Status Quo and Prospect of Millimeter Wave RoF Communication Technology

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Abstract:
The optical communication technology features low cost, wide band, low loss, and anti-electromagnetic interference performance. By combining the optical communication technology with the radio millimeter wave communication system, the Millimeter Wave Radio over Fiber (MM-RoF) system boasts a lot of advantages, including wide band, small size, light weight, low cost, low loss, and resistance of electromagnetic interference as well as high transmission quality. The MM-RoF technology solves the problems faced by traditional microwave transmission system at the millimeter wave band, namely, high loss and inability to resist interference efficiently. Meanwhile, it puts an end to the bottleneck of millimeter wave electronic devices and thus is deemed as with great potentials. The MM-ROF technology that supports multiple formats and services signifies one of the significant trends for future development of the MM-RoF system.

1 Overview of Optical Communication

Due to the wide applications in current economic and social arenas, the information communication technology stands out as a high technology that boasts the fastest development, widest coverage, strongest permeability and farthest-reaching applications in the modern world. It is the major force that drives the global information communication industry to grow and develop. With the information communication, not only the expenditures for economic transactions are cut down, hence the much lower social operation costs, but also knowledge and information are better spread and shared, thus the better quality of life. To put it simple, the information communication is of great significance to people's knowledge level and society's long-term economic development.

The optical fiber communication network based on the Wave Division Multiplexing (WDM) technology has become the optimal wireline platform for the developing high-speed and large-capacity information network in the world of today. Multiple multinational companies are competing against each other in the WDM-based information transmission experiments at Terabit level, and so far the 10.9 Tb/s transmission has been conducted successfully. The focus of the all-optical network has turned from the toll backbone network to the feeder part of trunk network and access network, and is now extending gradually to the distribution part. Up to 82% of China's toll networks are using optical fiber for transmission. However, while the optical fiber is getting to end users, the cost of optical fiber is also rising, which makes fiber to the home very difficult unless technological breakthroughs emerge as a solution. As China is concerned, fiber to the building, fiber to the neighborhood and fiber to the curb are comparatively realistic for the medium and near terms.

Nevertheless, radio access has become an important and popular trend of global communication because it is convenient, everywhere and able to provide personalized service. The mobile communication is evolving from the current 2.5G, for digital and voice services, to 3G and Beyond 3G (B3G), for video and multimedia services, and even to 4G and 5G, for high-speed wideband services. Meanwhile, the network is required to provide large-capacity combined services safely, flexibly and ubiquitously, as a result of the emerging services and broadband radio access technologies, for example, streaming, Radio Frequency ID (RFID), sensor network, Worldwide Interoperability for Microwave Access (WiMAX), and Local Multipoint Distribution Service (LMDS). As shown in

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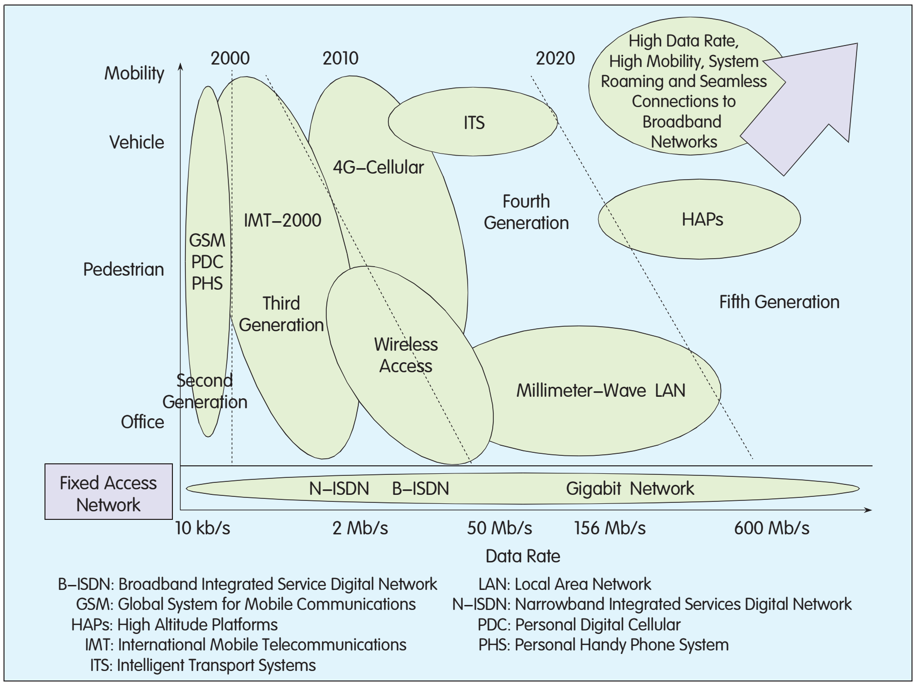


▲Figure 1. Development trend of wireless network system.

Figure 1, future wireless communication is expecting high speed, great mobility and seamless connection of services among different wireless networks. However, the fast-developing wireless network is facing many problems, typical of which include: The compatibility problem of current wireless access networks, the bottleneck of data rate especially in mobile circumstances, and the smooth transition of the current networks to next generation ones.

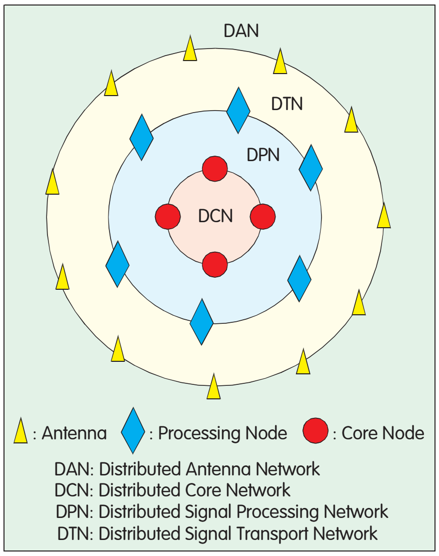
Regarding all current communication technologies and service demands and their developing directions, it is understandably clear that the global communication networks are changing into broadband, wireless, personal and packetized ones with converged multi-service networks. This ultimate target in turn makes the demand increasingly pressing so that the broadband radio signal and carrier frequency are extending to high-frequency millimeter wave, 40-60 GHz, for instance.

By combining the optical communication technology (wideband) with the radio millimeter wave communication system (flexibility), the Millimeter Wave Radio over Fiber (MM-RoF) system boasts a lot of advantages, including small size, light weight, low cost, low loss, resistance of electromagnetic interference as well as high transmission quality. The MM-RoF technology solves the problems faced by traditional microwave transmission system at the millimeter wave band, namely, high loss and inability to resist interference efficiently. Meanwhile, it puts an end to the bottleneck of millimeter wave electronic devices. Besides, by combining the enormous capacity of optical network with the adaptability and mobility of radio access network, the MM-RoF system is able to transmit various wireless services and information and provide the broadband wireless network with the "last mile" seamless access, that is, to make the idea of "communicate with anybody, anytime, anywhere and in any mode" come true.

Figure 2 depicts the architecture of the next generation broadband wireless communication system, which comprises Distributed Antenna Network (DAN), Distributed Signal Transport Network (DTN), Distributed Signal Processing Network (DPN) and Distributed Core Network (DCN). The DTN, DPN and DCN are related with millimeter wave signal processing and transport, which can be done with the optical integration device and technology of the optical system. Optical transmission can deliver the bandwidth and transmission quality for the radio signals that are impossible with the current cable-based transmission. It is expected that in 2010, transmission of more than 80% of millimeter wave radio signals will be fulfilled on the fiber technology basis. As for the DAN part, its antenna system is made up of the optical beam-forming intelligent antenna, which eliminates the bottleneck problem of electric processing faced by the broadband and large-capacity electric antenna, and thus is deemed as the ideal solution to wireless antenna system of tens of GHz with promising applications[1-3].

2 Status Quo of MM-RoF Communication Technology

The MM-RoF technology has now become one of the hottest spots of application-oriented research by academic organizations and universities around the globe including the US, EU, Japan and Australia. Chinese universities are working on it too, for example, Tsinghua University, Peking University, Beijing University of Posts and Telecommunications, Shanghai Jiao Tong University, Zhejiang University, University of Electronic Science and Technology of China, Shanghai University, and Huazhong University of Science and Technology. To make effective use of the optical fiber



▲Figure 2. Architecture of the next generation broadband wireless communication system.

bandwidth resource, and to connect the broadband multi-service network system, wireless network and wired network seamlessly, more and more researchers around the world are working on the MM-RoF system that supports broadband wireless multiple services[4-23].

In 2005, Georgia Institute of Technology of the US reported its research on the seamless integration of Wavelength-Division-Multiplexed Passive Optical Network (WDM-PON) with the wideband MM-RoF access system. The scheme uses the Raman-assisted Four-Wave Mixing (FWM) effect generated by the High-Nonlinear Dispersion Shifted Fiber (HNL-DSF) to perform all-optical up-conversion for the 8×2.5 Gb/s WDM signals, which turn into the 40 GHz microwave subcarrier signals as a result. Meanwhile, as a chromatic dispersion compensation, the scheme adopts the single side band filter technology for the longer-than-20 km transmission on the MM-RoF system. In 2007, the Institute reported a new full-duplex RoF system to realize the 40 km bi-directional transmission on the RoF system for the 2.5 Gb/s signal (Differential Phase-Shift Keying (DPSK) for downlink modulation, and On-Off Keying (OOK) for uplink re-modulation) that is under the 40 GHz carrier.

In 2007, the NEC Laboratories America, Inc. (NEC Labs) reported that it has realized transmission of the 40 GHz microwave signal and 2.5 Gb/s Non-Return-to-Zero (NRZ) signal on the RoF system. The Lab was reportedly working on wireline and wireless broadband services as well as the transmission technologies.

In Europe, the Gandalf Program was initiated in 2004 by University of Valencia (Spain), University College London (Britain) and several other EU research institutions. The Program has since set its ultimate target as "to study the multi-service RoF system, to provide broadband wireless and wireline mixed access network with the capability of gigabit transmission". In 2005, the Program reported its proceedings in optical generation of high frequency electric vector signals that it has realized the direct optical generation of 74.7 Mb/s Quadrature Phase-Shift Keying (QPSK) signals at the 37.5 carrier. In the same year, the Program worked out the RoF system with 2.5 Gb/s data signals at the 40 GHz carrier.

University College London in Britain works together with University of Cambridge and British Telecom on the RoF system to stage the optical transmission experiment for multiple services with the 60 GHz wireless signals.

In Japan, the multi-service millimeter wave RoF technology has become the hotspot of many research bodies. In 2003, Osaka University reported to have transmitted the 2.5 Gb/s baseband signal, 4.5-12 GHz microwave signal and 60 GHz-carrier 155 Mb/s signal over a signal optical source. In 2006, the University reported to have worked on the super-continuum source-based all-optical up conversion technology to produce the 60 GHz millimeter signal, to realize the 25 km RoF transmission with two channels. Communications Research Laboratory (CRL) of Japan has realized indoor wireless access network at the frequency of 60 GHz. At the band of 36-37 GHz, the Intelligent Transportation Systems Road-to-Vehicle Communication (ITS-RVC) system was capable of data transportation at a rate of up to 10-150 Mb/s. The Advanced Telecommunication Research Institute (ATR) of Japan has realized fiber-based transmission on the uplink system for the 400 Mb/s modulated Binary Phase-Shift Keying (BPSK) data at the 60 GHz frequency, and also fiber-based transmission on the downlink system for the 500 Mb/s modulated Binary Phase-Shift Keying (BPSK) data at the 50 GHz frequency.

In Canada, the Advanced Radio-Optics Integrated Technology Group (ADROIT) of Ryerson University has started research on the RoF system since the end of 1990s. It is currently focusing on the RoF-based multimedia wireless access network to provide the mixed RoF transmission system capable of various multi-media accesses, for example, IEEE 802.11 and Wideband Code Division Multiple Access (WCDMA).

In 2003, Yonsei University of Korea reported to have realized 20 km transmission for the 2×622 Mb/s signal in the 60 GHz RoF system. It mainly used the side band injection-locked technology with two lasers to produce the millimeter wave signals. In 2005, Gwangju Institute of Science and Technology (GIST) reported to have used the Semiconductor Optical Amplifier-Based Mach-Zehnder Interferometers (SOA-MZI) to perform all-optical up conversion to generate the WDM RoF signals, and then realized RoF transmission of double DPSK signals at the carrier frequency of 22.5 GHz and the rate of 155 Mb/s. In 2006, Yonsei University used Semiconductor Optical Amplifier-Based Electro-Absorption Modulator (SOA-EAM) to realize full-duplex RoF transmission of the QPSK signals at the carrier frequency of 60 GHz and the rate of 10 Mb/s.

In China, research agencies are also attaching importance to the research of RoF transmission. In 2005, Shanghai University published Study of Some Aspects on OFDM-RoF Transmission System, which focuses on the transmission performance of Orthogonal Frequency Division Multiplexing (OFDM) modulation signals on the RoF transmission system, supported by a simulation model. Afterwards, the University studied the use of optical PSK modulation in the RoF downlink system based on the principle of harmonic generation. Since 2006, the University has been studying the optical generator, system's power design and allocation modeling for the 60 GHz RoF system. Beijing University of Posts and Telecommunications conducted, around the year of 2003, simulation work for the RoF system to carry the second generation wireless system signals, and analyzed theoretically the RoF all-optical wavelength change based on the FWM. Peking University used the dual-mode-locked laser technology to realize the all-optical generation of 60 GHz millimeter wave, and conducted dispersion analysis for the RoF signal fiber transmission. Zhejiang University proposed, in 2005, to use the optical grating Brillouin dual-frequency laser for all-optical generation to produce microwave and millimeter wave, thus obtaining the microwave output near 11 GHz. Huazhong University of Science and Technology used the dual optical source technology and 60 GHz Electronic Absorption Transceiver (EAT) to realize single wavelength and dual wavelength modulation respectively on the downlink and uplink. Hunan University proposed a scheme using the improved dual side band modulation to produce the millimeter wave. Tsinghua University has researched with proceedings since 1999 on the optical generation of radio signals in the RoF system, up and down conversion, optical microwave filter, and cross interference in link transmission.

3 Future Development of MM–RoF Communication Technology

The MM–RoF system is now developing towards larger capacity, higher performance and better practicality, in a bid to meet the demands of the future broadband multi–service network system, and the seamless integration of wireline and wireless networks. Currently the research of MM–RoF system in support of wireless multi–service is focusing on the use of the wavelength resource in optical fiber and the WDM technology to provide transmission of multi–service signals in the MM–RoF system. To make better use of the limited optical wavelength resource, it is very important and definitely necessary to use a single optical source to transport multiple services based on the MM–RoF technology. Keys to making this happen include: Optical generation technology that produces several formats of radio signals at the microwave/millimeter wave bands on the same optical source, the technology that transports several formats of millimeter wave signals over the MM–RoF system, all–optical demodulation technology, and system performance analysis.

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