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SCM/WDM-PON with in-service baseband embedded OTDR monitoring

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ABSTRACT

Subcarrier Multiplexing and Wavelength Division Multiplexing Passive Optical Network (SCM/WDM-PON) is a promising solution to support Radio over Fiber (RoF) for the convergence of optical and wireless access networks. In this paper, we propose a novel SCM/WDM-PON system with in-service baseband monitoring, which uses an optical carrier to supervise the fiber infrastructure and several subcarriers to transmit data signals simultaneously. The performance of the proposed system is investigated where an embedded baseband Optical Time Domain Reflectometry (OTDR) signal is applied for fiber fault monitoring. The results have verified the feasibility of the proposed system and shown that with proper configuration the in-service baseband monitoring signals have negligible impact on data transmission.

1. Introduction

Optical communication systems using Radio over Fiber (RoF) techniques have been investigated by many research groups [1–5]. This is because the convergence of optical and wireless access systems has attracted much interest for increasing the capacity and mobility in high-speed access networks. Furthermore, the exploding demand for mobile broadband services, the emergence of high-capacity mobile devices and data intensive applications, are forcing mobile networks to continuously evolve to meet capacity and coverage requirements. Technologies such as Long Term Evolution Advanced (LTE-A) and heterogeneous deployment with small cells have been leading telecommunication industry to invest in solutions providing cost-efficiency, large bandwidth, and high reliability. On this scope, Subcarrier Multiplexing (SCM) based transmission is a promising candidate to be applied in optical analog Mobile Fronthaul (MFH) as they can effectively reduce the costs of the network by sharing one optical carrier to transport various radio channels to the cells. Combining SCM with Wavelength Division Multiplexing (WDM) can increase the number of optical channels. Therefore, SCM/WDM-Passive Optical Network (PON) is prominent to support RoF system for the convergence of optical and wireless access networks, particularly for dense areas where hundreds of antennas are used to meet the capacity and coverage requirements.

The development trends in new optical access technologies can be listed as multi-service integration and high bit-rates [6]. All those factors give rise to capacity increase and make a network failure become a critical point for service providers as many end users and a large amount of traffic can be affected at a time. The aim of preventive maintenance is to timely detect and localize any kind of deterioration in the network, which can disrupt services, without dispatching qualified personnel carrying dedicated and often expensive equipment for troubleshooting in the field.

As discussed in [7,8], an efficient monitoring system needs to fulfill the following requirements: (1) be able to quickly detect and localize faults in a cost-efficient way; (2) provide high resolution in distance measurement; (3) be centralized in the Central Office (CO); (4) monitor the network automatically and remotely; (5) avoid/eliminate impact on data transmission; and (6) be

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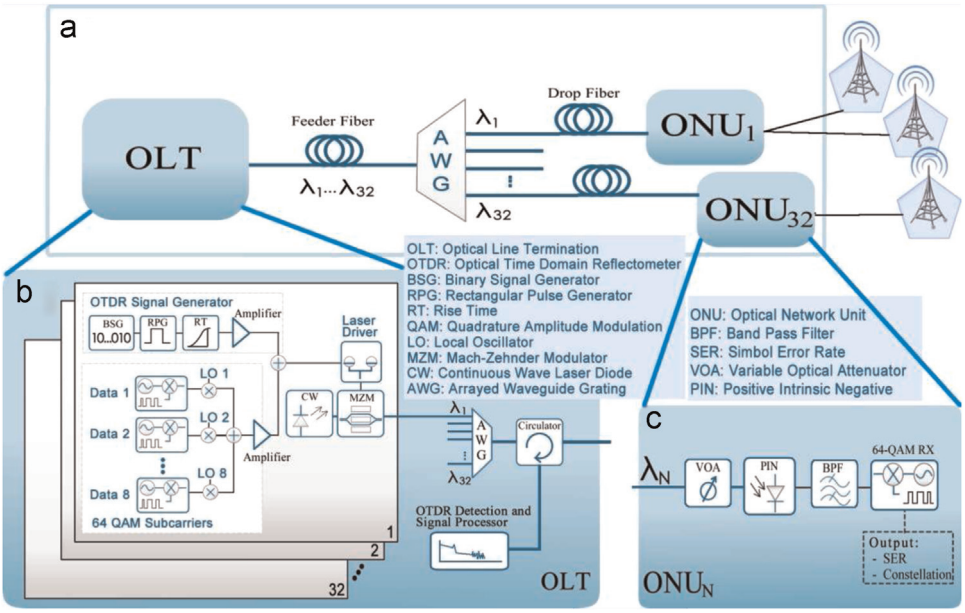

Fig. 1. (a) SCM/WDM-PON system, (b) OLT Setup with in-service baseband embedded OTDR monitoring and (c) ONU scheme.

scalable towards different network architectures.

Many Optical Time Domain Reflectometry (OTDR) based solutions have been proposed to monitor optical access networks up to date. OTDR is widely used for fiber infrastructure monitoring, where an optical pulse is transmitted over the fiber under test and the backscattered light is measured in a time-resolved way. This technique is usually done with a dedicated source utilizing a different wavelength from that used for data. A Tunable Laser OTDR (TL-OTDR) is proposed in [9]. With the integration of optical filters at the fiber ends, the TL-OTDR is able to identify fiber fault not only in the feeder segment but also in the drop link in contrast to the conventional OTDR. In another method proposed in [10] a combined technique of OTDR and Optical Transceiver Monitoring (OTM) is used to monitor power-splitter- and wavelength-splitter-based PONs. The method is applied without additional hardware or software at Optical Network Unit (ONU) side. In [11] the performance of a Tunable Photon-Counting OTDR (T-PC-OTDR) is evaluated for a WDM-PON with an Arrayed Waveguide Grating (AWG) in the Remote Node (RN) proving 32 dB of Dynamic Range (DR) without impact on data signal quality. Paper [12] focuses on SCM/WDM system, where a methodology is proposed for estimating the allowable OTDR light received at ONU. The impact of monitoring signals on data can be avoided by using an extra filter designed to prevent the OTDR light from entering ONU.

All techniques aforementioned use a dedicated source for reflectometry measurements, which increases system complexity (and cost) and decreases spectrum utilization. In this regard, embedded monitoring techniques, i.e., the ones using the same transceiver for both data and monitoring signals, have also been investigated, e.g., in [13–15]. In [13] an embedded OTDR supervision solution is demonstrated, which uses a quasi-continuous OTDR signal modulated on top of the data stream. This solution uses 10% of the relative amplitude for the OTDR signal which limits the DR performance. In order to increase the network and monitoring reach, in-line Semiconductor Optical Amplifiers (SOAs) are used in the field. In [14] the authors devise a technique which relies on data pattern designed in such a way that most of its energy is concentrated in a particular electronic frequency. The received echo is processed using a heterodyne electronic detector circuit. The Optical Frequency Domain Reflectometry (OFDR) is utilized in [15] which dedicates electronic frequency band for monitoring signal outside the baseband. Most of these techniques impose interruption of data transmission in order to perform fault monitoring. Moreover, all these embedded monitoring techniques are not proposed for SCM/WDM-PONs and consequently cannot be directly employed in such a type of PONs.

With all this in mind, we propose a novel SCM/WDM-PON system, which utilizes an optical carrier for fault monitoring of fiber infrastructure and multiple subcarriers for data transmission. By employing OTDR, our system is able to realize quick fault detection and localization, providing high resolution (10 m). The required monitoring equipment is located at central office and hence the proposed system can offer centralized monitoring in a remote way. We show and evaluate the feasibility of the monitoring system with respect to its potential impact on data channels. The results verify that the system can provide an acceptable DR for a SCM/WDM-PON with 32 wavelengths and each having 8 subcarriers while the data transmission is not interrupted and remains negligibly affected. To the authors' best knowledge, a system integrating SCM data transmission and in-service monitoring signal transmission in a common optical source for WDM-PONs, is for the first time proposed and evaluated.

2. Proposed system

The combination of multiplexing techniques of WDM and SCM has been presented in, e.g., [16–18]. It provides efficient fiber utilization for analog MFH and simplified radio heads, i.e., avoiding costly digital-to-analog converters. For the purpose of providing data-agile fiber monitoring solution for such links we propose a concept of baseband embedded OTDR combined with data subcarriers. It enables a single wavelength (and therefore, a single light source) to perform monitoring in parallel with SCM data transmission. The SCM/WDM-PON system is shown in Fig. 1 (a) where the OLT sends multiple wavelengths, each containing several subcarriers for data transmission and baseband for the monitoring signals.

Fig. 1(b) shows the architecture of the OLT. In order to monitor each of the WDM channels until the ONU (where also a radio head is co-located in case of analog MFH), an OTDR signal has been provided in the baseband of each optical carrier. To generate this