Scalable Computing: Practice and Experience, ISSN 1895-1767, http://www.scpe.org

Volume 24, Issues 3, pp. 389–397, DOI 10.12694/scpe.v24i3.2275

A METHOD FOR ONLINE MONITORING DATA RELEASE OF COMPOSITE SUBMARINE CABLE BASED ON HORIZONTAL FEDERATED LEARNING

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Abstract. Conventional online composite submarine cable monitoring data release mostly adopts the method and principle of blockchain dynamic zoning consensus. In the data release process, there are omissions, and it takes a long time to complete the task, which reduces the timeliness of online composite submarine cable monitoring data release. Based on this, a new data publishing method is proposed by introducing horizontal federation learning. First, the online monitoring data of composite submarine cables are collected and preprocessed to eliminate the high-frequency capacitive effect of submarine cables. Secondly, manage composite submarine cable data nodes, transform the status relationship of data nodes, and ensure the quality of subsequent data release. A horizontal federation learning model is established to design the online monitoring data release process. The experimental results show that the new data release method is highly feasible. With the increasing online monitoring data of composite submarine cables, the time required for data release is short, and the timeliness is high.

Key words: Horizontal federal learning; Reunite with; Monitor; Submarine cable; On-line; Data; Release;

1. Introduction. With the internationalization of power grid, the development and utilization of offshore oil platforms and offshore wind power, and the rapid development of island economy, the number of submarine cables has increased rapidly [3]. To solve the problems of dense power grid structure and unbalanced power generation structure, submarine cable projects have been carried out at home and abroad. Since 1990, the total length of submarine cable projects has been 13618km, with a full design capacity of 35618MW [6]. As the number of cables increases, many problems begin to surface. Compared with land cables, submarine cables are difficult to find faults, and the repair time is long, and the repair cost is expensive [8]. The submarine cable laying environment is complex and vulnerable to external forces such as anchoring and fishing [4]. When laying cables, it is easy to leave some defects, such as a damaged outer protective layer, armor layer and insulation layer [17], due to the influence of sea waves, seabed geology, personnel, and equipment.

The length of submarine cable varies from several kilometers to tens of kilometers, and there is no obvious cable route on the sea. It is impossible to accurately and timely detect the ships entering the cable reserve by relying on manual patrol and lookout [18]. Submarine cables are relatively heavy, requiring large engineering ships and professionals to lay and maintain them. The complexity of the submarine cable structure and the marine environment, ocean current, earthquake, and ship anchoring can not accurately and timely judge the damage or degree of damage caused to the cable after operation, and in turn, can not determine whether maintenance is required [20]. The routine test of power failure and maintenance of submarine cables is a loss of power and an additional investment. The online monitoring research of composite submarine cables is proposed to ensure the safe operation of submarine cables. According to the online monitoring data, the operating conditions of submarine cables are obtained, and the potential safety risks of submarine cables [22]are found in time. After the online monitoring of composite submarine cables is completed, the online monitoring data of submarine cables need to be released in real-time through the data release method to provide strong monitoring data support for staff [9]. Currently, the traditional online monitoring data release

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Table 2.1: Technical performance parameter settings of BOTDA series data acquisition optical fiber sensors

No	Technical parameter	Technical indicators
1	Fiber type	Standard single mode fiber
2	Optical fiber configuration	Dual fiber loop
3	Measuring distance	5km-100km
4	Measurement time	As low as 20s
5	Temperature measurement range	-190 ℃ $\sim$ 700 ℃ (depending on the fiber optic cable material)
6	Temperature measurement accuracy	1 ℃ (full range)
7	Temperature resolution	0.1 ℃
8	Strain measurement range	-4000 μ E to 6000 μ E (depending on cable material)
9	Strain measurement accuracy	$\pm$ 20 μ E (full journey)
10	Strain resolution	2 μ E
11	Sampling interval	0.1-1m

method of composite submarine cables has a poor timeliness problem. When faced with a large amount of online monitoring data, it takes a long time to complete the data release task [10].

The motivation behind this work stems from the limitations of the conventional method of online composite submarine cable monitoring data release, which utilizes blockchain dynamic zoning consensus. This method has drawbacks such as omissions in data release and a lengthy process, leading to reduced timeliness of the released data. To overcome these limitations and improve the efficiency of data release, the authors propose a new data publishing method by introducing horizontal federation learning.

Horizontal federated learning can improve the above problems, and it has been a popular machine learning method for multi-device joint modeling in recent years. In horizontal federated learning, the data provider can train the machine model [21] on the device according to the task published by the data requester. Then, the data provider will update the local model instead of the original data to the central server for global aggregation. Based on this, this paper introduces horizontal federated learning and proposes a new online monitoring data publishing method.

The main research question relies on:

"How can the timeliness of online composite submarine cable monitoring data release be improved by introducing horizontal federation learning?"

Additionally, the following sub-questions can be explored:

1. How can the online monitoring data of composite submarine cables be collected and preprocessed to eliminate the high-frequency capacitive effect?
2. How can the management of composite submarine cable data nodes be optimized to transform the status relationship of data nodes and ensure data quality?
3. How can a horizontal federation learning model be established to design the online monitoring data release process?
4. What are the experimental results of the proposed data release method in terms of feasibility, time required for data release, and timeliness of the released data?

2. Design of data release method for online monitoring of composite submarine cable.

2.1. Composite submarine cable online monitoring data acquisition. In the online monitoring data release method of composite submarine cable designed in this paper, online monitoring data collection is essential. It is the fundamental guarantee to ensure the accuracy of subsequent data release. First, select the data acquisition equipment [25] that meets the requirements of online monitoring data acquisition of composite submarine cables. After comprehensively considering the performance and operation characteristics of the data acquisition equipment, this paper selects the BOTDA series data acquisition optical fiber sensor as the acquisition equipment. Its technical performance parameters are shown in Table 2.1.

As shown in Table 2.1, these are the technical performance parameters of the composite submarine cable online monitoring data acquisition sensor selected in this paper. The data acquisition equipment collects real-time composite cable online monitoring data [14] under various working conditions. Due to the existence of capacitance to ground in each phase of the power cable, the capacitive current on the line is not equal during operation, and there is a high-order harmonic current in the line; when the cable is laid for a long distance, the capacitance current will be more discrete [16]. Therefore, it is necessary to process the online monitoring data of submarine cables to eliminate the high-frequency capacitive effect of submarine cables. The coaxial capacitor calculation method is used to characterize the capacitance characteristics of each phase of submarine cables and then judge the elimination of high-frequency capacitive effect [13]. The calculation expression of capacitance characteristics of each stage of submarine cable is:

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{In\left(R_2/R_1\right)}$$

Among them, ε_0, ε_r represent the dielectric constant of submarine cable insulator respectively; R_1, R_2 represent the outer radius and inner radius of submarine cable insulator respectively. After the elimination of the high-frequency capacitive effect of the submarine cable, it automatically communicates with the BOTDA data acquisition sensor through Ethernet and acquires and stores the monitoring data such as the optical fiber temperature, strain information, and power harmonic information collected by the equipment [5].

In the online monitoring data release method of composite submarine cables proposed in this paper, the online monitoring data collection process is crucial for ensuring the accuracy of subsequent data release. This discussion will focus on the techniques used for online monitoring data collection, with specific emphasis on selecting appropriate data acquisition equipment.

To begin with, selecting the right data acquisition equipment is essential to meet the requirements of online monitoring data acquisition for composite submarine cables. The choice of equipment plays a vital role in accurately capturing and recording the necessary data. In this work, the authors consider various factors, such as performance and operational characteristics, before finalizing the equipment selection.

One specific equipment selected in this study is the BOTDA (Brillouin Optical Time-Domain Analysis) series data acquisition optical fiber sensor. The selection is based on a comprehensive evaluation of its technical performance parameters, provided in Table 2.1. These parameters likely include measurement range, resolution, sampling rate, accuracy, and sensitivity. The BOTDA series data acquisition optical fiber sensor is known for capturing precise and reliable data from composite submarine cables, making it suitable for the proposed online monitoring data collection process.

The selection of appropriate data acquisition equipment ensures that the collected data is high quality and accurately represents the monitoring parameters of interest. Using the BOTDA series data acquisition optical fiber sensor, the authors aim to gather reliable and relevant data from composite submarine cables, which will serve as the foundation for subsequent data release and analysis.

2.2. Composite submarine cable data node management. After completing the online monitoring data collection of composite submarine cables, next, manage the collected online monitoring data nodes, transform the status relationship of data nodes, and ensure the quality of subsequent data release. A data node is a device that communicates with the system manager to complete data transmission, providing a running and maintenance environment [11]for database agents and data applications. Data providers who want to use the system to manage and share data sources need to create data nodes and add them to the system cluster network [1]in addition to acquiring the role of the system's data provider. The data node management module provides data node registration network, status detection, node authentication token management, and disable enable functions [23]. As shown in Figure 2.1, it is the state transformation relationship of data nodes designed in this paper.

According to the status transformation relationship of online monitoring data nodes shown in Figure 2.1, each data node is comprehensively transformed. The data node management module at the system management end receives the node heartbeat from the node status detector running at the data node end, confirms that the data node has successfully entered the network and is in a healthy running state, updates the node status to running, and records when the token expires [12]. After that, the system data node management module

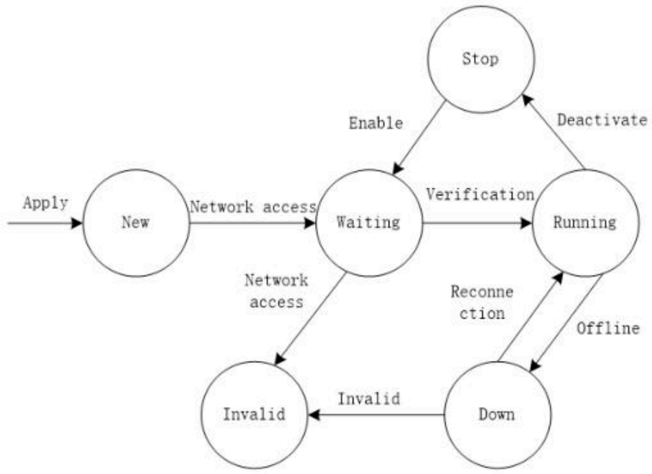

Fig. 2.1: Status transformation relationship of composite submarine cable online monitoring data nodes

Table 2.2: Maintenance data nodes of composite submarine cable online monitoring data node management module

Field Name	Field Type	Describe
Data Node ID	Int	Data node ID, a unique identifier of the node.
Data Node IP	String	Data node P address.
Name	String	Data node name.
User ID	Int	User ID. The data provider user ID to which the data node belongs.
Package Uri	String	The storage path of the data node access kit in Minio.
Token	String	Data node authentication token.
Toke Valid Time	Time	Token validity period.
Status	String	Data node status.

regularly queries the node status through the node status detector and updates it in the data node table [2]. The authentication token of the data node is valid within one week after the node successfully enters the network. The system data node management module regularly updates the permits of all online data nodes and their validity (the node status is Running) [7]. When updating the ticket, the discarded node will be found (the node status is Down), and the token update and node validity will be skipped [19]. Suppose the node reconnects within the token validity period. In that case, the node status is updated to Running, and the node that has not reconnected beyond the token validity period is judged invalid (the node status is invalid), the data provider needs to re-operate the data node into the network [24]. On this basis, the data node table maintained by the composite submarine cable online monitoring data node management module is constructed, as shown in Table 2.2.

According to the maintenance node table structure shown in Table 2.2, after the data provider deactivates the data node, it updates the node status to ”Stopped”. It clears the node authentication token until the data provider enables the data node to reapply for the node authentication token and update the validity of the ticket, and the node status.

2.3. Online monitoring data release based on horizontal federal learning. After the management of the above composite submarine cable online monitoring data nodes is completed, on this basis, the research on online monitoring data release is carried out using the horizontal federation learning principle. Federal

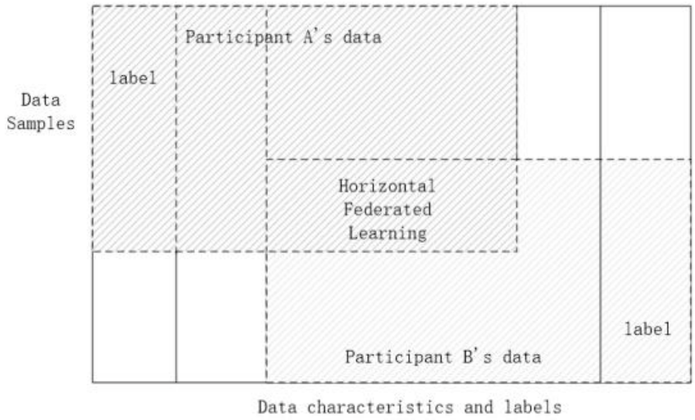

Fig. 2.2: Building a horizontal federation learning model

learning aims to solve the problem of joint knowledge for decentralized data sets. For all parties involved in federal training, "data is available but not visible to each other". First, a horizontal federation learning model is established, and the data processing of horizontal federation learning is obtained through the model structure. The flat federation learning model based in this paper is shown in Figure 2.2.

As shown in Figure 2.2, the horizontal federated learning model is applicable to the situation where the data characteristics of the data owned by each participant overlap. The data characteristics of each participant are aligned and the data samples are different, which can also be called federated learning by sample. In the training process of the horizontal federation model, the definition of system security is usually based on the assumption that the participants in the flat federation learning system are honest and trustworthy and pay attention to the Fusion Server [15] whose intermediate results converge. In order to protect the privacy and integrity of online monitoring data released by composite cables, it is necessary to avoid storing the eigenvalues of the model in clear text, and usually use secure multi-party computing and homomorphic encryption to ensure the security of intermediate results.

The online monitoring data release process of composite submarine cable based on horizontal federated learning designed in this paper is shown in Figure 2.3.

As shown in Figure 2.3, first use KL divergence to calculate the difference between the updated data at the current time point and the data published at the previous time point, and then add noise to the divergence value and predefined threshold. Compare the noise KL divergence of online monitoring data of composite submarine cable with the noise threshold D, and then judge how the data at the current time point should be released. If the KL divergence of the online monitoring data noise is greater than the noise threshold, the data shall be removed by independent data release method; If the noise KL divergence of online monitoring data is less than the noise threshold, the second judgment process will be started to judge whether the online monitoring data at the last adjacent time point is released independently. If the data at the last adjacent time point is released separately, the data will be released in greedy groups if the data at the last adjacent time point is not released separately. Then this data release will adopt the alternative release method to complete the online monitoring data release task of composite submarine cables. When some online monitoring data nodes are merged, their data sensitivity will also be reduced to varying degrees. After the above judgment and the selection of data release mode, the data can be released in an all-around way while meeting the timeliness and accuracy of data release.

3. Experimental analysis.

3.1. Experiment preparation. In order to test the feasibility of the online monitoring data publishing method of composite submarine cable based on horizontal federal learning proposed in this paper, and ensure its publishing effect, the experimental analysis is carried out as shown below. Firstly, according to the mechanical

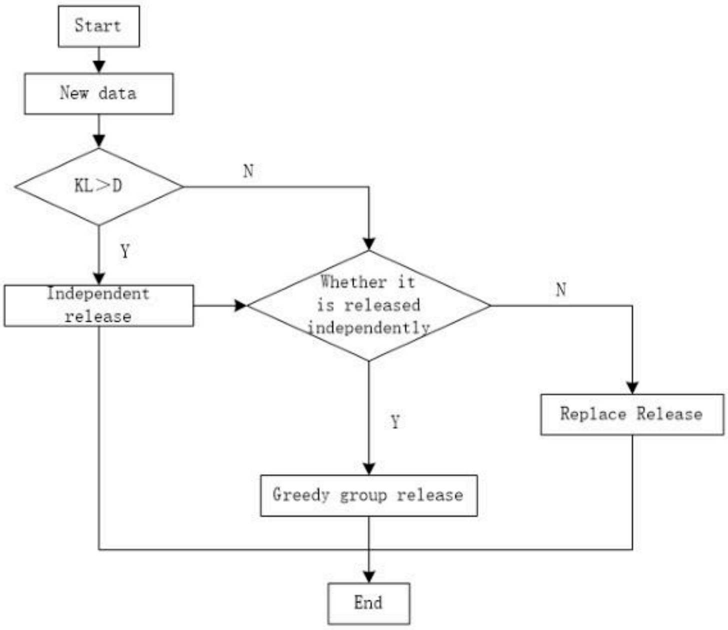

Fig. 2.3: Release process of composite submarine cable online monitoring data based on horizontal federated learning

test of submarine cable, the test environment is arranged, and the winding test device, linear tensile test device and tensile bending test device are selected respectively. In the winding test device, the inner diameters of the two submarine cable drums are set as 5m and 6m respectively, and the spacing between the two submarine cable drums is set as 15.8m. The submarine cable rises from one cable barrel and enters the other through the fixed pulley above the other cable pillar and the fixed pulley above the other cable barrel. The height of the fixed pulley is 14m, and the distance between two fixed pulleys is 21.2m. The maximum tension of the direct pulling device and the tension bending device is 35kN, and the diameter of the tension bending device drum is 6.5m. The submarine cable adopts YPLKY42110KV single-core optical fiber composite submarine cable. The length of the winding test cable is 220 meters, and the length of the straight tension and tension bending test cable is 27.6 meters. The tension of the submarine cable is measured by a tensiometer, and the strain and temperature of the composite optical fiber in the submarine cable are measured by BOTDR and ROTDR.

Due to the complex structure of submarine cable, if it is divided into four layers: conductor layer, insulation layer, inner lining layer, and outer protective layer, it will inevitably lead to large calculation errors. Only the layers with the same material thermal resistance coefficient are combined to take into account the simplification of the thermal path and calculation accuracy. In this experiment, the thermal resistance coefficient of structural component materials of each layer of submarine cable is shown in Table 3.1.

As shown in Table 3.1, it is the thermal resistance coefficient of the structural component materials of each layer of the submarine cable. On this basis, the online monitoring data release method of composite submarine cable based on horizontal federated learning proposed in this paper is used to release the data and test the application effect of the release method.

3.2. Result analysis. In order to make the test results of this experiment have corresponding persuasiveness, this paper specifically sets up two control groups, of which control group 1 is the monitoring data publishing method based on differential privacy, control group 2 is the monitoring data publishing method based on distributed optical fiber strain, and the monitoring data publishing method based on horizontal federated learning proposed in this paper is the experimental group. Through comparison, the feasibility of the

Table 3.1: Description of Thermal Resistance Coefficient of Structural Component Materials of Each Layer of Submarine Cable

No	Submarine cable structure	Material thermal resistance coefficient/K · m/W
1	Conductor	0.00
2	Peninsula resistance water zone	6.00
3	Bituminous PP rope cover layer	6.00
4	Asphalt anticorrosive coating	5.00
5	Insulation shield	3.50
6	Lead alloy sheath	0.03
7	Conductor shield	3.50

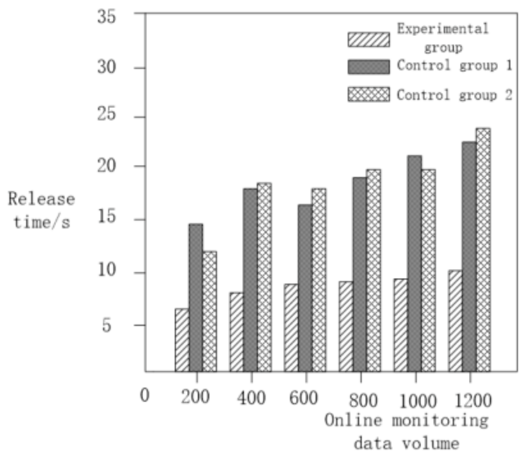

Fig. 3.1: Comparison Results of Online Monitoring Data Release Time of Composite Submarine Cable

proposed data release method is verified. The time required for the online monitoring data of composite submarine cables to complete the release task is selected as the evaluation index of this experiment. The shorter the time required for data release, the higher the feasibility of the data release method, and the better the timeliness of the release. Set the amount of online monitoring data of composite submarine cable as 200, 400, 600, 800, 1000, and 1200, use MATLAB simulation analysis software to simulate the release process of the three data release methods, using SPSS statistical analysis software to measure and integrate the time required for the three methods to complete the data release task, and draw a comparison chart of evaluation indicators.

It can be seen from the comparison results of the evaluation indicators in Figure 3.1 that the time required for the three data release methods to complete the online monitoring data release task is quite different when the amount of online monitoring data of composite submarine cables is gradually increasing. Among them, the data publishing method based on horizontal federal learning proposed in this paper shows good advantages. In each group of online monitoring data publishing tasks of composite submarine cables, the time required to complete the publishing is less than the other two methods, and the publishing timeliness is good, without a significant growth trend. While control group 1 and control group 2 took longer to complete the release task with the increase of online monitoring data. From the comparison results, it can be seen that the data release method proposed in this paper is highly feasible and more suitable for the online monitoring data release of composite submarine cables.

3.3. Result discussion. In this context, the data publishing method based on horizontal federation learning, as proposed in this paper, demonstrates clear advantages. Specifically, this method outperforms the other two methods in terms of completion time and timeliness of data release. For each group of online monitoring data publishing tasks for composite submarine cables, the proposed method consistently requires less time to complete the data release compared to the control groups (control group 1 and control group 2). Furthermore, the timeliness of the data release using the proposed method remains good and does not show a significant growth trend. In contrast, the control groups experience longer completion times as the amount of online monitoring data increases.

Based on the comparison results, it is evident that the data release method proposed in this paper is highly feasible and well-suited for online monitoring data release of composite submarine cables. The advantages of the proposed method, such as faster completion times and consistent timeliness, highlight its effectiveness in addressing the challenges associated with large volumes of online monitoring data.

These results imply that the proposed method based on horizontal federation learning offers a practical solution for efficient and timely data release in the context of composite submarine cable monitoring. Its superiority over the control groups suggests that it can effectively handle the increasing amount of online monitoring data, making it a favorable choice for composite submarine cable data release tasks.

4. Conclusion. The release of online monitoring data of composite submarine cables is of great significance for ensuring power transmission between coastal islands and cities. In order to improve the poor timeliness of traditional data release methods and the inability to release online monitoring data of composite submarine cables in time, this paper proposes a new method of online monitoring data release of composite submarine cables by introducing horizontal federation learning based on the traditional data release methods. Through the research in this paper, the time required for data release is reduced, the timeliness of data release is improved, and the monitoring data released can timely identify potential fault hazards in the operation of submarine cables, reduce the probability of damage to submarine cables, and ensure the safety of power grid operation.

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Edited by: Sathishkumar V E
Special Issue on: Scalability and Sustainability in Distributed Sensor Networks
Received: May 13, 2023
Accepted: Jul 10, 2023