Simplified PON with a dedicated bandwidth for upstream traffic for surveillance services

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SUMMARY Passive optical networks (PONs) have been mainly applied in fiber to the home (FTTH) networks. PONs can be also deployed in communication infrastructure in addition to various other fields. Originally, the transfer of downstream traffic was prioritized in PONs. However, to expand the application fields, a dedicated bandwidth needs to be assigned for upstream traffic. This study proposes a simplified mechanism with a dedicated bandwidth for upstream traffic for application in surveillance services as one of typical Internet of things (IoT) services. After a survey of the technical and standardization trends of PONs, this paper describes the proposed mechanism and its performance evaluation in consideration of real-life deployments.

Keywords: *PON, Optical Access Network, Dedicated Bandwidth, Traffic Aggregation, Surveillance service.*

1. Introduction

Originally, the passive optical network (PON) has been deployed to fiber to the home (FTTH) networks, because it makes for easy operation and a reduction in the number of optical fiber footprints in central offices. However, in recent times, its field of application has been expanded. For instance, it can now be applied to Internet of things (IoT) services, as reported in [1] and [2]. Reference [1] proposed new functionalities for IoT services through 5G mobile infrastructure aggregated by PONs and indicated the performance of bandwidth allocation (DBA). Reference [2] proposed energy efficient IoT services over PONs. The current study proposes the upstream traffic aggregation of surveillance services using a PON.

First, we survey the technical and standardization trends of PONs and clarify the requirements for traffic aggregation of such services. Then, we propose a new mechanism of a PON in compliance with the surveyed requirements and conduct a performance evaluation in consideration of real-world operations.

2. Survey of the technical and standardization trends in PON

The PON is configured as a point-to-multipoint topology using passive (i.e., unpowered) fiber optic splitters to split the single fiber bandwidth between endpoints, as shown in Figure 1, for FTTH. Generally, in downstream traffic, a broadcast with encryption is applied to each optical network unit (ONU). In upstream traffic, although dynamic bandwidth allocation (DBA) and optical burst multiplexing are applied, a dedicated bandwidth independent of other traffic flows is not provided.

The PON has been standardized by the **International Telecommunication Union** – Telecommunication Standardization Sector (ITU-T) and **Institute of Electrical and Electronics Engineers (**IEEE) [3], as shown in Figure 2. The bandwidth of downstream traffic is prioritized and expanded. The bandwidth of upstream traffic is shared among the ONUs using time-division multiplexing (TDM). In Figure 2, the first-generation PONs uses pure TDM for upstream access control. The second-generation of PONs integrate hybrid technologies via TDM and wavelength division multiplexing (WDM). Therefore, the standardization load map does not include a PON with a dedicated bandwidth for upstream traffic; for example, in the case of a pure WDM [4].

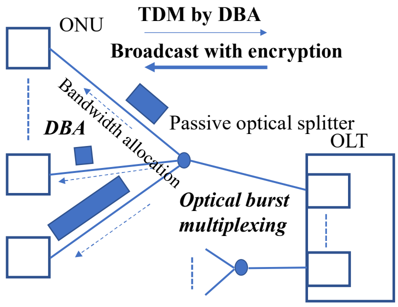

Fig. 1 System architecture of PON and its features

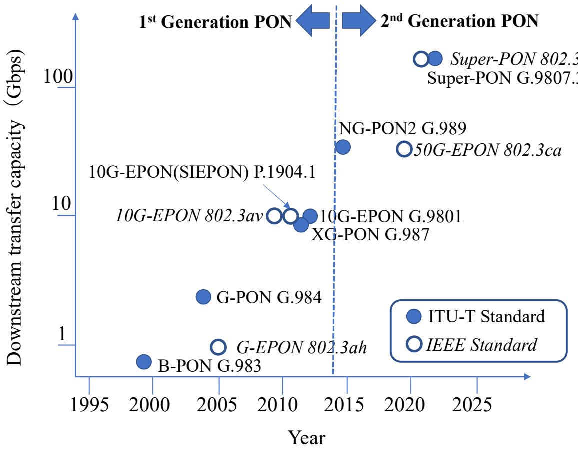

Fig. 2 Overview of standardization on PON

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3. Surveillance services using PON

Recently, various IoT services have been developed. One generic service is surveillance that involves the use of networked cameras based on IP [5]. The market size of this service continues to increase, as indicated in an estimation published in [6]. In [6], this market size is estimated to grow at a compound annual growth rate (CAGR) of 15.7% from 2020 to 2027. In a similar report, the market size of surveillance cameras has expanded to 10% per year since 2021 [7]. Moreover, the resolution of surveillance cameras has been enhanced, e.g., 4k base surveillance cameras. Cameras for multi-view point video has been popularized. Reference [8] surveys networked cameras for IoT services. In these situations, traffic volume seems to be increased.

In this situation, traffic aggregation in these services should be considered. One of the reasonable solutions is that the PON plays the role of such an aggregation from a physical configuration point of view, because traffic flows in these services center on servers from remote cameras, as shown in Figure 3. For example, surveillance cameras mounted on electric poles are the base stations for road monitoring services [9]. In this case, video traffic can be aggregated on PONs.

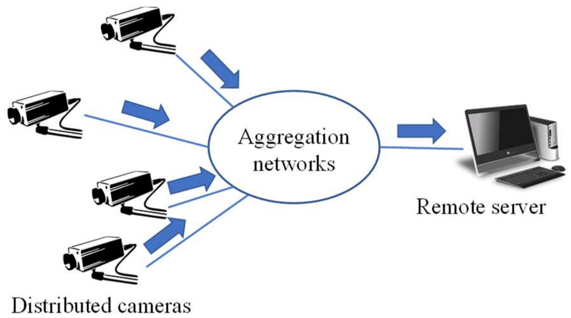

Fig. 3 System configuration of a surveillance system

However, in a conventional PON architecture, the shared bandwidth for upstream traffic and the smaller bandwidth for upstream traffic are less than those for downstream traffic. Although a dedicated bandwidth for upstream traffic has been developed by WDM technologies [4], this approach is not cost-effective. Therefore, a business case is established for a cost-effective PON architecture with a dedicated bandwidth for upstream traffic.

4. Proposals using PON with a dedicated bandwidth

This section proposes a simplified PON system with a dedicated bandwidth for upstream traffic, referred to as a subcarrier digital modulation PON (SDM-PON). This system is based on multiplexing and uses subcarriers, wireless network technologies, and digital modulation. The approach here is similar to multiplexing using WDM, that is, a WDM-PON. However, because this approach does not require WDM filters or arrayed waveguide gratings (AWGs), it cost-effective. The architecture of the SDM-PON for upstream traffic is shown in Figure 4; the optical spectrum for the multiplexing of 32 ONUs on the upstream traffic using a subcarrier is also indicated. Each ONU transfers information using a subcarrier assigned to the O-band aligned to the ITU-T standard. The O band was assigned for upstream traffic in earlier types of PON [10].

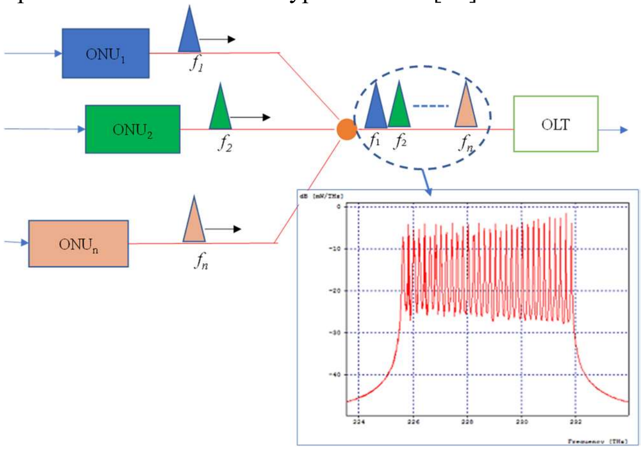

Fig. 4 Architecture of SDM-PON for upstream traffic

Figure 5 shows relationship between the wavelength applied to SDM-PON and the optical signal modulated with 16 QAM. The wavelength interval D is set to 0.8 nm (about 140 GHz). Therefore, the subcarrier frequency at ONUi, f_i, is derived from *Equation (1)*.

$$f_i = 2.8 + 0.8 \times (i - 1) \quad (1)$$

Subcarrier frequencies are alternately assigned to wavelengths such that the minimum value of interval d_n is maximized, as introduced in [11]. The interval indicates the bandwidth between the upper sideband and the lower sideband of the optical signal modulated by quadrature amplitude modulation (16 QAM) of adjacent subcarriers. This parameter setting has to be considered because some errors occur owing to interference when the interval d_n between the upper sideband and the lower sideband modulated by the adjacent subcarrier becomes lower than 110 GHz. To solve this problem, the wavelength interval D is increased to 200 GHz such that the interval d_n is always 110 GHz or higher.

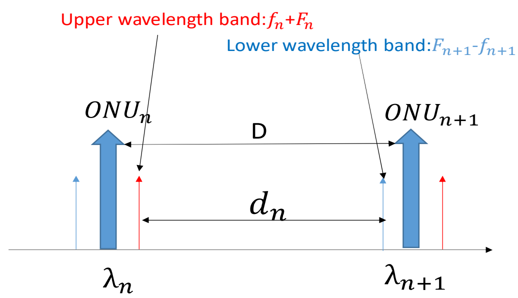

Fig. 5 Assignment of subcarrier intervals

In the SDM-PON, several options have been researched by the authors, see [12] and [13], which are categorized into bias transmission, that shifts levels, and clip transmission, that abstracts only positive parts of the signal, as shown in Figure 6. In this study, a clip transmission scheme was applied as the basic option. The operation of this scheme is illustrated in Figure 6(b). To improve the efficiency of the optical transmission power, the negative component of the electric 16QAM signal was removed, and only the positive component of the signal was transmitted. Because the clip transmission does not transmit the negative component, low power consumption of the ONU was realized. Figure 7 shows a detailed block diagram of the OLT in the proposed operation.

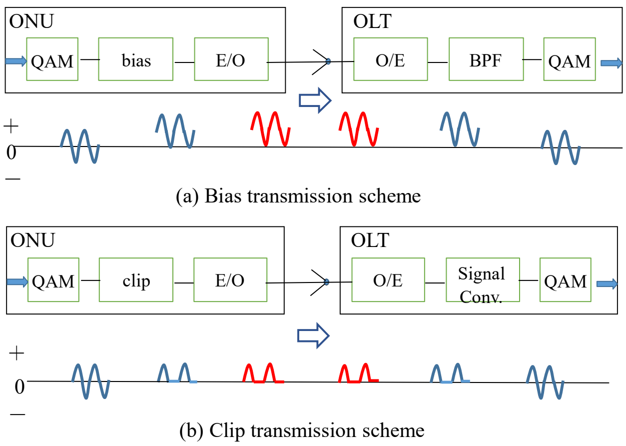

Fig. 6 Basic options on transmission schemes in SDM-PON

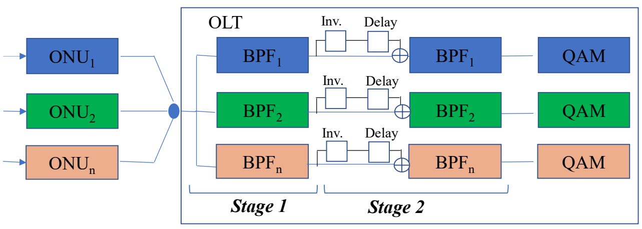

Fig. 7 The block diagram of an OLT in the proposed SDM-PON

These operations consist of two stages. In Stage 1, the multiplexed clipped signal on the optical splitter is demodulated after the first bandpass filter (BPF) for each ONU. In Stage 2, the signal is inverted and delayed. This signal is then added to the original signal and passed to the BPF. The delay in the signal of each ONU, τ, is derived using *Equation (2)*.

$$\tau = \frac{2i+1}{2f_i} \quad (i = 1, \dots, N) \qquad (2)$$

5. Performance evaluation

In surveillance systems, two service scenarios are considered, as shown in Figure 8. In Figure 8(a), one surveillance camera is connected to one ONU. However, in practice, multiple cameras can be connected to a single ONU through local networks.

Service scenario 1 intends to monitor specific areas as a type of a smart city service. In this scenario, ONUs with surveillance cameras are randomly deployed, and the distances between the optical splitter and ONUs are varied, up to 20 km. Service scenario 2 intends to monitor roadsides. In this scenario, the distances between the optical splitter and ONUs are linear because they are deployed along the road.

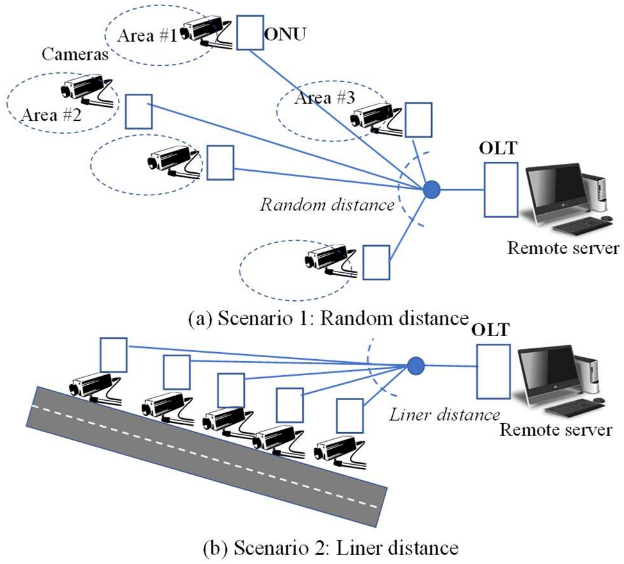

Fig. 8 Performance evaluation mode

Table 1 Key parameters for performance evaluation

The number of ONUs	8
Reach between OLT and ONUs	OLT—Splitter 1km. Splitter-ONU: 1 – 20km Scenario 1: Uniform distribution in [1, 20] km on each ONU Scenario 2: Equal distance in [1, 20] km from ONU#1 to ONU#8
Transmission rate	1Gbps bidirectional per ONU
Digital modulation	16QAM
Peak power of optical source	10dBm
Fiber loss of single mode fiber	0.34dB/km
Dispersion-slope of optical fiber	0.08 ps/nm^2/km
Splitter loss	1dB

The performance evaluation was performed using an optical transmission simulator [14]. The key conditions for the evaluation are listed in Table 1.

The results of the evaluation focusing on eye-opening rate are described in Table 2. In Scenario 1, there were four trials.

Table 2 List of eye-opening-rate (%)

	ONU							
	#1	#2	#3	#4	#5	#6	#7	#8
S. 1	66	66	70	92	57	84	76	84
	79	72	81	87	58	87	74	85
	60	83	75	68	91	76	82	77
	85	40	82	81	70	71	76	87
S. 2	78	78	80	78	63	61	65	52

Figure 9 shows the confidence intervals on 95%. Even in the worst case, the eye-opening rate that can be ensured is 38%. This case provides error-free transmission.

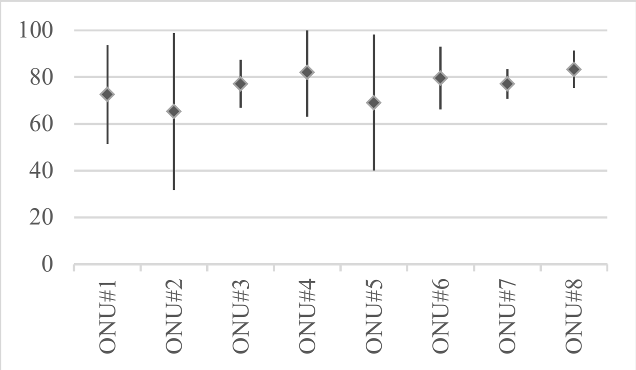

Figure 9 Confidence intervals on 95% of eye-opening rate (%) in Scenario 1

6. Conclusions

This study proposes a surveillance system that uses PON technologies. We propose a novel mechanism with a simplified and dedicated upstream bandwidth and refer to it as SDM-PON. We have evaluated the performance of the proposed mechanism, focusing on the eye-opening rate in two deployment scenarios, and have concluded on its suitability for use in surveillance systems.

Originally, PON technologies were applied to wide-area broadband services, such as FTTH. However, its advantages can be applied to other services such as traffic aggregation for utility services.

As a future research direction, a detailed performance evaluation of the SDM-PON should be conducted. Redundancy should be promoted at the system level.

Acknowledgments

The authors would like to thank Professor Hiromi Ueda of an emeritus professor in the Tokyo University of Technology for his guidance on PON and related technologies.

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