Coordinated and Unified Control Scheme of IP and Optical Networks for Smart Power Grid

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Abstract. As new services of the smart power grid emerge with diversity and complexity, great challenge and demand is presented for traditional IP data network and optical network to realize coordinated control. Benefiting from advantages of concentration, open, manageability and controllability, this paper proposes a power-grid oriented concentrated unification control architecture of IP and optical networks, together with coordinated services control mechanism, with the aim to achieve highly efficient coordination between IP network and optical network. Under this concentrated unification control architecture, an OpenFlow protocol based unified control scheme is also proposed and designed, by making full use of existing connections on optical layer to reach fast establishment for services produced by smart power grid. Therefore, the support ability of IP and optical networks to power-grid services can be greatly improved.

1. Introduction

With rapid development of energy internet and smart power grid, the deep convergence of information telecommunication technologies (ICT) and energy, will bring great evolution in fields of energy transmission and energy control [1-2]. As an important part of smart power grid, the communications network must not only satisfy high bandwidth and reliability demands on data collection and transmission for energy internet, but also deal with the challenge of controlling brought by increasingly large-scale network.

As these services of smart power grid shows the trend of diversification and complexity, the emerge of power mobile communication, data centre and cloud computation and so on, brings higher demand to current IP network and optical network in smart power grid. To support the dynamic services connections establishment and flexible resources allocation for end-to-end data services of smart power grid, the interconnection and convergence between IP network and optical network is urgently in need. Without the high bandwidth provided by optical network, the IP data network will fail to support various services of smart power grid. There exists great difference between the packet switching based IP data network and the circuit switching based optical network. Thus, the coordinated and unified control of IP and optical networks is necessary and must deal with great difficult.

The software defined network (SDN) has become a novel software defined network architecture and technology, and the separation of control plan and data plan and centralized network control allows the IP network and the optical network to support upper layer services with better performance. Benefitting from advantages of open architecture and centralized control of SDN technologies, this paper proposes and designs a coordinated and unified control scheme to realized high efficiency coordination between IP network and optical network of smart power grid. Moreover, the OpenFlow
protocol based unified control procedure of IP network and optical network is also designed to improve the service connection control function.

The rest of this paper is organized as follows. Section 2 discusses the IP and Optical network unified control demand; followed by the description of the coordinated and unified control scheme of IP and Optical network in Section 3. Section 4 gives the simulation results and analysis. Finally, Section 5 concludes this paper.

2. IP and optical network unified control demand analysis

Current information communication services of smart power grid, is characterized by diversification and coverage, and these services cover all fields of smart power grid, including electric power generation, transmission, distribution and schedule. According to services features, these services can be divided into two categories: producing services and management services. In fact, producing services mainly includes the relay protection, stability control, wide area phasor measurement and dispatching automation, etc. And management services mainly consist of the administrative telephone, the office information system, the video conferencing and the schedule management information system, etc. It must be pointed that these services mentioned above have strict demand on communication reliability with special requirements on time delay and bandwidth.

In current communication network of smart power grid, the IP network and optical network are separated and fail to reach inter-communication, where the route function in IP layer is unable to obtain network parameters from optical layer and to perform routing. Moreover, the optical layer also fails to be aware of services types and services requirements. Due to these problems, the utility rate of network resources and the service quality are both unavoidable.

Different from traditional networks in which the IP layer and optical layer are separated from each other, the “IP and Optical” network adopts the coordinated and unified control architecture, where the message interaction between the IP layer and optical layer can be achieved through signaling protocols. Thus, the routing operation in IP layer can be conducted according optical layer state parameters, and optical layer is able to be aware of IP services requirements for dynamic light path establishment.

3. Centralized control architecture of IP and optical network

Based on the open and unified control concept of SDN technology, this paper proposed a Coordinated and Unified Control Scheme of the IP and Optical converged network for smart power grid. The Coordinated and Unified Control architecture is given in Fig.1. This architecture mainly consists of IP layer network, optical network, the centralized controller and the application plan. The controller is able to provide support to application services through the north-Interface, and to conduct operation with the IP layer and the optical layer. Based on this Unified Control architecture, the highly efficient programmability of “IP and Optical” network control can be realized, with all topology control to support dynamic the end-to-end service connection.

In this OpenFlow based “IP and Optical” centralized controlled network architecture, the data plan consists of IP network and optical transport network, and the control plan is the OpenFlow protocol based controller, and the upper application plan can support various services. The unified controller is
responsible of services driven connections establishment and coordinated schedule of network resources. This unified controller is able to collect real-time topology information of data plan devices, IP layer and optical layer state information. Moreover, it can be aware of services connection requirements to provide support according control policy and computation results.

The unified controller obtains network nodes and topology information of the whole network, by control message channel between controller and all nodes in IP network and optical network. Through multiple layers interaction, the unified control of both IP network and optical network can be achieved. When the unified control policy of IP and optical network is conducted for connection requests, the centralized control will take all network devices and layers as a whole into consideration. Thus, this OpenFlow based centralized control architecture of the IP layer and the optical layer enable the whole network to become directly programmable and all devices on data plan can be abstracted as functional program and network services.

4. Unified control scheme of IP and optical network

The OpenFlow based IP and optical network adopts the unified flow table to realize centralized control of IP layer and optical layer. Therefore, flow table extension for IP layer and Optical layer is necessary, and the controller must be able to conduct coordination mapping between the IP layer flow-table and the Optical layer one, to achieve highly efficient control of the IP and optical network.

4.1. Unified controlled Flow-table mapping in IP and optical network

In this OpenFlow based IP and optical network, the unified coordinated control of both packet switching and circuit switching must be realized by defining the IP layer flow-table and the optical layer flow-table. The basic circuit switching connection table is defined in switches, including port, wavelength, virtual interface and time-slot. The controller takes each optical channel of wavelength or sub-wavelength as one service traffic and operates IP services traffic aggregation according to bandwidth requirements and priority, in order to transport these traffics through optical channel.

4.2. Unified controlling procedure

The unified control is responsible of services connections establishment and optical resources allocation, in order to provide end-to-end connection by coordinated control of IP and optical network. The controller collects real-time state parameters and topology information of both IP and Optical networks and bandwidth requirement from upper layer. By making full use of these data, related algorithm is used to compute new route and allocation proper optical resources for connection request, according to current network states and limited conditions. Then, corresponding flow-tables are generated by OpenFlow based controller and will be send to each involved switches and optical node. The coordinated and unified control procedure is given as follows.

Step 1: the IP switch receives services data packet, and search for its corresponding flow-table;
Step 2: if there is related flow-table record of this data packet, the IP switch transport the packet; otherwise, reports the connection request to the controller;
Step 3: the controller computes the route according to connection request and optical layer state;
Step 4: the OpenFlow based controller modifies flow-table information of involved IP layer switches and optical nodes;
Step 5: related optical nodes establish light-path in optical layer by OpenFlow agents embedded in optical nodes.
Step 6: all involved switches and optical nodes reply ACK messages to the controlled;
Step 7: the controller receives all ACK messages form these switches and nodes, and modifies IP switches and optical nodes;
Step 8: the connection for newly arrived services is successively complete.

5. Simulation results
To evaluate the proposed scheme, the simulation is conducted in this section, where the simulation environment is constructed by NS2 network simulation software tools and the NSFnet topology is adopted as network construction. And this simulated IP and optical network consists of 32 nodes and 41 links, including 16 IP-switches controlled by OpenFlow and 16 optical nodes. Services traffics generated by each IP-switch contain static traffics with Passion distribution and burst services with radon distribution. Each optical node works with capacity of 10 Gbps and IP switches can support 100M bandwidth at least. Simulation analysis is made in terms of services connection blocking rate and end-to-end delay time.

The comparison is made between this proposed scheme and the traditional one in IP and optical network, and the comparison results are given in Fig.3 and Fig.4. It must be pointed out that Case_1 and Case_2 are independently referred to traditional scheme and proposed scheme with 8 optical wavelengths, while Case_3 and Case_4 are ones under 16 wavelengths.

The Fig.2 shows the relation between connections request number and blocking rate under both schemes. It is obvious that the blocking rate soars as connection requests increase rapidly. With more wavelength resources, average blocking rates of both schemes are improved. And under the same wavelengths available, the scheme proposed by this paper shows better optimization on connection blocking rate.

The comparison result of time delay is also given in Fig.3. It can be drawn from Fig.3 that the proposed scheme has better delay time performance than the traditional one. Because the unified and coordinated control scheme is allowed to establish fast connection, and this advantage is more obvious as the service connection request soar and network scale is enlarged with great number of nodes.

6. Conclusion
This paper proposed a smart-power-grid oriented concentrated unification control architecture of IP and optical networks, together with coordinated services control mechanism, with the aim to achieve highly efficient coordination between IP network and optical network. Under this concentrated unification control architecture, an OpenFlow protocol based unified control scheme is also proposed and designed, by making full use of existing connections on optical layer to reach fast establishment for services produced by smart power grid. Therefore, the support ability of IP and optical networks to power-grid services can be greatly improved.

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