Intensity Modulated Remodulation Scheme Based on Single-Sideband Manchester Downstream Signal for Usage in Ring Tree Networks

Abstract — **A successful experimental demonstration of a wavelength agnostic next generation-passive optical network has been demonstrated by means of intensity modulation (IM)-IM remodulation along extended ring reach and with bidirectional tree architecture. The usage of single-sideband formats relaxes the downstream higher data rate signal limitations (imposed by dispersion) and by using Manchester coding the remodulation is improved greatly due to the absence of long "0" patterns. This allows the demonstration of more than 100 km downstream transmission without recurring to forward error correction and a remodulation, almost penalty free up to 140 km (limited by lab facilities available).**

I. Introduction

Passive optical networks (PONs) employ a passive point-to-multipoint topology allowing a good flexibility and scalability of fiber-to-the-home (FTTH) environment [1]. Nowadays, two standards are used for FTTH network: the cost-effective solution, Ethernet PON (E-PON) [2] and the bandwidth and quality of service efficient Gigabit PON (G-PON) [3]. Next generation passive optical networks (NG-PON) tend to achieve full duplex extended reach transmission, higher user density and bandwidth, scalability, flexibility, robustness, resiliency and migration from G/E-PON allowing the coexistence of different generations of equipment in the same network. Recently proposed Scalable Advanced Ring-based passive Dense Access Network Architecture (SARDANA) with wavelength division multiplexing (WDM) two fiber ring and time division multiplexing (TDM) tree with bidirectional transmission provides 100 km reach and 10 Gbit/s symmetrical full duplex transmission [4].

For low-cost realization of SARDANA, a simple architecture of optical network units (ONUs) is requested. This is achieved by using centralized light-generation and colorless ONU based on reflective semiconductor optical amplifier (RSOA), providing 10 Gbit/s downstream (DS) and 1.25, 2.5 Gbit/s upstream (US), while maintaining a completely passive fiber plant by remotely pumped amplification techniques [4]. With this architecture, the DS wavelength received at the ONU is reused as the US data carrier or US is remodulated by the DS signal, thus easing the wavelength management and network maintenance at the ONU side and avoiding the additional and costly light sources in ONUs. Therefore, the assessment of a DS format suitable to provide remodulated US signal for SARDANA system is an open critical issue. Several modulation formats as frequency-shift keying (FSK) [5] and subcarrier multiplexing (SCM) intensity-modulated (IM) [6] formats were suggested as DS, which provide good remodulation of the IM US signal, but for these modulation formats, complex and higher-cost receiver is needed. Recently, the low-cost remodulation of IM by IM formats was proposed with the simple non-return-to-zero (NRZ) [7] DS signal. However, very small extinction ratio of DS signal has to be used to be able to remodulate the US signal. The IM-IM remodulation has been successfully demonstrated by using the inverse return-to-zero (IRZ) and Manchester [8] formats as a DS, which each bit consists of "0" and "1" bits. Therefore, the downstream optical power received at the ONU can be directly remodulated by the upstream IM signal. Since Manchester or IRZ IM-IM remodulation is not based on small extinction ratio of the DS signal, the largest possible extinction ratio of the DS signal can be considered. Moreover, this eliminates the process of erasing the downstream data from the received optical carrier. However, with these modulation formats, the signal bandwidth is significantly increased. The single-sideband (SSB) IM formats have reduced signal bandwidth on half of the standard IM format [9]-[10]. Thus, it is interesting to combine SSB IM format with Manchester code in a purpose to have the best of both: good quality and low-cost remodulation of US signal with compact DS signal bandwidth occupancy therefore with extended reach.

In this paper, we propose to use a line IM format, namely SSB Manchester NRZ as the downstream signal format to facilitate the upstream data remodulation, to reduce signal bandwidth and increase signal's dispersion tolerance at the same time. We have experimentally demonstrated a SARDANA structure with downstream 13.5 Gbit/s SSB-Manchester IM signal. 2.125 Gbit/s US data remodulation on the downstream SSB-Manchester signal was successfully achieved. The remodulation is assessed after tree bidirectional transmission and for various ring fiber lengths.

II. Experimental Set-up

The SARDANA network is used for the experimental set-up as shown in Fig. 1. This network transparently unifies TDM single-fiber tree sections with a main WDM double fiber-ring by passive remote nodes (RN). The WDM is implemented by a double-fiber to avoid main Rayleigh Backscattering impairments. Bidirectional propagation takes place at the single-fiber TDM trees, only 1 wavelength per

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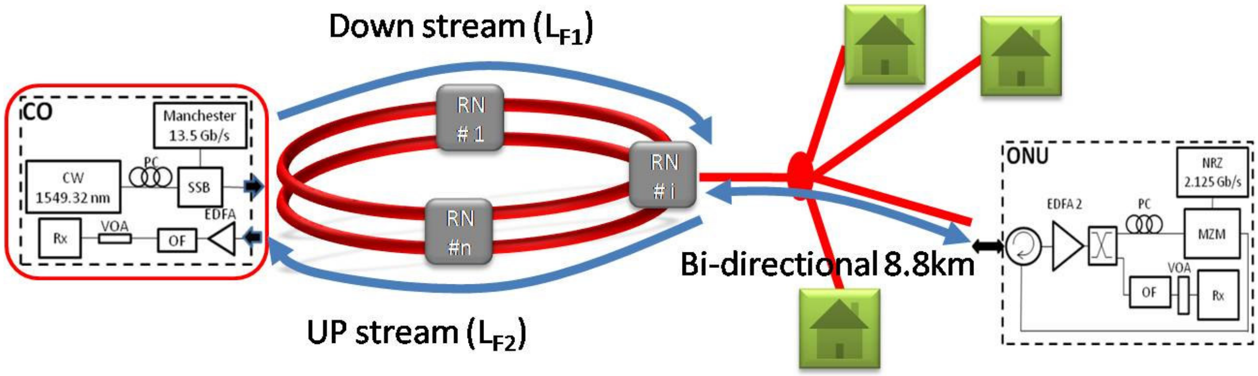


Fig. 1. Block diagram of experimental set-up used for the SARDANA network.

TDM tree is required. Protection and traffic balancing properties of the network are provided by the ring configuration and the design of the RNs, providing always a connection between each RN and the CO even in the case of fiber-cut. The passive RNs implement: Add and Drop function, selecting the operating wavelengths for each TDM tree; the 2-to-1 fiber sections interface; and enables resilience against ring-fiber cuts by means of athermal fixed filters and splitters. Each RN is transparent for the remaining wavelengths, allowing easy scalability of the network.

At central office (CO) (as shown in Fig. 1), the SSB Manchester signal is used as DS. A Manchester signal is obtained by feeding a continuous wave light into a Mach-Zehnder modulator (MZM) driven by a NRZ-shaped radio frequency signal. The 13.5 Gbit/s Manchester NRZ code is generated as in [8], which reaches up to 6.75 Gsymb/s of data rate. The wavelength of 1549.32 nm is used. The SSB signal is generated as described in [9] and has 17 dB of single-sideband suppression and 6 dB of extinction ratio. Downstream traffics are routed from the CO to ONU.

Regarding the ONU equipment, it is intended to be simple and low cost. At the ONU, a portion of received downstream signal power is fed into a PIN for detection, while the remaining power is fed into another conventional MZM for upstream data remodulation. The finite optical power in each bit of the downstream SSB Manchester signal provides the light source for the upstream data. The pseudorandom binary sequences of 2^{23} bits are considered for 2.125 Gbit/s NRZ US signal in ONU to rigorously assess the performance.

The two-fiber ring (one for DS, L_{F1}, and another for US, L_{F2}) consists of up to 140 km standard single mode fiber (SSMF) (attenuation parameter of 0.22 dB/km, dispersion parameter of 16 ps/(nm·km) and the tree line consists of 8.8 km SSMF with bidirectional transmission. In this work, only the ring fibers lengths are varied and the tree fiber is used always with the same length. For all lengths of the ring fiber, even for the ring fiber length of 0 km, the bidirectional tree fiber is always present in the system, except for the back-to-back operation.

Two couplers are used with 4 dB of loss to achieve the bidirectional transmission in the tree-fiber. The 10% coupler is used in ONU to separate the received DS signal and 90% of DS to achieve the remodulation of US signal. The EDFAs placed at CO and ONU are with the maximum capacity and the EDFA at RN sets the power at the tree-fiber input at 10 dBm and the average powers at the ring fibers input are 3 dBm. At the receiver side, an optical filter (OF) of 0.5 nm bandwidth and variable optical attenuator (VOA) are used. The PIN is used at the receiver. The electrical filters of 26 GHz and 2 GHz for DS and US signal are used, respectively.

III. Results and Discussion

To assess the robustness of the proposed remodulated IM US and the SSB Manchester IM DS signals on transmission impairments, the system with different ring fiber length is tested. Fig. 2 shows the measured bit error ratio (BER) of DS signal received at ONU as a function of the average power at the receiver input for different DS ring fiber length (L_{F1}). The average power at the receiver input is adjusted by VOA. In Fig. 2, it can be seen that even with 100 km of ring transmission, BER better than the FEC limit (BER = $2e^{-3}$ - the solid line in Fig. 2) is achieved for all the conditions. As insets figures, the eye-diagrams of the DS signal are shown for 0, 60, and 100 km of L_{F1}. Open eye-diagrams of DS can be noticed even for 100 km of transmission. Thus, high tolerance on dispersion is shown with the proposed SSB Manchester signal.

In Fig. 3 a) insets, the eye diagrams of the remodulated 2.125 Gbit/s US signal by DS for 0 and 140 km of L_{F2} are shown. Very residual degradation due to the remodulation of the 13.5 Gbit/s IM DS is achieved due to the usage of the Manchester code that grants always the existence of power for remodulation. Also, the remodulation penalty is much reduced by using very narrow low-pass electrical filter of 2 GHz of the electrical bandwidth after PIN at the receiver. In Fig. 3 a) is also shown the Q-factor of the remodulated

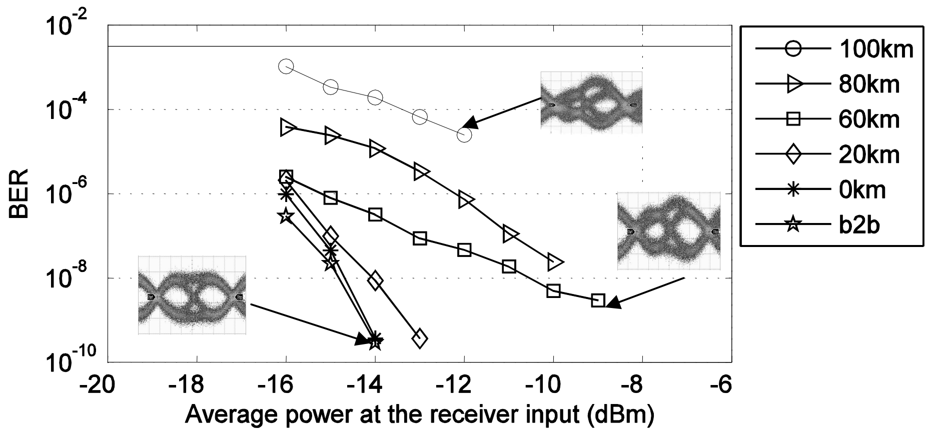
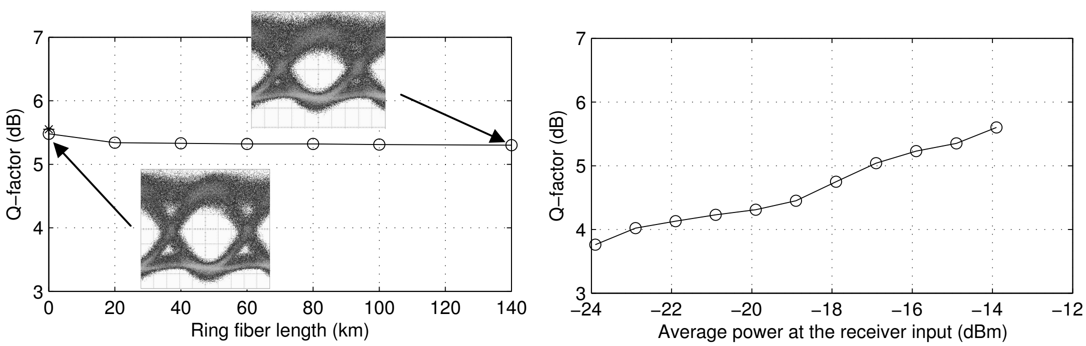


Fig. 2. BER of DS signal received at ONU as a function of the average power at the receiver input for different DS ring fiber length. Insets show the eye-diagrams of the DS signal for 0, 60, and 100km of L_{F1}. The solid line shows the BER FEC limit.



a) b)

Fig. 3. Q-factor (dB) of remodulated US signal received at CO as a function of the a) ring fiber length, L_{F2}, for the average power at the receiver input of 1dBm (‘*’ corresponds to back-to-back regime). Insets show the eye diagrams of the remodulated US signal for 0 and 140 km; and b) average power at the receiver input for L_{F2} = 100km.

2.125 Gbit/s IM US signal measured for different US ring fiber lengths (L_{F2}). It can also be seen that even after 140 km of ring transmission, less than 0.2 dB of Q-penalty is shown compared to the case without the ring fiber and back-to-back regime. Thus, high tolerance on dispersion is shown for the remodulated US signal.

Fig. 3 b) shows the measured Q-factor of US signal received at CO as a function of the average power at the receiver input for L_{F2} = 100 km. The average power at the receiver input is adjusted by a VOA. In Fig. 3 b), it can be seen that considerably high Q-factor is achieved for very small average power at the receiver input.

IV. CONCLUSION

The use of SSB Manchester format as a downstream signal has been proposed to achieve good remodulation in SARDANA systems. By using the IM Manchester coding as downstream signal, the easy remodulation of the upstream signal in low-cost ONUs are achievable without the need for the erasing the downstream data from the received optical carrier. Moreover, this allows using the high extinction ratio of the DS signal. However, increased data rate with Manchester coding is used.

On the other side, the SSB format relaxes the downstream higher data rate signal limitations (imposed by dispersion and increased signal bandwidth). Thus, the combination of these two formats improves greatly remodulation of the upstream signal and transmission performance of the downstream signal simultaneously.

To assess the robustness of the proposed the SSB Manchester IM DS and remodulated IM US signals on transmission impairments, the SARDANA system with different ring fiber length is tested. A successful experimental demonstration of remodulation at 2.125 Gbit/s IM of 13.5 Gbit/s IM SSB Manchester format is shown in ring-tree bidirectional transmission and the extended reach of 140 km is demonstrated with low penalty with the upstream signal and more than 100 km of downstream signal.

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