Bus-Type Optical Access Using DRA and Asymmetric Power Splitters for Accommodating Rural Users

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Abstract: We propose a long-reach bus-type optical access system by using distributed Raman amplification and asymmetric power splitters. The feasibility is experimentally verified by using 10G-EPON and its scale is estimated by bit error rate measurements. © 2020 The Author(s)
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1. Introduction

Passive Optical Network (PON) has been widely deployed in access areas. It typically uses passive double star topology for efficiently accommodating users in residential areas and business districts with high population densities. On the other hand, in rural areas where users are distributed over a wider distance range with relatively lower population densities, PON with the passive double star topology is not necessarily the best solution. In order to provide optical services in such rural areas, it is essential to drastically expand the transmission distance of optical access systems. In addition, we must efficiently accommodate users who are distributed over a wider range of distance.

A bus-type optical access system using asymmetric power splitters [1] is one of the candidates that might meet these requirements. Although a feasibility study is conducted in ref. 1, no study has addressed the possibility of further reach extension and the allowable number of accommodated users. To extend the reach of PON systems, several applications of distributed Raman amplification (DRA) to a star topology have been reported [2-4]. One important issue in applying normal 3-dB power splitters to bus-type networks is that the Raman pump power is halved when passing through 3-dB power splitters, which will reduce the system loss budget.

In this paper, we propose the application of DRA to bus-type optical access networks with asymmetric power splitters to achieve reach expansion. DRA works better because the power loss of the Raman pump can be mitigated through the use of the low loss paths provided by asymmetric power splitters. We experimentally evaluate the upstream transmission performance of a 40 km bus-type 10G-EPON where the users are distributed over three areas that are 10 km, 20 km, and 30 km from a central office. Here, the accumulation of amplified spontaneous emission (ASE) noise also becomes a key technical issue to be solved in addition to the efficient pump power propagation.

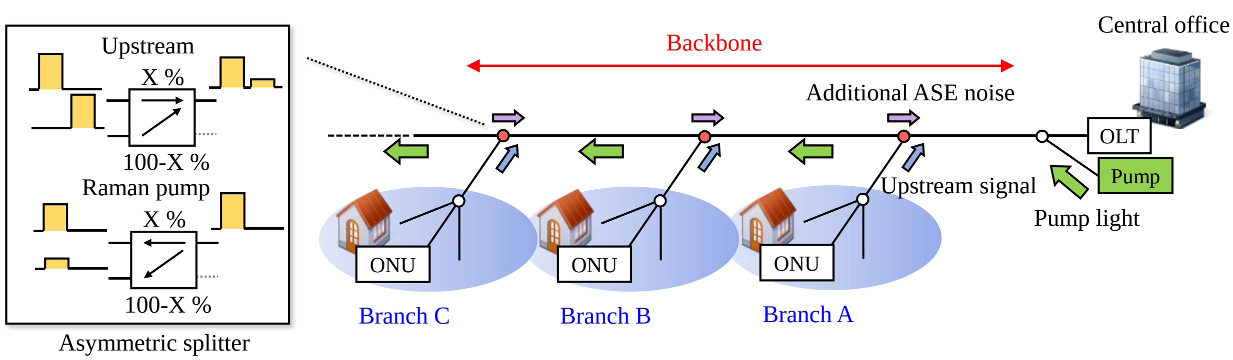


Fig. 1. Proposed bus-type optical access system.

2. Proposed bus-type optical access system using DRA and asymmetric power splitters

Figure 1 shows the proposed long-reach bus-type optical access system. The bus-type topology consists of access branches (lines after drop points) and backbone spans (main lines connecting each access branch). Our proposal sets an asymmetric power splitter at the point of connection between each backbone span and each access branch. Wavelength-independent asymmetric power splitters ([5] developed a wavelength-independent symmetric power splitter covering 1200-1700 nm) as well as wavelength-dependent ones can be applied by considering the wavelength allocation of optical access systems and Raman pump [6]. In this configuration, total transmission loss on the main line can be efficiently suppressed because most of the signal light from optical line terminal (OLT) passes through the backbone fiber at each splitting point. In addition, DRA is also employed to amplify upstream (US) signals. DRA offers better optical noise performance than the conventional pre-amplifier and it can be installed at OLT side, which is very important for greater cost effectiveness. The transmission characteristics of the bus-type optical access system using DRA strongly depends on the length and the loss of the backbone fiber including the losses of the asymmetric power splitters. Furthermore, transmission characteristics can be affected by the ASE noise accumulation in each span. Therefore, we experimentally investigate the transmission characteristics of a bus-type optical access system using DRA with asymmetric power splitters.

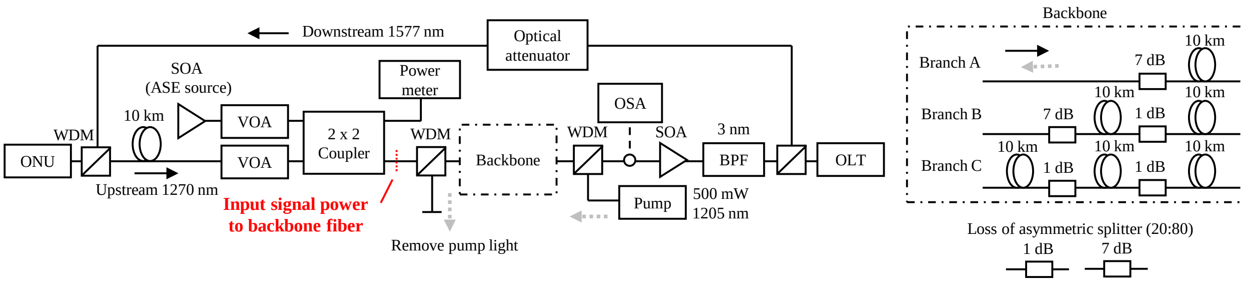
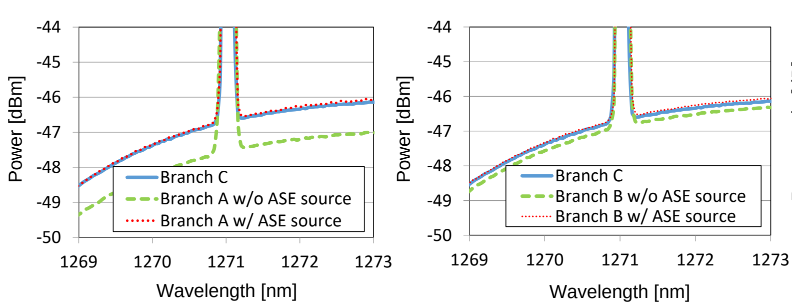


Fig. 2. Experimental setup of upstream transmission.

3. Experiments

To evaluate our proposed configuration, we conducted transmission experiments on a 10G-EPON system (line rate is 10.3125 G bit/s). Here, we employed a 40 km bus-type network consisting of three 10 km access branches (Branch A-C) and a backbone span whose span length between access branches was 10 km (see Fig. 1). The experimental setup to investigate US transmission performance is shown in Fig. 2. US signals transmitted from an optical network unit (ONU) were launched into the access fiber, and passed to the backbone fiber. A Raman pump is launched into the backbone fiber from OLT side to effectively compensate the transmission loss. To mitigate polarization dependent gain, two pump lights with orthogonal polarization are employed. The wavelength and total power of the Raman pump at fiber input were set to 1205 nm and 500 mW, respectively. After propagation, the Raman pump is dropped by a wavelength division multiplexing (WDM) filter placed at the connecting point between the backbone span and the access branch to protect ONUs and ensure users' eye safety. To investigate transmission performance of each access branch, three configurations (depicted as Branch A-C in Fig. 2) were tested. We did not have any wavelength-independent asymmetric power splitters that guarantee the splitting ratio even at the pump power wavelength. Thus, to emulate the loss of an asymmetric power splitter (here the splitting ratio was set to 20:80), attenuators with losses of 1 dB and 7 dB were inserted between 10 km backbone fibers, and between access fiber and backbone fiber, respectively. Since the backbone spans that are further from the OLT than the measured access branch are not connected in the experiment, the impact of the Raman ASE noise that is added to the measured US signal at the asymmetric power splitter cannot be evaluated. Therefore, a semiconductor optical amplifier (SOA) was employed as additional noise source to emulate the Raman ASE noise. The output power of the SOA (noise source) was adjusted by an optical variable attenuator (VOA) so as to match the ASE noise level of Branch A and Branch B to that of Branch C by monitoring the ASE level after transmission using an optical spectrum analyzer (OSA). After transiting the backbone span, US signals were amplified by another SOA used as a pre-amplifier (gain and noise figure of 16.1 dB and 7.6 dB, respectively) and ASE noise was removed by optical band pass filter (BPF) with pass-bandwidth of 3 nm.



(a) Branch A (b) Branch B

Fig. 3. Control of ASE noise level.

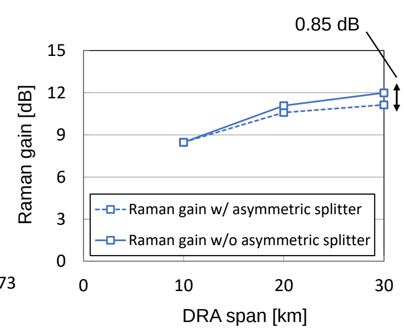
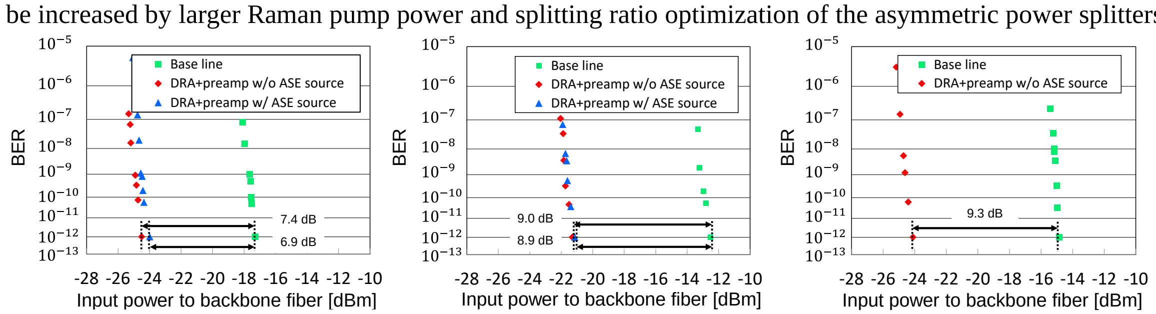


Fig. 4. Raman gain.

In previous work, we showed that this arrangement (Raman pump plus pre-amplifier) improves the system loss budget of a 40 km 10G-EPON system with star topology to 42.5 dB [4]. Extinction ratios of US signals from the ONU and receiver sensitivity (BER=10^{-12}) of the OLT were 6.6 dB and -28.3 dBm, respectively. Loss of fibers used (standard single mode fiber) at 1270 nm was around 4.0 dB/km.

Figures 3 (a) and (b) show measured Raman ASE noise spectra for Branch A and Branch B, respectively. It can be seen that the Raman ASE noise level of Branch A is much less than that of Branch B, thus more ASE noise was loaded in Branch A than Branch B. Fig. 4 shows measured Raman gain. Here, solid and dashed lines indicate the cases without and with 1 dB attenuator emulating the loss of an asymmetric power splitter. As shown in this figure, the proposed bus-type configuration (with 1dB attenuators) attained Raman gains for Branches A-C, of 8.5 dB, 10.6 dB, and 11.1 dB, respectively. Even for Branch C, the gain loss by inserting 1 dB attenuators was just 0.85 dB.

Figure 5 (a)-(c) plot measured BERs for Branches A-C, where 80 percent data traffic is loaded to US signals. Horizontal axis indicates input powers of US signals to backbone fiber as defined in Fig. 2. Squares indicate the base line data gained without employment of the Raman pump, SOA as a pre-amplifier, WDM filters, and BPF. On the other hand, rhombi and triangles indicate the data gained by employing the Raman pump and the SOA as a pre-amplifier without and with ASE loading, respectively. Loss budget improvements for Branch A-C, where ASE noise was not loaded to Branch A and B, were 7.4 dB, 9.0 dB, and 9.3 dB, respectively. In the case of Branch A and Branch B, additional ASE penalties of 0.5 dB and 0.1 dB were caused by the ASE noise loading. As a result, actual loss budget improvements for Branch A-C become 6.9 dB, 8.9 dB, and 9.3 dB, respectively. On the other hand, the minimum input powers to the backbone fiber for bit error free (BER=10^{-12}) transmission of Branch A-C were -24.0 dBm, -21.2 dBm, and -24.0 dBm, respectively. Since the output power from the ONU transmitter for PR30 class, which supports the highest power budget of 10G-EPON, is 4 dBm, the loss budgets of Branch A-C were 28.0 dB, 25.2 dB, and 28.0 dB, respectively. Here, a 10G-EPON system with power budget of 29 dB typically offers 10 km reach and 64 splits. Assuming the splitting loss of a 3 dB splitter is 3.5 dB, the loss budgets required for 32 and 16 split systems are 25.5 dB, and 22 dB, respectively. Therefore, allowable number of users at Branch A-C can be estimated as 32, 16, and 32, respectively. It is expected that the loss budget and the number of accommodated users can be increased by larger Raman pump power and splitting ratio optimization of the asymmetric power splitters.



(a) Branch A (b) Branch B (c) Branch C

Fig. 5. BER vs input signal power.

4. Summary

This paper proposed a long-reach bus-type optical access system that uses DRA and asymmetric power splitters. Its feasibility was experimentally verified by conducting 10G-EPON transmission over a 40-km bus-type optical access network with three branches. We showed that the net improvement in loss budget is 6.9 dB, 8.9 dB, and 9.3 dB, for 20-km, 30-km, 40-km branches (including 10 km access fiber), respectively. Those results indicate the possibility of a long-reach bus-type 10G optical access system accommodating approximately 16 to 32 users in each branch by applying DRA and asymmetric power splitters.

5. References

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