

Wavelength Division Multiplexing Transmission Method for 5G Radio Access Networks to Achieve 40 km Transmission

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We have developed a wavelength division multiplexing transmission method to efficiently connect radio base stations and antennas with a small number of optical fibers. In the fifth generation (5G) radio access networks, there is demand for a technology that can economically transmit 25G Ethernet signals over up to 40 km by wavelength division multiplexing (WDM). This paper introduces the half-rate transmission method that enables 40 km WDM transmission by dividing 25.8 Gbit/s signals into two channels of 12.9 Gbit/s signals and transmitting them.

Keywords: 5G radio access networks, 25G Ethernet, wavelength division multiplexing transmission, half-rate transmission

1. Introduction

In 5G radio access networks*¹, the number of cells is expected to increase due to the shift to small cells*² and the use of radio transmission and reception technologies such as massive multiple input multiple output (MIMO)*³, which will increase the number of optical fibers to connect radio base stations.

There is a concern regarding the future shortage of existing unused fibers (dark fibers), and wavelength division multiplexing (WDM)*⁴ technology is expected to become an efficient means of utilizing optical fibers.

In order to support large capacity and high speed, evolved Common Public Radio Interface (eCPRI)*⁵, a communication specification that uses high-speed optical communication such as 10G Ethernet and 25G Ethernet, has been specified for radio access networks, and 25G Ethernet is expected to be used for 5G.

Radio access networks require transmission distance of up to 20–40 km. However, degradation of optical signal waveforms caused by wavelength dispersion*⁶ of optical fibers poses an issue.

For example, in the C-band (1530–1565 nm), which is used in the dense wavelength division multiplexing (DWDM), the wavelength dispersion of optical fibers is high. A dispersion penalty of more than 5 dB has been reported in the 20 km transmission by 25G Ethernet,⁽¹⁾ making it difficult to achieve stable communication.

In the O-band (1260–1360 nm), with small wavelength dispersion, the available wavelengths are limited due to the interference between wavelengths, etc., making it difficult to achieve high concentration.

Therefore, there is a need for a WDM transmission method that can transmit 25G Ethernet signals over up to 40 km by DWDM in the C-band.

This paper introduces the half-rate transmission method, which reduces the influence of the wavelength dispersion by dividing 25G Ethernet signals into two half-rate channels for transmission and achieves 40 km DWDM transmission in the C-band, and explains the transmission characteristics of the method.

2. Half-Rate Transmission Method

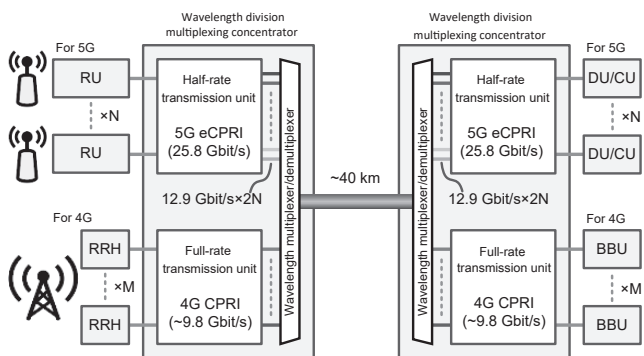
2-1 Wavelength division multiplexing concentration system

Figure 1 shows a configuration example of a wavelength division multiplexing concentration system that uses the half-rate transmission method.

A pair of WDM concentrators is installed between the radio antenna units (radio unit (RU) and remote radio head (RRH)) and the radio signal processing/data processing units (distributed unit/central unit (DU/CU) and base band unit (BBU)), both of which make up radio base stations.

N channels of eCPRI (25G Ethernet, 25.8 Gbit/s) for 5G mobile communication and M channels of CPRI*⁷ (1.2 Gbit/s to 9.8 Gbit/s) for 4G mobile communication are concentrated, and optical signals from the radio units and radio signal processing/data processing units are wavelength-converted and the WDM transmission is performed using a single optical fiber.

Here, the eCPRI signals for 5G mobile communication are converted into two channels of half-rate signals (12.9 Gbit/s) for transmission, and these channels are restored to the original eCPRI signals after transmission.



RU: Radio Unit, DU: Distributed Unit, CU: Central Unit
RRH: Remote Radio Head, BBU: Base Band Unit

Fig. 1. Example of a half-rate wavelength division multiplexing concentration system

In general, the transmission penalty attributed to wavelength dispersion is proportional to the distance and to the square of the transmission rate. The dispersion penalty can be reduced to one fourth by halving the transmission rate, enabling WDM transmission in the C-band, with high wavelength dispersion.

In the configuration example in Fig. 1, the N channels of eCPRI for 5G are transmitted at the half-rate with $2N$ wavelengths and the M channels of CPRI for 4G are transmitted at the original rate with M wavelengths. Totally, the WDM transmission is performed with the $(2N + M)$ wavelengths in the upstream and downstream directions, respectively.

DWDM optical transceivers for 10G Ethernet are used for the WDM transmission of half-rate signals. The transmission rate of half-rate signals (12.9 Gbit/s) is 1.25 times higher than that of 10G Ethernet (10.3 Gbit/s). The dispersion penalty is expected to increase by about 1.6 times.

10GBASE-ZR specification supporting transmission of up to 80 km has been standardized for 10G Ethernet. The dispersion penalty can be reduced to the practical level up to about 50 km by using this optical transmission technology.

2-2 Half-rate conversion and restoration

Next, the conversion to and restoration from half-rate signals are explained using Figs. 2 and 3. The same processing applies to the upstream and downstream directions. Figure 2 shows the data configuration of 25G Ethernet signals and half-rate signals. Figure 3 shows the configuration of a converter and restorer of a half-rate transmission unit in the concentrator.

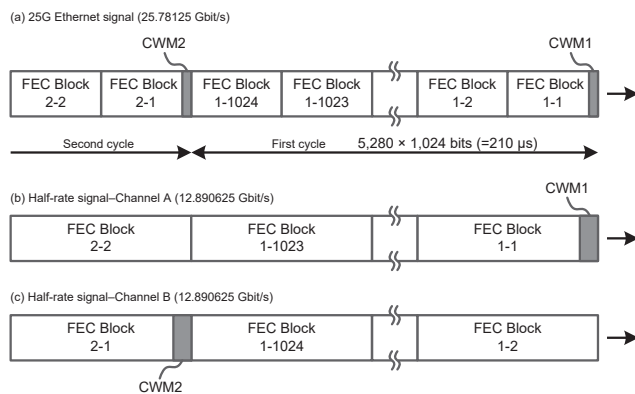


Fig. 2. Data configuration of 25G Ethernet and half-rate signals

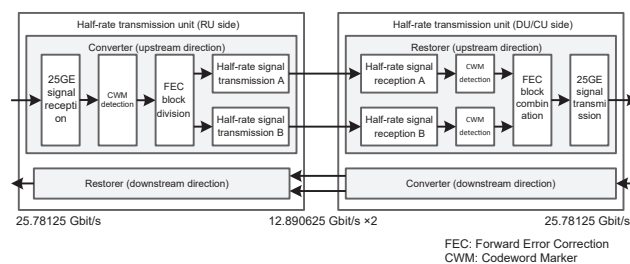


Fig. 3. Half-rate conversion and restoration

In the half-rate transmission, 25G Ethernet signals are divided into two channels for transmission. Thus, the propagation delay difference between the channels of half-rate signals needs to be compensated by restoration process on the receiver side.

In this paper, the propagation delay difference is detected by utilizing the data configuration of 25G Ethernet. In 25G Ethernet, the Reed-Solomon code^{*8} RS (528, 514) is used for error correction^{*9} (forward error correction (FEC)). A set of FEC blocks of 5,280 bit length is transmitted, as shown in Fig. 2 (a).

A special code called a code word marker (CWM) of 257 bit length is transmitted every 1,024 blocks (i.e., in the cycle of about 210 μ s) at the head of FEC blocks (1-1, 2-1, ...).⁽²⁾

The converter in Fig. 3 detects the CWMs of the 25G Ethernet signals. For example, the 25G Ethernet signals are divided into two-channel half-rate signals A and B in FEC blocks, monitoring the position of the CWM as the reference. Here, the signals are allocated so that the CWMs are assigned in both channels.

In the example of Fig. 2, the 25G Ethernet signals are divided into FEC blocks (1-1024). In the first cycle, odd-numbered blocks (1-1, 1-3, ..., 1-1023) are allocated to Channel A, while even-numbered blocks (1-2, 1-4, ..., 1-1024) are allocated to Channel B.

In the second cycle, odd-numbered blocks (2-1, 2-3, ..., 2-1023) are allocated to Channel B, while even-numbered blocks (2-2, 2-4, ..., 2-1024) are allocated to Channel A.

The allocation of odd-numbered and even-numbered blocks to Channels A and B is changed in each cycle, making it possible to arrange the CWM in both channels, as shown in (b) and (c) of Fig. 2.

In Fig. 3, the restorer detects the CWMs of the half-rate signals and determines the boundary of the FEC blocks by monitoring the CWM position as a reference, making it possible to correct the propagation delay difference between the channels and restore the original 25G Ethernet signals.

It should be noted that the error correction is performed, not by the concentrator but by the radio antenna unit and radio signal processing/data processing unit of the base station.

3. Transmission Characteristics

In this study, a prototype of the half-rate transmission unit shown in Fig. 3 was fabricated using field-programmable gate array (FPGA)^{*10} to evaluate the half-rate transmission characteristics of 25G Ethernet.

For the optical transmission of half-rate signals (12.9 Gbit/s), a DWDM optical transceiver (10GBASE-ZR specification; transmitter wavelength, 1558.17 nm; transmitter power, + 2.15 dBm) for the 10G Ethernet 80 km transmission was used.

While the transmission rate was higher than that of 10G Ethernet, an equalizer^{*11} was implemented in the receiver of the restorer to compensate for the bandwidth shortage of the optical transceiver.

Figures 4 and 5 show the receiver sensitivities in the half-rate transmission (0 km, 40 km, 50 km). In Fig. 4, the general limiting receiver*¹² was used in the optical transceiver. In Fig. 5, the linear receiver*¹³ was used. The receiver sensitivity of the linear receiver (which is suitable for the equalization process) was about 0.7 dB higher than that of the general limiting receiver.

For both types of receivers, the transmission error was generated by the optical attenuator, which was inserted into one of the channels of the half-rate transmission while lowering the received optical power. The bit error ratio (BER) was measured as the frame error ratio of the 25G Ethernet frames, which was then converted to the bit error ratio.

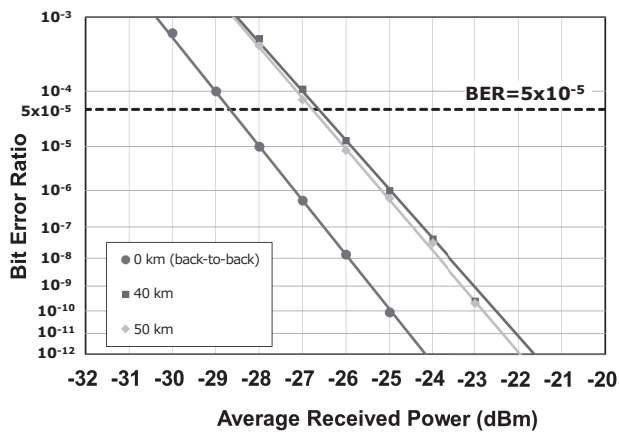


Fig. 4. Receiver sensitivity (limiting receiver)

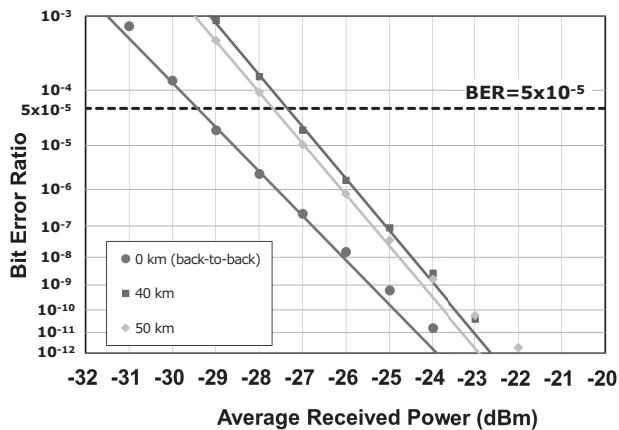


Fig. 5. Receiver sensitivity (linear receiver)

In measurement, the error correction processing for 25G Ethernet was disabled, and the received power at the bit error ratio of 5×10^{-5} (error-free when the error correction processing is enabled) was evaluated as a reference.

Table 1 presents the results summarized as the power budget*¹⁴ of the half-rate transmission (except for the wavelength multiplexer and demultiplexer loss).

The budget for the 40 km transmission was 28.8 dB

Table 1. Power budget measurement results

Transmitter Power (dBm) A	Receiver type	Distance (km)	Receiver Sensitivity BER= 5×10^{-5} (dBm) B	Power budget (dB) A-B
+2.15	Limiting	0	-28.64	30.8
		40	-26.63	28.8
		50	-26.90	29.1
	Linear	0	-29.29	31.4
		40	-27.31	29.5
		50	-27.66	29.8

for the limiting receiver and 29.5 dB for the linear receiver. Both results met the budget of 27 dB, which is expected for the 40 km WDM transmission.

Here, the value of 27 dB consists of the estimated loss of the wavelength multiplexer and demultiplexer (arrayed waveguide grating*¹⁵) (11 dB) and the estimated loss of the optical fibers (16 dB [0.4 dB/km]).

4. Conclusion

This paper explained the half-rate transmission method that can transmit the 25G Ethernet signals, which are used in 5G radio access networks, 40 km by WDM. It also introduced an example of application to a WDM concentration system.

The method can use the 10G DWDM optical transceiver technologies and inexpensively improve the usage efficiency of optical fibers in 5G radio access networks.

Technical Terms

- *1 Radio access network: A network comprising radio base stations and antennas (which connect the core networks and mobile devices) in a mobile communication system.
- *2 Small cell: A small area where communication is enabled. Large-capacity communication is achieved by arranging radio antennas with high density.
- *3 Massive multiple input and multiple output (MIMO): A radio communication technology for data transmission and reception using multiple antennas.
- *4 Wavelength division multiplexing (WDM) technology: A technology for multiplex of multiple optical signals in a single optical fiber by using different wavelengths.
- *5 Evolved CPRI (eCPRI): An Ethernet-based communication standard that applies to communication between radio base stations and antennas.
- *6 Wavelength dispersion: A phenomenon in which a differential delay occurs in the optical fiber propagation time depending on the wavelength.
- *7 Common Public Radio Interface (CPRI): A communication standard that applies to communication between radio base stations and antennas. The standard is based on the digital sampling of analog signals.
- *8 Reed–Solomon code: One of the error correction codes with a high correction performance.

- *9 Error correction: A technology to detect and correct the code error in data.
- *10 Field-programmable gate array (FPGA): A rewritable integrated circuit device.
- *11 Equalizer: A circuit compensating for the degradation of signals. Here, the equalizer compensates for the bandwidth shortage in the transmission and reception processing of the optical transceiver.
- *12 Limiting receiver: Receiver in which the received signals are subject to saturation (limiting) amplification with a high gain.
- *13 Linear receiver: Receiver in which the received signals are subject to linear amplification while maintaining the shape of the signals. It is suitable for equalizing the received signals.
- *14 Power budget: Difference between the transmitter power and the received power at the expected sensitivity.
- *15 Arrayed waveguide grating: A wavelength multiplexer/demultiplexer that uses optical diffraction by an arrayed waveguide. It is suitable for size reduction and multi-channeling and is used for dense wavelength division multiplexing (DWDM).

References

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