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Research on Digital Network Communication System for Distribution Network Based on Improved EPONs

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Abstract. *The characteristics of various communication services in distribution network include large amount of data, wide coverage and high signal stability requirements. In addition, the performance requirements of communication equipment are strict, and it is necessary to ensure the reliability, real-time and security of data transmission. Aiming at the features of many kinds of communication services and strict performance requirements of distribution network, a digital network communication system for distribution network on the ground of enhanced Ethernet Passive Optical Networks (EPONs) is studied. Firstly, the dynamic bandwidth allocation algorithm of EPONs is optimized, relied on the characteristics of network traffic autocorrelation, the periodic network traffic is predicted, the threshold value is dynamically set and sent in advance, the services are classified according to the order of priority and the bandwidth allocation is calculated. Then, on this basis, the enhanced EPONs technology is adopted to build a digital network communication system for distribution networks, which includes data communication wiring, communication network organization, topology design based on the improved EPONs and bandwidth allocation. Finally, a simulation model of the distribution network system is built up, and the improved scheme and the comparison scheme are implemented in the OPNET simulation environment, and the outcome indicates that the suggested method has better performance in terms of network delay and bandwidth utilization, which greatly enhances the effectiveness and reliability of the digital distribution network.*

Keywords: Distribution network; Ethernet Passive Optical Networks; bandwidth allocation; network topology; data communication

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1. **Introduction.** Distribution network is the network that distributes electricity in the electric power network and directly faces the customers. It has a wide range of distribution and mounted equipment, including overhead lines, buried lines, box-type and pole-type transformers, circuit breakers, and various knife gates, etc. [1]. With the deepening of the smart grid construction, power operators have increased their investment in the distribution network and its digital system. Power distribution digital system has not been a large-scale rollout, an important technical difficulty is that the distribution digital system in a variety of network communication problems have not been resolved [2]. As the communication access network technology growing, especially the development and maturity of Ethernet Passive Optical Networks (EPONs) technology, the power system has also begun to introduce it as a communication technology for the digitalization and intelligentization of the distribution network.

EPON is a passive optical network based on Ethernet technology. EPON uses optical fiber as the medium, uses passive distributed devices to distribute and concentrate optical signals, and uses Ethernet protocol for data transmission. As a communication platform, EPONs can be used to carry distribution network automation, power consumption information collection, and other signal uploading and downstream control [3, 4].

1.1. **Related Work.** Since its inception, power distribution network has been highly valued by the world's major power enterprises and power workers. Especially the western developed countries represented by Europe and the United States have taken the lead in carrying out the research and application of distribution network construction technology [5]. Siemens of Germany applied Ethernet networking technology for the first time in the construction of intelligent distribution network (digital distribution network) process layer network, and conducted large-scale experimental tests with remarkable results [6]. Gonzalez et al. [7] studied the Ethernet-based serial connection interface technology and network segmentation technology, and confirmed through experiments that this technology can meet the requirements of serial interface on the real-time network communication. Kunz et al. [8] proposed the use of priority labeling to ensure the security and real-time transmission of network message point-to-point transmission, and confirmed the validity of the method through simulation. Kumpulainen et al. [9] solved the problem of abnormal operation of intelligent electronic devices under IEC61850 standard, and provided a direction for the intelligent and diversified development of power distribution communication network. Bottura and Borghetti [10] used OPNET network simulation software to conduct a comprehensive simulation analysis of real-time transmission in power distribution network, and put forward the relevant solutions. Zhang et al. [11] implemented a virtual LAN VLAN-based distribution network segmentation scheme, but the network latency is high. Fordyce et al. [12] implemented a priority tag-based distribution network configuration scheme, but the bandwidth utilization is low.

Recently, the emerging EPONs communication technology has gradually matured. Due to its flexible network organization, high service quality assurance, better upgrade and expansion, and the ability to realize distributed Ethernet functions, it has been increasingly valued by power system staff [13, 14, 15, 16]. Liem et al. [17] proposed a static bandwidth allocation algorithm for the shortage of EPON bandwidth resources to meet the network operators' low-cost and high-reliability quality of service requirements. Nguyen et al [18] proposed the design of three core network modes: optical circuit switching, optical burst switching, and optical packet switching based on EPONs. Xiao et al. [19] proposed a smart distribution network communication system with interleaved polling with adaptive cycle time EPONs, which adopts a first-come-first-served strategy for bandwidth allocation and authorization, but the system cannot adapt to the multi-service requirements of the communication network. Choi et al. [20, 21] proposed a smart distribution network communication system with periodic polling allocation for multi-service. The algorithm has a fixed polling period, but there is a waste of idle time slots and insufficient bandwidth allocation for medium-priority services. With the continuous development of technology, high bandwidth and low latency will become the main direction of EPONs development in the coming years [22, 23, 24].

1.2. **Motivation and contribution.** On the basis of analyzing the advantages and disadvantages of the above schemes, the traditional centralized authorization method and bandwidth allocation strategy of EPONs are improved, and a digital network communication system based on improved EPONs is proposed in combination with the characteristics of power distribution communication network with many services. First of all, the important services are protected according to the priority level, and at the same time, the overall bandwidth allocation efficiency of EPONs is improved from the perspective of improving the utilization rate of time slots, so as to achieve the purpose of optimization of EPONs, and then, on the basis of the above work, the detailed design and introduction of the networking scheme of the distribution communication system is carried out from the perspective of the construction of the communication system, focusing on the adoption of the communication technology of EPONs. Simulation outcome indicates that the method can allocate different bandwidth resources to services with different priorities, reduce the idle time slots of uplink channel, and significantly improve performance indexes such as network delay and bandwidth utilization rate.

2. Theoretical analysis.

2.1. **The Communication Principles of EPONs.** Ethernet passive optical networks (EPONs) are the key technology to solve the access network communication [25]. With the advantages of high bandwidth and low cost, the application of the industry is becoming more and more extensive. EPONs consists of three parts, including the local equipment Optical Line Terminal (OLT), the user-side equipment Optical Network Unit (ONU), and Optical Distribution Network (ODN). The general system structure is shown in Figure 1.

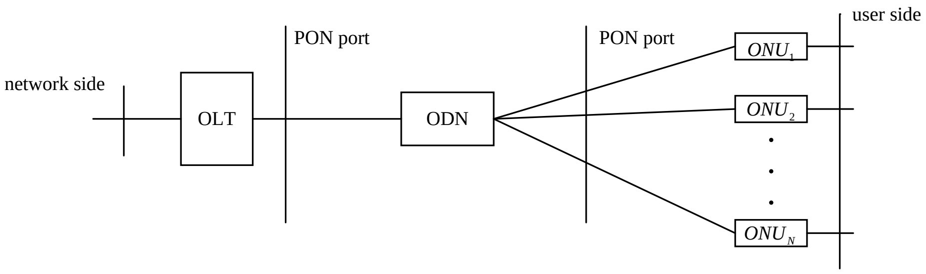

Figure 1. The general system structure of EPONs

When data is transmitted in the EPONs system, it can only be communicated between the OLT and the ONU. The uplink direction adopts Time Division Multiple Access (TDMA) technology, and OLT controls the transmission of information from ONU to OLT by allocating time slots. In order to avoid conflicts, ONUs can only communicate on the time slots allocated by OLT, which make up for the differences in the distance between ONUs. The downstream direction adopts the broadcasting method, when the ONU registers, the OLT assigns a unique LLID to the ONU, when the ONU receives data, it first compares the LLID, and only accepts the packets that match with the LLID.

2.2. **Bandwidth allocation algorithm for EPONs.** The bandwidth allocation algorithm for EPONs mainly adopts the classical algorithm based on interleaved polling [26]. The OLT polls each ONU using time slice polling. In order to avoid that some ONUs with large data volumes monopolize the entire bandwidth for a long time, the OLT sets a maximum transmission window for the transmission time slots applied by each ONU during the bandwidth allocation.

$V_{\max}$ is defined as the maximum transmission window of ONU_i. The size of the $V_{\max}$ value directly determines the value $T_{\max}$ of the polling period during heavy load as shown in Equation (1). The protection time between each ONU is denoted by A and the uplink rate is denoted by W_U in the equation.

$$T_{\max} = \sum \left(A + \frac{V_{\max}^{[i]}}{W_U} \right) \tag{1}$$

When $T_{\max}$ is too large, the data transmission time of individual ONUs is longer, which increases the service delay, including high-priority real-time services; when $T_{\max}$ is too small, the data transmission time of individual ONUs is very small, and the authorization information will be sent frequently, which leads to excessive waste of bandwidth.

In addition, $V_{\max}$ determines the minimum guaranteed bandwidth $V_{\min}$ of ONU_i, i.e., the maximum number of bytes that ONU_i can be authorized to send in the maximum time ($T_{\max}$), as indicated in Equation (2).

$$V_{\min}^{[i]} = \frac{V_{\max}^{[i]}}{T_{\max}} \tag{2}$$

The polling period of this mechanism is continuously adjusted to suit the prevailing network load, and bandwidth is automatically allocated according to the load of each ONU.

3. **Improvement of bandwidth allocation algorithm for EPONs.** The performance of the dynamic bandwidth allocation algorithm directly affects the application quality of EPONs. In this paper, we propose an improved dynamic bandwidth allocation algorithm for EPONs, which firstly divides the different services into sequential order in accordance with the currently specified priorities, and then lets the OLT, when allocating the bandwidth to the services of different priorities, firstly make corresponding predictions on the amount of the services that have a long queuing time in the waiting queue, and then adjust the prediction value constantly to be close to the real value, and then finally make bandwidth allocation according to the priorities, so that the existing bandwidth resources can be maximally utilized.

3.1. **Prediction of business volume.** For the purpose of precision forecasting the amount of new services arriving at the ONU in the waiting queue, the prediction error value of ONU_i is analyzed to continuously adjust the prediction value so that the prediction value is closer to the real value and the accuracy is improved. The bandwidth predicted by ONU_i in the set fixed period is as follows.

$$H_{i,D}^{P}(n+1) = \sum_{l=0}^{K-1} \beta(n) H^{V}(n-l) \tag{3}$$

where $H^V(n)$ is the real bandwidth arriving at the ONU, $H_{i,D}^{P}(n)$ is the predicted value of new arrivals in the waiting queue for each class of service, K is a predicted bandwidth parameter adjusted for the prediction error, $\beta(n)$ is a weighting factor, and D denotes the amount of each class of service (A, B, and C), with the A service being the highest priority, the B service being the medium priority, and the C service being the next highest priority.

$$\beta(n+1) = \beta(n) + \rho(n)\frac{e(n)}{H_{i,D}^{P}(n)} \tag{4}$$

$e(n)$ is the prediction error and $\rho(n)$ is the step size and they are given as follows.

$$e(n) = H^{V}(n) - H^{P}(n) \tag{5}$$

$$\rho(n) = \frac{L}{\sum_{l=0}^{K-1}[H_{i,c}^{P}(n-l)]^2} \tag{6}$$

In summary, the relationship between the total bandwidth value requested by the ONU from the OLT and the predicted bandwidth is as follows.

$$H^{S}(n+1) = H^{q}(n) + H_{i,D}^{P}(n+1) \tag{7}$$

3.2. **Enhanced EPONs dynamic bandwidth allocation methods.** This article first forecasts the network performance based on the probability of whether the bandwidth is allocated successfully or not, i.e., we calculate the prediction error. Successful prediction is indicated when $e_{i,D} = H_{i,D}^{r} - H_{i,D}^{P} \leq 0$, where $H_{i,D}^{r}(n)$ denotes the number of queues of the n-th cycle ONU_i that actually arrive at the corresponding time. Therefore, the bandwidth prediction success rate is defined as $P_{i,D}^{R} = \{e_{i,D} \leq 0\}$. Assuming that the mean square of the prediction error is $n_{i,D}$ and the variance is $\delta_{i,D}^2$, the prediction error follows $e_{i,D} \sim N(n_{i,D}, \delta_{i,D}^2)$. The probability of bandwidth forecasting is given by:

$$P_{i,D}^{R} = \frac{1}{\sqrt{2\pi}\delta_{i,D}}\int_{0}^{\infty} e^{-(x-n_{i,D})^2/2\delta_{i,D}^2}dx = 1 - G\left(\frac{n_{i,D}}{\delta_{i,D}}\right) = G\left(\frac{n_{i,D}}{\delta_{i,D}}\right) \tag{8}$$

The probability of prediction failure is then given by:

$$P_{i,D}^{f} = 1 - P_{i,D}^{R} \tag{9}$$

From the prediction error, we infer the status of the overall service volume. If $e_{i,D} < 0$, the ONU occupies the allocated bandwidth in $n-1$ rounds of time slots without requiring adjustment. If $e_{i,D} = 0$, the predicted traffic equals real traffic, meaning no adjustment is necessary. When $e_{i,D} > 0$, the bandwidth prediction fails, and $H_{i,D}^{P}$ must be adjusted using the EPONs algorithm with the adjustment value $\Phi_{i,D}(n)$:

$$\Phi_{i,D}(n) = \frac{H_{i,D}^{P}(n)}{H_{i,D}^{P}(n-1)}P_{i,D}^{f} \tag{10}$$

The OLT receives the REPORT message from ONU_i and performs bandwidth allocation calculations for different priority services. Assuming that in the n-th cycle, the total allocated bandwidth to ONU_i by the OLT is $H_i^{T}(n)$, the following equation holds:

$$H_i^{T}(n) = H_{i,A}(n) + H_{i,B}(n) + H_{i,C}(n), \quad D \in (A, B, C) \tag{11}$$

From this equation, the OLT initially allocates bandwidth to the highest priority A, then to B if there is remaining bandwidth, and finally to C. The detailed process follows:

$$H_{i,A}(n) = \min\left\{H_i^{T}(n), \min\left\{S_{i,A}(n) + H_{i,D}^{P}(n) - \Phi_{i,A}(n)\right\}\right\} \tag{12}$$

$$H_{i,B}(n) = \min\left\{H_i^{T}(n) - H_{i,B}(n), S_{i,B}(n) + H_{i,D}^{P}(n) - \Phi_{i,B}(n)\right\} \tag{13}$$

$$H_{i,C}(n) = \min\left\{H_i^{T}(n) - H_{i,C}(n) - H_{i,C}(n), S_{i,C}(n) + H_{i,D}^{P}(n) - \Phi_{i,C}(n)\right\} \tag{14}$$

where S represents the allocated time slot.

4. Research on digital network communication system for distribution network based on improved EPONs.

4.1. Data communication wiring scheme. To enhance bandwidth allocation in EPONs, various data communication technologies are employed to construct a digital network communication system for distribution networks , which includes a data communication wiring scheme, a communication network organization scheme, a topology design based on improved EPONs, and a bandwidth allocation scheme. The architecture of the system is indicated in Figure 2.

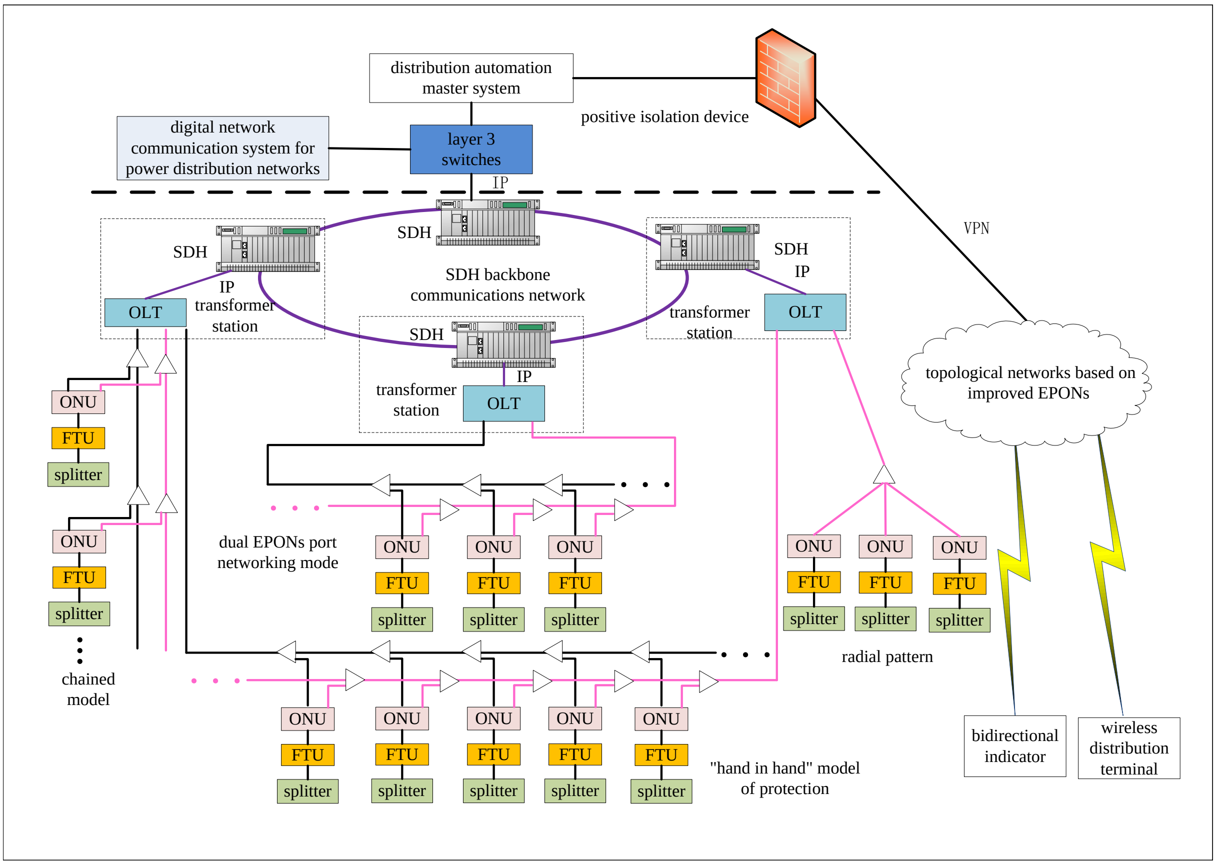

Figure 2. The architecture of the designed system

According to the overall architecture design scheme, the data communication mode is mainly EPONs passive fiber optic communication, and all ONU terminal facilities adopt hardware equipment supporting dual PON interfaces to achieve self-protection in the communication process. All ONU facilities are deployed in the ring network box or column switch terminal equipment cabinets for physical deployment. OLT terminal facilities carry out data communication through the internal communication network of the substation to realize the transmission of data information from the substation nodes to the main station system, and ultimately connected to the electric power fiber optic backbone network as shown in Figure 3.

In the wiring process, one OLT device is used as the main device and the other OLT device is used as the standby support device to establish a fiber optic network that supports dual PON protection mode. At the same time, the ODN equipment adopts a parallel approach to fiber convergence processing and physical access according to the specific location of the splitter, which is used to cope with the multi-point failure problem that may occur in the process of data interaction. At the same time, according to the specific laying and direction of the main line, the specific connection mode of optical fiber interface is flexibly selected as ring or chain, thus effectively improving the robustness of data communication system in substation nodes.

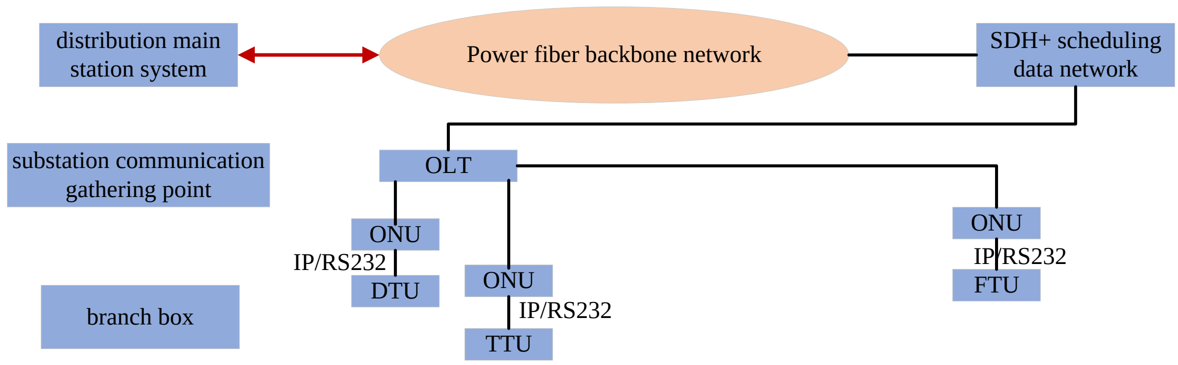

Figure 3. Distribution network digital network communication wiring

4.2. **Communications network organization programme.** Through the construction of power distribution communication system, it realizes that the power distribution communication convergence points in all substation nodes are connected to the backbone network and finally connected to the communication master station of the power supply company. In the process of network organization, it is necessary to achieve OLT facilities access to SDH backbone network, and at the same time, the two backbone networks in the process of entering the main station system adopt dual communication channels to provide channel redundancy for the communication network, and the network organization scheme of the whole communication system is shown in Figure 4.

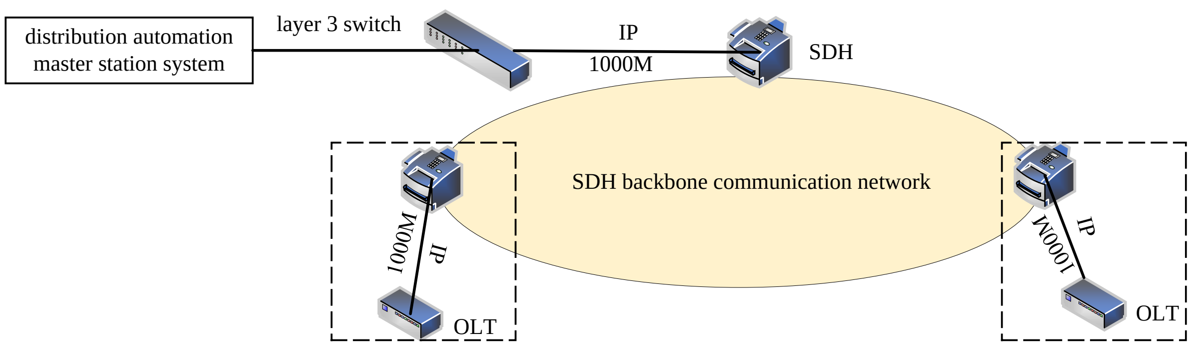

Figure 4. Communication network construction scheme

In terms of access point networking, in order to cope with the demand for SDH outgoing communication and the access demand of other sub-networks, the specific access point adopts two parallel SSH-M300 switches to deal with the support of upstream and downstream channels at the same time, and at the same time, it can also rely on the SSH-M300 switches to achieve the hierarchical partitioning of the whole communication network and network segmentation.

4.3. **Topology design and bandwidth allocation scheme based on improved EPONs.** In the design of EPONs network topology, the Layer 3 switch is directly accessed to the management system of the ground control network, the SDH communication channel in EPONs is adopted for the network interconnection of OLT and ONU, and SDH is adopted for the independent communication of all the network management data to ensure the reliable and real-time communication of configuration data and maintenance data in the process of EPONs network management by utilizing the excellent network communication performance of SDH. The excellent network communication performance of SDH is utilized to ensure reliable real-time communication of configuration data and maintenance data during EPONs network management. The communication network topology of power distribution communication access network is shown in Figure 5.

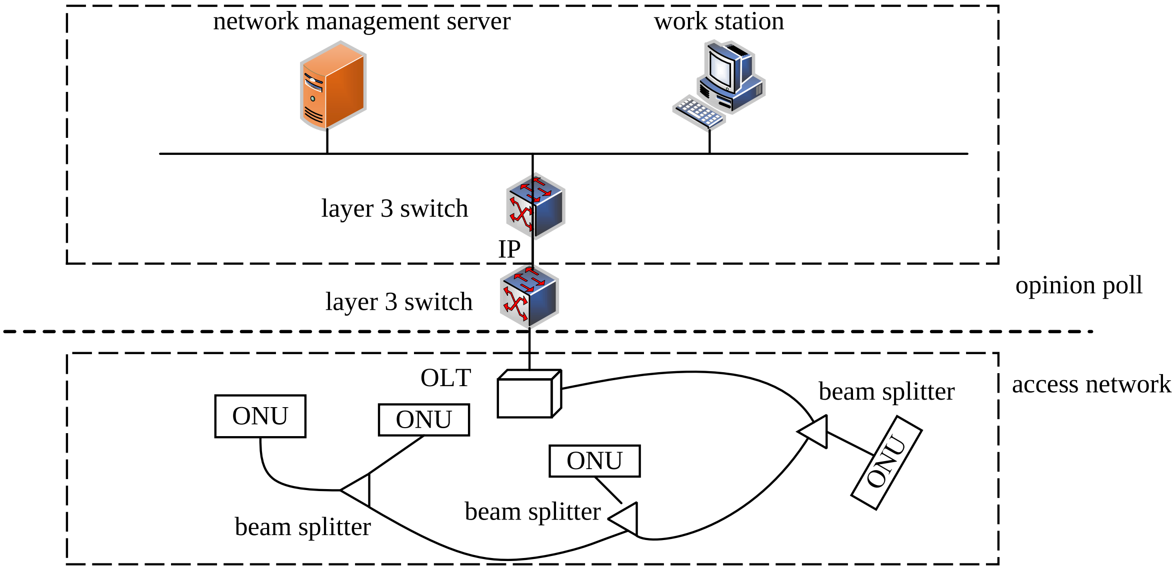

Figure 5. Improved network topology for EPONs

In the EPONs bandwidth allocation process, the total length of time slots occupied by all ONUs to obtain authorization and finish sending the authorized data is called a cycle [27]. In order to improve the bandwidth utilization and reduce the idle time slots, based on the improved EPONs bandwidth allocation method, an early authorization threshold calculation method is proposed to predict the amount of data that can be sent in the idle time slots and dynamically determine the ONUs that will be sent in advance, and the steps are as follows.

(1) After receiving the report frames from all ONUs in the $n-1$-th cycle, determine the bandwidth H_n that can be allocated in the n-th cycle, which will be between $T_{min}S_N$ and $T_{max}S_N$. Also, based on the total authorized bandwidth H_{n-1} for the $n-1$-th cycle, predict the total authorized bandwidth for the $n+1$-th cycle as follows.

$$H'_{n+1} = \alpha H_n + \beta H_{n-1} \tag{15}$$

(2) Based on the ratio between the length of free time slots and the total cycle length, the threshold of the amount of data that can be sent to the ONU in advance in the n-th cycle is as follows.

$$T_w^n = H'_{n+1} \frac{T_{id} S_N}{H_n} \tag{16}$$

(3) In the n-th cycle, when the ONU bandwidth request received by the OLT is less than T_n, the ONU is authorized according to the current idle time slot allocable bandwidth.

The step is repeated until the free time slot allocable bandwidth is zero, then the n-th cycle of advance transmission is ended, and the remaining ONUs undergo unified bandwidth calculation and authorization at the end of the cycle.

According to the improved dynamic bandwidth allocation method for EPONs, the bandwidth is first allocated for the A service and then for the medium-priority B service if $S_{i,B} < H_i^{min} - H_{i,A}$. The authorized bandwidth for B service for this part of ONU is as follows.

$$H_{i,A} = H_i^{min} - \sum S_{i,B} \tag{17}$$

If $S_{i,B} > H_i^{min} - H_{i,A}$, the B-service authorized bandwidth for this portion of the ONU is as follows.

$$H_{i,B} = H_{\text{left}} \frac{H_{i,B}}{\sum S_{i,B}} \tag{18}$$

In terms of the above, after the allocation of bandwidth for service B, there is no bandwidth left, i.e., $H_{i,C} = 0$.

5. Performance testing and analysis.

5.1. Network latency analysis.

For the sake of illustration, the digital network communication system based on improved EPONs for distribution networks designed in this paper is denoted as DNC-EPONs, and the literature [21] is denoted as CPB-EPONs, and the feasibility of this DNC-EPONs is verified by using the network simulation software, OPNET simulation. The simulation adopts the settings common to the EPONs system model, and the algorithm simulation starts from cold start and ends when the OLT receives 5×10^6 packets. Considering the multi-tasking requirements, the CPB-EPONs algorithm in the literature [21] has a better performance in the comprehensive network performance of multi-service, so the comparison algorithm adopts the CPB-EPONs algorithm to compare with the DNC-EPONs.

This article refers to the maximum overall delay and minimum overall delay models of EPONs network established in the literature [28] to calculate the network delay for DNC-EPONs. In this paper, we set the maximum number of uploaded data frames per ONU element in the DNC-EPONs network to be 1518 bytes, and the farthest distance between all ONUs and the center OLT to be 1000 meters. The center OLT polls the underlying ONUs according to a maximum period of 250 μs, the upstream and downstream data transmission control processing time are both set to 2 μs, and the internal processing delay of the center OLT is set to 20 μs.

To further prove that the network designed in this paper has good real-time performance, this paper selected five commonly used data sizes, such as 64 bytes, 128 bytes, 256 bytes, 512 bytes, 1024 bytes, etc., to carry out the theoretical calculation of network delay, the calculation method is the same as that in the literature [28], and the theoretical calculation results are indicated in Table 1.

Table 1. Theoretically calculated values of network delay for DNC-EPONs

Data length (byte)	**Minimum polling period (μs)**	**Maximum polling period (μs)**	**Minimum latency (μs)**	**Maximum latency (μs)**
64	57.493	253.175	87.631	541.917
128	57.493	241.359	93.152	517.238
256	57.493	219.063	89.359	462.931
512	57.493	193.437	93.155	427.348
1024	57.493	187.153	104.627	438.353

After calculation, the maximum overall delay of the DNC-EPONs network designed in this paper is $Delay_{\max} = 541.917\ \mu s$, and the minimum overall delay is $Delay_{\min} = 87.631\ \mu s$. After theoretical calculation, when the bottom ONU sends 256 byte of data, the minimum polling period is 57.493 μs, the maximum polling period is 219.063 μs, and the minimum delay is 89.359 μs, and the maximum delay is 462.931 μs. When the rate of sending 64 byte of data from the bottom ONU is lower than the guaranteed service data rate, the delay of this ONU on the opposite side of the network reaches the minimum value, which is 87.631 μs. When the rate at which the underlying ONU sends 64 byte data is lower than the ensured service data rate, the delay of the ONU's contralateral network reaches the minimum value, which is 87.631 μs. When the rate at which the underlying ONU sends 64 byte data is equal to the ensured service data rate, the delay of the ONU's contralateral network reaches the maximum value, which is 541.917 μs.

In the formal test, the network analyzer will be connected to the center OLT any PON interface, at this time the network data analyzer can send data streams through the OLT to all the underlying ONU. In order to further prove that the network designed in this paper has good real-time, this paper was selected 64 byte, 128 byte, 256 byte, 512 byte, 1024 byte and other five commonly used data size for network latency test, after the test to obtain test results indicated in Table 2.

Table 2. Actual test results of DNC-EPONs network delay

Data length (byte)	**Minimum latency (μs)**	**Maximum latency (μs)**
64	83	306
128	107	331
256	127	335
512	125	367
1024	149	372

As shown in Table 2, the minimum delay occurs in the DNC-EPONs network when the size of data transmitted in the network is 64 byte, and the maximum delay occurs in the DNC-EPONs network when the size of data transmitted in the network is 1024 byte. Comparing the above measured minimum and maximum delays with the theoretically calculated minimum and maximum delays, it can be seen that the measured minimum delay of 83 μs and the maximum delay of 372 μs are located within the theoretically calculated minimum delay of 87.631 μs and the maximum delay of 541.917 μs, which meets the real-time requirements, and proves that the DNC-EPONs network designed in this paper has good real-time performance. EPONs network designed in this paper has good real-time performance. Further comparison and analysis of Tables 1 and 2 show that when five different byte of data are transmitted in the network, the minimum delay shown in both tables is positively correlated with the size of the data byte transmitted in the network. The above results further confirm that the DNC-EPONs network designed in this paper has good real-time performance.

5.2. **Comparative analysis.** Through OPNET simulation experiments, the comparison curves of the uplink bandwidth utilization of the DNC-EPONs method and the CPB-EPONs method in the EPON system with the change of load are shown in Figure 6. The change is not obvious when the network load is before 0.5, and when the network load is more than 0.5, the bandwidth utilization of the DNC-EPONs method is significantly better than that of the CPB-EPONs method. EPONs method. In summary, dynamic bandwidth algorithm is very important to solve the last-mile problem of access network. In this paper, a simulation model of E uplink channel based on OPNET is established.

From the simulation results, it can be seen that the DNC-EPONs method has a greater degree of bandwidth utilization than the CPB-EPONs method; the DNC-EPONs method has more advantages than the CPB-EPONs method in terms of resource utilization, which can further satisfy the user demand and has more practical application value.

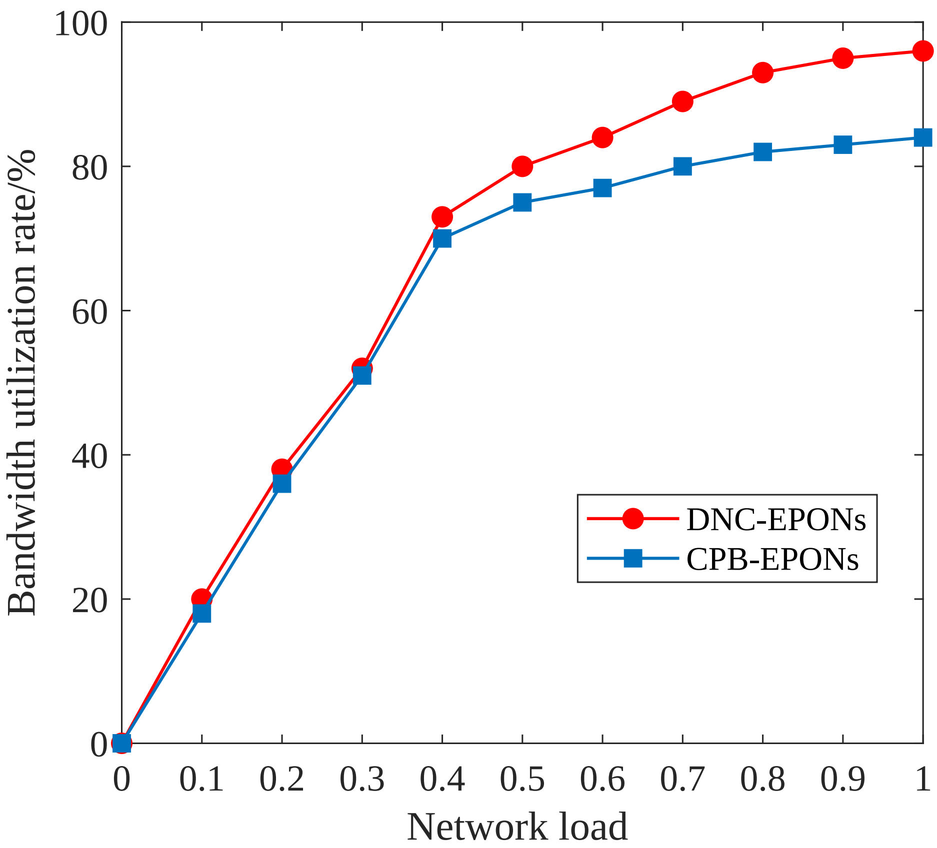

Figure 6. Comparison of bandwidth utilization

6. **Conclusion.** Aiming at the problem of scarcity of bandwidth allocation resources faced in the current construction of distribution network systems, this paper investigates a digital network communication system for distribution networks based on improved EPONs. Firstly, according to the network traffic characteristics, the same priority service request size of all ONUs is considered comprehensively, and differentiated bandwidth authorization is carried out according to the service definition for the purpose of optimizing EPONs, and then on this basis, from the perspective of the construction of the communication system, the detailed design and introduction of the grouping scheme of the distribution communication system focusing on the adoption of the improved EPONs communication technology is carried out. Simulation results show that DNC-EPONs can allocate different bandwidth resources to services with different priorities, which significantly improves the performance indicators such as network delay, bandwidth utilization and packet loss rate.

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REFERENCES

[1] M. Swaminathan, J. Kim, I. Novak, and J. P. Libous, "Power distribution networks for system-on-package: Status and challenges," *IEEE Transactions on Advanced Packaging*, vol. 27, no. 2, pp. 286-300, 2004.

[2] S. Mishra, D. Das, and S. Paul, "A comprehensive review on power distribution network reconfiguration," *Energy Systems*, vol. 8, pp. 227-284, 2017.

[3] T.-Y. Wu, F. Kong, Q. Meng, S. Kumari, and C.-M. Chen, "Rotating behind security: an enhanced authentication protocol for IoT-enabled devices in distributed cloud computing architecture," *EURASIP Journal on Wireless Communications and Networking*, vol. 2023, no. 36, 2023.

[4] T.-Y. Wu, F. Kong, L. Wang, Y.-C. Chen, S. Kumari, and J.-S. Pan, "Toward Smart Home Authentication Using PUF and Edge-Computing Paradigm," *Sensors*, vol. 22, no. 23, 9174, 2022.

[5] T.-Y. Wu, X. Guo, Y.-C. Chen, S. Kumari, and C.-M. Chen, "SGXAP: SGX-Based Authentication Protocol in IoV-Enabled Fog Computing," *Symmetry*, vol. 14, no. 7, 1393, 2022.

[6] K. Renuka, S. Kumar, S. Kumari, and C.-M. Chen, "Cryptanalysis and Improvement of a Privacy-Preserving Three-Factor Authentication Protocol for Wireless Sensor Networks," *Sensors*, vol. 19, no. 21, 4625, 2019.

[7] M. J. Gonzalez-Redondo, A. Moreno-Munoz, V. Pallares-Lopez, and R. J. Real-Calvo, "Influence of data-related factors on the use of IEC 61850 for power utility automation," *Electric Power Systems Research*, vol. 133, pp. 269-280, 2016.

[8] G. Kunz, J. Machado, E. Perondi, and V. Vyatkin, "A formal methodology for accomplishing IEC 61850 real-time communication requirements," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 8, pp. 6582-6590, 2017.

[9] L. Kumpulainen, A. Jäntti, J. Rintala, and K. Kauhaniemi, "Benefits and performance of IEC 61850 Generic Object Oriented Substation Event-based communication in arc protection," *IET Generation, Transmission & Distribution*, vol. 11, no. 2, pp. 456-463, 2017.

[10] R. Bottura, and A. Borghetti, "Simulation of the volt/var control in distribution feeders by means of a networked multiagent system," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 4, pp. 2340-2353, 2014.

[11] Z. Zhang, X. Huang, B. Keune, Y. Cao, and Y. Li, "Modeling and simulation of data flow for VLAN-based communication in substations," *IEEE Systems Journal*, vol. 11, no. 4, pp. 2467-2478, 2015.

[12] R. Fordyce, L. Heemsbergen, T. Apperley, M. Arnold, T. Birtchnell, M. Luo, and B. Nansen, "Things, tags, topics: Thingiverse object-centred network," *Communication Research and Practice*, vol. 2, no. 1, pp. 63-78, 2016.

[13] V. Sharma, and S. Sharma, "Hybrid multiplexed OFDM-DWDM-EPON access network," *Optik*, vol. 125, no. 21, pp. 6404-6406, 2014.

[14] S. B. Hussain, W. Hu, H. Xin, and A. M. Mikaeil, "Low-latency dynamic wavelength and bandwidth allocation algorithm for NG-EPON," *Journal of Optical Communications and Networking*, vol. 9, no. 12, pp. 1108-1115, 2017.

[15] W. Wang, W. Guo, and W. Hu, "On the efficiency and fairness of dynamic wavelength and bandwidth allocation algorithms for scheduling multi-type ONUs in NG-EPON," *Optical Fiber Technology*, vol. 45, pp. 208-216, 2018.

[16] D. P. Van, L. Valcarenghi, M. Chincoli, and P. Castoldi, "Experimental evaluation of a sleep-aware dynamic bandwidth allocation in a multi-ONU 10G-EPON testbed," *Optical Switching and Networking*, vol. 14, pp. 11-24, 2014.

[17] A. T. Liem, I.-S. Hwang, and A. Nikoukar, "An autonomous recovery mechanism against optical distribution network failures in EPON," *Optical Fiber Technology*, vol. 20, no. 5, pp. 552-560, 2014.

[18] T. D. Nguyen, T. Eido, and T. Atmaca, "An enhanced QoS-enabled dynamic bandwidth allocation mechanism for Ethernet PON," *Computer Society*, vol. 20, pp. 135-140, 2009.

[19] F. Xiao, Z. Zhang, and X. Yin, "An improved weighted IPACT algorithm of EPONs in smart distribution networks based on the requirements of relay protection," *International Transactions on Electrical Energy Systems*, vol. 26, no. 10, pp. 2107-2122, 2016.

[20] S.-I. Choi, S. J. Yoo, and J. B. Cho, "SLA aware dynamic bandwidth allocation for EPONs," *Photonic Network Communication*, vol. 2, pp. 258-261, 2010.

[21] S.-I. Choi, "Cyclic polling-based dynamic bandwidth allocation for differentiated classes of service in Ethernet passive optical networks," *Photonic Network Communications*, vol. 7, pp. 87-96, 2004.

[22] W. Wang, W. Guo, and W. Hu, "On the efficiency and fairness of dynamic wavelength and bandwidth allocation algorithms for scheduling multi-type ONUs in NG-EPON," *Optical Fiber Technology*, vol. 45, pp. 208-216, 2018.

[23] D. P. Van, L. Valcarenghi, M. Chincoli, and P. Castoldi, "Experimental evaluation of a sleep-aware dynamic bandwidth allocation in a multi-ONU 10G-EPON testbed," *Optical Switching and Networking*, vol. 14, pp. 11-24, 2014.

[24] A. Mercian, M. P. McGarry, and M. Reisslein, "Impact of report message scheduling (RMS) in 1G/10G EPON and GPON," *Optical Switching and Networking*, vol. 12, pp. 1-13, 2014.

[25] G. Kramer, B. Mukherjee, and G. Pesavento, "Ethernet PON (ePON): Design and analysis of an optical access network," *Photonic Network Communications*, vol. 3, pp. 307-319, 2001.

[26] J. Zheng, and H. T. Mouftah, "A survey of dynamic bandwidth allocation algorithms for Ethernet Passive Optical Networks," *Optical Switching and Networking*, vol. 6, no. 3, pp. 151-162, 2009.

[27] C. M. Assi, Y. Ye, S. Dixit, and M. A. Ali, "Dynamic bandwidth allocation for quality-of-service over Ethernet PONs," *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 9, pp. 1467-1477, 2003.

[28] R. Roy, G. Kramer, M. Hajduczenia, and H. J. Silva, "Performance of 10G-EPON," *IEEE Communications Magazine*, vol. 49, no. 11, pp. 78-85, 2011.