# Ultra-High-Capacity Wireless Transmission Technology Achieving 10 Gbps Transmission

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## Abstract

Demand for higher-capacity wireless mobile backhaul has been increasing in recent years, making the achievement of 10 Gbps transmission a significant target. Microwaves have conventionally been used in this field, however, microwaves have reached the limit of capacity expansion and a broader bandwidth is needed to achieve increased capacity. Therefore, there is an increasing expectation for millimeter wave, especially E-band, which can ensure broadband speed. This paper introduces LOS-MIMO as a component technology for a 10 Gbps transmission system in E-band currently under development, as well as NEC's approach to an increase in wireless transmission capacity.

**Keywords**

10 Gbps, LOS-MIMO, E-band, XPIC, multilevel QAM

## 1. Introduction

In mobile backhaul, the networks connecting base stations, wireless communications systems are playing an increasingly important role. NEC has been delivering these wireless communications systems to markets all over the world under the product name "PASOLINK."

Accompanying the rapidly increasing demand for mobile communications traffic in recent years, there is a strong need for higher capacity, necessitating the achievement of 10 Gbps transmission.

This paper introduces key technologies required for a system currently under development that will enable 10 Gbps transmission as well as an approach to the expansion of transmission capacity.

## 2. Challenges for Increased Capacity

### 2.1 Increased Microwave Capacity

In the range of microwave communications (6 GHz to 42 GHz), the CS (Channel Separation) of one channel's bandwidth is tens of MHz. It is, for example, 56 MHz at maximum according to the European standard. It uses multilevel QAM (Quadrature Amplitude Modulation) as the modulation scheme. Thanks to recent improvements in digital signal processing and device technology, ultra-multilevel modulation as high as 2048 QAM is now available for practical use. If 2048 QAM is applied to 56 MHz CS, nearly 500 Mbps transmission capacity can be obtained.

Moreover, transmission capacity can now be doubled through PM (Polarization Multiplexing), which transmits independent signals on two polarized waves, vertical (V) and horizontal (H), in the same frequency range. Implementation of XPIC (Cross Polarization Interference Canceller), which eliminates mutual interference between polarized waves, makes it possible to apply PM even to ultra-multilevel modulation with a high required CNR (Carrier to Noise Power Ratio). When PM is applied to 56 MHz CS and 2048 QAM, transmission capacity as high as almost 1 Gbps can be obtained.

The modulation level has nevertheless already reached the limit attainable at reasonable cost. For this reason, even if the 112 MHz CS that will be available in the future is assumed, 2 Gbps is the limit, with no way to achieve 10 Gbps in the range of microwaves.

According to the transmission capacity formula proposed by

the Shannon-Hartley theorem, increases in modulation level are effective for expanding transmission capacity only logarithmically, while increases in bandwidth directly contribute to it. In order to achieve further expansion of capacity, it is necessary to use higher-frequency bands that allow the use of broader bandwidth.

## 2.2 Status of Millimeter-wave

In this paper, the frequency of the millimeter-wave is considered as over 60GHz.

The V-band (60 GHz band) and E-band (70 to 90 GHz band) have been attracting attention in recent years as bands permitted for use for communications systems in the field of millimeter-wave, and their application has started all over the world. The V-band uses 50 MHz CS as its minimum unit and allows the selection of CS in integer-multiplied values. Provided with an even broader bandwidth, the E-band has a 10-GHz bandwidth in total (5 GHz in one direction) and enables the use of up to 2 GHz CS, with 250 MHz CS as its minimum unit. Due to the fact that bandwidth a few dozen times as wide as with microwaves can be used, it seems that the around 10 Gbps can easily be attained. On the other hand, it has drawbacks, such as attenuation due to absorption by rainfall or air as well as decreased SNR (Signal to Noise Power Ratio) due to bandwidth expansion. Consequently, millimeter-wave is restricted in signal transmission distance and modulation levels.

In addition, broadband signals require higher signal processing speed for their modulation/demodulation circuitry, raising the bar of difficulty for this achievement.

Owing to these problems, the E-band wireless systems that have been put into practical use thus far typically employ a low-level modulation method that enables the configuration of a modulator/demodulator with analog circuitry at 1 GHz CS. The transmission capacity of this first-generation system is about 1 Gbps. To achieve higher capacity, it is necessary to apply multilevel QAM using digital circuitry. The development of this second-generation system using multilevel QAM was launched against this background around 2012, and systems that make 1Gbps transmission possible with 250 MHz CS, 64 QAM are now about to be put into practical use.

## 2.3 Capacity Expansion in E-band

Considering the performance of digital signal processing devices and the decrease in SNR caused by bandwidth expansion, it is reasonable to assume that the bandwidth should be 500 MHz CS for now. Further expansion of the bandwidth beyond this is also not desirable from the viewpoint of frequency administration.

Now, let us examine the transmission capacity with 500 MHz CS. Assume that the roll-off factor for bandwidth restriction is 0.25 and the relationship between the CS and the symbol rate (fs) is fs = 0.8 CS. Moreover, assume that the ratio of the payload that carries the information transmission is 90% of the whole, considering the redundancy of error correction codes. When the modulation method is set as high as 256 QAM, the maximum transmission capacity (C) can be found by the following expression:

C = 500 MHz • 0.8 • 0.9 • 8 bits = 2,880 Mbps.

When PM is combined with this, the resulting value is 5,760 Mbps. To achieve 10 Gbps, however, a means to further double the capacity is required. It is precisely because of this that we have applied the technology of LOS-MIMO (Line of Sight Multiple Input Multiple Output).

## 3. LOS-MIMO

### 3.1 Principles of LOS-MIMO

MIMO technology is already commonly used in the mobile communications field, but it is based on NLOS (Non Line of Sight) communications, where there is a scattering propagation environment. Although transmission capacity is multiplied by the number of antennas, it is stochastic and fluctuates according to changing environmental conditions from moment to moment. Besides, if LOS (Line of Sight) is obtained, the effect of the transmission capacity increase would be lost. According to this fact, in a LOS environment such as a microwave communications system, it has been conventionally argued that MIMO has no effect on increase of transmission capacity. However, it has become known that an increase in transmission capacity is possible even for LOS condition, adopting the special geometric allocation of the Tx/Rx antennas[1]. This is called LOS-MIMO.

Let us take a quick look at the principles of this LOS-MIMO. **Fig. 1** is an overall configuration diagram of 2 × 2 LOS-MIMO using two sets of Tx/Rx antennas.

Independent signals at the same frequency are transmitted from the two Tx antennas. The signals from the two Tx antennas reach the two Rx antennas at almost the same level. Since
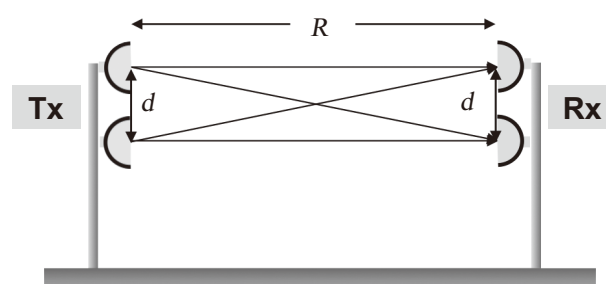


Fig. 1 LOS-MIMO overall configuration diagram.

the two signals are added at the same level, neither signal can be demodulated without any special signal processing. However, when the relationship between the three factors (antenna spacing $d$, link distance $R$, and carrier frequency $f$) meets the following conditions, the path length difference between the two signals that reach one reception antenna from the two Tx antennas becomes 1/4 (equivalent to 90°) of the wavelength, and then they are orthogonal to each other. As a result, it is possible for them to be separated as independent signals by the signal processing on the Rx side, as shown in **Fig. 2** (These parameters are in MKS unit system).

$d=\sqrt{\lambda R/2}$, $\lambda=c/f$, The "c" stands for the light speed.

LOS-MIMO has such a geometric condition. This is a significant difference from NLOS-MIMO, which requires the presence of reflected waves.

### 3.2 Features and Problems of LOS-MIMO

**Fig. 3** shows the optimal antenna spacing according to frequency and link distance. The link distance of microwaves usually ranges from a few kilometers to a few dozen kilometers; however, under these conditions, the antenna spacing becomes as impractical as 10 meters or more. With E-band, on the other hand, because the link distance is limited to 1 to 2 kilometers in the first place due to the effect of rainfall attenuation at higher frequencies, the required antenna spacing is 2
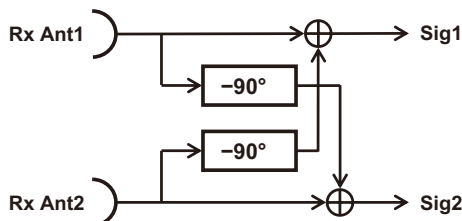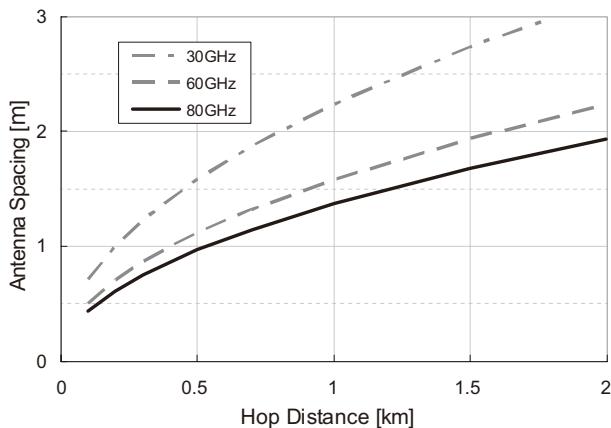
meters or less, which is a practical range.

In terms of fluctuation in transmission capacity, LOS-MIMO enables stable transmission capacity since it does not take advantage of the surrounding scattering environment. However, to satisfy the requirements of a LOS-MIMO system using geometric conditions alone, millimeter-scale precision would be required for the link distance and antenna spacing. On top of the fact that such precision cannot be expected for ordinary installation work, the fluctuation of antenna positions caused by wind or vibration can easily exceed this precision requirement. Therefore, the adaptive control of the phase shifter shown in Fig. 2 will be indispensable for the maintenance of signal orthogonality.

In addition, although it is desirable to set the antenna spacing as close as possible when considering actual installation, shortening of the separation will result in a decrease in SNR, that is to say, a decrease in transmission capacity.

### 3.3 Combination of PM+XPIC and LOS-MIMO

As a technology to double transmission capacity, the combination of PM and XPIC - for which a pair of antennas is sufficient - is more economical than 2 × 2 LOS-MIMO. LOS-MIMO can therefore be regarded as an additive system on PM to be used only when further expansion of capacity is required. In other words, an applied LOS-MIMO system should be built on the assumption that PM is performed. It is required that there be no characteristic degradation of LOS-MIMO caused by cross-polarization interference and that the addition of LOS-MIMO bring no adverse effect upon the characteristics of polarization demultiplexing (interference compensation).

On the other hand, it can be theoretically proven that cross polarization interference neither affects nor is affected by the operation of spatial separation circuitry as long as the fluctuation of XPD (Cross Polarization Discrimination) remains the same between two polarized waves. Consequently, cross polarization interference can be compensated by XPIC at a subsequent stage, regardless of MIMO. When an ordinary XPIC-equipped demodulator is implemented at the spatial separation circuitry output shown in Fig. 2, a receiver for a combination of LOS-MIMO and PM can be configured.

### 3.4 System Characteristics

Finally, let us take a look at the system characteristics of this LOS-MIMO + XPIC configuration[2].

In order to achieve 10 Gbps with 500 MHz CS, 128 QAM is the optimal modulation scheme. The Link distance versus RSL (Received Signal Level) margin and availability are shown in the graph in **Fig. 4**. The system specifications are provided in **Table**.

It is clear from this graph that a link distance of about 1 km can be ensured even with 30 cm-diameter antennas.
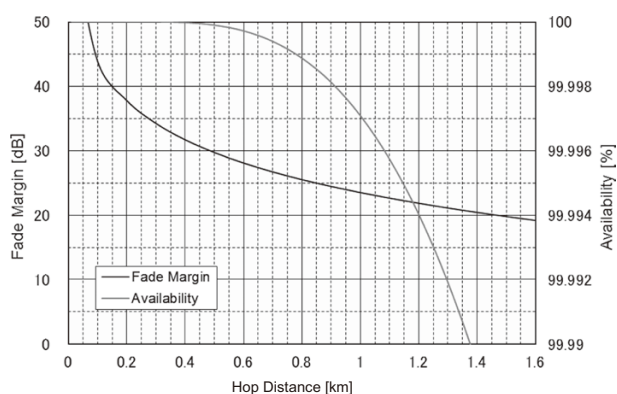
Fig. 2  Spatial separation circuitry on the reception side.

Fig. 3  Optimal antenna spacing with respect to link distance.

Fig. 4  Link distance vs. RSL margin and availability.

Table  Specifications of E-band LOS-MIMO 10Gbps transmission system.

| Item | Value |
|------|-------|
| Modulation & Coding | 128QAM + RS code |
| Symbol Rate | 400Mbaud |
| Required CNR @1E-6 | 27dB |
| Transmitter Power | +12dBm |
| Antenna Diameter | 30cm |
| RF Frequency | 80.0GHz |
| Gas Attenuation | 0.4dB/km |
| Noise Figure | 12dB |
| Rain Zone | K(42mm/h) |

**Reference**

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## 4.  Conclusion

We have seen the approaches to the expansion of transmission capacity and technology for high-capacity wireless communications systems using millimeter-wave, particularly E-band.

It is possible to achieve 2.5 Gbps when 500 MHz CS is used and 5 Gbps when PM is applied, while application of LOS-MIMO will even make it possible to achieve 10 Gbps.

Realizing of 10 Gbps transmission makes it possible to apply wireless systems to the fields in which only fiber optics can be applied today, for example communications between a BBU (Base Band Unit) and RRHs (Remote Radio Heads) of a mobile base station, it is called "fronthaul."

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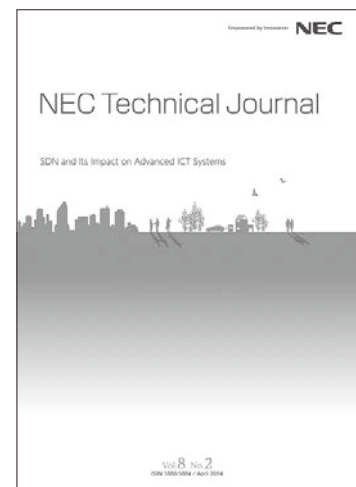
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