Third Asia Pacific Conference on Advanced Research (APCAR, Melbourne, July, 2016)
ISBN:978 0 9943656 20
www.apiar.org.au

OPTICAL TECHNIQUES FOR FRONTHAUL NETWORKS

Ajung Kim [a], K. Cho [b], J. Choi [c]
[a] Sejong University, Seoul, Korea
[b] HFR, Kyungi, Korea
[c] Hanyang University, Seoul, Korea
Corresponding email: akim@sejong.ac.kr

Abstract

This paper introduces various techniques for a new fronthaul network segment applied in centralized radio access networks (C-RAN) architecture. The promising fronthaul interfaces are described which are considered to meet physical requirements for the fronthaul network segment and to build a new radio access network solution. Various optical solutions including CPRI (Common Public Radio Interface) over optical transport networks (OTN), CPRI over WDM (wavelength division multiplexing) rings /WDM-PON (passive optical networks), radio over Ethernet (RoE) and radio over fiber (RoF) are analysed and regarding parameters are presented.

Keywords: Fronthaul, Centralized Radio Access Networks, Mobile Communications

1. Introduction

As traffic of the applications of multimedia data transmissions have been growing, strong demands for broadband wireless communication systems and mobile networks have been also raised. Along the line, small size cell architecture is being applied to reduce CAPEX/OPEX of ISP (Internet Service Provider).

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) and the legacy distributed RAN (D-RAN) has been substituted by C-RAN. Fronthaul is a network segment between DU and RU that appears in C-RAN architecture (Pizzinat, 2015).

Recently, vigorous research activities have been in progress to develop optical network systems supporting the broadband wireless fronthaul and backhaul networks. 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,v.6.1), other optical solutions to support networking in fronthaul segments has been investigated. Low-attenuation, EMI-free optical fiber transmission techniques are considered attractive for transport of mobile signals in the micro wave band. For example, an option of optical analog RF wave transmissions requires much less bandwidth compared to the CPRI option and optical RF and microwave signals find applications in fronthaul networks and small cell wireless communications (ChihLin, 2015).

This paper includes the following sections. Section 2 presents the system requirements for fronthaul networks and small cell wireless communication application. Section 3 investigates the options for optical solution supporting mobile fronthaul networks in conjunction with the legacy systems, mainly, CPRI over OTN and CPRI over WDM. Section 4 introduces RoE systems as a cost effective solution for signal transport in the fronthaul. Section 4 suggests RoF system

ISBN:978 0 9943656 20
www.apiar.org.au

for RF broadband wireless communications adopting OFDM and SC-FDMA techniques and shows the results of experiments to measure its link performances. Finally, a summary and concluding remarks are given in Section 6.

2. Requirements for fronthaul network

The internal interface between RU and DU has been defined as the result of the digitization of the radio signal according to CRPI(Common Public Radio Interface), OBSAI(Open Baseband Remote Radiohead Interface), ORI(Open Radio Interface) for the fronthaul and X2 between DU and DU for the midhaul. NGFI(Next Generation Fronthaul Inferface) has recently launched to define a new interface for the fronthaul.

In case of CPRI, for LTE Carrier bandwidth of 20MH and the use of 2x2, 4x2, 8x2 MIMO antenna (that is, maximum IP throughput of 150, 300, 600Mb), capacities of the CPRI links are 2.5, 5, 10 Gbp, respectively. System requirements for the fronthaul are summarized in Table 1. Digital data compression is available up to 50% and frequency error is limited to ± 2ppb(parts per billion) and jitter is to 64ns.

Table 1: Requirements for a fronthaul segment

Parameters	**Fronthaul requirements**
BER	$_{10}$-12
Roundtrip latency	400μs
Roundtrip latency without fiber	5μs
Frequency error	±2ppb
Jitter	±32ns
Latency Accuracy without fiber	±16.276ns
Digital data compression	50%
EVM *	QPSK: 17.5% 16QAM: 12.5% 64QAM: 8%

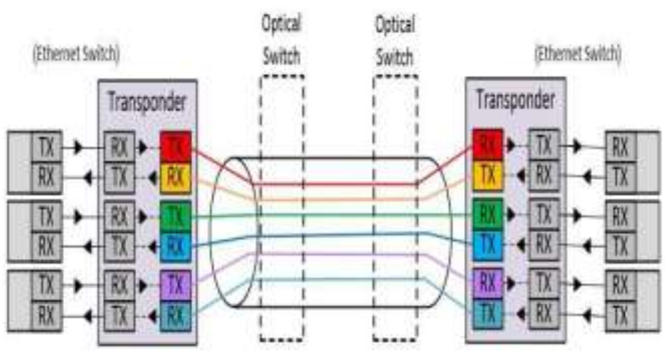
(* is a specification required in 3GPP specifications.)

ISBN:978 0 9943656 20

3. CPRI over OTN / WDM

OTN defined in ITU-T G.872 consists of optical channel transport structure employing WDM and digital transport structure. The digital transport structure consists of OPU(Optical channel Payload Unit), ODU(Optical channel Data Unit) and OTU(Optical channel Transport Unit). Mapping in CPRI over OTN is defined in the Appendix of ITU-T 의 SG15 G.709. CPRI signals multiplexed as OUT signals are multiplexed again over fiber employing WDM, in order to save faber cost. Hybrid WDM technique in conjunction with DWDM or DWDM defined in ITU-T G.694 1/2.

CPRI over WDM is the technique to transport CPRI signals over an optical fiber using WDM. It achieves very low delay and latency and high reliability compared to CPRI over OTN or RoE. While the technique of multiplexing multiple CPRI channels over a fiber reduces fee for installation of optical fibers and for establishment of fronthaul networks, it requires expensive optical devices, such as optical switches. WDM based systems with various topologies have been built, employing WDM-PON or ring for protection.



*(Source HFR)
Figure: Configuration of CPRI over OTN with active WDM with wavelength conversion

4. Radio over Ethernet

The cost effective solution of using Ethernet is appealing for transport in the fronthaul networks. Given the maturity of Ethernet technology and compatibility with backhaul networks, OAM (Operation, administration and maintenance) functions of Ethernet provide a standardised means of maintenance and dominant Ethernet based equipment over fronthaul and backhaul enables low cost devices and infrastructure.

Figure 2 shows use cases of hybrid and native RoE systems. The hybrid system supports the legacy format, such as CPRI and requires mappers to RoE format in conjunction with RoE switches, whereas the native system does not require mappers. The native RoE aggregation of multiple RRHs as in (d) can be established with ease as each flow of different RoE packets is handled independently and packet switched.

Research and development of RoE chips and systems are further accelerated for many applications in 5G and beyond.

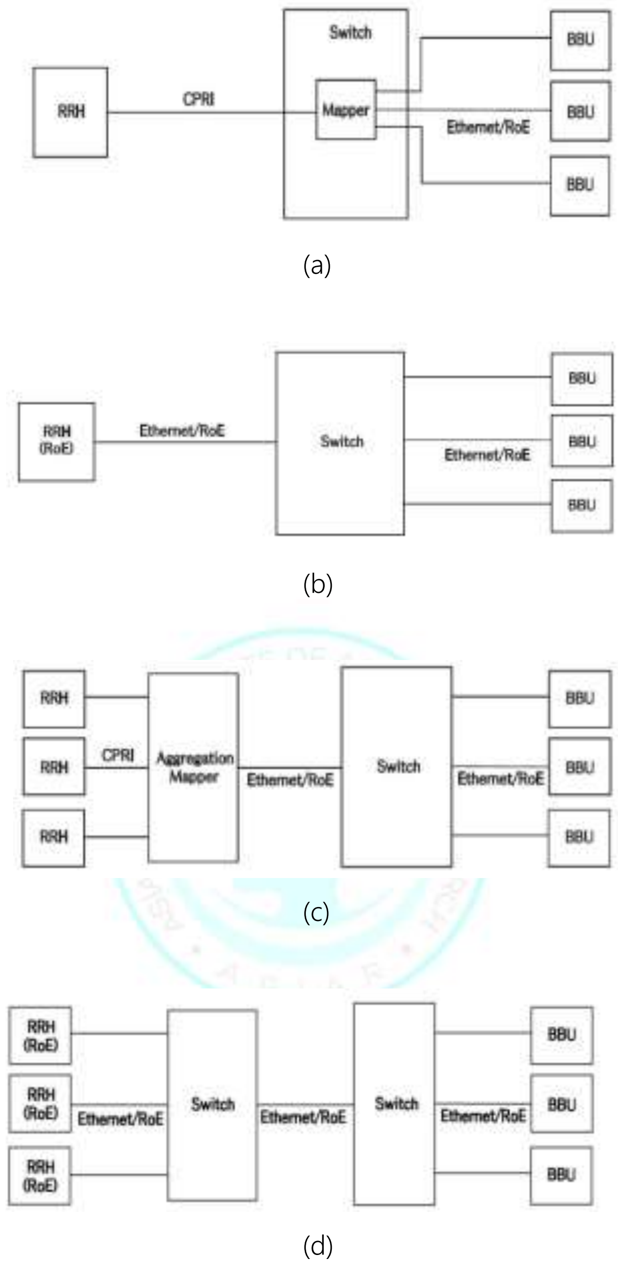


Figure 1: System structures of RoE: (a) hybrid RoE, (b) native RoE e2e, (c) hybrid RoE aggregation, (d) native RoE aggregation

5. Optical RF signal transport

Among the options for fronthaul networks, the solution for significant reduction of the bandwidth is optical RF and microwave signal transport in RoF applications in fronthaul networks and small cell wireless communications (ChihLin, 2015). While the internal interface between RU and DU has been defined as the result of the digitization of the radio signal according to CPRI, an option of optical analog RF wave transmissions requires much less bandwidth compared to the CPRI option.

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 et al., 2008). While 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) and consequently, OFDM-based systems are robust to ISI due to multi-path fading phenomena and have an additional advantage of low complexity in implementing an equalizer. For wireless micro/mm wave systems in conjunction with optical systems in backhaul networks, we elected a radio over fiber system in a RF band of a center frequency 2.1GHz employing OFDM and SC-FDMA techniques, as in LTE or LTE-A. Subcarrier multiplexing (SCM) was used for interfacing the optical fiber link with the wireless system for high speed transmission of signals.

Figure 1 shows experimental results of a uplink RoF system: signal constellation of received 64QAM SC-FDMA signals (left) and spectrum (right). Optical radio signals of 2.1GHz are transmitted over a fronthaul fiber of 20km, using OFDM techniques for the downlink or SC-FDMA techniques for the uplink. 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 have not been standardized yet for fronthaul networks, the 3GPP (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%.

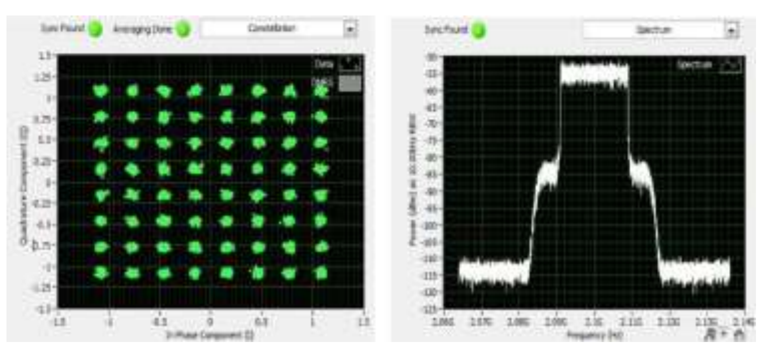


Figure 1: experimental results of a uplink RoF system: signal constellation of received 64QAM SC-FDMA signals(left) and spectrum (right)

ISBN:978 0 9943656 20
www.apiar.org.au

6. Conclusion

We analysed various techniques for a new fronthaul network segment applied in centralized radio access networks (C-RAN) architecture. The promising fronthaul interfaces were described which are considered to meet physical requirements for the fronthaul network segment and to build a new radio access network solution. Various optical solutions including OTN, WDM rings /WDM-PON, RoE and RoF, were analysed and these allow utilizing the legacy infrastructure readily connected with optical backbone systems and further expands the range of deployment. These promising solutions will open an era for future mobile communications toward 5G.

Acknowledgement

This research was supported by the MSIP and supervised by IITP (R0127-16-1048, IITP-R0992-16-1017)

ISBN:978 0 9943656 20
www.apiar.org.au

References

i. Armstrong, J., 2009. OFDM for Optical Communication. *J. of Lightwave Tech*, 27, pp. 189-204.

ii. Chih-Lin, I., Yuan, Y., Huang, J., Ma, S., Cui, C. & Ran Duan. 2015. Rethink Fronthaul for Soft RAN. *IEEE Communications Magazine*, 53(9), pp. 82-88.

iii. ETSI. 1999. *Broadband Radio Access Networks (BRAN)*. In HIPERLAN Type2 Technical Specification; Physical (PHY) Layer Vol. DTS/BRAN-0023003.

iv. Pizzinat, A., 2013. *C-RAN Architecture and Fronthaul Challenges*. LTE Backhaul Summit, Amsterdam.

v. Pizzinat, A., 2015. Things You Should Know About Fronthaul. *Journal of Lightwave Technology*, 33(5), pp.1077-1083.

vi. Schmidt, B. J. C., Lowery, A. J. & Armstrong, J., 2008. Experimental Demonstrations of Electronic Dispersion Compensation for Long Haul Transmission using Direct Detection Optical OFDM. *J. Lightwave Tech*, 26, pp. 196-203

vii. Shieh, W., Yi, X., Ma, Y. & Yang, Q., 2008. Coherent Optical OFDM: Has It's Time Come? *Journal of Optical Networking*, 7, pp. 234-255.

Other Resource:

viii. CPRI Interface Specification. Available at: http//www.ieee1904.org/3/meeting_archive/2015/02/tf_1502_ashwood_1.pd f