

Radio over Fiber Systems for Small Cell Wireless Communications

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Abstract: We established a radio over fiber system applicable to broadband wireless communications for small cell applications and to mobile fronthaul network segment in cloud-radio access networks (RAN). Optical radio signals are transmitted over a fronthaul fiber using orthogonal frequency division multiplexing (OFDM) techniques and subcarrier frequency division multiple access (SC-FDMA). System parameters are evaluated for various subcarrier modulations and the results of link performance measurements are analyzed.

1 INTRODUCTION

Recently strong demands for broadband wireless communication systems to support the applications of multimedia data transmissions have been growing. The micro/mm wave band is considered to be a promising solution owing to its spectrum availability, compact size of radio frequency (RF) devices, and its severe atmospheric attenuation characteristic.

In transmission of high speed data up to several hundreds of Mbps via the broadband RF wireless channel, error performance is considerably degraded by intersymbol interference (ISI) due to multi-path fading phenomena. To reduce the degree of ISI, preferred are parallel signal transmission techniques which provide much longer symbol duration than the spread of a fading channel impulse response (ETSI, 1999). Especially, an orthogonal frequency division multiplexing (OFDM) technique is being widely used for broadband wireless access applications (Shieh, 2008).

The RF wave signals, however, suffer from severe loss along the transmission line as well as atmospheric attenuation. Low-attenuation, EMI-free optical fiber transmission is considered attractive for transport of wireless signals in the micro/mm wave band. Recently, vigorous research activities have been in progress to develop optical network systems supporting the broadband wireless communication systems (Pizzinat, 2015).

Optical RF and microwave signals find applications in fronthaul networks and small cell wireless communications (ChihLin, 2015).

This paper includes the followings. Section 2 presents system design and requirements for fronthaul networks and small cell wireless communication application. Section 3 suggests the configuration of a hybrid fiber radio system for RF broadband wireless communications adopting OFDM and SC-FDMA techniques. Section 4 shows the results of experiments to measure its link performances. Finally, a summary and concluding remarks are given in Section 5.

2 SYSTEM DESIGN OF OPTICAL RADIO LINKS

Traditional base stations (BS) are composed of a digital unit (DU) or Baseband Unit(BBU), and a radio unit (RU) or remote radio head(RRH). DU performs digital signal processing and RU contains the RF components and is connected to the antenna. To support a steep increase of wireless traffic, the network architecture has evolved into small size cell architecture and a cloud radio access network (C-RAN) (Pizzinat, 2013). Fronthaul is a network segment between DU and RU that appears in C-RAN architecture (Pizzinat, 2015).

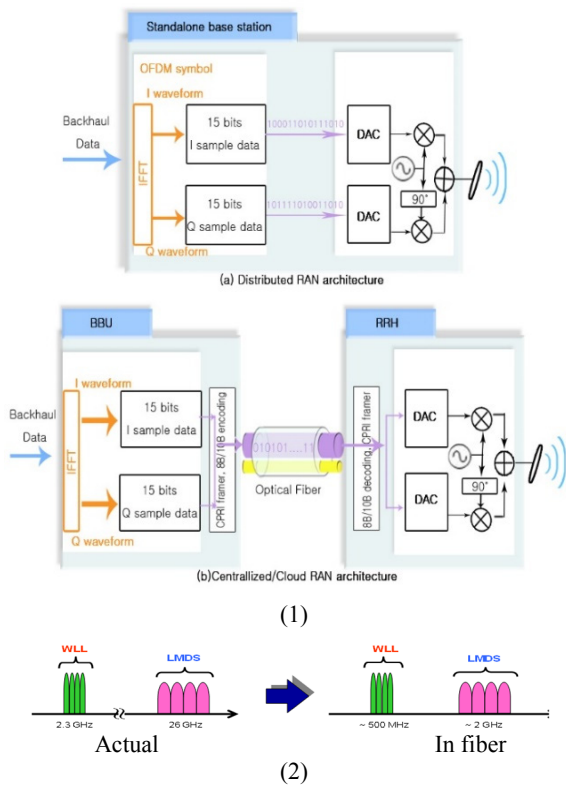


Figure 1: (1) System architectures of D-RAN (a) vs. C-RAN (b) and (2) Frequency allocation in backhaul networks for WLL (wireless local loop) and LMDS (local multipoint distribution service).

The comparison between distributed RAN (D-RAN) and C-RAN is shown in Figure 1. While the internal interface between RU and DU has been defined as the result of the digitization of the radio signal according to common public radio interface (CPRI) (CPRI, v.6.1), an option of optical analog RF wave transmissions requires much less bandwidth compared to the CPRI option.

In addition, wireless micro/mm wave systems in conjunction with optical systems in backhaul networks have several options for band conversion between radio and carrier frequencies. Among system options of baseband, intermediate frequency (IF), and optical micro/mm-wave transmission, the IF around 2GHz option is considered as a cost-effective and efficient solution as shown in frequency allocations Figure 1 (b).

For wireless systems where signal fading is fatal, OFDM and SC-FDMA techniques are parallel transmission schemes modulating data symbols on multiple carriers simultaneously through an FFT procedure (Armstrong, 2009). The resulting OFDM symbol has much longer symbol duration than

temporal dispersion of fading channel. Consequently, OFDM-based systems are robust to ISI due to multipath fading phenomena, and have an additional advantage of low complexity in implementing an equalizer.

With all analysis, we adopted a radio over fiber system in a RF band of a center frequency 2.1GHz employing OFDM and SC-FDMA techniques. Subcarrier multiplexing (SCM) was used for interfacing the optical fiber link with the wireless system for high speed transmission of signals.

3 SYSTEM CONFIGURATION

Considering downlink application in fronthaul networks, we elected 16QAM-OFDM and employed forward error correction (FEC) and pilot tones for spectral efficiency. Accumulated synchronization errors were correctable by using some of the subcarriers in the signal band as pilot tones. The FEC coding rate was 2/3 and the errors of the sampling clock in the FEC were less than 10^{-4} . The data loaded subcarriers and the pilot subcarriers were 176 and 24, respectively.

Signals modulated with 16 QAM scheme and coded with FEC were transmitted at a data rate of 150 Mbps. Trellis coded modulation (TCM)-OFDM with an FFT size of 512 was used in multiplexing RF signals. Spectral efficiency was greater than 2 bits/sec/Hz.

The system configuration is depicted in Figure 2. The system mainly consists of OFDM/SC-FDMA modems, baseband signal processing modules, RF up/down converters, an optical single mode fiber link. The upper part in Figure 2 corresponds to a DU in a fronthaul network or a Tx in a backhaul network, and the lower part does to a RU or a Rx. The system mainly consists of OFDM/SC-FDMA modems, baseband signal processing modules, RF up/down converters, an optical single mode fiber link. The baseband signals were up converted to RF signals of 2.1GHz by mixing signals from the local oscillator (LO). The OFDM signals at 2.1 GHz of a center frequency with the signal bandwidth of 100 MHz modulate a DFB-LD (distributed feedback laser diode) with a wavelength of 1550nm and are fed to 20 km of a G.652 fiber. For the system analysis, the signals were O/E converted in a PD (photo detector) and then down-converted to the baseband by a LO and equalized with an automatic gain control (AGC) mechanism in baseband signal processing. Digital-to-analog (D/A) and analog-to-digital (A/D) conversion were carried out as well. In the baseband processing

in the Tx part, S/P (serial to parallel) conversion, QAM modulation, IDFT (inverse discrete Fourier transform), GI (guard cyclic prefix insertion) are carried out in order, and in the Rx part, the inverse process are performed in reverse order.

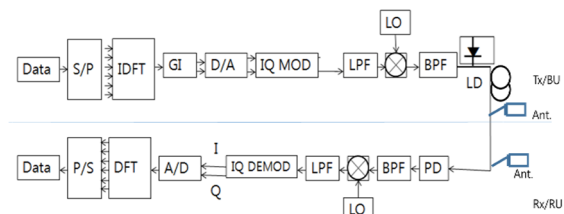


Figure 2: Configuration of a radio over fiber system for OFDM signals.

For uplink application in fronthaul network, we also built a 16 QAM SC-FDMA system, where an additional DFT process is inserted after QAM modulation in OFDM signal process.

4 RESULTS AND ANALYSIS

System evaluations were performed for 16 QAM OFDM and SC-FDMA systems. The waveform of OFDM signal has noise-like envelopes with very high peak-to-average power ratio (PAR), which cause nonlinear distortions in amplifying the signal at a power amplifier (PA). Those distortions degrade the performance of an OFDM-based system so severely that a large value of output back-off (OBO) should be assigned to a PA.

The power measured before the S band down-converter was not amplified with the AGC. The attenuation level was adjusted to 37dB for input power of 7 dBm on the RF link. For lower attenuation or higher input power, system degradation ensued as the power was carried over into the nonlinear region of the amplifier and so nonlinear effects became significant. Figure 3 shows spectrum of the received RF signals with OFDM and with SC-FDMA.

Transmission over a G.652 fiber was performed without dispersion compensation and amplification, as fiber dispersion is not significant in 20 km transmission of the 2.1 GHz directly modulated signals (Schmidt, 2008).

Signal constellation of the received 16 QAM OFDM signals and 16QAM SC-FDMA signals are shown in Figure 4. An EVM (error vector magnitude) value was measured as 6.7% for 16 QAM OFDM signals with a CNR (carrier to noise ratio) of 23.5dB. Although EVM requirements has not been standardized yet for fronthaul networks, the 3GPP

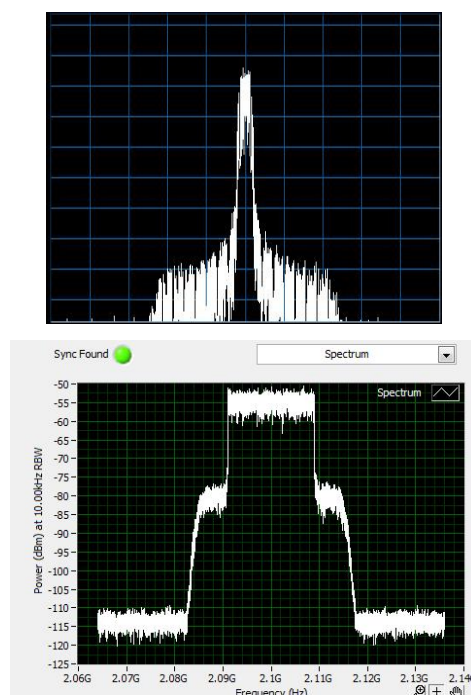


Figure 3: Spectrum of the received RF signals with OFDM (above) and with SC-FDMA (below).

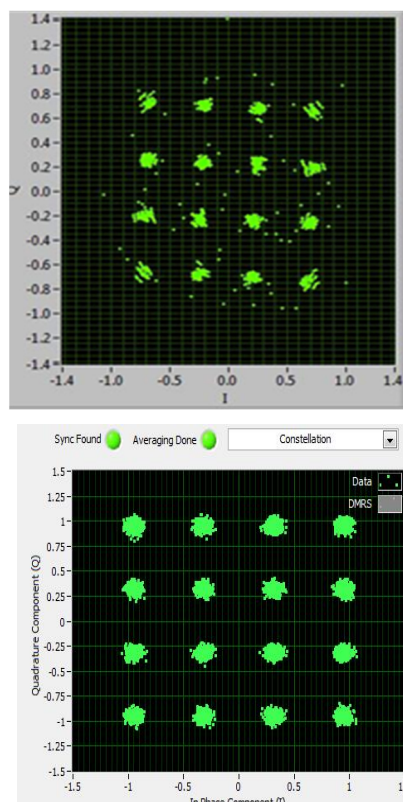


Figure 4: Signal constellation of the received 16 QAM OFDM signals (above) and SC-FDMA signals (below).

(3rd generation partnership project) specification puts a limit on EVM as less than 12.5% for 16 QAM OFDM signals. Given that this requirement corresponds to eNodeB case, the coverage of which includes fronthaul segment, the fronthaul segment itself requires stricter values on EVM than those for eNodeB. Considering a system margin of 5dB on CNR in fronthaul segment, a tolerable CNR value is estimated as 23dB, from which the maximum EVM value allowed for fronthaul segment is obtained as 5%.

For optical OFDM transmission outperforming optical RZ-OOK transmission in system reach, it was analysed that optical QPSK-OFDM can be employed in long reach systems for error performance enhancement, and optical 16 QAM-OFDM in short reach for spectral efficiency improvement. The link penalty of 16 QAM-OFDM can be compensated by coding with the synchronization and channel estimation algorithm and forward error correction coding.

5 CONCLUSIONS

We established radio over fiber systems applicable to broadband wireless communications for small cell applications and to mobile fronthaul network segment in C-RAN. Optical radio signals are transmitted over a fronthaul fiber using OFDM techniques or SC-FDMA techniques.

The proposed system design of radio over fiber systems allows utilizing the legacy infrastructure readily connected with optical backbone systems and further expands the range of deployment. The resulting system can be utilized in applications of small cell mobile systems, high speed wireless LANs and home networking system and provide a promising solution for future mobile evolution toward 5G and beyond.

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REFERENCES

ETSI, 1999. "Broadband Radio Access Networks (BRAN)," in HIPERLAN Type2 Technical

Specification; Physical (PHY) layer vol. DTS/BRAN-0023003, V0.k, ed.
Shieh, W., et al., 2008. "Coherent optical OFDM: has its time come?," J. Opt. Networks, vol. 7pp. 234-255.
Pizzinat, Anna, 2015. "Things You Should Know About Fronthaul", Journal of Lightwave Technology, vol.33, no.5, pp.1077-1083.
Chih-Lin, I., Yuan, Y., Huang, J., Ma, S., Cui, C., Ran Duan., September 2015. "Rethink Fronthaul for Soft RAN", IEEE Communications Magazine, pp. 82-88,
Armstrong, J., 2009. "OFDM for optical communication," J. of Lightwave Tech., vol. 27, pp. 189-204.
Pizzinat, Anna, 2013, "C-RAN architecture and fronthaul challenges", LTE Backhaul Summit 2013, Amsterdam.
CPRI Interface Specification, v. 6.1 http://www.ieee1904.org/3/meeting_archive/2015/02/tf_1502_ashwood_1.pdf
Schmidt, B. J. C., et al., 2008. "Experimental demonstrations of electronic dispersion compensation for long haul transmission using direct detection optical OFDM," J. of Lightwave Tech., vol. 26, pp. 196-203.