A Low-latency DSM-based ONU Activation Scheme for In-service TDM-PON without Quiet Windows

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Abstract: An activation method using DSM generated electrical tone as the identity of joining ONUs is proposed. The activation requests can be detected and distinguished without a quiet window or degradation on the upstream traffic. © 2022 The Author(s)

1. Introduction

Next-generation mobile networks are expected to incorporate ultra-reliable low latency communication (URLLC) [1]. This requires one-way transport latencies to be less than 100 µs [2]. However, the activation and ranging (AR) process of optical network units (ONUs) in time division multiplexed (TDM) passive optical networks (PONs) may provoke conflict to this requirement. In traditional AR processes, registration of joining ONUs repeatedly pauses the upstream (US) traffic with quiet windows of 250/450 µs duration for 20/40 km differential fiber distance [3]. To address this issue, Whisper Ranging (WR) is proposed to reduce the interruption time of US traffic, and the quiet window can be shortened to 5 µs [4]. The pre-ranging scheme utilizes an additional laser and delay monitoring field (DMF) to measure the relative propagation delay induced by power crosstalk [5]. However, schemes similar to photon ranging, which avoids any modification to the already specified physical layer of ONUs without quiet windows, are still expected to be developed [6].

This paper proposes a novel low-latency ONU activation method to identify joining ONUs. The electrical tone signals of different frequencies can be carried through binary sequences by using delta-sigma modulation (DSM). Thus, the frequency identity information proposed in this scheme can be easily sent by existing ONU physical layer devices such as optical modules. By doing so, no extra complex chips, such as digital-analog converters (DACs), are required [7]. In addition, under the same signal generation power, DSM can create a tone signal with ~30 dB higher SNR over the data signal. Namely, since the useful signal of DSM signal can spectrally “pop up”, the activation request (defined as the “registration” signal) can be detected at very low received optical power without deteriorating the signal quality of operational ONUs (defined as the “data” signal). Results of a proof-of-concept experiment show that the proposed scheme can detect the frequency identities of joining ONUs at different distances in an optical distribution network (ODN) consisting of a 25km fiber link and a 1:32 splitter. Moreover, the bit error rate (BER) of data signal maintains at the same BER level (~1e-3) with or without the registration signal.

2. Operation Principles

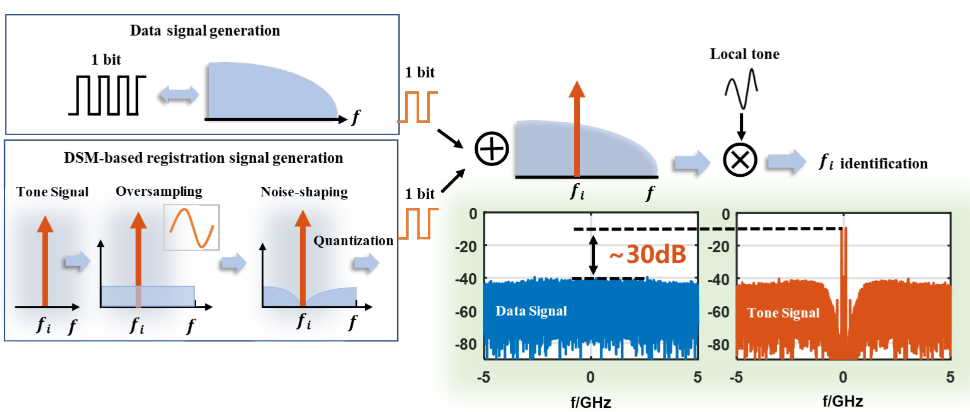


Fig. 1. Schematic diagram of the proposed low-latency ONU activation scheme.

At the ONU side, each joining OUN is assigned a certain frequency as its identity. We use DSM to generate tone signals with different central frequencies into bit sequences [8]. The processes of DSM are as follows: Firstly, delta-sigma modulator digitally oversamples the tone signal to expand the area of quantization noise, and then pushes quantization noise out of the signal band through noise shaping. After 1-bit quantization, the tone signal is converted into OOK signal. Therefore, the registration information carried by electrical tone can be sent by existing optical modules without adding any additional components. The spectrum of the superposition of delta-sigma modulated sinusoidal signal and data signal at the same power is shown in Fig.1. It can be seen that the delta-sigma modulated signal can spectrally "pop up" above the data spectrum with ~30dB higher SNR. This makes it possible to recover the "pop-up" frequency part of the signal at very low received optical power. To prevent significant power penalty on the data signal itself, the registration signal needs to be superimposed on data signal at a very low launch power, and they are transmitted together to the OLT. At the OLT side, the upstream data signal can be retrieved from the combined signal. The registration signal can be identified from the combined signal by multiplying with the local tone signal. Finally, it is normalized and compared with a threshold to determine whether there is a registration request. Different ONUs can be distinguished by selecting different tone frequency.

3. Experimental setup

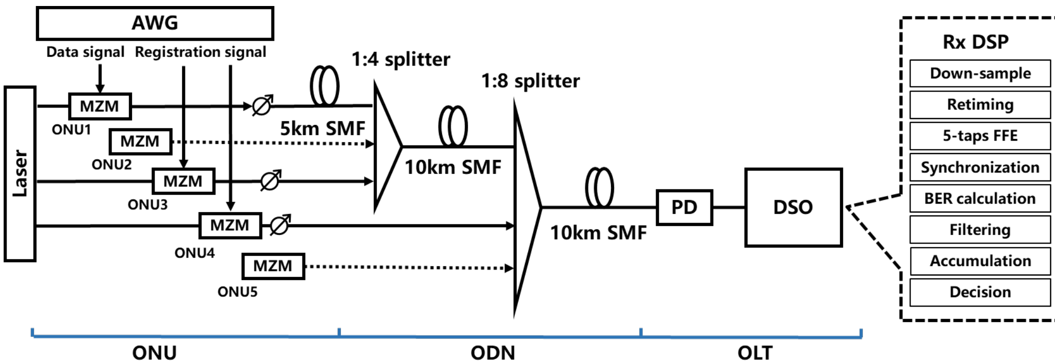
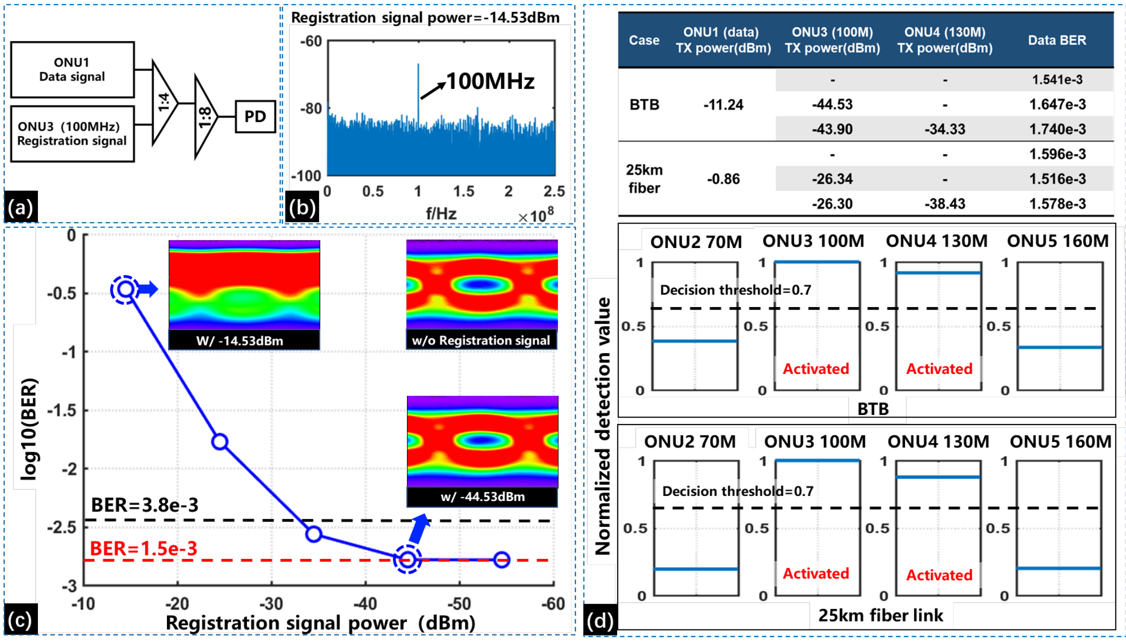


Fig. 2. Experimental setup.

Fig. 2 shows the experimental setup for the proposed DSM-based low-latency ONU activation scheme. The identification tone frequency allocated to the upcoming ONU2 to ONU5 are 70MHz, 100MHz, 130MHz, and 160MHz, respectively. The 10Gb/s OOK signal of operational ONU with sequence lengths of 2e5 is generated by an arbitrary waveform generator (AWG, Keysight M8195A) working at 30 GSa/s. The binary DSM signals of joining ONUs are generated offline and then sent into the AWG, which simulates the ONU ports with 10GS/s sampling rate. The signals are carried by multi-channel 1550nm CW lasers with Mach-Zehnder modulators (MZMs). A variable optical attenuator (VOA) is cascaded after each MZM output to adjust the launch power. Two-stage splitters are cascaded by 10-km single-mode fiber (SMF) to simulate the ONU activation situation in actual PON. At the OLT side, a combination of APD and trans-impedance amplifier (TIA) (Oclaro AT10EC-J57) is used for optical-to-electrical (O/E) conversion. The combined electrical signal is captured by a digital sampling oscilloscope (DSO, LeCroy SDA 830Zi-A) and processed offline in MATLAB. For data signal recovering, after resample and retiming, a T-spaced 5-tap feed forward equalizer (FFE) is adopted.

4. Results and discussions

In order to evaluate the influence of the registration signal in the proposed scheme on data signal, a setup shown in Fig. 3 (a) is used for experimental exploration. Fig. 3 (c) depicts the relationship between launch power of a single registration signal (ONU3) and BER of the data signal. Initially, the launch power of data signal is fixed at -11.24dBm and the corresponding received optical power (ROP) is -27.78dBm. The BER of data signal without registration signal interference is 1.541e-3. The corresponding BER level and the eye diagram of the OOK signal at this time are marked and displayed in Fig. 3 (c). It can be seen that as the launch power of registration signal increases, the BER of data signal continues to deteriorate. Only when the launch power of registration signal is lower than -44.53dBm, the BER of data signal can be maintained at the initial level of 1.541e-3. Fig. 3 (b) shows the electrical spectrum of the frequency of interest of the received signal when the launch power of registration signal is -14.53 dBm. The 100MHz frequency point corresponding to ONU3 "pops up" in the data signal spectrum. In addition, the eye diagrams of data channel OOK signal at the registration signal launch power of -14.53dBm and -44.53dBm are attached.



Case	ONU1 (data) TX power(dBm)	ONU3 (100M) TX power(dBm)	ONU4 (130M) TX power(dBm)	Data BER
BTB	-11.24	-	-	1.541e-3
		-44.53	-	1.647e-3
		-43.90	-34.33	1.740e-3
25km fiber	-0.86	-	-	1.596e-3
		-26.34	-	1.516e-3
		-26.30	-38.43	1.578e-3

Fig. 3. (a) Explorative experimental setup (b) Electrical spectrum of the received signal, (c) BER performances of data signal vs. different launch power of registration signal, and eye diagrams of the received signals, (d) BER of data signals corresponding to different registration signal launch powers and results of detecting and distinction registration signals for back-to-back and 25km fiber link.

Bottom half of Fig. 3 (d) shows the results of the proposed detection scheme under the worst condition of both cases, that is, when multiple ONUs need to be activated simultaneously. A horizontal line is used to indicate the level of the test. We set the decision threshold at 0.7. Both activation requests of ONU3 and ONU4 can be detected and separated. The launch power and BER of the data signal and joining ONUs signal corresponding to the test results are shown in the table at the top of Fig. 3 (d). As can be seen from the table, when the registration signal is detected and correctly distinguished, the BER of all data signals remains at the level without interference of the registration signal.

5. Conclusions

A novel low-latency ONU activation method is proposed to identify joining ONUs. The electrical tone signals of different frequencies can be carried through binary sequences generated by DSM. The frequency identity information can be easily sent by existing ONU modules. The experimental results show that the target ONUs can be activated through two-stage splitters and 25-km fiber without causing power penalty on the data signal.

Acknowledgements

This work was supported by the National Key R&D Program of China (2021YFB1808200)

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