LTE RoF 2 × 2 MIMO

Technology Reports

RoF System for Dual W-CDMA and LTE Systems

NTT DOCOMO began a high-speed, high-capacity, low-latency service using the LTE system in December 2010, and we have developed an RoF system, which can be used for dual W-CDMA/LTE service in the 2-GHz band and supports MIMO transmission, in order to implement this service in indoor areas as well. Up to 256 remote units can be connected to the base unit of the RoF system for applications in large-scale indoor areas, and optional digital transmission between the base unit of the RoF system and the W-CDMA BTS or/and LTE eNB can be used, which improves robustness of long-distance transmission on optical fiber. Using this RoF system, we have made it possible to build indoor areas supporting LTE quickly and economically since we can reuse existing infrastructure from earlier RoF systems, such as optical fiber, power lines and installation space.

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1. Introduction

Since the days of analog mobile phones, NTT DOCOMO has made a great effort to improve reception in indoor dead areas in order to expand the indoor service area as much as the outdoor service area. Various types of equipment have been developed and installed to improve reception in indoor dead areas, depending on the size, location or other characteristics of the target indoor area. Femtocells [1] or low-power repeaters are used for small indoor areas, while Radio-over-Fiber (RoF) systems, which transmit Radio Frequencies (RF) optically [2] are used for larger dead areas. By the end of March 2010, approximately 24,700 of these stations were in use.

There are also plans to quickly roll out the LTE services which began in December 2010. So that it can be used equally in outdoor and indoor areas, 1,000 LTE evolved NodeB (eNB) will be installed by March 2011. The basic plan is to expand LTE services both indoors and outdoors by installing LTE eNB together with the existing W-CDMA Base Transceiver Stations (BTS). Therefore, the dual W-CDMA/LTE service on the RoF system can be implemented simply as follows: For downlink transmission, the RF signals from both W-CDMA BTS and LTE eNB are combined at the transmitter end, and for uplink reception, the received RF signals are separated at the receiver end, and these are received by the W-CDMA BTS and LTE eNB respectively. However, one of the main purposes of launching LTE is to provide high speed, high capacity communication, so the system must also support Multiple Input Multiple Output (MIMO) transmission. For outdoor service, since most existing W-CDMA BTS for outdoor areas use transmit diversity[*1] and receive diversity, and both transmitter and receiver already have two RF ports, no changes are required to the antenna equipment. On the other hand, for indoor service areas, neither transmitter nor receiver equipment support the above diversity methods, so finding a cost-effective and quick way to implement a system that handles two RF signal is an issue for providing LTE services.

One simple way to provide MIMO transmission with existing RoF systems, is to install the same type of RoF system together with the existing RoF system. However, this would require costs similar to the initial cost of the existing RoF system, and installation time equal or longer than that of the existing system. Another major demerit of this approach is that, in older offices and other buildings, space for installing optical fiber and other cables (Electric Pipe Space: EPS) is limited, and in most cases an additional RoF system cannot be added.

To resolve these issues, NTT DOCOMO has developed a new RoF system that achieves MIMO transmission of the RF signals and makes use of the optical fiber and power supplies already in use by the existing RoF systems.

In this article, we describe the configuration and strengths of this RoF system which supports MIMO transmission (hereinafter referred to as "new RoF system"), as well as the antenna technology used.

2. New RoF System

An overview of the new RoF system is shown in **Figure 1**. The new RoF system equipment can take either of two forms, the basic configuration or the extended configuration, and comprises the following equipment.

- BASE unit: Connected to the RF signals of the W-CDMA BTS and the LTE eNB. Also connected to each remote unit by a single optical

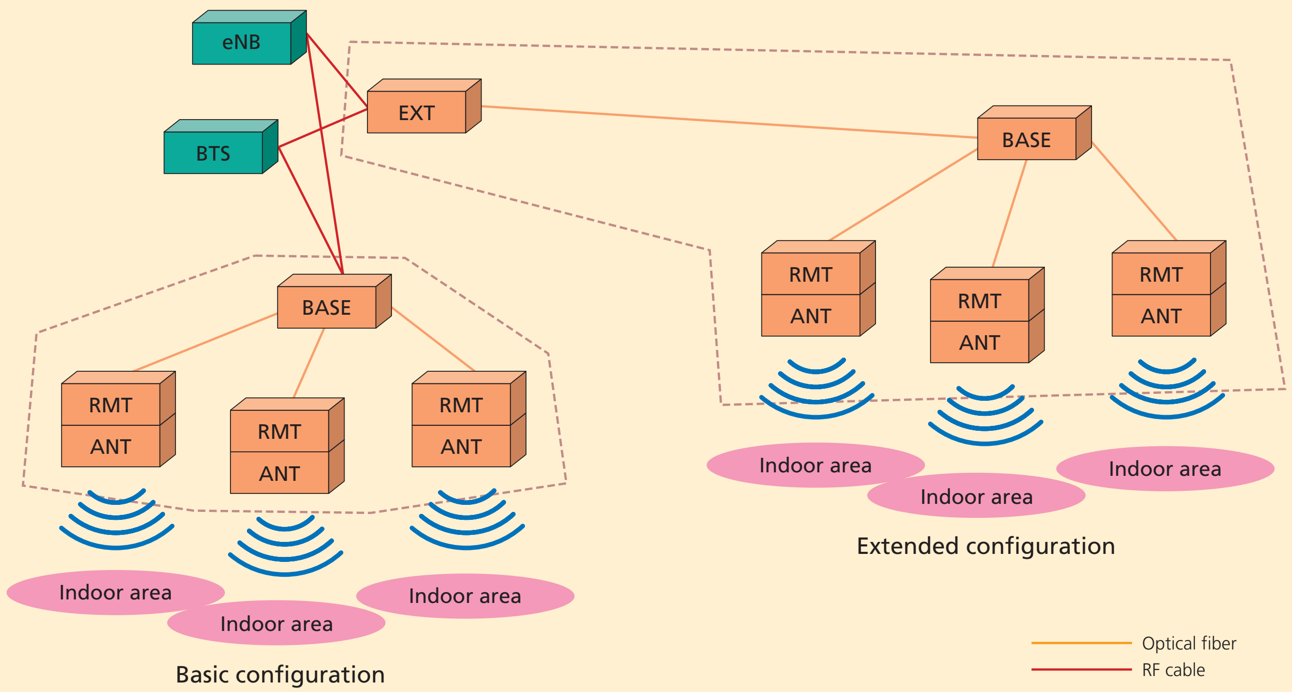


Figure 1 Overview of the new RoF system

*1 **Transmit diversity**: Technology which utilizes the differences in channel fluctuation between transmission antenna channels to obtain diversity gain.

fiber. Up to 256 remote units can be connected to a single BASE unit. Also able to supply power to each of the remote units.

- Remote unit (RMT): Connects to the BASE unit by a single optical fiber and to the antennas by two RF cables. Able to operate using power from the BASE unit or from commercial power.
- Antenna (ANT): A newly developed two branch antenna using orthogonal polarization[*2] to support MIMO transmission. Incorporates two elements for 2-GHz transmission and reception.
- Optical extension unit (EXT): Used when installing basic configuration of the new RoF system in a different location than the base station equipment. Connects to the RF signals of the W-CDMA BTS and LTE eNB. Also connects by a single optical fiber to a BASE unit with an alternate interface component.

The advantage of the extended configuration is that we can centralize the W-CDMA BTS and LTE eNB, which are connected to the optical extension unit of the new RoF system, in the existing node building of other W-CDMA BTS or LTE eNB, which is remote from the indoor dead area served by the new RoF system. By centralizing the W-CDMA BTS and LTE eNB, we can share facilities with other W-CDMA BTS and LTE eNB, and it can help increase maintenance efficiency and reduce running costs. It is also meaningful to note that most of the hardware components are shared between the extended configuration and the basic configuration, The remote units and antennas use the same hardware regardless of configuration, and the BASE unit requires only a change of interface component to connect to the optical extension unit. This means that the new RoF system can also be reused flexibly in other indoor dead areas regardless of the configuration required.

The basic specifications of the new RoF system are shown in **Table 1**.

Earlier RoF systems could support multiple frequency bands, but for cost considerations, the new RoF system is specialized for the 2-GHz band.

By allowing up to 256 remote units to connect to a single W-CDMA BTS or LTE eNB, we are able to improve reception in large indoor areas using single W-CDMA BTS or LTE eNB, where multiple W-CDMA BTS or LTE eNB were required earlier.

Although the new RoF system can be extended to use up to 256 remote units, warnings regarding their operational state can be monitored to the same standard as earlier RoF system. The state of the new RoF system can be checked from the monitoring center at any time, and if a fault occurs, the operational state of any of the remote units can also be checked in detail from either the BASE unit or optical extension unit using monitoring tools.

Each unit supports both AC and DC power sources, and the BASE unit can supply power to the remote units. Remote units also consume less power, so when replacing existing RoF systems with the new RoF system, existing power lines between BASE and remote units can be used. The dimensions of the new RoF system equipment have also been designed with consideration for scenarios where older equipment is being upgraded. External views of the

Table 1 Basic specifications of the new RoF system

	Downlink (from base station to mobile station)	Uplink (from mobile station to base station)
Frequency bands	2,130 to 2,150 MHz	1,940 to 1,960 MHz
System gain	25 dB	0 dB
ACLR	45.8 dB or more, or −32.8 dBm/MHz or less	——
Noise figure	——	13.4 dB or less (basic configuration, one RMT)
Optical fiber transmission distance	4 km (between BASE and RMT) 20 km (between EXT and BASE)	
Optical return loss characteristic	40 dB or more (between BASE and RMT) 27 dB or more (between EXT and BASE)	
Power supply voltage	DC −57 V to −40.5 V, AC 90 V to 110 V	

*2 **Polarization**: The direction of fluctuation of the electric field as a radio wave propagates through space. Generally, the electrical field can have fixed, linear polarization, or elliptical polarization. The system described in this article uses a shared-polarization antenna that uses the properties of linear polarization.

new RoF system equipment are shown in **Photo 1**.

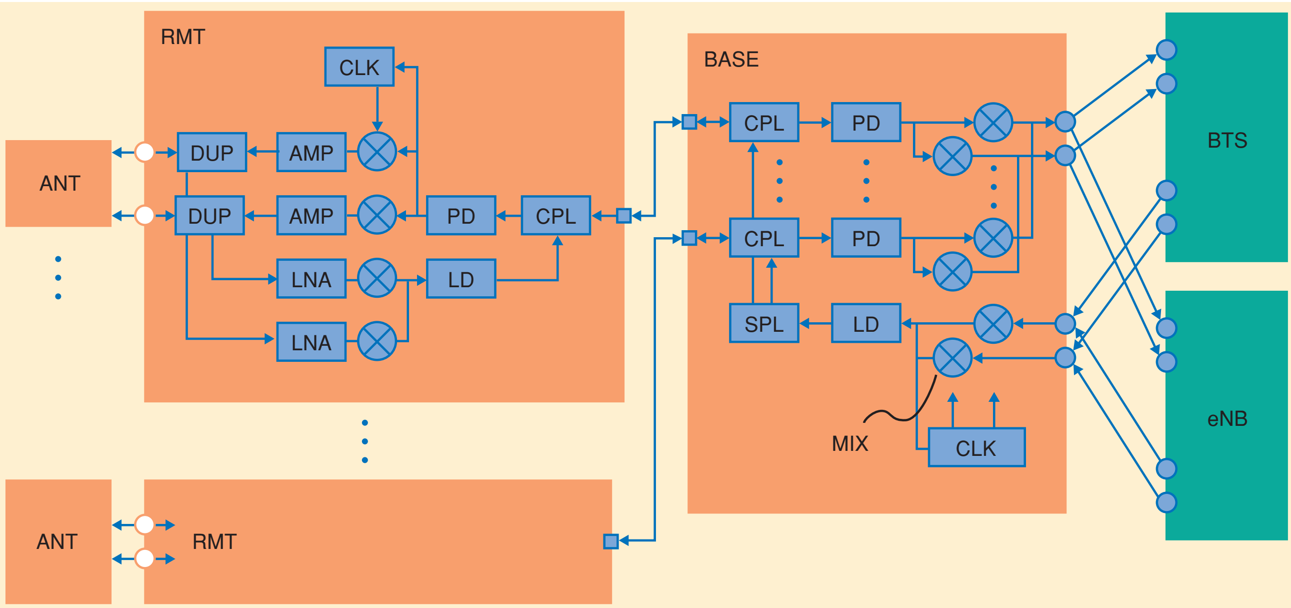
3. Technology Supporting the MIMO Transmission

The basic configuration of the new RoF system is shown in **Figure 2**. To implement MIMO transmission, we use multiplexing technology that converts to Intermediate Frequencies (IFs)*3 to multiplex RF signals for two systems each on the uplink and downlink. The IF bands were selected such that the reference signals used in the conversion or their image signals*4 would not affect the transmitted or received signal bands. The reference signal is supplied by simple oscillators in the BASE and optical extension units, multiplexed with the RF signals in each frequency-converter, so frequency error does not occur in frequency conversion.

In order to be able to utilize the optical fiber from existing RoF systems, the new RoF system uses optical wavelength division multiplexing*5

(a) BASE unit (b) Remote unit (c) Optical extension unit

Photo 1 External views of the new RoF system



AMP: Amplifier
CLK: Reference signal generator
CPL: Optical coupler
DUP: Combiner/Divider
LD : Laser diode
LNA: Low-noise amplifier
MIX: Frequency converter
PD : Photodiode
SPL: Optical splitter

Figure 2 Basic configuration of the new RoF system

*3 **IF**: A frequency to which a high-frequency signal is converted to enable demodulation.

*4 **Image signal**: A type of signal that can cause interference when a signal in a different band than the target frequency lands in the IF frequency (the target frequency) due to a local oscillation or other cause.

*5 **Optical wavelength division multiplexing**: A technique for multiplexing multiple optical signals of different wavelength on a single optical fiber cable. Allows multiple signals to be transmitted on a single cable at the same time, so it is used for high speed and high capacity.

between the BASE unit and remote units, and also between the optical extension unit and BASE unit as implemented earlier, so only a single-core optical fiber is required. By requiring only a single core, a remote unit can be installed even if there is only a single optical fiber, and when installing the new RoF system in new facilities, only half the amount of fiber is required, rather than the two fibers required earlier.

We have also improved resistance to optical reflection by using a digital optical transmission method between the optical extension unit and the BASE unit. Till now, analog optical transmission was used in RoF system extension configurations, so there was degradation to the analog signal due to diffuse reflection, resulting in degradation to the RF signal characteristic. This degradation to the RF signal characteristic can be suppressed with the digital optical transmission method. Because of this, an improvement in RF signal characteristic can be expected when upgrading existing RoF systems, and even with new installations of the new RoF system, the requirements for optical return loss characteristics of the optical fiber can be relaxed, making it easier to guarantee optical fiber procurement and reducing construction time.

4. Radio Characteristics of the New RoF System

The Adjacent Channel Leakage power Ratio (ACLR)[*6] on the downlink and the noise figure[*7] on the uplink are performance indexes for RoF systems, and both of these are improved over previous RoF systems. The system also supports W-CDMA transmit and receive diversity as well as LTE MIMO transmission, so the quality of wireless communication in indoor areas is improved over existing RoF systems. Therefore, when upgrading existing RoF systems, installing remote units in the same locations as earlier will secure the same or better areas than earlier equipment, and also it may be possible to reduce the number of remote units and antennas relative to the previous RoF system, reducing equipment costs.

5. Antennas for the New RoF System

We have developed two types of antennas for the new RoF system. The basic specifications of the antennas are shown in **Table 2**. The developed antennas are composed of vertically and horizontally polarized antenna elements and these elements are installed in a single cover. This achieves the dual-branch antenna required for MIMO transmission in a single piece of equipment and contributes to using the space of existing antennas effectively and simplifying installation. Also, considering the upgrade of existing RoF systems, the mounting for the antenna installation was made compatible with the existing indoor antennas (mounting-hole positions and RF connector positions) to reduce installation time. Generally, mounting the two antennas near each other results in an increase in fading correlation[*8], which is important for MIMO transmission. The increase of fading correlation causes degradation in MIMO transmission performance. For this antenna, however, the orthogonal polarization characteristics of the antenna contribute to decreasing fading correlation between the antennas even though they are close. This reduces degradation of MIMO transmission performance. The antennas developed are an omni-directional type antenna, which is suitable for various types of areas, and a bi-directional type antenna, which is suitable for areas such as a corridor in an underground shopping center (**Figure 3**).

6. Conclusion

In this article, we have described the characteristics, the configuration and the antenna technology of a new RoF system which supports MIMO

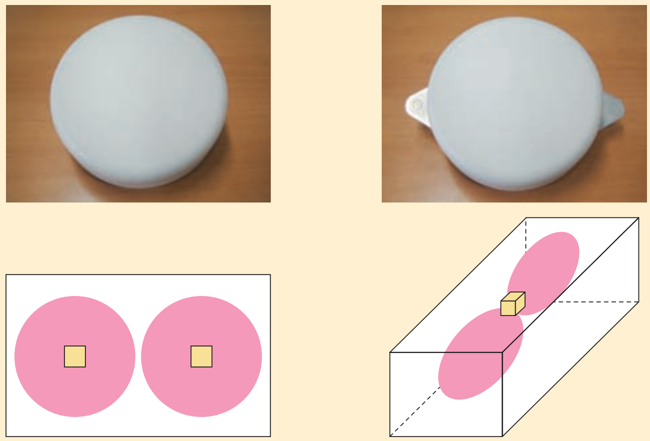
Table 2 Basic specifications of the antenna for the new RoF system

Item	Omni-directional antenna	Bi-directional antenna
Polarization	Vertical/Horizontal polarization	Vertical/Horizontal polarization
Antenna gain	2 dBi or more	4 dBi or more
Size (excluding mountings)	130 mm $\phi \times$ 40 mm height	130 mm $\phi \times$ 41mm height

*6 **ACLR**: When transmitting a modulated signal, the ratio between the transmitted signal band power and undesired power generated in the adjacent channels.

*7 **Noise figure**: The level of noise power generated inside a piece of equipment. It is defined as the ratio between the Signal-to-Noise (SN) ratio of input signals and the SN ratio of output signals.

*8 **Fading correlation**: In this article, an index indicating the correlation of fading between different antennas used in MIMO transmission.



(a) Omni-directional antenna (b) Bi-directional antenna

Figure 3 Directionality of the antenna

transmission and will enable the rapid expansion of LTE services in indoor areas.

In the future, we will continue improving systems that make it possible to upgrade existing RoF systems more easily and quickly.

References

[1] T. Watanabe et al.: "Super-compact Base Station for Femtocells," NTT DOCOMO Technical Journal, Vol. 10, No. 2, pp. 64-68, Sep. 2008.

[2] A. Hikuma et al.: "Radio Base Stations Equipments toward Economical Expansion of FOMA Coverage Areas," NTT DoCoMo Technical Journal, Vol. 6, No. 1, pp. 52-59, Jun. 2004.