## A Broadband ASE Light Source-based FTTX RoF-WDM Optical Network System

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ABSTRACT. A enhanced network quality factors with noise interference elimination over FTTX RoF-WDM Optical Network System. This solution combines the concepts of longdistance transmission and ring topology. It is effective in expanding the bandwidth to overcome network congestion and in addressing the issues in wired optical fibers and wireless microwave communication systems. The potential amplified spontaneous emission broadband light source and spectrum-slicing technology are integrated with the dynamic reconfigurable optical add-drop multiplexer to decentralize the management of FTTX RoF-WDM-wavelength-division multiplexed optical network, which optimizes the transmission performance and eliminates multi-path crosstalk. We proved that the flat-gain signal optimization and the semiconductor optical amplifier structure enhance the optical signal and optical signal-to-noise ratio. The downlink quality factor curves in the Q6 data showed an -18.8 dBm increase in the received optical power. Application of the FTTX RoF-WDM broadband access network system achieved low crosstalk, a clear eye diagram, and an eye 3D graph. Since our proposed system uses only a broadband ASE light source to achieve multi-wavelengths transmissions, it also reveals an outstanding with simpler and more economic advantages.

**Keywords:** Amplified spontaneous emission (ASE), Fiber to the X (FTTX), Optical add-drop multiplexer (OADM), Radio-over-fiber (RoF), Semiconductor optical amplifiers (SOAs).

1. Introduction. At present in 2017, and the worldwide network system of information circulation has explosively increased. The fast-growing communication networks are not able to adequately meet the increasing traffic. To solve the problem of insufficient bandwidth, to simplify the network with multi-standard platforms, and to protect the communication network industry operator investments with flexibility that can grow as the business grows, we propose a new generation of fiber-optic networks centered on a combined enhanced network quality factors with noise interference elimination over a hybrid radio-over-fiber (RoF)-wavelength-division multiplexed (WDM) broadband system. This solution is effective in expanding the bandwidth to overcome Internet congestion and allow a broader range of flexible transmission communication networks.

This paper presents a study on the combination of wired optical fibers and wireless microwave communication systems. The objective is to upgrade the current communication network with cost benefits and higher performance in terms of speed and reliability so that the communication network can meet the different system requirements across several telecommunication industry services. We recommend a FTTX RoF-WDM system because the signal's attenuation is significant when wireless signals are transmitted in air. Should we want to use microwave signals to be transmitted over a large area, the antenna's power must be very large. Considering the effect of electromagnetic waves on human health and the huge cost involved in increasing the distance from a receiver to the base station, we recommend the FTTX RoF-WDM transmission system as an alternative. This system not only combines the advantages of the optical fiber and wireless microwave but also compensates for their shortcomings. The strength of the FTTX RoF-WDM and the resulting economic value result from the combination of the optical fiber and wireless microwave communication systems. In densely populated metropolitan areas, the main line must have a high bandwidth and low-loss optical fiber transmission. [1]

A FTTX RoF-WDM wired/wireless transponder system is a configuration that provides both wireless and wired communication between a hybrid headend and one or more client devices. The FTTX RoF-WDM is proposed to provide full communication services, including telecommunication, Internet protocol television (IPTV)-triple play, code-division multiple access (CDMA) (3G cellular phone), wireless local area network (WLAN) 802.11g, and digital television (DTV)signal broadband integrated services [2-5]. This hybrid RoF technology optical distributed antenna system provides uniform radio coverage and can transport various radio signals at frequencies ranging from 800 to 2,500 MHz, covering cellular and WLAN applications [6]. This particular system can be fixed or configured for mobile broadband networks that can provide commercial reality for indoor applications in the form of distributed antenna systems, as well as outdoor wireless systems [6-8].

## 2. System Overview.

2.1. "Opti-System" System Design Software. The key to successful implementation of the proposed system is the selection of appropriate design and test tools. As the optical fiber and wireless microwave communication systems become more complex, scientists and engineers must adopt increasingly advanced software simulation techniques to address vital design issues.

The "Opti-System" is a level simulation package for an innovative optical communication system. It possesses a powerful new simulation environment and a truly hierarchical definition of the components and systems. The communication applications range from the central station (CS) light source transponders to the combination of the optical fiber and wireless microwave communication systems. The design and analysis of these systems, which normally involves multiple signal channels, different topologies, non-Gaussian noise sources, and nonlinear devices, are highly complex. Advanced communication system design software tools can make the design and analysis of these systems quick and efficient. By using the "Opti-System" software-defined modular instruments, we can maximize the equipment investment by lowering the cost in creating a test system.

2.2. Employing the Amplified Spontaneous Emission (ASE) Light Source in the FTTX RoF-WDM System Scheme. In the general partial FTTX RoF-WDM system, different wavelengths are produced by different lasers in the conventional WDM systems. This process increases not only the cost of construction but also the system's complexity. Our proposed system simplifies the light source and reduces the system complexity. By using only a broadband light source, the broadband transmission scenarios and a low system cost can be realized. An erbium-doped fiber amplifier (EDFA) is widely used in optical fiber networks because of its high ASE output power [9]. In this study, we use only one ASE broadband light source to achieve multi-wavelength transmission. The result is an outstanding scheme that is simple and economical [10-12].

In addition, some techniques are implemented, such as using spectrum slicing to overcome the light source problem [13-16]. Spectrum slicing is an attractive technology in which a narrow wavelength is filtered from a broadband light source and externally modulated to transmit a signal. It does not require multiple laser diodes and exhibits an outstanding performance with simple, economical, and competitive advantages. The experimental configuration of the proposed system is shown in Fig. 1. For downlink transmission, the CS includes an ASE broadband light source and uses an amplified light source from the preamplifier. The modulation signal is use by Mach-Zehnder, and the data rate is recorded as 10 GHz/2.5 GBit/s for the external modulation. The AWG tool is then used to build MUS and DEMUS. The AWG characteristics appear periodically in the signals; the distance between adjacent peaks is called the free spectral range periodicity of the AWG [17]. The use of the AWG tools for spectrum slicing of ASE results in four multiple FTTX RoF-WDM system channels that range from G1-BS1 to G4-BS4. The technical signal interference should be considered. In designing the system, we use an even number of channel wavebands for transmission to reduce crosstalk interference from similar wavelengths. The biggest advantage of this system is that the headend only uses one ASE broadband light source to complete the FTTX RoF-WDM system while overcoming the multi-channel crosstalk noise interference, thereby reducing the equipment cost and system maintenance complexity.



FIGURE 1. Experimental configuration of the proposed FTTX RoF-WDM ring network with optical carrier supply scheme and spectrum-slicing transport system.

Furthermore, to achieve a higher signal-to-noise ratio and more stable high-quality reception, the power amplifier should be specifically defined. The result shows that the optimizing components of the equalization system can equalize the gain of the amplifier in the semiconductor optical amplifier and Erbium Doped Fiber Application Amplifier and achieve dynamic gain equilibrium in the signal power. Therefore, a signal gain equalization system is added into the experiment.

2.3. FTTX ROF-WDM of the OADM Ring Network Configuration and Network Elements. As optical technologies continue to advance, the optical add-drop multiplexer (OADM) is considered as a potential medium to provide the downlink and uplink using simple and compact equipment. The dynamically reconfigurable OADM method is used to decentralize the management of the FTTX RoF-WDM optical network in uploading and downloading information [18]. OADM is an element that integrates multiple parts in a single substrate. It allows higher dispatching efficiency of the bandwidth and eliminates the cost and complexity of some optical layers [19-20]. The benefit that can be gained from using the OADM is the fiber channel protection provided by the choice of wavelength routing. The signals transmitted through the fiber link are received from 40 to 160 km, and the signal frequency is reduced by

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the low-pass filter. The optics are then transformed into electrical pulses for quality factor measurement and eye-diagram signal observation.

2.4. Amendment of the Average Signal Intensity in the Equalization Optimization Technology. In a long-haul transmission system, very weak and messy output optical signal power intensity could lead to an unacceptable BER in some channels owing to the low optical SNR (OSNR). The G1-BS1 to G4-BS4 average signal power is expressed as signal uniformity flatness = maximum peak power-minimum peak power. The optical carrier spectrum module analyzer measured data, average signal power intensity is  $\geq \pm 5$  dB.

The data show the simulation results using the equalizer to optimize the modified signal and the optical spectrum flatness from 1,530 to 1,560 nm. The average signal power intensity is (uniformity flatness) = maximum peak power - minimum peak power  $\leq \pm 0.1$  dB. The 25-nm bandwidth of the signal amplitude yields a 5-dB spectrum flatness improvement down to 0.1 dB. Therefore, we applied both equalization optimization techniques in the simulation and chose the one that led to better system performance in each case. Figs. 2 and 3 show the optical spectra of the G1-BS1 to G4-BS4 that were selected. The data were selected by simulation using an equalizer to optimize the modified signal.

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FIGURE 2. Optical spectrum without the equalization optimization scheme.

2.5. Amendment of the SOAs and Improvement of the SNR and Signal Gain. The performance of an optical signal receiver depends on the OSNR. The OSNR is defined as the power ratio between the signals and the background noise.



FIGURE 3. Optical spectra with the equalization optimization scheme.

$$Gain_{OSNR} = \frac{PG_{Signal}}{PG_{noise}} = \left(\frac{AG_{Signal}}{AG_{noise}}\right)^2 \tag{1}$$

For clarity, the terms are defined as follows:

P signal power, A signals amplitude, G power gain.

If the OSNR is very low, it might produce unacceptable BER. The analysis shows the following:

$$BER = \frac{1}{2} erfc \left( \sqrt{\frac{OSNR}{2}} \right) \tag{2}$$

To increase the signal power, researchers and communication system providers in the past used the in-line- EDFA to strengthen the attenuated data messages in most communication systems. EDFA is a type of a fiber optic amplifier used to re-amplify an attenuated signal without converting the signal into electrical pulses. This amplification effectively increased the signal power gain and the OSNR. However, the increased signal power gain adversely increased the signal noise gain, as shown in formulas 3.

In-line amplitude system gain.

$$RE_{Inlineamplifer} = \sum_{n=0}^{\infty} \left( Gi^2 k_{an} (EPl_n t_{Signal} + EPjl_n t_{noise}) \right)$$
(3)

$$RE_{Pre-Amplifer} = \sum_{n=0}^{\infty} \left( Gi^2 k_{an} [P_{Signal} + (SEPl_n t_{Signal} + SEPj^* l_n t_{noise}) \right]$$
(4)

In the system design of the communication electronic circuit amplifier shown in formulas 4. (Preamplifier, SOA and EDFA system gains), the added pre-amplifier in the CS-TX prevents interference of the gain by the accumulated noise in the system and effectively strengthens the optical signals, thus increasing the SNR. In addition, in a system transmission channel where the SOAs (which can amplify the signal source with extremely low noise) are connected after the EDFA, the optical signals enter the fiber-optic line after being amplified by the EDFA. This configuration increases the transmission distance of the optical fiber without relay, which can reach over 200 km. If used in the CATV or IPTV-triple play network applications, this configuration ensures an effective distribution of the optical power for a star architecture, which is a point-to-many-points network structure.

The SOA differs from the EDFA in that the amplified modulation of the SOA is based on the fluctuation of the electric current across the components that cover the entire fiber-optic window spectra from 1,250 to 1,680 mm, which results in high gain (approximately 20 dB) [23-24] and faster rise time, small size, and ease of integration in the design of ICs. However, in the high-speed gigabit-per-second system, the semiconductor laser that directly modulates the signal is likely to produce chirps. The combination of the SOA and the EDFA, which amplifies the output power before entering the fiber-optic line, can yield both advantages and complement each other, thereby producing better effect. The combination has been widely applied in the present hybrid ROF communication system, CATV, IPTV-triple play, and data transmission. It will certainly play an important role in the integration of the all-optical communication systems.

## 3. Experimental Results and Discussions.

3.1. Measurement Functions of the Eye-Pattern Analysis. In experiments, the analysis of the signals using the eye diagram is a common indicator of performance in digital transmission systems and can offer insight into the nature of channel imperfections [25-26]. The area contained in the eye diagram is the eye opening, and in the ideal case where the signal crosstalk and the noise between channels are absent and the waveform is without distortion, the "eye" opens the largest and the best signal. The height of the eye opening shows the noise margin of the system. If the eye diagram is not opened clearly, the noise could bring an incorrect estimation and increase the potential for errors. Using these guidelines, the eye diagram can be used to observe the codes' crosstalk noise and to evaluate the advantages and disadvantages of the transport system's performance. Such comparison is done by computing the eye aperture GT (t/bit time) and GV (signal intensity received by the "eye") defined in [27]. It can help predict the performance and identify the source of the system impairments. In this experiment, we recommend using the 160-km transmission for full confirmation. In our study, we have a good, open, clear eye diagram, and an open, round, three-dimensional (3D) eye graph is achieved in our proposed systems, as shown in Fig. 4(a) without suppression-produced crosstalk noise suppression scheme systems.



FIGURE 4. Eye diagram and 3D eye graph of the system (a) without crosstalk and (b) with crosstalk, with fiber length = 160 km.

Furthermore, we obtain the optical signal intensity data, as shown in Fig. 5. The receiving data sequence using G1-BS1 to G4-BS4 are as follows: (a) the ideal "eye" receives the signal intensity. (b) Representative measurements are performed on the received data for levels 0.86, 0.85, 0.80, and 0.78 (a.u), which are the spectral responses of the waveguide signal intensity. Signal after 160 km transmission was

only losses 0.09 (a.u). These data show that the four received optical signals of the G1-BS1 to G4-BS4 have nearly equal intensity. In this experiment, the FTTX ROF-WDM transmission system is very stable with little loss of optical signal intensity. An ideal, open, clear eye diagram is achieved in our proposed excellent systems.



FIGURE 5. Structure of a generic high-speed data communication signal. (a) Ideal judgment eye-received signal intensity. (b) Spectral response of the received waveguide eye signal intensity loss.

3.2. Receiver Sensitivity of the BER Quality Factor. The Q-factor from the BER is calculated numerically by [28]

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{5}$$

A commonly used criterion for digital receivers requires the following:

$$Q(quality) factor \cong 6$$
, to be above  $BER \cong 10^{-9}$  (6)

The measured downlink Q factor curves of the sample rate is 10 GHz, the bit rate is 2.5 GBit/s, the sequence length is 128, and the number of samples is 8,192. The non-return-to-zero pulse data signals from CS to BS3 (120-km fiber links) without and with crosstalk are shown in Fig. 6. At  $Q \cong 6$  for an error rate of  $10^{-9}$ , the received optical power levels for the -18.8 dBm without crosstalk is  $Q \cong 6$ , and that with crosstalk is  $Q \cong 0$ . This quality factor value difference yields better communication signal receive quality performance, results in received optical power reduction, and provides the best sensitivity.

4. **Conclusion.** We have demonstrated the communication system structure of the integrated RoF system consisting of OCDMA and WCDMA from the hardware physical layer to the transmission application layer. The solutions obtained with the integrated RoF-WDM transmission system offer flexible interconnections among the simple multi-standards of the platform and increase network capacity. The high-bandwidth and low-loss optical fiber transmission can be used in densely populated cities and metropolitan areas. Simple antennas can be used for transmission in rural areas. These methods will expand the coverage of mobile broadband, which are the most promising methods to introduce the next-generation integrated service broadband access network. This method will effectively reduce the complexity and the cost of the system.

The proposed "enhanced network quality factors with noise interference elimination over hybrid RoF broadband system" has the potential of achieving more than 160 km of the long-haul microwave fiber link transmission signal for better broadband communication and transmission service qualities. The feasibility of our research is proven by the clear eye diagram and the "enhanced network quality factor."



FIGURE 6. Curves of the Q-factor for different values of power.

Our proposed method will increase the quality and efficiency enjoyed by the end-users, solve design challenges, and grow along with business expansion.

The "Opti-System" system design software experimental simulation of platform that can evaluate and verify new system schemes has been established. A series of key technologies such as the ASE broadband light source, AWG spectrum-slicing technology combined with the dynamic reconfigurable OADM, noise-interference elimination, equalization optimization technology, SOA, WCDMA/OCDMA, and link adaptation that can be applied in the hybrid RoF broadband communication systems have been investigated by the platform. A hybrid RoF cell structure with antennas distributed around the cell through optical fiber connections is being constructed. Some radio resource management "Opti-System" simulation platform schemes related to the hybrid RoF cell structure are being studied. Significant improvement in the system performance is expected to be obtained.

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