Evolution of Optical Access Network Technologies in Radio Systems

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Abstract *Radio system architecture has drastically changed thanks to the evolution of optical fibre technologies. This paper describes optical access technologies that contribute to the efficient construction of radio systems including mobile communication and terrestrial digital media broadcasting.*

Introduction

Major radio systems including broadband mobile access systems and terrestrial digital media broadcasting are essential for today's advanced information and communication society. The deployments of 3G mobile phone systems (CDMA2000 and UMTS) and broadband wireless access systems (WiMAX[1,2]) are accelerated due to the explosion of high-speed mobile multimedia communications and Internet services. Long Term Evolution (LTE) is emerging as the leading choice for next-generation mobile access networks worldwide. In addition, digital television (DTV) is an advanced broadcasting technology that enables users to offer television with better picture, sound quality, multiple programming, and interactive capabilities. There are several DTV standards (DVB-T, ATSC and ISDB-T) developed and deployed in different countries.

The architectures of their radio systems have drastically changed thanks to the evolution of electronics and communication technologies. The optical fibre communication technologies play a major role in the development of the radio systems. The important optical communication technologies in radio systems are composed mainly of a RF waveform transmission and an end-to-end synchronization capability.

This paper describes some of the optical access techniques that contribute to the efficient construction and deployment of radio systems including mobile communication and terrestrial digital media broadcasting applications. This paper also discusses development activities of optical access network technologies for radio systems.

Broadband mobile access systems

Radio over fibre (ROF)

In mobile access architecture, ROF technology[3] enables the direct transmission of radio (RF) signals over optical fibre with low propagation loss and long-reach feeding instead of a coaxial cable, and allows mobile operators to deploy base stations with more freedom and fewer restrictions at lower cost within wireless systems.

In-building radio coverage systems

The in-building radio coverage system consists of a network of antennas distributed throughout a building via coaxial cable and optical fibre to provide dedicated in-building radio coverage. Optically converted RF signals by ROF are distributed to the antenna units located on each floor via the optical fibres and converted back into RF signals. The RF network consists of a network of coaxial cables and power splitters that distribute the RF signal to antennas located throughout the building. The in-building radio coverage system based on ROF technology is effectively used to deliver RF signals in the building and enables users to significantly reduce operating costs, and thus optimally exploit existing equipment.

Distributed Base Station Architectures

The ROF approach makes it possible to centralize large base station facilities, and makes it easier to add new radio cell sites, upgrade radio technology and accommodate multi-service signals. The analogue ROF system is attractive in terms of system cost. However, transmission performance such as carrier to noise ratio (C/N) and spurious RF are susceptible to optical losses and optical reflections that occur in optical fibre links.

The digitized ROF system has therefore been developed to overcome these problems. This technique rather than the analogue ROF system has robustness against such optical fibre characteristics. Frequency converted radio signals with the IF (Intermediate Frequency) band are digitally converted into binary data from RF signals (analogue waveform), and can be delivered to the whole system without influence caused by optical reflections occurring in optical fibre links. A data speed of approximately 1Gbit/s is required to deliver a RF bandwidth of 20MHz with sufficient signal quality. C/N degradations due to multiple optical reflections with -15dB were evaluated[4]. Based on the evaluation, no degradation was observed in the digitized ROF system, although significant degradation was observed in the analogue ROF system.

Trends in base station architecture

Base station equipment with the common public radio interface (CPRI) specification[5] has been developed. Using this specification, waveform digitizing and generation process are only achieved in a remote head at the antenna site. Consequently, the wasteful signal conversion processes used in the digitized ROF system can effectively be reduced.

Recently, on the other hand, small base stations with Ethernet interface to cover a smaller cell area are emerging instead of conventional large base stations. In this architecture, ROF is becoming less useful. Alternatively, the Ethernet based entrance line is growing as mobile backhaul. However, they still require frequency synchronization as well as global timing for proper base station and mobile call hand-off operations. Typically, the base stations therefore synchronize operation with a coordinated universal time (UTC) reference obtained by the global positioning system (GPS).

As an alternative to the GPS, packet based synchronization such as IEEE 1588 precision timing protocol[6] is expected, but it is still under study to meet the requirements used in the wireless systems. It is a critical issue to expand service areas for mobile operators from a deployment cost perspective. In particular, in the case of expansion of service areas in places not reached by radio signals from the base station, such as in buildings and underground, new access solutions are expected.

Terrestrial DTV broadcasting systems

Program transmission link

In Japan, terrestrial digital television broadcasting by the integrated services digital broadcasting-terrestrial (ISDB-T) standard[7], which provides fascinating content for both residential and mobile scenes, has started. The microwave networks among a broadcasting studio and transmitter stations have been deployed to relay transport stream (TS) packets as broadcast programs over 64QAM at the super high frequency (SHF). These networks are usually called the studio to transmitter link (STL) and transmitter to transmitter link (TTL). In order to maintain reliability of the program transmission, STL/TTL has redundant routes by the wireless and wired links. An analogue STL optical link based on ROF technology has been deployed to deliver 64QAM-IF signals[8]. A digital STL optical link that conveys TS packets was also commercialized to avoid performance deteriorations due to optical losses and optical reflections in optical fibre links. As other optical STL/TTL link techniques, two transmission systems based on synchronous optical network/synchronous digital hierarchy (SONET/SDH) deployed nationwide have been developed: TS[9,10] and an orthogonal frequency division multiplexing (OFDM)-IF[11]. These techniques are based on the end-to-end synchronous feature of SONET/SDH.

RF distribution network over FTTH

To achieve RF distribution, the ROF technique as an analogue optical transmission is widely used in hybrid fibre-coaxial (HFC) and FTTH networks. RF video distribution over a passive optical network (PON) system that uses wavelength division multiplexing (WDM) has been widely deployed. The delivery of an RF broadcasting signal that can be directly received by using existing televisions and recorders is therefore preferred for residential users.

Synchronous transport system using IP network

Dedicated analogue optical transmission links are necessary to maintain sufficient RF signal performance for metropolitan area networks. Thus system cost will be increased in accordance with propagation distance to avoid C/N degradation of RF signals. Hybrid IP-RF architecture will be attractive to ensure both RF performance and system cost reduction. Since the broadband IP network has been deployed nationwide, a television program distribution within the district boundary can easily be realized using IP multicast technology with low-cost delivery mechanisms.

A re-modulation system of digital broadcast programs with a full end-to-end synchronous delivery mechanism based on IP multicast and IP-RF conversion has been demonstrated[12]. OFDM signal is demodulated to MPEG2 TS packets and converted into IP multicast packets with encryption and forward error correction (FEC). IP multicast packets are distributed in accordance with prioritizing policies in the IP multicast network, and the delivered IP packets are re-modulated to an ISDB-T standard based OFDM signal at an edge node of the network. This delivery system maintains end-to-end accurate synchronization of the frequency of an OFDM clock, i.e. Inverse Fast Fourier Transform (IFFT) clock, MPEG2 bit-rate as well as broadcasting program contents almost-completely. This technique is expected to be applicable to both the STL/TTL and RF delivery applications over packet switched networks.

Advanced optical access network technologies

Passive optical network

There are various broadband access network techniques. Ethernet media converters (M/C) are usually used for appropriate access portions from a central office (CO) to enterprise users, wireless base stations, and multi-tenant units/multi-dwelling units (MTUs/MDUs). On the other hand, FTTH is rapidly deployed as fixed broadband access infrastructure to provide broadband pipes for a triple-play service that consists of telephony, high-quality video and high-speed Internet access services. The key technology to realize FTTH is a low-cost PON in which optical line terminal (OLT) equipment and a trunk fibre line are shared by multiple users simultaneously. Among several PON technologies, such as Gigabit Ethernet PON (EPON[13]) specified in IEEE, and B-PON[14] and G-PON[15] as specified in ITU-T, EPON is proven broadband technology for access networks serving both residential and business uses and is extensively used in Japan.

The commercial EPON system[16] provides all the built-in functionality and performance required for delivering triple-play services. The EPON features a configurable dynamic bandwidth algorithm (DBA) that supports hierarchical fairness for guaranteed service level agreement (SLA) contracts, and has various virtual local area network (VLAN) functions for service and management domain transition. EPON is therefore sufficient to ensure the performance required for mobile backhaul access and can be used as common optical access infrastructure. The recent commercial EPON system allows up to 64 subscribers to be connected to one OLT located at a central office over a single fibre. In terms of the geometrical cable wiring of the EPON system, it is easy to achieve quick deployment of radio nodes by attaching to an optical splitter in a subscriber cluster. Common optical access infrastructure is especially effective for MTU/MDU to create in-building coverage areas.

Time distribution over optical access network

In radio systems, time and frequency synchronization are necessary to ensure proper radio operation. Most systems utilize the UTC reference obtained by the GPS. Two techniques to deliver accurate UTC time over EPON can be considered for radio systems[17]. Both cases are based on EPON for a broadband access line to the base stations.

First, the ROF technique is an easy way to simultaneously transport the GPS signal over the EPON system. This method can directly deliver an RF component with GPS-L1 frequency (1575.42 MHz) by using a dedicated wavelength multiplexed optical signal. The GPS-L1 signals received from GPS satellites are converted to an optical signal and are distributed through an optical distribution network (ODN) consisting of optical fibres and power splitters. In a base station, one pulse per second (1PPS) pulse train is generated from the GPS-L1 signal by a GPS receiver (GPSR) and is not only used as timing clocks but also fed into a delay-locked loop (DLL) to create reference clocks. A time of day (ToD) timing information for handoff control and equipment management is also obtained from the GPSR. Ethernet link is established by both the EPON-OLT and the EPON-ONU.

Second, a simple UTC time transfer technique using the current multi-point control protocol (MPCP) process over the EPON has been developed[18]. A UTC-traceable 1PPS pulse and 10MHz clock provided from a GPSR are directly distributed through the EPON system only. In order to obtain timing information, the GPSR in the OLT is necessary. However, since the 1PPS pulse train is directly delivered from the OLT to each ONU, the GPSR and the analogue O/E in the radio nodes as well as the analogue E/O in the OLT are not required.

In order to verify the synchronization capability of two techniques over the optical access network, connectivity between the access systems and WiMAX base station has been demonstrated[17]. This result indicated that the UTC time transfer techniques allow us to provide precise time and synchronization capability for radio systems.

Future optical access infrastructure

10Gbit/s EPON technology is emerging as a next generation broadband access and the standardization of 10G-EPON has started in the IEEE standards developing group 802.3av[19]. This can be adopted as a seamless upgrade from existing 1Gbit/s EPON and is attractive because the existing deployed ODN for EPON can be used. This technology is extremely attractive to provide the entrance lines for high speed wireless access networks such as WiMAX and LTE. The feasibility of the 10G-EPON system has been experimentally investigated[20,21]. In addition, UTC time transport capabilities described in the previous section can easily be implemented by using a similar mechanism of EPON.

A WDM-PON is also attractive for radio systems and provides large-capacity optical infrastructure by assigning a dedicated wavelength to radio nodes. Each optical path is transparent and not dependent on the line-rate and frame format as well as the modulation scheme. The use of WDM-PON architecture facilitates the elimination of aggregation sites between the central office and radio nodes. This scheme can accommodate many types of access lines with different bit rates and data frames. In this scenario, the optical access platform aggregates the high speed Internet access lines for business users, condominium and apartment buildings. It also concentrates entrance lines for broadcasting and mobile access systems[22].

A major issue in the WDM-PON systems is the coloured transceiver cost in both the OLT and the ONU. A colourless transceiver technology is expected to reduce the total system cost[23,24].

Conclusions

This paper described the revolution of optical fibre communication techniques and optical access network technologies in broadband mobile access and broadcasting systems. Advanced optical fibre technologies that allow us to deploy radio systems efficiently in cooperation with the optical access infrastructures are expected.

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