

Research and Development of Millimeter Wave Technology

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Abstract—This paper introduces the concept of millimeter wave, analyzes the advantages and disadvantages and propagation characteristics of millimeter wave, and expounds the research status of millimeter wave ground communication and millimeter wave satellite communication. The military application of millimeter wave communication technology in electronic countermeasures is taken as an example. Finally, the outlook for millimeter wave communication technology will open up new application fields in the future and have broad development prospects.

Keywords-Millimeter Wave; Millimeter Wave Propagation

I. INTRODUCTION

With the rapid development of mobile communications, satellite communications, and on-board electronics, there is an increasing shortage of spectrum resources. However, users continue to put forward higher requirements on the speed, throughput and distance in wireless mobile communication, and the capacity requirements of the system are also getting higher and higher. Due to the extremely rich spectrum resources in the high-frequency microwave band, modern communication systems are developing towards high-frequency microwaves, especially in the millimeter-wave band. Millimeter wave communication has many unique features compared with traditional radio short wave, ultrashort wave and microwave communication. Since the millimeter wave is made up of microwaves and light waves (its wavelength is between the microwave and the light wave), it has some advantages of microwave and light waves. The communication device is small in size, and can be used with a small-sized antenna to obtain high directivity, which facilitates concealment and confidentiality of communication. The extremely high attenuation rate of millimeter waves propagating in wireless space is the biggest obstacle faced by millimeter wave systems in outdoor wireless communication applications. Fortunately, the

millimeter wave has a small wavelength, allowing a large number of antennas to be installed without increasing the volume of the existing communication device, and the resulting large-scale antenna array can provide high beamforming gain, thereby obtaining sufficient link balance. the amount[1].

At present, Bell Labs USA has achieved significant capacity improvement and related efficiency improvements by using large-scale MIMO technology (multi-input and multi-output technology) in the millimeter wave band. With prototypes with peak transmission rates in excess of 50 Gbps, Bell Labs has successfully achieved spectral efficiencies of up to 100 bps / Hz in the 28 GHz millimeter-wave band, and its transfer rate allows users to download faster using the network, enabling only A few hundred megabytes of data transfer is reached in a few seconds. The realization of millimeter wave communication technology has provided a new development direction for future research on the realization of touchable Internet, low latency virtual reality and future applications such as 3D.

II. MILLIMETER WAVE CHARACTERISTICS

Compared with light waves, millimeter waves use the atmospheric window (millimeter waves and submillimeter waves propagate in the atmosphere, the attenuation due to the absorption of gas molecules is a small frequency, the attenuation is small), the attenuation is small, by natural light and The influence of the heat radiation source is small.

A. Advantages

1) *Extremely wide bandwidth.* The millimeter wave frequency range is generally considered to be 26.5 to 300 GHz, and the bandwidth is as high as 273.5 GHz. More than 10 times the total bandwidth from DC to microwave. Even considering atmospheric absorption, only four main windows can be used for propagation in the atmosphere, but the total bandwidth of the four

windows is also up to 135 GHz, which is five times the sum of the bandwidths of the bands below the microwave. This is undoubtedly very attractive today when the frequency resources are tight.

2) *The beam is narrow.* The millimeter wave beam is much narrower than the microwave beam at the same antenna size. For example, a 12cm antenna has a beamwidth of 18 degrees at 9.4 GHz and a beamwidth of only 1.8 degrees at 94 GHz. It is therefore possible to distinguish small targets that are closer together or to see the details of the target more clearly.

3) *Compared with lasers, the propagation of millimeter waves is much less affected by the climate and can be considered to have all-weather characteristics.*

4) *Millimeter wave components are much smaller in size than microwaves.* Therefore, the millimeter wave system is easier to miniaturize.

B. Disadvantages

1) *The attenuation in the atmosphere is severely attenuated.*

2) *The processing precision of the device is high.*

III. MILLIMETER WAVE TRANSMISSION CHARACTERISTICS

Usually the millimeter wave band refers to 30 GHz to 300 GHz, and the corresponding wavelength is 1 mm to 10 mm. Millimeter wave communication refers to communication in which millimeter waves are used as a carrier for transmitting information. At present, most of the applied research focuses on several "atmospheric window" frequencies and three "attenuation peaks" frequencies[2][3].

A. Is a typical line of sight transmission

The millimeter wave belongs to the very high frequency band, and it propagates in space in the form of direct waves. The beam is narrow and has good directivity. On the one hand, since the millimeter wave is seriously affected by atmospheric absorption and rainfall fading, the single-hop communication distance is short; on the other hand, since the frequency band is high and the interference source is small, the propagation is stable and reliable. Therefore, millimeter wave communication is a typical communication technology with a high quality, constant parameter wireless transmission channel.

B. Has "atmospheric window" and "attenuation peak"

"Atmospheric window" refers to the 35 GHz, 45 GHz, 94 GHz, 140 GHz, and 220 GHz bands where

millimeter wave propagation is less attenuated near these special frequency bands. In general, the "Atmospheric Window" band is more suitable for point-to-point communication and has been adopted by low-altitude air-to-ground missiles and ground-based radars. The attenuation near the 60 GHz, 120 GHz, and 180 GHz bands has a maximum value of about 15 dB / km or more, which is called the "attenuation peak". Often these "attenuation peak" bands are preferred by multi-channel concealed networks and systems to meet the network safety factor requirements.

C. The attenuation is severe during rainfall

Compared with microwaves, millimeter-wave signals are much more attenuated under harsh climatic conditions, especially during rainfall, which seriously affects the propagation effect. The conclusion of the study is that the attenuation of the millimeter wave signal during rainfall is closely related to the instantaneous intensity of the rainfall, the length of the distance and the shape of the raindrop. Further verification shows that: Generally, the greater the instantaneous intensity of rainfall, the farther the distance, and the larger the raindrops, the more severe the attenuation. Therefore, the most effective way to deal with rainfall attenuation is to leave enough level attenuation margin when designing a millimeter-wave communication system or communication line.

D. Strong penetration of dust and smoke

Atmospheric lasers and infrared light have poor penetrating power for dust and smoke, and millimeter waves have a clear advantage at this point. A large number of field tests have shown that millimeter waves have a strong penetrating power for dust and smoke, and can pass sand and smoke almost without attenuation. Even under the conditions of higher intensity scattering caused by explosions and metal foil strips, even if fading occurs, it is short-lived and will recover quickly. As the ions diffuse and fall, they do not cause severe disruption of millimeter wave communication.

IV. RESEARCH STATUS OF MILLIMETER WAVE COMMUNICATION

Current millimeter wave communication systems mainly include point-to-point communication on the earth and communication or broadcasting systems via satellite. Point-to-point millimeter-wave communications on Earth are now commonly used in relay communications where privacy is critical. The millimeter wave itself has strong concealment and anti-interference. At the same time, due to the attenuation of the millimeter wave in the atmosphere and the use of

a small-diameter antenna, a very narrow beam and a small side lobes can be obtained, so the interception of millimeter wave communication is obtained. And interference becomes very difficult[4].

A. Millimeter wave ground communication

The traditional application of millimeter wave terrestrial communication systems is relay (relay) communication. Numerous tests of millimeter wave propagation have shown that multi-hop millimeter wave relay (relay) communication is feasible. In order to reduce the risk, we start with the low end of the millimeter wave band and the high end of the centimeter wave band. At the same time as the development of high-band and large-capacity communication systems, medium- and low-capacity short-range millimeter-wave communication devices in higher frequency bands have also been introduced.

In the 1990s, the wave of global informationization was ushered in. With the rapid development of the Internet, the rapid growth of interactive multimedia services, broadband video services, and private network and radio communication, there is an urgent need to improve transmission rate, transmission bandwidth, and transmission quality. The demand for broadband access has become increasingly strong, and the development of various broadband access networks and devices has been promoted. Wireless broadband access technologies using millimeter waves have emerged[5].

B. Millimeter wave satellite communication

Due to the abundant frequency resources, millimeter wave communication has been rapidly developed in satellite communication. For example, in the interstellar communication, the 5mm (60GHz) band is generally used because the atmospheric loss is extremely large at this frequency, and the ground cannot detect the interstellar communication content. In the interstellar, because the atmosphere is extremely thin, it will not cause the signal to decline. The US "tactical, strategic, and relay satellite systems" is an example. The system consists of five satellites with an upstream frequency of 44 GHz, a downstream frequency of 20 GHz, a bandwidth of 2 GHz, and an interstellar communication frequency of 60 GHz.

Compared with other communication methods, the main advantages of satellite communication are: a) the communication distance is long, and the cost of establishing the station is independent of the communication distance. b) Working in a broadcast mode to facilitate multiple access. c) The communication capacity is large, and there are many

types of services that can be transmitted. d) can be spontaneous, self-receiving, monitoring, etc. In the 1970s and 1980s, satellite communications were mostly carried out using geostationary orbits (also known as synchronous orbits). After the 1990s, satellite communication systems using medium and low orbits came to the fore. However, in the case of large-capacity communication services, satellite communication systems using geostationary orbit are still the protagonists. According to statistics, in the 10 years of the 1990s, as many as 200 communication satellites were launched into the synchronous orbit, with the C-band being the most and the Ku-band being the second. The resulting spectrum congestion of satellite communications has also become increasingly prominent, and the move to higher frequency bands has become an inevitable trend.

In fact, experimental research on millimeter-wave satellite communications began in the early 1970s. Most of the development work in this area is carried out in the United States, the former Soviet Union and Japan. In the late 1980s and 1990s, in addition to the introduction of the experimental satellites in the millimeter-wave band that continued to be used in a wider range and more content, the practical Ka-band satellite communication system began to appear. It should be noted that many of these satellites use a range of advanced technologies, including multi-beam antennas, on-board switching, on-board processing, and high-speed transmission.

V. MILLIMETER WAVE APPLICATION

Military needs are an important factor in promoting the development of millimeter-wave systems. At present, millimeter waves have been widely used in radar, guidance, tactical and strategic communication, electronic countermeasures, remote sensing, and radiation measurement. Among them, strategic communication and electronic countermeasures are very important application directions. Electronic confrontation refers to the electromagnetic struggle between both hostile parties using electronic equipment or equipment, and is an important means in modern warfare.

With the development of millimeter-wave radars and guidance systems, corresponding electronic countermeasures have also developed. In addition to strong firepower and high density in modern warfare, an important feature is that the entire battle is carried out in intense electronic confrontation. Therefore, communication equipment is required to have strong anti-interference ability, and millimeter wave shows a

clear advantage in this respect. For example, the selection of ship-to-ship millimeter-wave communications in the three "attenuation peak" bands of 60 GHz, 120 GHz, and 200 GHz, using the characteristics of severe attenuation of signals in these bands, can greatly improve the anti-jamming and anti-jamming of ship-to-ship communication. Interception ability. In foreign countries, the development of electronic countermeasure devices such as direction finding machines, jammers and signal analyzers in the millimeter wave band has been vigorously carried out.

The millimeter wave beam is very narrow, and the side lobes of the antenna can be made very low, making reconnaissance and active interference more difficult. Therefore, passive interference has a great development in the millimeter band. For millimeter waves below 35 GHz, the most common means of interference is to place non-resonant millimeter-wave chaffs and aerosols to scatter the enemy millimeter-wave radar beam, which can interfere with a wider frequency band without having to accurately measure the enemy radar in advance. Frequency of. In addition, it is also possible to generate plasma by explosion, thermal ionization or radioactive elements to absorb and scatter millimeter waves to interfere with enemy radar.

The frequency coverage of most radar reconnaissance and warning systems in service has been extended to 0.5 GHz to 40 GHz. According to reports, part of the radar reconnaissance equipment in the US electronic countermeasures equipment can reach 110 GHz and is developing to 300 GHz. The frequency of radar warning equipment has been extended to 40 GHz to 60 GHz. NATO is developing a vehicle-mounted millimeter-wave warning device with a frequency range of 40 GHz to 140 GHz. In addition, the communication reconnaissance band covers the 10 GHz millimeter band, and the communication interference portion below 40 GHz has been put into practical use and is developing to 110 GHz. Stealth technology can also be utilized in the millimeter band. When dealing with an active millimeter wave radar, as in the microwave band, it is possible to reduce the shape of the radar cross section or apply a millimeter wave absorbing material such as ferrite to the surface to reduce the intensity of the reflected wave. For a passive radar that tracks the target by detecting the contrast between the low millimeter wave radiation of the metal target and the background radiation, a target with a strong millimeter wave radiation is applied to make the radiation and background radiation

substantially equal. Thereby merging the target into the background.

In short, millimeter-wave communication is very necessary and significant for military applications. It is a promising communication means with narrow beam, high data rate, concealed radio waves, good confidentiality and anti-interference performance, and rapid opening. Easy to use and flexible, and working around the clock. In addition to its application in the field of electronic countermeasures, the application of military millimeter wave communication includes far (outer space) near (atmosphere) distance communication, rapid emergency communication, submarine communication, satellite communication, interstellar communication, and the way down the microwave trunk line. Cable breaks the device, etc. [6]

VI. RELATED TECHNOLOGY RESEARCH

A. Millimeter wave multi-antenna system

Marconi proposed in 1908 to use MIMO technology for anti-channel fading. In the 1990s, AT&T (American Telephone & Telegraph Company) made a lot of groundbreaking work on the application of MIMO technology to communication systems. In 1995, Teladar derived the system capacity of MIMO under fading channels in the laboratory. In 1996, Foschini developed an algorithm for preprocessing signals in the MIMO channel—D-BLAST (Diagonal-BLAST) algorithm. In 1998, Wolinansky et al. used the V-BLAST (Vertical-BLAST) algorithm in the laboratory to build a MIMO system and obtained a spectrum utilization rate of 20 bps/Hz. This experiment caused great sensation in the communication industry and played a huge role in promoting the development of MIMO technology. However, as LET enters the commercial age, the demand for communication has increased year by year, and the performance of current MIMO systems cannot meet the demand for communication. Therefore, the Massive MIMO system has been proposed in recent years. Massive MIMO systems can make full use of space resources, greatly improve spectrum efficiency and power efficiency, and their system performance is greatly improved compared with MIMO systems.

Massive MIMO was first developed by Thomas L. of Bell Labs, USA. Researchers such as Marzetta suggested. Thomas L. Researchers such as Marzetta found that when the number of base station antennas tends to infinity, channel effects such as additive white Gaussian noise and Rayleigh fading are negligible, greatly increasing the data transmission rate. Massive MIMO has hundreds of antennas and even thousands

of antennas at the base end, which is 1-2 orders of magnitude higher than the number of base station antennas in the existing LTE-A, thus providing a higher transmission rate.

The main consideration is the typical Massive MIMO system, which assumes that there is an antenna at the base station and serves a single antenna user (and receives signals). The downlink system block diagram is shown in Figure 1. The received signal can be expressed as Equation 1-1:

$$y = \sqrt{\rho} H W p^{1/2} x + n \quad (1)$$

Among them, ρ is the downlink transmission power, $H \in \mathbb{C}^{K \times N}$ is the downlink channel matrix, $CN(0,1)$ obeys the distribution, $W \in \mathbb{C}^{N \times K}$ is the downlink precoding matrix, $p = \text{diag}(p_1, \dots, p_k)$ is the power allocated by the base station to each user, $x \in \mathbb{C}^{K \times 1}$ is the signal vector before precoding, $n \in \mathbb{C}^{K \times 1}$ is additive Gaussian white noise.

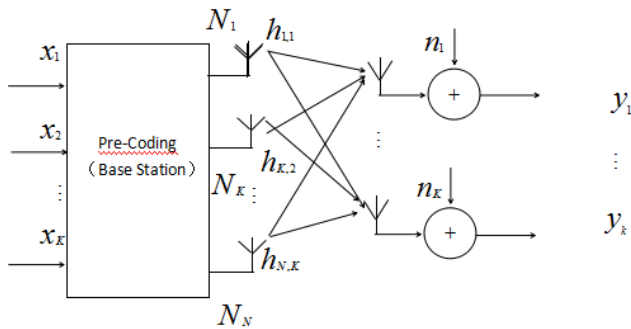


Figure 1. Block diagram of the downlink system of the millimeter wave multi-antenna system

B. Interference alignment

Interference alignment technology is an emerging method of interference management. When multiple users perform wireless communication, there will be interference between each other, and the interference will affect the signal reception quality and reduce the channel capacity of the receiver. Existing techniques for handling interference, such as frequency division multiplexing (FDMA), time division multiplexing (TDMA), and code division multiplexing (CDMA), primarily eliminate the effects of interfering signals on desired signals by orthogonalizing the signals. In fact, when multiple users share spectrum resources, this processing method can only allocate spectrum resources among K users. For example, when the number of users interacting with each other is K, the

spectrum resource that each user can obtain is $1/K$ of a single user. Therefore, when the number of users is large, the spectrum resources available to each user are still very limited.

The interference alignment technique was proposed to solve this problem. In 2008, the system description was first given by Professor Syed A. Jafar and his student Viveck R. Cadambe. The core idea is to jointly design the transmitter precoding matrix to divide the signal space into two parts: the desired signal space and the interference signal space. The precoding technique is used to make the interference overlap at the receiving end, thereby compressing the signal capacity occupied by the interference and eliminating interference. The effect on the desired signal is achieved for the purpose of increasing the channel capacity.

Taking the implementation of spatial interference alignment as an example, the core idea of interference alignment is to limit the interference signal to a range of stator space at the receiving end. After decoding the received interference suppression matrix, the subspace where the desired signal is located and the interference signal are located. The subspaces are just orthogonal, so the desired signal is not affected by the interfering signal. In the spatial interference alignment algorithm, the transmission precoding matrix and the reception interference suppression matrix are designed according to information such as the obtained channel matrix.

VII. PROSPECT

Millimeter wave communication technology is a typical dual-use technology. In the military field, it can be applied to inter-satellite communication or relay, secret communication in the millimeter wave band, and millimeter wave enemy and foe identification system; in the civilian field, it can be applied to broadband multimedia mobile communication systems, measurement radar, vehicle and ship collision avoidance, topographic mapping, radio astronomy, interactive large-capacity television broadcasting and satellite millimeter wave link system and many other aspects, and will further expand its market. In short, a large amount of research work has been carried out in the field of domestic and foreign millimeter wave communication, covering everything from basic communication theory to practical system application, which fully demonstrates that millimeter wave communication is a promising wireless communication technology.

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