# PtMP Multi-IF-Over-Fiber Systems Using Remotely Shared Local Oscillators for Plural Antenna Sites

**Kazuki Tanaka, Shinji Nimura and Ryo Inohara**
*KDDI Research. Inc., 2-1-15 Ohara, Fujimino-shi, Saitama, 356-8502 JAPAN*
*au-tanaka@kddi.com*

**Abstract:** A multi-channel intermediate frequency-over-Fiber (IFoF) system with remotely shared local oscillators (LO) is proposed. IF-to-RF conversion by a shared LO is experimentally verified meeting the 3GPP error vector magnitude (EVM) criterion for 64-QAM OFDM signal. 

## 1. Introduction

The fifth generation (5G) mobile service has been launched in many countries. Use cases and requirements for 6G systems have also been discussed in various organizations such as NGMN Alliance, Hexa-X, Next G Alliance and Beyond 5G Promotion Consortium. The required data rate for 6G eMBB is expected to be more than 100 Gbit/s [1]. For such high-speed mobile services, higher radio frequencies such as millimeter and sub-terahertz waves will be used to utilize wider bandwidth (BW). Due to the large propagation loss of high frequencies, however, the number of deployed antenna sites will increase to keep the coverage to users. Therefore, simple configuration of antenna-site equipment with the characteristics of low power consumption and small footprint will be required in addition to high-speed optical transmission links for antenna site accommodation. Analog radio-over-fiber (RoF) including intermediate frequency-over-fiber (IFoF) is considered one of the attractive technologies to meet the demand above and has been extensively studied [2,3]. IFoF with subcarrier multiplexing (SCM) technology can transmit high-capacity multi-channel wireless signals by using a single wavelength. In antenna sites, demultiplexing/multiplexing and frequency conversion process between IF and RF signals are needed. These signal processing can be conducted either by analog processing or by hybrid analog and digital processing. While both processing scheme have their own advantages and disadvantages, analog processing is more preferable from the perspective of power-saving and ultra-low latency. In the analog processing, a band-pass filter (BPF) for extracting one IF signal and a stable and precise local oscillator (LO) for the IF to RF conversion are required for each of the IF signals. To simplify configuration of the antenna sites as much as possible, LO-less architecture has been studied in which the LO is removed from the antenna site and transmitted from remote central office side instead. In ref. [4], fundamental experiment of uplink frequency conversion from RF to IF using remote LO was conducted. In this experiment, a single channel of 64-QAM signal with 4-MHz BW at the center frequency of 5.4 GHz was converted to IF at 200 MHz by a remote LO signal transmitted from central office side [4]. However, to our knowledge, there are no reports on remotely shared LOs among multiple antenna sites for point-to-multipoint (PtMP) multi-channel IFoF application. Requirements for frequency and time accuracy in 6G will be more severe due to higher frequencies and advanced wireless communication technologies such as distributed MIMO and cell-free massive MIMO [5]. Therefore, LO-less antenna sites, where LOs are shared among plural antenna sites are required to simplify the configuration of analog frequency conversion and to operate multiple antenna sites in sync by sharing the same clock source for such timing-critical applications.

In this paper, downlink PtMP multi-IFoF transmission with a remotely shared LO among plural antenna sites are experimentally demonstrated for the first time, and frequency conversion quality of the downlink signal from IF to RF is evaluated. In the experiment, successful up-conversion of IF 64-QAM OFDM signal with 380.16-MHz BW to RF signal at 28 GHz with small error vector magnitude (EVM) deterioration of 0.9 percent point was confirmed with utilizing a remotely shared LO.

## 2. Multi-IFoF Systems with Remotely Shared LOs

Fig. 1 shows the proposed architecture of PtMP multi-IFoF systems with remotely shared LOs. For simplification, only downlink is described. The “LO site” in Fig. 1 means the site where LOs shared among remote antenna sites are located in this paper. The plural LOs are prepared according to the frequencies of multi-IF signals to generate desired RF signals after mixing process at the antenna sites. The frequency-multiplexed LOs are broadcasted to plural antenna sites. The number of total LOs decreases from $M \times N$ to $N$, where $M$ and $N$ are the numbers of antenna sties and IF signals transmitted to each antenna site, respectively. The detailed configuration including multi-IFoF systems operation is explained as follows. In an LO site, radio units (RU) of base stations that include

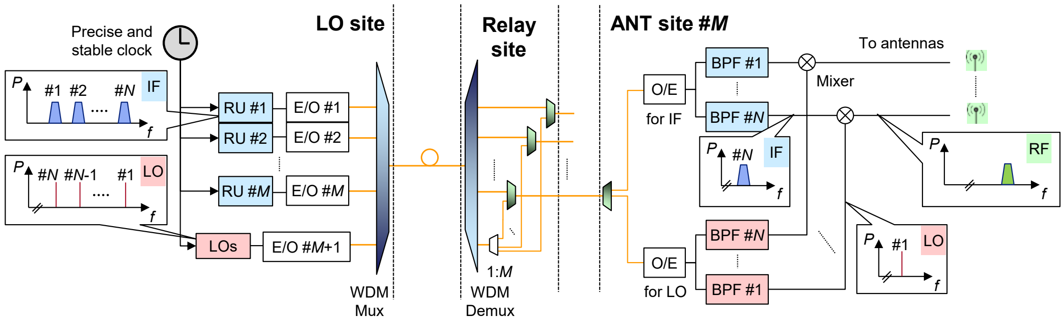


Fig. 1. Concept of PtMP multi-IFoF systems using remotely shared LOs.

RF functions are placed. Each of the RU generates $N$-channel multi-IF signals, and the multi-IFoF signals from $M$ RUs are transmitted to a relay site by WDM. The frequency-multiplexed $N$-channel LOs are also modulated to an optical signal with different wavelength and transmitted to the relay site after WDM mux. In the relay site, the multi-IFoF and LO signals are separated with WDM demux, and the LO signal is split by a 1:$M$ power splitter. Each of the multi-IFoF signal and the LO signal are transmitted to each antenna site. In the antenna site, each channel of the multi-IF signal and LO signal is extracted by BPFs, and the desired RF signal is generated by mixing proper frequency combination of IF and LO signals.

## 3. Transmission Experiment

Fig. 2 illustrates the experimental setup to confirm the possibility of remotely shared LOs for PtMP multi-IFoF systems. An arbitrary waveform generator (AWG) generated three 64-QAM OFDM signals with 380.16-MHz BW and 120-kHz subcarrier spacing at IF of 2.8 GHz, 5.1 GHz, and 7.4 GHz. The output signals were amplified by an RF amplifier and passed through low-pass filter (LPF) and high-pass filter (HPF) for undesired noise reduction. Directly modulated laser diode (DML) at 1552.5 nm was used for an electrical- to-optical converter (E/O) in multi-IFoF transmission. The temperature, DC laser current, and average total OFDM signals' power to the DML were 25 °C, 75 mA, and -3.0 dBm, respectively. The output power of the DML was increased to +10.5 dBm by an EDFA, and the optical signal after EDFA was connected to a 100-GHz-interval WDM multiplexer (MUX). To emulate optical signal transmission for four antenna sites, three dummy IFoF signals at 1550.9 nm, 1551.7 nm, and 1553.3 nm were also connected to the WDM MUX with the same power as the IFoF signal. For LO signal transmission, laser diode (LD) with 100-kHz line width and lithium niobate Mach-Zehnder modulator (LN-MZM) were used as an E/O. The frequencies of LO signals were set to 20.6 GHz, 22.9 GHz, and 25.2 GHz by signal generators (SGs) to obtain 28-GHz RF signals after up-conversion process in an antenna site. The double side band signal from LN-MZM was converted to single side band signal by an optical tunable filter. This process was for mitigation of RF power fading caused by chromatic dispersion of single mode fiber (SMF). The power of the LO signal was increased to +18.7 dBm by an EDFA. The launched power of IFoF signal and LO signal to a 5-km SMF were around + 5.5 dBm and +13.2 dBm, respectively. After transmission, IFoF and LO signals were separated by a WDM demultiplexer (Demux). The IFoF signal from the WDM demux was transmitted over 1-km SMF and converted to the electrical IF signals by an optical-to-electrical converter (O/E) with the received optical power of +0.4 dBm. One of the IF signals at 5.1 GHz was extracted by a BPF for 3 GHz to 6 GHz and input to an RF mixier. The LO signal after the WDM demux was also transmitted over 1-km SMF and connected to a 1:4 optical splitter for emulating four antenna sites. One of the output signals was received by an O/E with the power of -1.3 dBm. One of the LO signals at 22.9 GHz was extracted by a BPF, and the output LO signal from the BPF was amplified by RF amps before being connected to the mixer. After the mixing process, the 28-GHz RF signal was filtered by a BPF and amplified before being input to a signal/spectrum analyzer (SA). The 28-GHz RF spectrum and EVM performance after demodulation of 64-QAM OFDM signal were measured by the SA. Due to the limitation of the optical and RF components, WDM transmission over a 1-km SMF and EVM performance measurement from 2.8-GHz and 7.4-GHz IF signals were not conducted.

Fig. 3 shows RF spectra for IF signals with SA resolution BW of 100 kHz; (a) in electrical back-to-back (BtB) and after 6-km SMF, and (b) before mixer. In Fig 3(a), higher IF signals have higher power by pre-emphasis in electrical BtB, to compensate the frequency response of RF and optical components and the influence of power fading caused by 6-km SMF transmission. It is confirmed that, after fiber transmission, electrical power is almost same among three IF signals. In Fig. 3(b), the OFDM signal at 5.1 GHz before the mixer is confirmed whereas a part of 2.8-GHz IF signal remains due to the BPF performance limitation. Fig. 4 depicts RF spectra for LO signals. It is noted that relative power in Fig. 4 is different from that in Fig. 3. In Fig 4(a), LO signals at higher frequency have

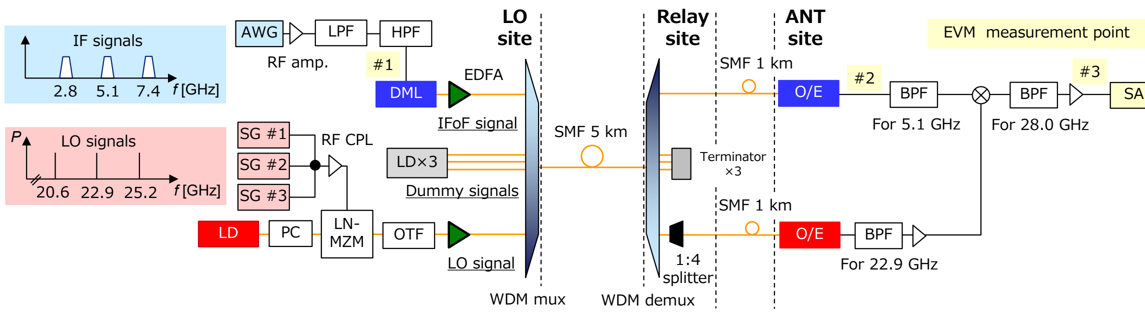


Fig. 2. Experimental setup.

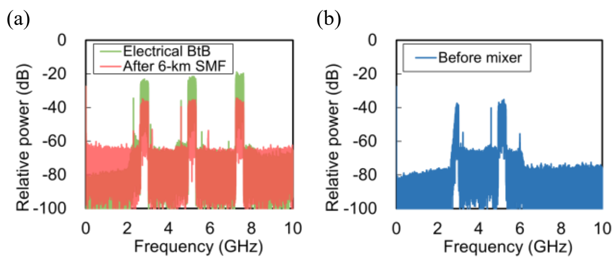


Fig. 3. RF spectra for IF signals at three measurement points.

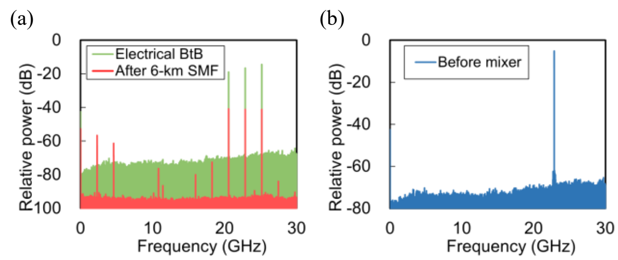


Fig. 4. RF spectra for LO signal at three measurement points.

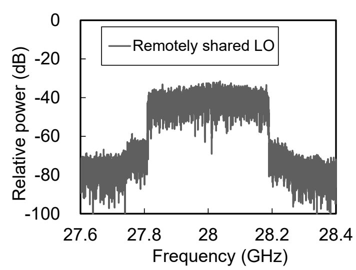


Fig. 5. RF spectra for 28-GHz RF signal.

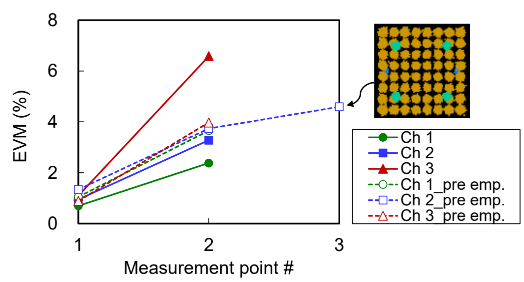


Fig. 6. Measured EVM performance at three measurement points.

higher power in electrical BtB to compensate the frequency response of RF and optical components. LO power is almost same among three LO signals after 6-km SMF transmission. In Fig. 4(b), the LO signal at 5.1 GHz before the mixer is found. Fig. 5 describes the RF spectrum after frequency conversion from 5.1 GHz to 28 GHz. Signal distortion may be caused by the frequency conversion process. Fig. 6 plots EVM values at three measurement points shown in Fig. 2. Results without pre-emphasis for IF signals are also shown as reference. Without the pre-emphasis, EVM values after 6-km SMF transmission are from 2.4% at 2.8 GHz to 6.6% at 7.4 GHz. Thanks to the pre-emphasis, EVM values becomes 3.7% to 4.0%. After up-conversion from 5.1 GHz to 28 GHz, EVM performance deteriorates from 3.7% to 4.6%. As reference, EVM value after the up-conversion by a 22.9-GHz LO placed in the antenna site was measured to be 4.1%. Small EVM degradation was confirmed in remotely shared LO usage.

## 4. Conclusion

To simplify the configuration of analog frequency conversion in antenna sites, PtMP multi-IFoF transmission with remotely shared LOs were introduced. In the transmission experiment, three 64-QAM OFDM signals with 380.16-MHz BW were transmitted over 6-km SMF by IFoF with SCM and, after transmission, one of the IF signals was upconverted to RF at 28 GHz by the remotely shared LO with small EVM degradation of 0.9 percent point. This result shows the possibility of simple LO-less antenna sites in PtMP multi-IFoF systems for 6G.

## 5. References

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