Two-layer QoS-guaranteed backbone communication network modeling for power protection services

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Abstract. In order to ensure that the smart grid backbone communication network architecture model has a good universality, a two-layer QoS (Quality of Service) optimization modelling method of the backbone communication networks for power protection services is proposed. Firstly, taking the communication network capacity as a constraint, the minimum value of time-QoS of the system protection service is the optimization goal, and a two-layer capacity optimization model of service quality assurance is constructed. Secondly, the optimization model is simplified and a simulation experiment is designed. The validity of the proposed method is verified by numerical examples. The simulation results of the optical layer and the electrical layer satisfy the power system protection time delay specified in the power system protocol should meet the requirement of less than 50 ms.

1. Introduction

With the construction of Smart Grid and the rise of Energy Internet, the scale of the power backbone communication networks has been expanding, in which the topologies and related functions have become increasingly complex [1]. On the other hand, the power system is transformed from a traditional single power distribution role to a new power exchanging node, which integrates all the power-related functions such as the power storage and the power distribution. Therefore, a new technology challenge is created in the architecture design and related planning for the power backbone communication network, which is key to the effective deployment of Smart Grid and related Energy Internet.

Many works have been done on the backbone communication network modeling and its related modeling optimization [2-5]. An integrated OTN capacity optimization model is proposed to solve the explicit modeling of IP/MPLS over OTN over DWDM, which is used for the multilayer network considering the OTN layer as a distinct layer [2]. In [3], an energy-efficient multicast tree construction protocol is presented for real-time data streaming, which considers using real time estimated routing delay from source node to other nodes. A preprocessing and dynamic programming algorithm has been proposed to modify the weights of the edges at a minimum cost under unit Hamming distance [4]. In [5], a label setting algorithm has been presented to solve the problem that the k-shortest path problem, which is given that departure and arrival are constrained within specified time windows.

Given the fact that the power related services require considering Quality-of-Service (QoS) in the power backbone communication network, this paper proposes a two-layer QoS optimization modelling method for power protection services is proposed. The proposed model constructs the communication
network architecture into two layers, which includes an electric layer for the paths’ control and an optical layer for the data transmission. Moreover, the proposed model is based on the transmission capacity of the related grid communication network, which aims at optimizing the time-delay QoS index for the grid-related protection services. The rest of the paper is organized as follows. In section 2, the two-layer QoS model is described. Section 3 discusses the simulation experiment. Finally, the conclusion is drawn in Section 4.

2. Two-layer QoS modelling

2.1. Network layered architecture
Considering that the optional technologies of existing technology architecture mainly include SDH, MSTP, and OTN, and smart control technologies such as SDN which can be used in the mid-to-long term to achieve flexible configuration of the network layer, the architectural model design idea is to construct a general model of a two-tier structure including an electrical layer and an optical layer, which shows in figure 1. This can ensure that the architecture model has a good universality. The model can achieve flexible control of the services with smart control technology such as SDN taken into account. The existing electrical layer is further divided into an electrical control sublayer and an electrical transport sublayer.

As shown in figure 1, (a) the electrical layer and the optical layer implement the communication service bearer of the optical layer through the parameter mapping of the electrical layer communication capacity and the link; (b) The electrical layer upward interface is connected to the network application layer to implement data conversion of the application service, and the lower layer interface is connected to the optical control layer to implement the photoelectric conversion before data transmission; (c) The optical control sublayer implements control and conversion before protecting the optical data physical path of the service data, and the lower layer interface is connected with the optical transport layer; (d) The optical transport sublayer implements the protection of service data optical channel transmission and its QoS control.

2.2. Two-layer QoS model
The layered QoS model for optimizing time delay is constructed, with the communication network capacity as a constraint and the minimum value of the average delay of the grid-related service as the optimization goal. The related constraints and optimal function of the proposed model is depicted as follows.
Inter-layer capacity constraint
The inter-layer capacity matching constraints of the model are shown in equation (1).

\[ F_e = F_o \]  

In equation (1), \( F_e \) and \( F_o \) respectively represent the electrical layer routing communication traffic capacity and the optical wavelength communication traffic capacity of optical layer transport sublayer.

Electric layer time delay constraint
Given a time-delay restraint grid-service \( d \) formulated as equation (2), it is necessary to define the time delay of the electrical layer, the optical control sublayer, and the optical transport sublayer.

\[ d = 1, 2, \ldots, N^e_s \]  

In equation (2), \( N^e_s \) represents the total number of grid-realted services S.

For each given service \( d \), if \( P_e \) represents the logical path of the electrical layer, \( t^e_{dp} \) represents the delay for the logical path of the electrical layer and \( \delta^e_{dp} \), which takes 0 or 1, represents whether the given service \( d \) transports from the path, the delay \( T^e_d \) of this service layer may be formulated as equation (3).

\[ T^e_d = \sum_{p=1}^{P_e} \delta^e_{dp} t^e_{dp} \]  

Optical layer time delay constraint
Similarly, for the service \( d \), if \( P_o \) represents the physical path of the optical transport sublayer, \( t^o_{df} \) represents the delay for the physical path of the optical transport sublayer and \( \delta^o_{df} \), which takes 0 or 1, represents whether the given service \( d \) transports from the path, the delay \( T^o_d \) of this service layer is formulated as equation (4).

\[ T^o_d = \sum_{f=1}^{P_o} \delta^o_{df} t^o_{df} \]  

Path time delay constraint
Assume that the time delay for the service is limited to \( T_{upper} \), the delay \( T_d \) of the service \( d \) will satisfy the constraint above as equation (5).

\[ T_d = T^e_d + T^o_d \leq T_{upper} \]  

Optimal time-delay function
The objective function in the proposed model is as equation (6).

\[ \min_{T_{QoS}} = \frac{1}{N^e_s} \sum_{d=1}^{N^e_s} T_d \]  

In equation (6), \( T_d \) represents the time delay for the service \( d \).

3. Simulation and analysis
Based on an algorithm that solves the two paths with the shortest total delay between any two nodes, we find the minimum delay between any two nodes and the service transmission path. The total delay includes transmission delay, node forwarding delay, and mapping/demapping delay. As shown in figure 2, based on the cost239 network, we number the links and determine the distance of the link. We can see that there are 11 nodes and 22 links in total.

![Figure 2. COST239 network topology.](image)

We take a node (from 1 to 11) as the starting node and another node as the end node. A service is loaded between two nodes, and the service is passed from the starting node to the destination through the shortest path found. We repeat this process until all nodes have been calculated, and then, we count the average latency of each service and the occupancy rate of each link.

The simulation experimental parameters of OTN technology are shown in table 1 and this is based on the existing operating system parameters.

| PARAMETERS | T_G (us) | T_z (us) | T_y (us) | T_q (us) |
|------------|----------|----------|----------|----------|
| OTN        | 5        | 200      | 40       | 40       |

In table 1, \(T_G\) represents the optical cable delay per unit distance, while \(T_z\) represents the direct connection delay. Moreover, \(T_y\) represents the mapping delay and \(T_q\) represents the canceling mapping delay.

Firstly, we study the relationship among the service average time delay (short for average delay), the service start node and service end node. X axis is the service starting node ID ranging from 1 to 11, and Y axis is the service end node ID ranging from 1 to 11. Moreover, the service average time delay is Z axis which unit is ms. The service start node and the service end node cannot be the same node. The simulation results are shown in the figure 3(a). As the observations can be seen from figure 3(a): (1) the average delay of Node a to Node b is consistent with the average delay of Node b to Node a. It indicates the transmission path is bidirectionally transmitted, and the shortest total delay of the two is consistent. (2) The service average delay is 2.32 ms, and the standard deviation is 0.81 ms. (3) The service average delay is 4.102 ms when the starting node ID is 5 and the end node ID is 10. It meets the QoS requirements of less than 50 ms for the protection services.

Secondly, we study the performance by using different links to support services by their minimum latency path. There is a total of 22 links, each with a maximum service capacity of 50. The link resource occupancy rate is counted and the experimental results are shown in figure 3(b). X axis is link ID ranging from Link a to Link v, while Y axis is link resource occupancy rate (short for occupancy rate) in percentage. As the observations can be seen from figure 3(b): (1) the occupancy rates of
different links are different. It indicates that the transmission delays introduced by different links are different. (2) The maximum occupancy rate of Link j is 92%, while Link h has the minimum occupancy rate 16%. It indicates there is no restriction on the use of better links and resulting in a large influx of service. (3) The average occupancy rate is 44.18%, and the standard deviation is 20.29%. (4) There are 5 links which occupancy rate exceeds 50%, which also satisfies the existing restraints.

![Figure 3](image)

**Figure 3.** Experiment average time-delay and link occupancy rate results. (a) average time delay and (b) link occupancy rate.

### 4. Conclusion

This paper proposes a two-tier QoS model for backbone communication networks for power protection services based on the universality of the architectural model in the backbone communication network, combined with recent technology options available in the existing technologies and smart control technologies that can be adopted in the mid-to-long term. The existing electrical layer portion is further divided into an electrical control sublayer and an electrical transport sublayer. Through simulation and analysis, it can be seen that the double-layer QoS optimization model proposed in this paper can meet the power system protection delay specified in the power system protocol to meet the requirement of less than 50ms. For today's backbone communication network architecture modeling has practical reference significance.

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