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POSSIBILITIES OF USING THZ-BAND RADIO COMMUNICATION CHANNELS FOR SUPER HIGH-RATE BACKHAUL

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The results of investigation of basic trends and promising of development for the mobile backhaul are provided. On the basis of performed theoretical estimations, computations and physical simulation it is designed a THz band radio communication channel with the possibility of building super high-rate (over 1 Gbps) backhauls.

KEY WORDS*:* *THz band, mobile backhaul, throughput rate, super high-rate U-WB communications, radio communication channel*

1. INTRODUCTION

The results of investigation of basic trends and prospects for the mobile backhaul development [1-3] demonstrate that at going to high-rate HSPA+ and 4G/LTE networks they often turn out to be a "weak link" in the network infrastructure. As it is known [2], a classic mobile backhaul network used by a mobile communication operator consists of two main segments:

- the backhaul connecting base stations with the controllers and mobile switching centers (MSC),
- the backbone providing for the high-rate transport between the switching centers.

Under the conditions of fast traffic of mobile data transmission and development of the 4G/LTE networks, typical data transmission rates for which are up to 1 Gbps and more, there occurs upgrading of the mobile backhaul networks by means of both an implementation of high-rate radio relay links and the using of advanced technologies for provision of communication links to base stations. In particular, there occurs a going from traditional TDM-channels to the separated Ethernet channels that allows a more efficient use of the mobile backhaul throughput bandwidth and provides for the possibility of further network development (for example, implementation of the HSPA + LTE technologies [4]). At that, transition from the channel switching technologies (TDM) to the package switching technologies (Carrier Ethernet, IP/MPLS) is the basic technological trend in the process of domination of data traffic over the voice traffic. Apparently, that tendency would remain in future, therefore, after a short while wireless communication would dominate at the market of telecommunication services [6-9].

Due to active deployment of the networks the market of microwave band telecommunication equipment will grow as well – both in the segment of microcells and in the small cells segments. We shall discuss the opportunities provided by various wireless backhaul technologies, which include wireless backhaul networks without the line-of-sight (NLOS), line-of-sight (LOS) point-to-point (PTP), microwave band, millimeter-wave band backhaul networks as well as the LOS point-to-point (PTP) THz wave band networks.

2. TENDENCIES OF MOBILE BACKHAUL DEVELOPMENT

The 4G LTE standard [5] was developed in order to provide the users of smartphones based on 3GPP LTE releases 7 or 8 with the access having average data transmission rates of 30 Mbps and the peak rates – of up to 100 Mbps. The new devices, which are being developed presently, possess a potential for a theoretical increase of mobile data transmission rates up to 1 Gbps on the basis of the characteristics included into the most recent LTE releases, like 3GPP, release 12.

Considering that dimensions of the cell are limited by the values of attainable power, the operators would be forced to increase the number of cells, which would have still less and less dimensions, known as microcells or picocells. The present-day average throughput rate of the backhaul is of 35 Mbps per a cell. To comply with the increasing volumes of transmitted mobile data, the throughput rate, as it is shown in Fig. 1, must be increased to 1 Gbps per a cell during the next five years only.

It means that there exists a demand in high density of base stations (connected with the backbone network via communication channels possessing a broad throughput bandwidth) and the necessity of their free positioning. By now, this requirement set to the backhaul has been satisfied by means of combination of the optic fiber and the currently being licensed wireless microwave ‘point-to-point’ (P2P) links, using the selected domains of spectrum within the bandwidth of up to 40 GHz. The present wireless systems without the line-of-sight (NLOS) lower than 6 GHz and the 60/80 GHz line-of-sight systems (LOS) cannot provide for the required throughput rate at an affordable price, and high costs of communication in the subject to licensing bandwidths acts practically everywhere worldwide as a powerful economic brake for deployment of the P2P telecommunication lines. Highly efficient optic fiber is capable of providing an ideal communication in the backhaul, but it is often non-affordable in the places where small cells are necessary. Besides, laying of optic fiber requires performance of costly construction works, which are hardly possible to accomplish at an attempt to expand the network in accordance with the new demands from the customer. The 60 GHz band, typical operation range of which is normally limited to 1 km approximately [14], possesses certain possibilities of deploying of the backhaul network with the help of repeated use of frequencies and simultaneous solution of a number of other technological problems.

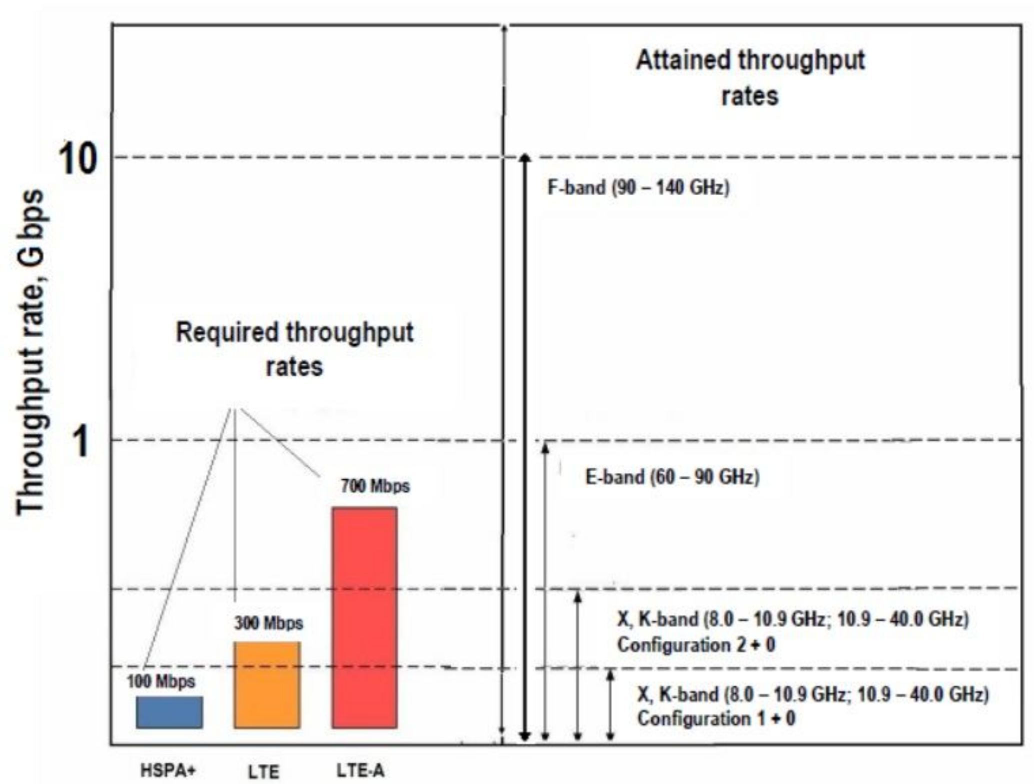

FIG. 1: Strategy of increasing of the backhaul throughput rate with evolution of access networks from 3G/HSPA+ to LTE-A

Wireless point-to-point backhaul links are widely applied for transmission of information to the base stations of macrocells especially in those points where optic fiber is not available. These systems are normally operating within the spectrum of 6 GHz to 80 GHz. They require strict compliance with the line-of-sight conditions between the transceivers of two nodes. In practice, it means that 60% of the first Fresnel zone is free from obstacles. For higher frequency bandwidths this zone would be less (thus, it can be assumed that the zone dimension determined for a low-frequency band would be acceptable for higher frequency bandwidths as well). It means that in most cases using of the above bandwidths allows decreasing the costs of licensing that forms a good base for economic feasibility of the project of creating a backhaul network for a small cell serice. We also consider the solutions for millimeter waves at the frequency of 60 GHz, which operate within a non-licensable band because they are well suitable, first of all, for finding solutions to the backhaul networks servicing the networks formed on the basis of small cells. From the point of view of economic feasibility the principal difference between the microwave solutions and the solutions for millimeter waves covers the price of spectrum, equipment costs and the difference in the time spent for assembly and on-site tuning. There are several practical issues that might increase the costs significantly, if they are not considered at the preliminary stage of the project (for example, the necessity of higher rigidity of the supports in the case of application of the millimeter wave backhaul networks due to a small width of the beam). Considering that microwave and millimeter wave PTP systems require the line-of-sight conditions for their operation, there might occur certain difficulties at realization of communication between the small cell base station location and the transmitter module positioned in the point of aggregation with the base network. This is a very important problem exerting a direct influence upon economic feasibility of the project.

As a rule, PTP microwave systems operate within the bandwidth of 7 to 42 GHz with the radio channel throughput bandwidth of 7 to 56 MHz in the FDD (frequency duplex) mode. Various countries apply different licensing procedures with any and all forms of the correlation between such procedures. In addition to the operation bandwidth they include the channel throughput bandwidth, the path length, the radio link readiness and the data transmission rate. In the case with the backhaul networks servicing small cells it is expected that for the cases of using microwave PTP systems they would operate in the high frequency bands, the typical license fees for which are less costly than those applied for low frequency bands. The necessity of selection of high-frequency bands is stipulated by the fact that antenna dimensions would be less in them, and the antennas could be positioned lower (a serious public resistance can be expected if large-dimension antennas are installed at low heights in the urban area).

During propagation within the 60 GHz band the radio waves are subject to a strong attenuation due to absorption in the atmosphere (in particular, by the atmospheric oxygen), the value of which is of the order of 15 dB per a kilometer (compare with the absorption in the atmosphere within the bands lower than 6 GHz, which is less than 0.01 dB per a kilometer). For that reason, in most countries the 60 GHz band is not licensable, and, as a rule, the bandwidth of up to 7 GHz (57-63 GHz) is accessible in it. Thus, the price of the spectrum for solutions in the 60 GHz band can be excluded from estimations of the deployment costs.

During recently the USA and some European countries have passed new regulations, under which it is permitted increasing of the maximally allowable level of power for the devices operating outside of the premises in the 60 GHz band. Having higher power wireless devices are capable of providing for operation of broadband wireless telecommunication systems for the ranges of up to 1.5 km at the data transmission rates of up to 7 Gbps that would allow refusing in most cases of application of additional wire means or providing for the opportunity of further use of the existing wire means with insufficient throughput value supplementing them with the wireless solutions.

3. THZ BAND RADIO COMMUNICATION CHANNEL FOR SUPER HIGH-RATE BACKHAUL NETWORKS

Main objective of this paper is to investigate the possibility of using a terahertz radio communication channel for super high-rate backhaul networks by means of creating a transceiver for the radio relay system in 130-134 GHz frequency bandwidth.

Using of a THz frequency as the carrier frequency is one of the most promising ways for realization of the Gigabyte radio communication link [10-12,15-17], because the throughput of the radio communication link, as it is shown in Fig. 2, is increasing with the increase of the accessible frequency bandwidth of the signal.

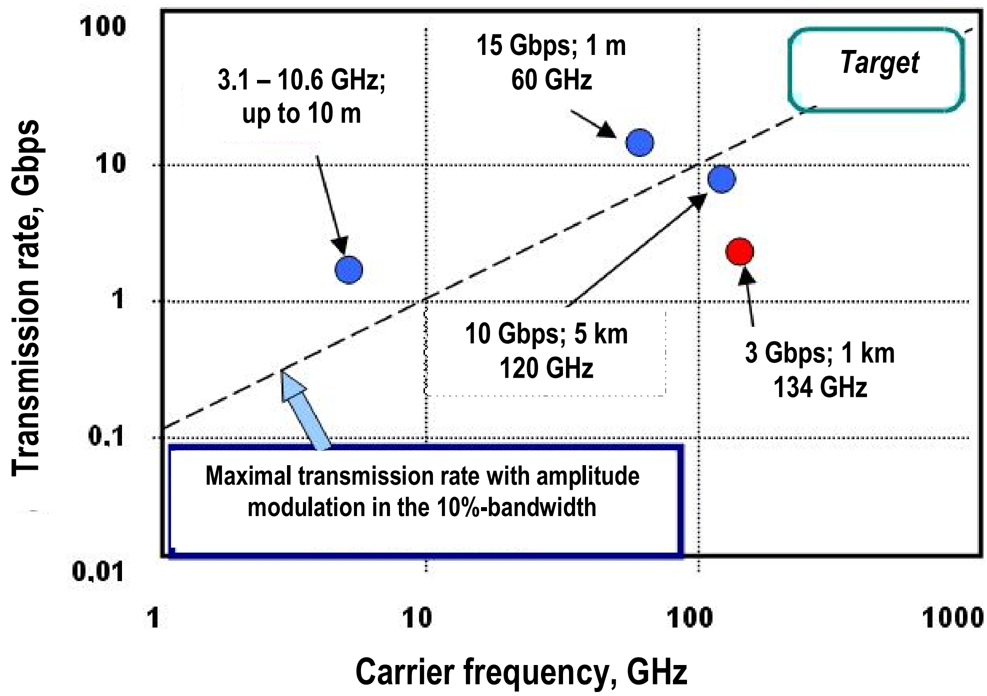

FIG. 2: Correlation between the carrier frequency and the transmission rate in wireless networks

A relatively strong attenuation in the atmosphere caused by rain and resonant absorption by the molecules of water and oxygen is a particular feature of terahertz waves. That is why they do not fit for the purposes of close-range radio communication. The communication range is estimated in the THz band by several kilometers due to the restrictions imposed by the output power of the transmitter and the receiver sensitivity. At the same time, the possibility of transmission of a large volume of data per a unit of time might allow, in particular, a multiplex transmission of non-compressed TV signals with high resolution. These facts indicate on perspectiveness of using the terahertz band for deployment of local telecommunication systems possessing high throughput. In particular, the Japanese experts created a radio relay line in the 120 GHz band that provides for data transmission at the rate of 10 Gbps to the range of over 800 m [4].

On the basis of computer and physical simulation of functional nodes of the telecommunication system it was designed an analog part of the transceiver, the block-diagram of which is provided in Fig. 3.

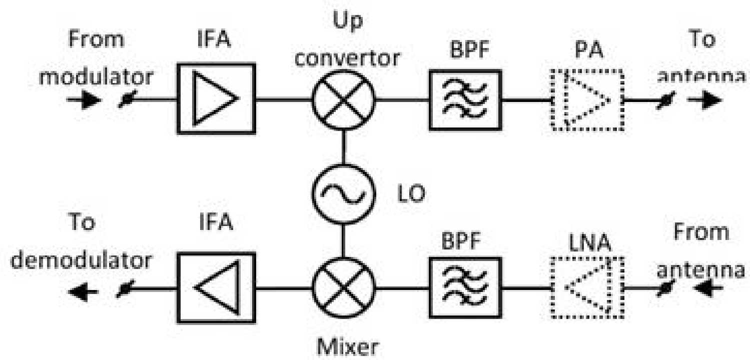

FIG. 3: Block-diagram of the transceiver

The block diagram contains:

- the transmitting channel including: input intermediate frequency amplifier (IFA), up-frequency converter and the output bandpass filter (BPF);
- the receiving channel including: input BPF, mixer and output IFA.

High-frequency (HF) circuits of the transmitter and receiver ducts operate within the 127-133 GHz frequency bandwidth. The intermediate frequency (IF) circuits operate within the 1-2 GHz band.

Using of a common local oscillator for the transmitter and receiver ducts is a specific feature of the system. At that, the transmitter and receiver ducts are operating at different side bands of frequency converters. High-frequency BPF provide for separation of ducts from each other and from the second harmonic of the heterodyne.

Frequency converters and namely – the transmitter mixer and the receiver up converter are of identical circuits and design. However, they are different in terms of the signal propagation directions according to their functional use. It was selected the sub-harmonic circuitry of the converters that allowed using of the local oscillator with the frequency, which is by two times lower than that of the standard converter. This selection substantially facilitated the problem of building of the heterodyne circuit that is especially important at such high operation frequencies.

At the selected local oscillator frequency $f_{het} = 64.8$ GHz the radio communication channel frequencies would lie within the bandwidths of $f = 2\ f_{het} \pm F_{IF}$, that makes 130.6-131.6 GHz and 127.6-128.6 GHz.

The GaAs Shottky barrier diodes are applied as the mixing diodes. The diodes possess the zero-shift barrier capacitance of $C_{j0} = (8\ldots12)$ fF and the serial loss impedance of $R_{loss} = (6\ldots8)$ Ohm. Frameless structure with beam-lead contacts is convenient for embedding of the diodes into the integral circuit of converters.

The measured conversion losses were 12 dB both in the mixer and in the up converter; in doing so the required heterodyne power was not exceeding 15 mW.

The circuit using a highly stable setting quartz oscillator with a subsequent chain of multiplying and amplifying stages was selected among various options for building of the local oscillator circuit. This structure of the heterodyne circuit is characterized by a minimal number of parasite harmonics and combinational frequencies and is much more cost-efficient as compared to the circuit with a frequency synthesizer. The 100 MHz Crystek Crystals quartz oscillator with the level of phase noises not higher than -143 dB at the offset from the central frequency by 1 kHz was used as the setting oscillator. The setting oscillator parameters are primarily determining the frequency stability and phase noises in the local oscillator.

In addition to the multiplier and amplifier functions the output part of the heterodyne circuit is also performing splitting of the local oscillator signal for two channels. The measured output power levels of the local oscillator for the transmitter and receiver ducts amounted to 15…20 mW.

The septum-filters, which are the most suitable for the terahertz band from the points of view of selectivity and low losses, were developed as the BPF.

Development of separate functional nodes of the transmitter and receiver duct of the terahertz band radio relay system allowed performing design and manufacturing of all of the analog part of the transceiver.

Structurally the transceiver is manufactured as a single unit including all of the developed nodes. Modular manufacturing of the nodes provides for a compactness of the entire device, convenience of its assembly and mounting. Reliable operation of the transceiver is secured by maximal use of microwave integral microchips in the structure.

The throughput frequency characteristic of the transmitter and receiver duct was measured by means of supplying a calibrated IF band signal from the sweep oscillator to the transmitter input with observing of the above signal from the transmitter output on the screen of the panoramic measuring unit indicator. At that, the high frequency output of the transmitter was coupled with the receiver input by a section of the waveguide. Those measurements allowed determining the transmitter output power that amounted to minus 10 dBm. A substantial improvement of the transceiver energy characteristics can be attained by using of the high frequency amplifiers shown with dash lines in the block diagram.

The designed THz band telecommunication system using the WiGig equipment based on the IEEE 802.11ad standard [5.13] is capable of transmitting the data at the rate of 1 to 7 Gbps via a radio channel with the width of 2 GHz by means of a flexible combination of modulation modes (bipositional phase shift-keying or BPSK, quadrature phase shift-keying or QPSK, 16-position quadrature amplitude modulation or 16QAM and 64-position quadrature amplitude modulation or 64QAM), access modes (a single carrier or orthogonal frequency-division multiplexing - OFDM), and the method of preliminary encoding of signals using the low-density parity-check code (LDPC). These modes are selected automatically while entering into the operation. For the purpose of comparison, the backhaul link with a typical throughput rate less than 1 Gbps servicing the base station of a small LTE cell may normally use the modulation of a relatively low level like QPSK, with the help of which it is possible to transmit at the rate of over 2 Gbps. It is more reliable than the modulations of a higher level (up to 1024 QAM) used in the backhaul modems operating in the systems with narrow microwave channel and possesses the potential to increase the data transmission rate by implementing higher order modulation methods in its future versions. But during the time when WiGig with the QPSK modulation providing for the rate of up to 2 Gbps is used for development of backhaul telecommunication lines, it will be required a certain flexibility at planning of the commercial data transmission rate and operation range. Another option for increasing of the throughput value is in increasing of the radio communication line budget at the expense of decreasing the throughput bandwidth of the channel. For example, each decreasing of the throughput bandwidth of the channel by two times improves the receiver sensitivity by 3 dB (see Fig. 4).

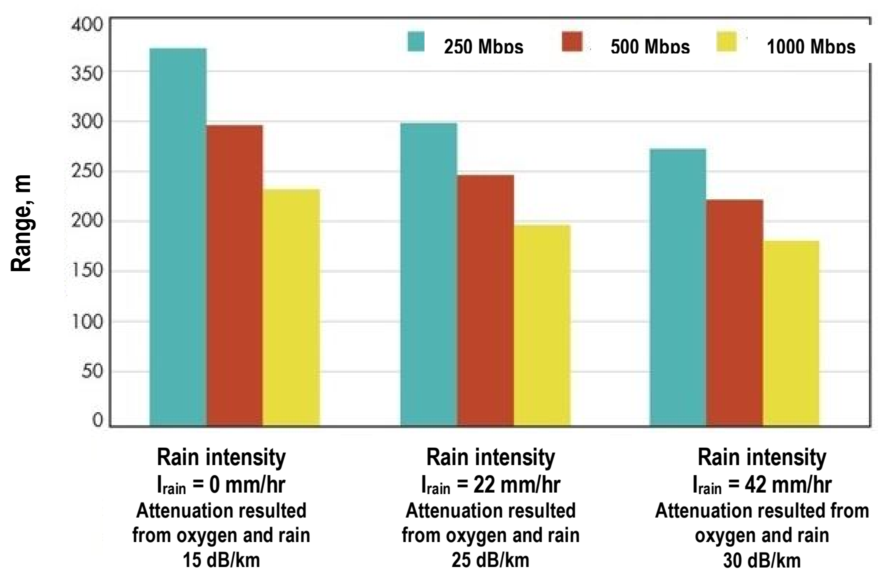

FIG. 4: Block diagram of variation of the backhaul telecommunication link range at 60 GHz under the ideal and real urban conditions at the assumption that the maximal equivalent isotropically radiated power = 40 dBm (FCC 15.255), telecommunication link readiness = 99.99%; SC modem 802.11ad Wi-Fi QPSK; 20% load and 1:1 full duplex data flow

Here the block-diagram provides the measurement results for a full duplex telecommunication link with the throughput of up to 1000 Mbps at the power levels equal to a half and a quarter of the initial one in order to demonstrate what a compromise in the ratio between the range and data transmission rate is possible at different values of attenuation in the rain. A flexible forming of the main frequency bandwidth allows scaling of the channel throughput bandwidth permitting increasing of the range and couple with any option of the scenario provided by the operator.

The value of throughput within the 130-134 GHz frequency bandwidth as the function of the channel width and the type of modulation is provided in Table 1.

TABLE 1: Potentiality of the proposed telecommunication link

Modulation mode	Throughput bandwidth, MHz	Throughput rate, Mbps
QPSK	500 1000	1000 2000
16QAM	500 1000	2000 4000
32QAM	500 1000	2500 5000
64QAM	500 1000	3000 6000
64QAM with multiplexing*	355	1200

*Here: The group signal of the direct link in the 2.172-2.527 GHz band is fed to the transmitter unit (frequency converter) that transfers it to the 130.000-130.355 GHz frequency bandwidth.

The backhaul signals of the 133.500-133.855 GHz bandwidth are received and transferred by the receiver converter to the 2.172-2.527 GHz bandwidth.

An experimental sample of the transceiver for the 130 GHz band digital radio relay system capable of providing for transmission and reception of digital data at the rate of up to 1.5 Gbps at the radio communication range within the limits of up to 1 km is developed for the first time. This type of a wireless telecommunication system can be efficiently used for provision of a temporary radio access; in particular, it could be the key component of restoring the communication after a failure in an emergency case, when optic fiber networks cannot operate due to the failure.

4. CONCLUSIONS

Ever increasing requirements to base stations of the access networks in terms of their throughput characteristics that results from a sharp growth of user traffic observed during recently cause a similar increase of the requirements to capacitance characteristics of backhaul networks. Decreasing of the cell dimensions in the access network with subsequent complication of the backhaul network used for their servicing is another consequence of the traffic increase. Multiple base stations of small cells have to be connected to the backbone network with the help of the deployed and highly efficient backhaul network. In this conditions the area of backhaul network operation in urban area with a high density of positioning of the subscribers could even become somewhat less (for instance, to 1.5 km) while total data transmission rate has to be increased up to several Gbps.

The preliminary estimate performed for the forecasted quality of the communication channel within the 130-134 GHz band based on the obtained results of attainable parameters in the transceiving former of the super high-rate data flow and in the linear transceiver circuit, demonstrated the opportunity of high-Q (the error probability is within the limits of 10^{-6}) data transmission to the range of 1…2 km under the real conditions.

Limitation of the communication range in the terahertz band is stipulated primarily by an insufficient output power of the transmitter and by insufficient sensitivity of the receiver.

There are determined two basic approaches to creation of backhaul networks for HetNet:

1) using in the backhaul networks of the mobile wireless network equipment of the most recent releases (for example, LTE-A and Wi-Fi 802.11ac) operating under the NLOS conditions;

2) using in the backhaul networks of the millimeter wave and THz band equipment to develop the 802.11ad standard (60/80 GHz), operating in the LOS mode.

A new market outlooks for the industry are opened and we have all the reasons to expect that acceptable in terms of the price chip sets and finished modules, on the basis of which there could be created cost-efficient backhaul network suitable for servicing of the heterogeneous networks, would be suggested in the nearest future.

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