Development of Radio on Free Space Optics System Toward Heterogeneous Wireless Services

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Abstract

Radio on Fiber (RoF) can realize a cost effective universal platform for heterogeneous wireless services. The concept of RoF can be realized by Radio on Free Space Optics (RoFSO), which can provide a free space for various types of wireless services in an optical wireless link. This paper proposes a new RoFSO system, describes its concept and features, and furthermore, shows some evaluation results of the developed RoFSO transceiver and Radio-RoFSO interface equipments, which can directly transmit a RoF signal from an optical fiber and can receive an RoFSO signal from air into a fiber core.

1. Introduction

In current wireless networks, however, various operators independently overlaid their own radio base stations and networks. Toward future ubiquitous networks with heterogeneous wireless services, however, this leads redundant equipments and investments on infrastructures, and prevents the quick start of a new wireless service and the employment of micro- and pico- cellular architecture improving the radio frequency efficiency. These problems are revealed especially in building, underground at urban areas, and also rural areas where it will be difficult to construct broadband fiber-infrastructures due to their high cost and a low population.

Radio on Fiber (RoF) technologies can realize a cost effective universal platforms for future ubiquitous wireless services. Furthermore, RoF networks can be extended to Virtual Radio Free Space Network with layer 1 routing[1, 2]. This benefit can be obtained not only by RoF but also by RoFSO (Radio on Free Space Optics), which can provide a free space for heterogeneous wireless services in an optical wireless link. This paper proposes a new RoFSO system for heterogeneous wireless services including digital terrestrial broadcasting service. In sec. 2, we introduce Virtual Radio Free Space Network with layer 1 routing realized by RoF and RoFSO, which transparently transmit heterogeneous wireless services. In sec. 3, we describe the concept and features of our developed RoFSO system, and furthermore, show some evaluation results of the developed RoFSO transceiver and Radio-RoFSO interface equipments.

2. Radio on Fiber and Free Space Optics Enabling Heterogeneous Wireless Services Transmission

Radio on Fiber (RoF) links shown in Fig. 1 have a function of transmitting radio signals to remote stations with keeping their radio formats. Consequently, RoF link becomes a hopeful candidate of a common platform for various wireless access networks. When RoF equips photonic routing functions, any radio signal can be forwarded to its destination control station. We call such RoF networks “ Virtual Radio Free Space Network (VRFSN)” [1, 2]. By using RoF, architecture for radio access zones easily employs micro or pico cellular systems. A RBS receiving or transmitting radio signals in each radio zone, equips only O/E and O/E converters. The RBS requires neither the modulation functions nor demodulation functions of radio signals. The radio signals converted into optical signals are transmitted via a RoF link with the benefits of its low transmission loss and broadband. Therefore, RoF links can be independent of radio signal formats and can provide universality for various types of radio access methods. This means that VRFSNs are very flexible to the modification of radio signal formats, the opening of new radio services, or the accommodation of different types of radio signal formats.

VRFSNs with layer 1 routing are required for heterogeneous wireless services especially in radio dead zones at private or public spaces such as in-house, building, and underground at urban areas, and at rural areas where broadband fiber-infrastructures have not yet been constructed due to their high cost and a low population. The layer 1 routing concept shown in Fig. 2 can be also extended to RoFSO (Radio on Free Space Optics) networks, which can provide a free space for heterogeneous wireless services in an optical wireless link. In the RoFSO network, radio signals are converted into optical wireless signals with a wideband electrical-to-optical conversion. The Layer 1 routing would be important for the transparency not only for various protocols on Layer 2 and upper, but also for various types of air interfaces.

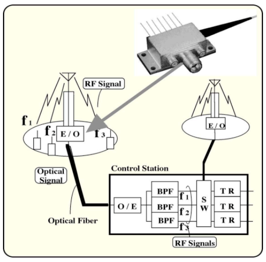


Figure 1 Radio on Fiber (RoF) links.

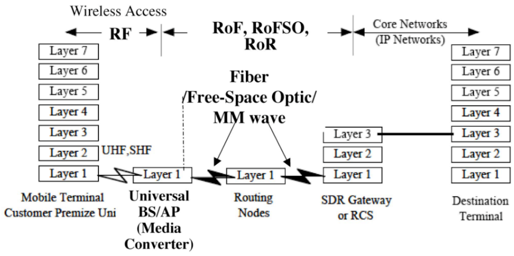


Figure 2 Layer 1 routing and Radio on Free Space concept.

3. Development of RoFSO System

3.1 Concept, Object, and Features of RoFSO System

The development of DWDM RoFSO link system has been started to realize an effective and quick provide of heterogeneous wireless services for not only urban area but rural area, that has a little or no infrastructure for broadband services[3]. Figure 3 illustrates the concept of advanced DWDM RoFSO system. An object of the development is to realize an advanced RoFSO link, which can transparently transfer cellular phone, wireless LAN, digital terrestrial broadcasting, and future coming new wireless services by using DWDM optical wireless channels.

Figure 4 illustrates features of RoFSO system. Conventional FSO system has been prepared for each of digital data transmissions with different data rates such as Ethernet, cellular entrance, digital CATV, and so on. Recently, next generation FSO system[4] has successfully realized a stable 10Gbps WDM FSO transmission. Therefore, a protocol-free digital FSO link with an equivalent performance as an optical fiber has been realized. On the other hand, the object of our development is to realize RoFSO link that has an equivalent capacity for heterogeneous wireless services as RoF. We will employ the direct optical amplification and emission of RoF signal into free space, and direct focusing of the received optical beam into the core of SMF (single mode fiber), that technologies have been developed in the next generation FSO system[4]. Since RoF and RoFSO are essentially analog transmission links, higher stability and reliability will be required. One object of the development is to improve accuracy of the optical beam tracking system. The target is more than 1km link distance, DWDM with more than 4 wavelengths, transmission of more than 4 different wireless services including terrestrial digital TV broadcasting.

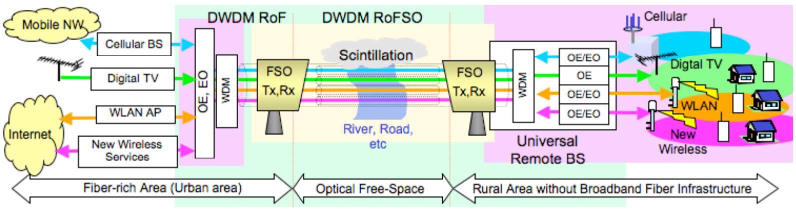


Figure 3 Concept of Advanced DWDM RoFSO System.

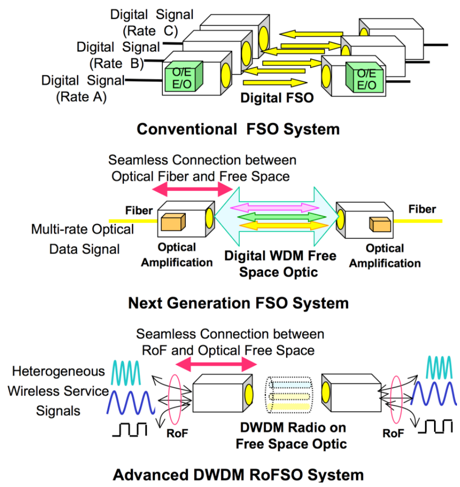
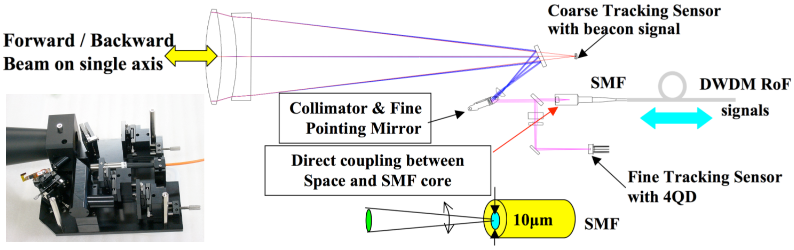


Figure 4 Features of RoFSO system.

3.2 DWDM RoFSO Transmitter / Receiver

Figure 5 illustrates the developed RoFSO transmitter / receiver with a fine beam tracking optic system[5] to emit DWDM RoF signals directly from SMF into free space and focus a received optical beam directly into a core of SMF. Objective design parameters are followings: Optical Transmitting Power: 20dBm/wave, Geometric Loss: 2.6dB at 1km (Beam angle width : 47.3 μ rad at 1.55 μ m), Equipment Loss: < 10dB (Tx & Rx total). Therefore, we are developing an optical free space with 1km haul for heterogeneous wireless services with its loss of less than 30dB in radio frequency band.

(a) Photograph of RoFSO TX/RX



(b) Fine Beam Tracking Optic System

Figure 5 Developed RoFSO Transmitter / Receiver with fine beam tracking optic system, which emits DWDM RoF signals directly from SMF into free space and focuses a received optical beam directly into a core of SMF.

3.3 Interface Equipments Seamless Connecting between Radio and RoFSO

We have developed four types of Radio-RoFSO interfaces (I/F) equipments for 3G cellular at 2GHz, WiFi (802.11g) at 2.4GHz, WiFi (802.11a) at 5GHz, and digital terrestrial broadcasting at UHF radio to be seamlessly connected from/into wireless optic signals. Figure 6 shows a photograph of I/F equipment for WiFi at 2.4GHz. To design RoFSO link, we have to examine a total performance through RoF, RoFSO and wireless access links. Since different wireless services have different data-rate, modulation formats, and sensitivity, we have to investigate the influence of distortion or disturbances suffered on RoF and RoFSO links for each wireless services.

As a basic evaluation, we have conducted an indoor short-range experiment to confirm a FSO loss compensation effect with optical amplifiers. A RoF signal with 1.55μm wavelength modulated by WLAN signals at 2.4GHz is amplified at an booster EDFA, transmitted directly from SMF into FSO channel, directly focused into a core of SMA, amplified at a post EDFA up to 0dBm and then received at PD. Figure 7 shows experimental results of RF carrier and 3rd order intermodulation distortion (IMD3) power at the output of RoFSO link versus RF input power, when the optical loss between Tx and Rx was 50dB, and received optical power, $P_{opt\,R}$ was -3.75dBm. In this figure, experimental results for RoF when $P_{opt\,R}$ = -3.3dBm are also shown for comparison. It is seen from the figure that booster and post EDFAs can compensate the loss of RoFSO link without any IMD3 increase, and realize RoFSO link equivalent to RoF link. By using RoFSO Transmitter / Receiver shown in Figure 5 and I/F equipments, an outdoor transmission experiment of 3G cellular (WCDMA) radio signal have been conducted at a short range of 300m. As shown in Figure 8, the ACLR (Adjacent Channel Leakage Ratio) of less than -50dB at +-10MHz was achieved when input RF power, transmitted optical signal power, and received optical power are -20dBm, +6dBm, and -1.2dBm, respectively. We have not observed a significant distortion or spurious in the transmitted WCDMA radio signal. We will conduct a long-term and long haul demonstrative transmission experiment at Waseda Univ. from spring, 2008.

Figure 6 Photograph of Radio-RoFSO interface equipment for WiFi signals at 2.4GHz.

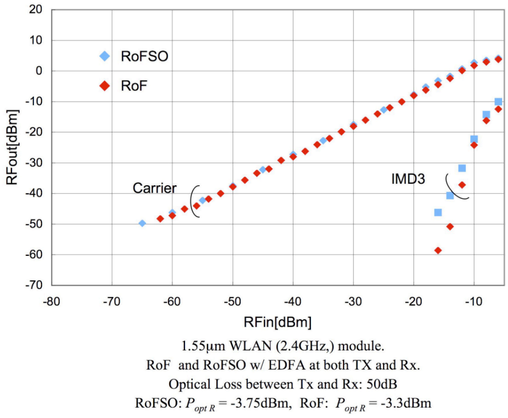


Figure 7 Experimental results of RF carrier and 3rd order intermodulation (IMD3) power versus RF input power at the output of RoFSO link.

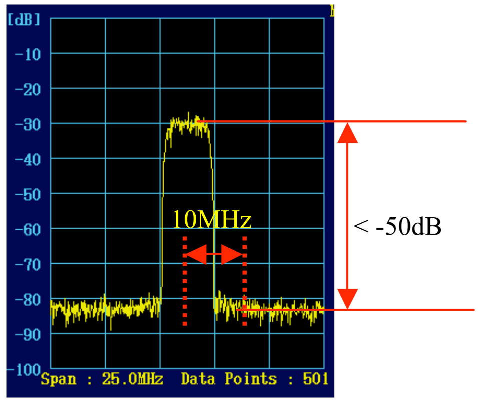


Figure 8 Experimental result of ACLR for WCDMA RF signal transmission.

4. Conclusion

We have proposed the concept of advanced DWDM RoFSO system, and described its development and some investigation results. We will conduct a long-term demonstrative measurement in the next phase.

5. Acknowledgments

This work is supported by a grant from the National Institute of Information and Communications Technology (NICT) of Japan.

6. References

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