Low-cost Asymmetric Point-to-multipoint Coherent Architecture for Access Networks

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Abstract: We propose a low-cost asymmetric point-to-multipoint coherent architecture for access networks. In this architecture, the coherent transmitters for the unlink are greatly simplified and the tolerance to laser frequency offset is significantly improved. © 2022 The Author(s)

1. Introduction

Driven by the demand of increasing data rates and massive interconnections in access networks, novel transmission architectures with lower cost and latency are needed [1]. The point-to-multipoint (PTMP) coherent architecture has attracted increasing attention as a promising solution for access networks, including 5G-Xhaul and passive optical networks [2, 3]. This architecture substitutes several low-speed transceivers with a high-speed coherent transceiver on the convergence side. Combined with the digital subcarrier multiplexing (DSCM) technology, the PTMP coherent architecture has the advantages of high router efficiency, high flexibility, and reduced operating expense (OpEx) [4, 5]. Despite the above advantages, the cost of coherent transceivers will be an important issue for the PTMP coherent architecture when applied in access networks. Some researches have been conducted for low-cost coherent solutions in short-reach transmission [6-8]. However, they are targeted for a point-to-point (PTP) transmission scenario and may not be suitable for PTMP access networks.

In this paper, we first propose an asymmetric PTMP coherent architecture for access networks, which employs a dual-polarization four-level pulse amplitude modulation (DP-PAM4) transmitter for the uplink communication to save cost and power consumption. Compared to the DP quadrature phase shift keying (DP-QPSK) system of the same date rate, additional 3.5 dB link budget can be achieved. Secondly, based on the asymmetric architecture, we propose a pilot-tone-aided frequency aliasing recovery (FAR) algorithm. This algorithm enables the adoption of low-cost lasers with large frequency offsets (FO). The simulation and experiment results show that the tolerance of FO is up to nearly half of the symbol rate.

2. The Proposed Architecture and Algorithm

2.1 Low-cost Asymmetric PTMP Coherent Architecture

The uplink communication of the proposed architecture is shown in Fig. 1 (a), where *N* spokes independently transmit subcarriers to the hub. Different from the downlink which sends DP-QPSK signals, the transmitters of spokes in our proposed architecture are simplified to send DP-PAM4 signals, making this architecture asymmetric. Compared with a DP-QPSK transmitter, the DP-PAM4 transmitter halves the numbers of DACs and RF drivers, and replaces two IQMs with two Mach-Zehnder modulators (MZMs). This simplification is very beneficial for access networks since the spokes are more sensitive to cost and power consumption. Moreover, the reduced number of IQ splitters and combiners in the modulators can help to avoid 6 dB power loss, which is significant in power-constraint short-reach scenarios. Fig. 1 (b) compares the receiver sensitivity of the DP-PAM4 system and the DP-QPSK system in simulation. When transmitting the same data rate, the DP-PAM4 system has about 2.5 dB received optical power (ROP) penalty compared with the DP-QPSK system at the forward error correction (FEC) threshold is 1.25×10^{-2}. However, since the output power of the DP-PAM4 can be 6 dB higher as explained above, the DP-PAM4 system actually improves the link budget by 3.5 dB compared to the DP-QPSK system.

2.2 Frequency Aliasing Recovery (FAR) Algorithm

To further reduce the cost of transmitter at the spoke side, we propose a pilot-tone-aided FAR algorithm implemented in the above architecture to improve the tolerance of FO. In the PTMP coherent architecture, subcarriers from different spokes are coupled to one light path in the optical domain. The different FOs of these subcarriers may cause frequency aliasing between two subcarriers and result in transmission failure. To ensure successful transmissions, sufficient guard band must be reserved. In particular, two times of the maximum laser FO should be reserved between the adjacent subcarriers, which causes a waste of bandwidth of the receiver at the hub side. With the proposed FAR algorithm, the tolerance of FO can be up to half of the symbol rate, which significantly saves the receiver bandwidth at the hub. The process of the proposed FAR algorithm is detailed as follows.

The schematic diagram of the FAR algorithm is illustrated in Fig. 1 (c) and the overall digital signal process (DSP) of the proposed architecture for the uplink communication is shown in Fig. 1 (a). At the transmitter, each spoke generates and transmits a real-valued subcarrier combined with a pair of conjugated pilot tones. The spectrum of the transmitted signals is conjugate symmetric. At the receiver, when the subcarrier is frequency aliased, we extract the pilot tone on the unaliased side to estimate FO and laser phase noise. By utilizing the conjugate symmetry of the transmitted signals, we copy the half of the unaliased signals and flip the conjugate of it to substitute the aliased side. This operation completely avoids the impact of FO as long as it is smaller than half of signal bandwidth at the cost of some performance penalty.

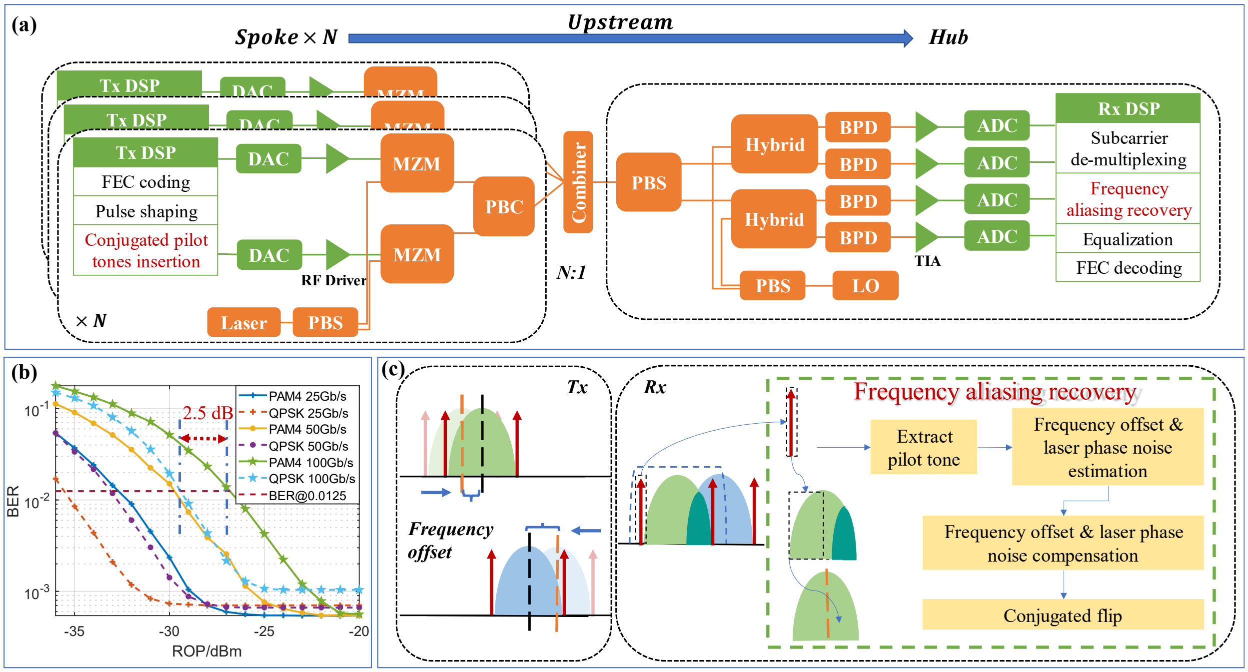

Fig. 1. (a) The uplink of the low-cost asymmetric PTMP coherent architecture; (b) Receiver sensitivity of DP-PAM4 and DP-QPSK systems; (c) Schematic diagram of the FAR algorithm.

3. Numerical and Experimental Results

Without loss of generality, we simulate two subcarriers to verify the benefit of the proposed FAR algorithm. The data are modulated on each subcarrier and pass through a root raised cosine (RRC) filter with a roll-off factor of 0.02. Then the conjugated pilot tones are inserted beside the subcarriers. After passing through a combiner, the two subcarriers are multiplexed in frequency domain. At the receiver, the multiplexed subcarriers are received coherently and digitally processed. In the receiver DSP, the subcarriers are first de-multiplexed digitally. Then, the proposed FAR algorithm and least mean square (LMS) based adaptive equalization are used to recover the signals. For coherent transceivers, the linewidths of lasers at the transmitter and receiver are both set as 100 kHz. We set the responsivity of the photodiode (PD) as 0.8 A/W, the dark current as 5×10^{-9} A and power spectral density of thermal noise as 14×10^{-12} W/Hz.

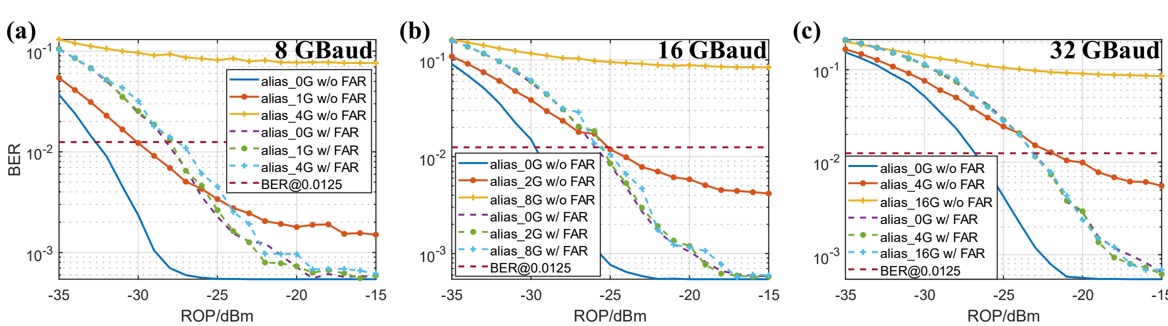

Fig. 2. Simulation results of BER versus ROP with different frequency aliasing for symbol rates of (a) 8 GBaud; (b)16 GBaud; (c) 32 GBaud.

We first simulate the performance of two subcarriers with the modulation format of PAM4 under different frequency aliasing. The curves of BER versus ROP for symbol rates of 8 GBaud, 16 GBaud and 32 GBaud are shown in Fig. 2 (a), (b) and (c), respectively. Without the FAR algorithm, the system can only tolerate the aliasing of no more than 1/8 (1/8, 2/16, 4/32) of the subcarrier spectrum. With the FAR algorithm, the system can tolerate a large FO up to half of the spectrum. When there is no frequency aliasing, the FAR operation induces about 4 dB ROP penalty at the FEC threshold of 1.25×10^{-2}. This is because half of the signal spectrum is cut during the FAR operation and the noise destroys the conjugate symmetry characteristic.

The performance of the FAR algorithm is also evaluated in experiments. The experimental setup is shown in Fig. 3 (a). Limited by the number of transmitters, we conduct PTP transmission with two subcarriers as a proof-of-concept experiment. At the transmitter, each subcarrier is modulated as 10 GBaud PAM4 and then passes through a RRC filter with a roll-off factor of 0.02. To emulate the FO aliasing between subcarriers in the optical domain, we add FO in the offline DSP before multiplexing subcarriers. The multiplexed subcarriers are converted into analogue signals via an 80 GSa/s arbitrary waveform generator (AWG). Then, a dual-polarization IQM (DP-IQM) modulates the signals using a tunable laser with a nominal linewidth of 100 kHz at a central wavelength of 1550 nm. An erbium-doped fiber amplifier (EDFA) is added to amplify the signal. The length of standard single mode fiber (SSMF) is 10 km. At the receiver side, a variable optical attenuator (VOA) is applied to change ROP. After an integrated coherent receiver (ICR), the signals are sampled via a 100 GSa/s digital storage oscilloscope (DSO). The offline DSP at the receiver is the same as the above simulations shown in Fig. 1 (a). The experimental results of BER versus ROP with different FOs are shown in Fig. 3 (b). By using FAR algorithm, the system can tolerate 5 GHz frequency aliasing, which is equal to half of the signal bandwidth. Due to the impact of residual laser phase noise, IQ errors and other jitters in the system, the ROP penalty increases to 6 dB.

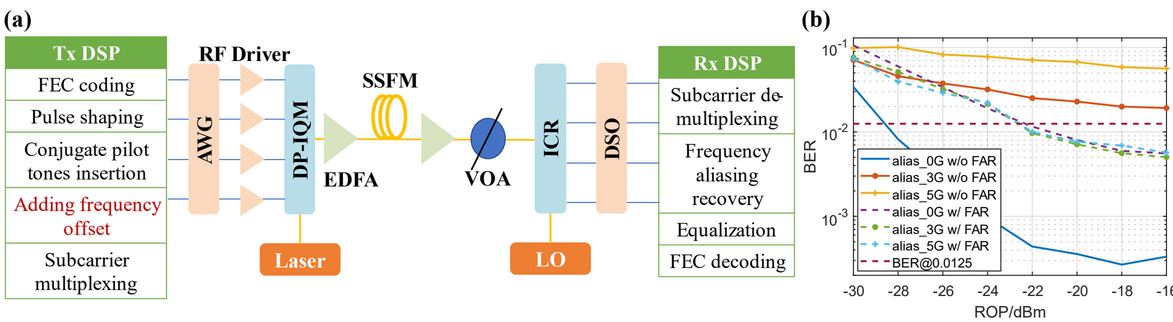

Fig. 3. (a) Experimental setup; (b) Experimental results.

4. Conclusions

In this paper, we proposed a low-cost asymmetric PTMP coherent architecture combined with a FAR algorithm for uplink communication in access networks. Compared with the traditional coherent system, the transmitter components in our architecture can be significantly reduced and the link budget can be improved. In addition, with the proposed FAR algorithm, a large FO can be tolerated, saving the receiver bandwidth at the hub. Simulations and experiments show that even when half of the signal spectrum is aliased due to FO, the signals can still be recovered.

5. Acknowledgement

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6. References

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