зокрема, для надання послуг 3D-відео, а застосування радіомодулів для частот міліметрового діапазону в якості пікосот на вулицях, дозволять розширити можливості існуючих стільникових мереж і забезпечити збільшення пропускної здатності. Тому, дослідження характеристик даного спектру є актуальною задачею на сьогоднішній день.

Мета дослідження. Метою даної роботи є представлення результатів дослідження характеристик радіолінії міліметрового діапазону для забезпечення високошвидкісного доступу користувачів до IP мереж передачі даних та можливість використання стандарту IEEE 802.11ad на відкритій місцевості.

Методи реалізації. Досліджуються структурно-функціональні методи побудови безпроводової мережі міліметрового діапазону в міській забудові на основі апаратних засобів стандарту IEEE 802.11ad.

Результати дослідження. Дослідження проводились з використанням випробувального стенду з топологією «точка-точка», розгорнутого в міському середовищі (м. Київ) при наявності прямої видимості без значних перешкод. При проведенні досліджень перевірялась можливість використання апаратних технологій міліметрового діапазону стандарту IEEE 802.11ad, який застосовується всередині приміщень, для застосувань в міській забудові.

Використання вузьконаправленої антени на базі антенної гратки дозволяє керувати діаграмою направленості для обходу невеликих перешкод, які блокують пряму передачу, що дозволяє зменшити завади та отримати/передати сигнал.

Висновки. Проведено експериментальне тестування апаратних можливостей стандарту IEEE 802.11ad. Відпрацьовано сценарії побудови радіолінії міліметрового діапазону при різних погодних умовах.

Ключові слова: міліметровий діапазон хвиль; пропускна здатність; стандарт IEEE 802.11ad; мережі 5G.

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Исследование характеристик радиолинии миллиметрового диапазона стандарта IEEE 802.11ad в городской застройке

Проблематика. Стремительный рост использования мобильного широкополосного доступа значительно увеличивает требования к пропускной способности. Спектр миллиметрового диапазона необходим сетям 5G для достижения скорости передачи данных порядка Гбит / с, в частности, для предоставления услуг 3D-видео, а применение радиомодулей для частот миллиметрового диапазона в качестве пикосоты на улицах, позволят расширить возможности существующих сотовых сетей и обеспечить увеличение пропускной способности. Поэтому, исследования характеристик данного спектра является актуальной задачей на сегодняшний день.

Цель исследования. Целью данной работы является представление результатов исследования характеристик радиолинии миллиметрового диапазона для обеспечения высокоскоростного доступа пользователей к IP-сетей передачи данных и возможность использования стандарта IEEE 802.11ad на открытой местности.

Методы реализации. Исследуются структурно-функциональные методы построения беспроводной сети миллиметрового диапазона в городской застройке на основе аппаратных средств стандарта IEEE 802.11ad.

Результаты исследования. Исследования проводились с использованием испытательного стенда с топологией «точка-точка», развернутого в городской среде (г. Киев) при наличии прямой видимости без значительных препятствий. При проведении исследований проверялась возможность использования аппаратных технологий миллиметрового диапазона стандарта IEEE 802.11ad, который применяется внутри помещений, для применений в городской застройке.

Использование узконаправленной антенны на базе антенной решетки позволяет адаптивно управлять диаграммой направленности для обхода небольших препятствий, блокирующих прямую передачу, что позволяет уменьшить помехи и получить / передать сигнал.

Выводы. Проведены экспериментальное тестирование аппаратных возможностей стандарта IEEE 802.11ad. Отработаны сценарии построения радиолинии миллиметрового диапазона при различных погодных условиях.

Ключевые слова: миллиметровый диапазон волн; пропускная способность; стандарт IEEE 802.11ad; сети 5G.