Convergence of WDM Access and Ubiquitous Antenna Architecture for Broadband Wireless Services

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Abstract—This paper proposes a novel network architecture for Giga-bit throughput in broadband ubiquitous networks. A convergence of WDM access and RoF ubiquitous antenna architecture can realize universality of remote base stations for various types of air interfaces and the scalabilities of WDM technologies are expected to improve the throughput in wireless service area covered by RoF-MIMO antenna. We discuss the distribution of MIMO antenna, method of RoF MIMO signals over WDM PON, and configurations of center station and remote base stations.

1. INTRODUCTION

To comfortably connect various types of broadband wireless internet services at any places and any time, such as real time high definition videos and applications in cloud computing, an object of next generation wireless access is to realize higher bit-rate equivalent to that in current optical access. A strict limitation in radio frequency spectrum accelerates the reduction of cell size and the use of higher frequency band including microwave, millimeter-wave and terahertz band. Consequently, a huge number of radio access points (AP) will be required. The femtocell architecture, where broadband optical access network is used as entrance networks between core IP network and small APs, is expected as an attractive architecture to realize such a ubiquitous broadband wireless access, as shown in Fig. 1.

In this paper, we propose a novel architecture for broadband wireless services around gigabit/s as a convergence of WDM access [1] and ubiquitous antenna architecture with MIMO technologies [2]. Since the optical access has generally a star network topology, we employ a WDM-PON as the WDM access. The WDM-PON is a physically shared system, but a logically unshared system. This provides certain advantages as follows.

1) The bandwidth for each user can be easily upgraded.
2) Various services can be provided per wavelength.

Figure 1: Concept of ubiquitous broadband wireless services over optical access.
From the viewpoint of advantage 2, we will flexibly provide broadband wireless services with the use of RoF technologies to achieve the universality for various types of air interfaces and to increase the flexibility for non-uniform traffic distribution and users’ mobility. Recent proposals establish to provide wireless and/or wired services over WDM-PON [3–5]. The proposed network architecture is expected to improve the throughput up to one Gbps in wireless service area provided by RoF-MIMO antenna system over WDM-PON.

In Section 2, the features of distributed and concentrated MIMO antenna systems over WDM-PON are discussed. Section 3 describes the accommodation of RoF-MIMO signal in WDM-PON, and configuration of center station (CS) and remote base stations (BSs) in the proposed network.

2. MIMO DISTRIBUTED ANTENNA SYSTEM

Figures 2(a) and (b) illustrates configurations of MIMO femtocell for wireless services provided and BS equipments which are accommodated over WDM-PON. We suppose a square cell provided by remote four MIMO antennas. There are following two kinds of cell configurations:

(1) Concentrated MIMO antenna system as shown in Fig. 2(a); Each BS is located at the center of a cell. Four MIMO antennas located in the same cell.

(2) Distributed MIMO antenna system as shown in Fig. 2(b); four MIMO antennas are around a cell. A BS equips four antennas each of which is used for each of four cells around a BS.

In the former system, four MIMO signals have equal delay over optical feeder, therefore, no delay compensations are needed. The latter system requires some delay compensations among four MIMO signals, and a little complicated configuration at CS to deliver each of MIMO signals to different BSs. However, distributed MIMO antenna can increase the throughput in cell because it emphasize rich scattering environment and reduce the correlation among four signals over wireless multipath channels [6]. In the next section, we discuss configurations of WDM-PON based on the distributed MIMO antenna system, wavelength allocations in WDM-PON, and configurations of CS and BS.

3. ROF-MIMO DISTRIBUTED ANTENNA SYSTEM OVER WDM-PON

Figure 3(a) illustrates a configuration of WDM-PON where different wavelengths are assigned to different BS. This configuration enable us to use a 2xN AWG as a wavelength router at wavelength demultiplexer. The use of 2xN AWG provide following advantages to WDM-PON:

- Easy design in optical loss budget
- Improvement of wavelength utilization efficiency by using cyclic property of AWG that can re-use a wavelength in up link as that for down link.

The configuration of WDM-PON shown in Fig. 3(a), therefore, has a large scalability in accommodating a large number of BS and femtocells.
Figure 3: Configuration of WDM-PON. (a) Configuration. (b) Wavelength allocation.

Figure 4: Configuration of Tx and Rx. (a) Tx and Rx in CS. (b) Tx and Rx in BS.

At the CS in Fig. 3(a), a MIMO signal processing for RF signals is equipped, and four different RF signals for different four MIMO cells are multiplexed in electrical stage. Each BS employs optical circulator without any wavelength selectivity to easily add upstream signal and drop down-stream signal. Optical filters; e.g., optical fiber gratings at the BS are used to select a wavelength assigned to the BS. This configuration achieves the transparency of transmission fiber through lack of optical filters, thus lead to increasing wavelength channels in future. To decrease the costs of operation, administration, and maintenance functions, as well as the production cost, we can introduce wavelength tunability in LDs and fiber gratings of BSs; that is colorless BS [1].

Figure 3(b) illustrates wavelength allocation for upstream and downstream. By using cyclic property of AWG, wavelength for upstream are shifted with one wavelength against those for downstream. We require \( N + 1 \) wavelengths to accommodate \( N \) BSs over the WDM-PON, thus lead to improving the wavelength utilization efficiency.

Figure 4 shows a configuration of transmitter (Tx) and receiver (Rx) at CS and BS. In the proposed distributed MIMO antenna architecture, each of four RF MIMO signals has to be transmitted to each of four BSs. We employ an electrical multiplexing technique to multiplex four RF signals each of which is transmitted to each cell around a BS as shown in Fig. 2(b). When each femtocell is operated with different radio frequency, four RF signals can be transmitted to the same BS by using subcarrier-multiplexing (SCM) method. However, recent wireless access tends toward
one cell re-use of the same radio frequency to get higher radio-frequency utilization efficiency. To achieve this trend, some electrical multiplexing of four RF signals over a wavelength should be considered in the proposed architecture. Not to degrade the transparence of radio air-interfaces, frequency conversions at CS and BS are not desirable.

Therefore, we propose TDM (time division multiplexing) or CDM (code division multiplexing) with bandpass sampling of RF signals to multiplex the four RF signals. As for the TDM, each of four RF signals is naturally sampled with two times faster than its signal bandwidth, and then the sampled four RF signals are multiplexed over one wavelength channel. Fig. 5 illustrates the example of proposed WDM-PON configuration with the use of CDM technique. Data \((j, i)\) modulates RF carrier, \(f_1\), and divided into four signals. Co-channel and independent four signals to BS \((j, i)\) are electrically multiplexed at CDM encoder, and modulates optical carrier with its wavelength \(\lambda(j, i)\). At BS \((j, i)\), optical signal with \(\lambda(j, i)\) is dropped and received at PD. The output of PD is demultiplexed with CDM decoder, and then four RF signals for different four cells are obtained.

As compared with TDM, CDM is complicated, and the sampling rate is higher than that of TDM. In Ref. [7], however, the CDM can improve the capacity of MIMO channel with controlling the correlation among spreading codes. The further study of spreading code for correlation control will be needed. When transmitting broadband wireless signals with larger bandwidth, the encoding/decoding of CDM can be realized by using a high-speed optical switch [8].

4. CONCLUSION

This paper proposed a novel network architecture for Giga-bit throughput in broadband ubiquitous networks. A convergence of WDM access and RoF ubiquitous antenna architecture can realize a large scalability of WDM and higher throughput in femtocell covered by RoF-MIMO antenna. We discussed the distribution of MIMO antenna, accommodation of RoF MIMO signals over WDM-PON, and configurations of center and base stations.

REFERENCES


