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Experimental demonstration of RoF-DAS over WDM-PON with bandpass-sampling and optical TDM techniques

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Abstract: This paper reports the demonstration of a radio over fiber (RoF) - distributed antenna system (DAS) over a wavelength division multiplexing - passive optical network (WDM-PON) with multiple input multiple output (MIMO) by employing bandpass-sampling and optical time division multiplexing (TDM) techniques to realize next generation broadband wireless access with a gigabit-class throughput. We experimentally evaluate the performance of two optical transmissions of radio frequency (RF) signals, which are multiplexed 2.4 and 5 GHz bands 802.11n RF signals in the time-domain and distributed 2.4 GHz band 2 × 2 MIMO 802.11n RF signals with 2 channels WDM.

Keywords: RoF, WDM-PON, MIMO, DAS, bandpass-sampling, optical TDM, mobile backhaul network

Classification: Fiber-optic communication

References

[1] K. Prince, et al., "Converged Wireline and Wireless Access over a 78-km Deployed Fiber Long-reach WDM PON," *IEEE Photon. Technol. Lett.*, vol. 21, no. 17, pp. 1274–1276, Sept. 2009.

[2] W.-T. Shaw, et al., "An Ultra-Scalable Broadband Architecture for Municipal Hybrid Wireless Access Using Optical Grid network," *OSA OFC/NFOEC 2009*, San Diego, USA, OThP2, March 2009.

[3] Z. Jia, et al., "Key Enabling Technologies for Optical-Wireless Networks: Optical Millimeter-Wave Generation, Wavelength Reuse, and Architecture," *IEEE/OSA J. Lightwave Technology*, vol. 25, no. 11, pp. 3452–3471, Nov. 2007.

[4] T. Yamakami, et al., "An Experimental Investigation of Applying MIMO to RoF Ubiquitous Antenna System," *Proc. IEEE Topical Meeting on*

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Accepted December 20, 2011
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MWP/APMP 2008, pp. 201–204, Sept. 2008.
[5] S. Okamura, et al., "Impact of Successive Interference Canceller on the Performance of Ubiquitous Antenna-Based SDMA System," *IEICE Electronics and Communications in Japan, Part 3 (Fundamental Electronic Science)*, vol. J86-A, no. 12, pp. 1340–1355, Dec. 2003.
[6] K. Iwatsuki, et al., "Access and Metro Networks Based on WDM Technologies," *IEEE/OSA J. Lightwave Technology*, vol. 22, no. 11, pp. 2623–2630, Nov. 2004.
[7] K. Tsukamoto, et al., "Convergence of WDM Access and Ubiquitous Antenna Architecture for Broadband Wireless Services," *Proc. 6th PIERS Conf.*, no. 4, pp. 385–389, April 2010.
[8] A. Kohlenberg, "Exact Interpolation of Band-limited Functions," *AIP J. Applied Physics*, vol. 24, no. 12, pp. 1432–1436, Dec. 1953.
[9] IEEE Std 802.11n-2009.

1 Introduction

Recently, various types of broadband wireless internet services have been growing very rapidly, and there is a clear need for a higher throughput for next generation wireless access equivalent to that of optical access. When we increase the throughput of wireless access, the strict limitation imposed by the radio frequency (RF) spectrum will reduce the cell size. Therefore, a huge number of base stations (BSs) will be needed to cover a wide area equivalent to the current macro cells.

To accommodate such a huge amount of different types of high bit-rate wireless data traffic efficiently, recent proposals have aimed at providing wireless services over wavelength division multiplexing - passive optical network (WDM-PON) [1, 2, 3]. WDM techniques can increase the total throughput as well as ensure the easy scalability of the network by allocating/dedicating wavelengths to each BS.

On the other hand, multiple input multiple output - distributed antenna system (MIMO-DAS) technologies have been emerging recently [4, 5]. In MIMO-DAS, MIMO antennas are distributed to several BSs with the help of radio over fiber (RoF) technology. This configuration minimizes the correlation of the multiple paths in a MIMO transmission, so that the transmission performance can be improved.

When applying the MIMO-DAS to WDM-PON architecture [6], an important requirement is the efficient and economical distribution of several different types of MIMO RF signals to each BS. It is not practical to allocate different wavelength(s) to both different antennas and different services, because this would results in the need for a huge number of wavelengths.

To realize MIMO-DAS in a simpler way, we have proposed RoF-DAS over WDM-PON [7] employing bandpass-sampling [8] and optical time division multiplexing (TDM) for several RF signals in each BS, in addition to employing WDM for data transmission from/to each BS. This architecture can accommodate various types of broadband MIMO air-interfaces, includ-

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ing those expected to realize a gigabit-class throughput, and can provide the flexibility needs for both non-uniform traffic distribution and user mobility in wireless service areas.

In this paper, we experimentally demonstrate the feasibility of RoF-DAS over WDM-PON with bandpass-sampling and optical TDM techniques. Two 802.11n [9] RF signals in the 2.4 and 5 GHz bands are multiplexed in the time-domain, and 2-channel WDM with 2×2 MIMO 802.11n RF signals in the 2.4 GHz band is demonstrated.

2 RoF-DAS over WDM-PON architecture with bandpass-sampling and optical TDM

Fig. 1 shows the configuration of the proposed RoF-DAS over WDM-PON, where different wavelengths are assigned to each BS. A $2 \times N$ arrayed waveguide grating (AWG) is used as a wavelength router, i.e. a wavelength multi/demultiplexer. The cyclic property of the AWG gives the architecture a large scalability for accommodating a large number of BSs.

Each BS employs an optical circulator without any wavelength selectivity to make it easy to add upstream signals and drop downstream signals. Optical filters such as fiber gratings are used to select a wavelength assigned to the BS. This configuration achieves the transparency of transmission fibers through the lack of optical filters, and thus offers the scalability to allow the easy upgrading of wavelength channels in the future. To reduce operating, administration, and maintenance function costs, as well as production costs, we can introduce wavelength tunability in laser diodes (LDs) and the fiber gratings of the BSs to realize colorless BSs [5].

In this architecture, downstream MIMO RF signals corresponding to a cell (a set of MIMO RF signals) are transmitted from the center station (CS) to different BSs at different wavelengths. Also a set of upstream MIMO RF signals are transmitted from different BSs to the CS at other different wavelengths. In other words, in both the upstream and downstream directions, each wavelength transmits multiplexed RF signals, each of which belongs to

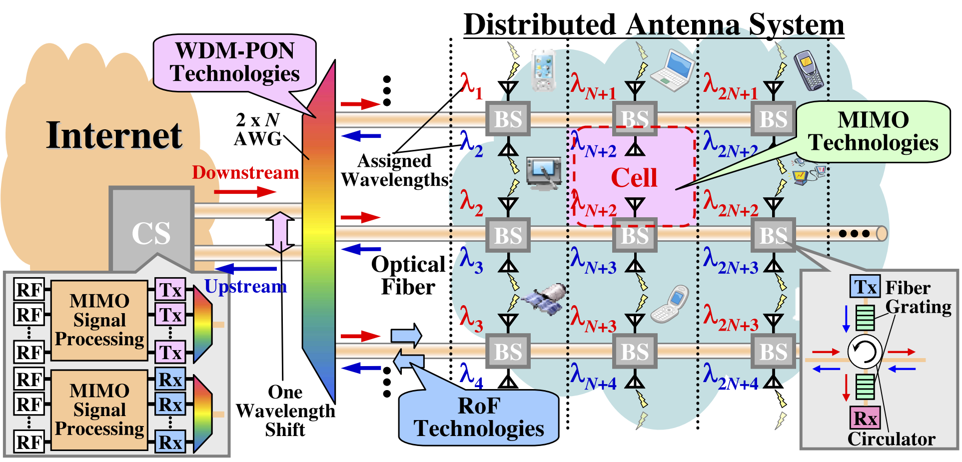

Fig. 1. Conceptual diagram of RoF-DAS over WDM-PON

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a different cell, i.e. a different set of MIMO RF signals.

To simplify the configuration of BSs and thus reduce production costs, we propose multiplexing the RF signals by applying bandpass-sampling and optical TDM techniques in both the upstream and downstream directions. On the transmitting side, each MIMO RF signal is sampled by a pulse train with a repetition frequency that is sufficiently higher than the bandwidths of each RF signal, and then multiplexed with others in the optical time-domain. On the receiving side, the original RF signals can be regenerated by demultiplexing TDM signals and simply filtering the bandwidth of each RF signal. The details are provided along with experimental configuration in the next section.

3 Experimental setup

Fig. 2 shows the experimental setup for transmitting downstream signals with the proposed architecture. A conceptual diagram of the signal transitions at each component is also shown. We assumed a 2×2 MIMO signal transmission in each cell to confirm the feasibility. Two wavelengths were assigned to achieve the MIMO RF signal distribution, where two 802.11n RF signals in the 2.4 and 5 GHz bands were multiplexed with optical TDM and transmitted to the BS.

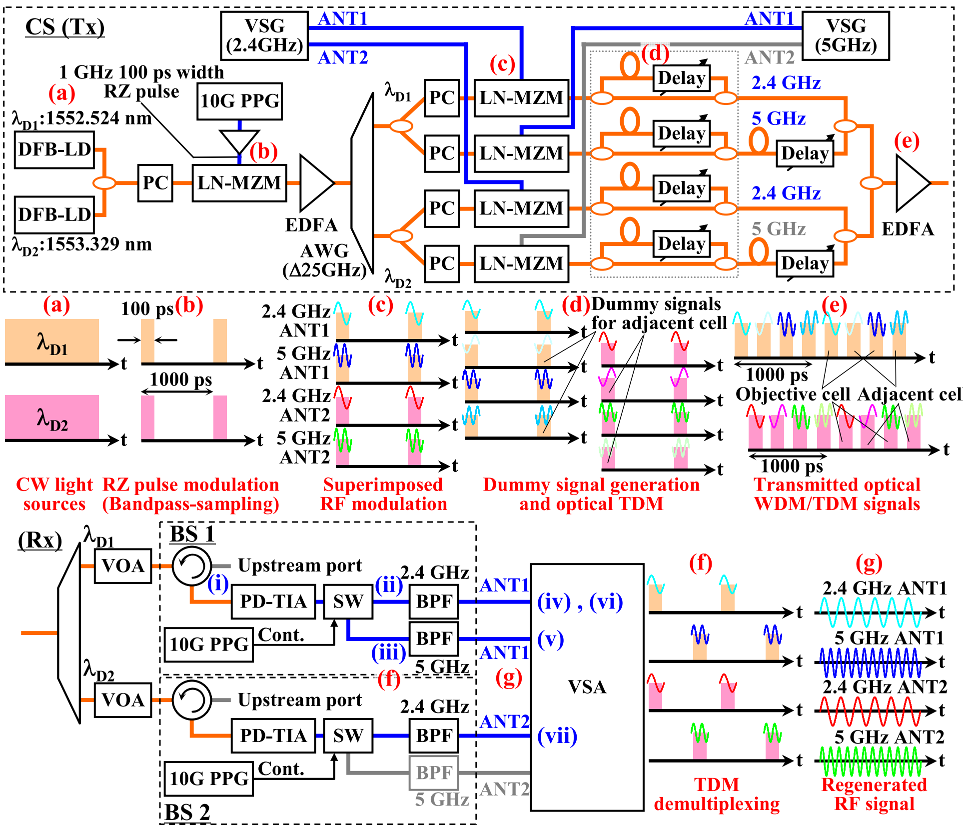

Fig. 2. Experimental setup of 2 × 2 MIMO RF downstream signal transmission over the RoF-DAS over WDM-PON and conceptual diagram of signal transitions at each components

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Continuous wave (CW) lights emitted from distributed feedback - LDs (DFB-LDs) were wavelength-multiplexed as shown in Fig. 2 (a), and modulated with a lithium niobate - Mach-Zehnder modulator (LN-MZM) driven with a return to zero (RZ) pulse width of 100 ps at a 1 GHz repetition rate as shown in Fig. 2 (b). The optical pulse trains at two wavelengths were amplified with an erbium doped fiber amplifier (EDFA) and demultiplexed by using 2 channels of AWG with 25 GHz spacing that were isolated 4 channels between each other. Each wavelength signal was divided and modulated with an LN-MZM driven by 802.11n RF signals with a 40 MHz bandwidth at center frequencies of 2.422 and 5.230 GHz from the vector signal generator (VSG) as shown in Fig. 2 (c). Bandpass-sampled RF signals were obtained at the output of each LN-MZM. We used 802.11n RF signals where the modulation and coding scheme (MCS) index was 15 [9] i.e. 64-quadrature amplitude modulation (QAM) orthogonal frequency division multiplexing (OFDM) signals. We employed optical delay lines and 3 dB couplers to generate dummy signals for an adjacent cell and to multiplex the bandpass-sampled RF signals as shown in Fig. 2 (d). The optical TDM RF signals were again wavelength-multiplexed, amplified with an EDFA and transmitted to the feeder fiber as shown in Fig. 2 (e).

Downstream WDM signals containing RF signals were demultiplexed into fiber blanches by the AWG (i.e. wavelength router), and the only allocated wavelength of WDM signals propagating through one of blanches was dropped by a circulator at the target BS. After that, the downstream signal was converted to an electrical signal with a photo diode - transimpedance amplifier (PD-TIA) and demultiplexed with a high-speed electrical switch (SW) as shown in Fig. 2 (f). The SW was driven by using a control signal consisting of a 300 ps pulse at a 1 GHz repetition rate. The demultiplexed RF signals were converted to original RF signals with band pass filters (BPFs), which were launched as wireless signals to the vector signal analyzer (VSA) as shown in Fig. 2 (g).

4 Experimental results

We performed two kinds of back-to-back transmission experiments. The former was designed to confirm the feasibility of the applied multiplexing/demultiplexing techniques in the time-domain; one wavelength λ_{D1} without/with modulated 802.11n RF signals in both the 2.4 and 5 GHz bands. The latter was designed to confirm the feasibility of the MIMO signal distribution for each antenna; two wavelengths of λ_{D1} and λ_{D2} were modulated with 2×2 MIMO 802.11n signals in the 2.4 GHz band. We evaluated the signal quality from the waveforms of time division multiplexed/demultiplexed signals and from the constellations and error vector magnitude (EVM) values of demodulated 64-QAM OFDM signals.

The experimental results are shown in Figs. 3 corresponding to the measurement points in the experimental setup in Fig. 2. Fig. 3 (i) shows a transmitted optical pulse train without the RF modulation from the CS, and

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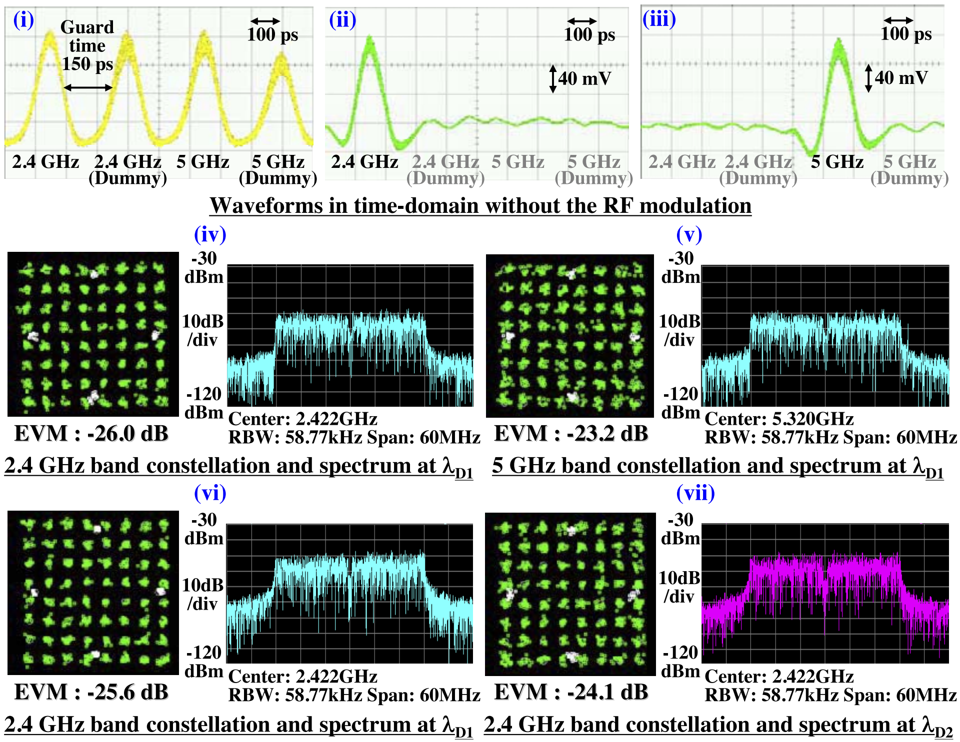

Fig. 3. Experimental results of feasibility tests in RoF-DAS over WDM-PON. From (i) to (iii) show the TDM operation performances without the RF modulation, (iv) and (v) show the RF signal performances of two different RF signals (in 2.4 and 5 GHz bands) multiplexed in the same wavelength, and (vi) and (vii) show the RF signal performances of 2 × 2 MIMO RF signals (in 2.4 GHz band) distributed to different two BSs with using two different wavelengths

Fig. 3 (ii) and (iii) show the electrical pulses assigned as 2.4 and 5 GHz bands RF signals at the SW of the BS. We confirmed the good TDM operation performance of our experimental setup.

Fig. 3 (iv) and (v), respectively, show the analyzed 2.4 and 5 GHz band RF signals after the BPF. EVM values of −26.0 and −23.2 dB were obtained. The system parameters, which were the optical powers at the PD-TIA input and the electrical powers at the VSG output, were, respectively, −3 and 5 dBm for (iv) and −3 and 10 dBm for (v).

Fig. 3 (vi) and (vii), respectively, show the analyzed 2.4 GHz band 2 × 2 MIMO RF signals from each BS. EVM values of −25.6 and −24.1 dB were obtained. The system parameters for (vi) and (vii) were the same (−1 and 8 dBm). These results confirm the preliminary feasibility of the proposed RoF-DAS over WDM-PON with bandpass-sampling and optical TDM.

5 Conclusion

We introduced bandpass-sampling and optical TDM techniques to our proposed RoF-DAS over WDM-PON, with the efficient use of large bandwidth of

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optical access to accommodate broadband wireless signals in femtocells. The preliminary experiments of downstream transmission characteristics were evaluated, and confirmed the feasibility with good performance of optical TDM and bandpass-sampled RF signal transmission.

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