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Energy efficiency with QoS control in dynamic optical networks with SDN enabled integrated control plane

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ABSTRACT

The paper presents energy efficient routing algorithms based on a novel integrated control plane platform. The centralized control plane structure enables the use of flexible heuristic algorithms for route selection in optical networks. Differentiated routing for various traffic types is used in our previous work. The work presented in this paper further optimizes the energy performance in the whole network by utilizing a multi-objective evolutionary algorithm for route selection. The trade-off between energy optimization and QoS for high priority traffic is examined and results show an overall improvement in energy performance whilst maintaining satisfactory QoS. Energy savings are obtained on the low priority traffic whilst the QoS for the high priority traffic is not degraded.

1. Introduction

Research in energy efficient networking has considered various network domains (e.g. core, metro and access networks) and network layers. Various solutions have been identified, e.g. node/link sleeping during off-peak hours [1], low-power idle [2] and traffic engineering [3]. However, few works consider how to maintain a high level of Quality of Service (QoS) at the same time, which is a concern for operators. The techniques used in node/link sleeping or traffic engineering are usually accompanied by certain QoS compromises. In this paper, to maintain the QoS whilst building an energy efficient optical network, a flexible routing mechanism is proposed using a novel integrated control plane platform.

The proposed integrated control plane platform improves the traditional network operations by efficient communication across multiple network domains. Network control mechanisms today are horizontal separations between core and access networks, and vertical separations between application, transport and physical layers. These separations can lead to high operational and energy costs, low network efficiency and high latency in path provisioning. The emergence of applications with high data rates and low delay demands, i.e. HDTV and VoIP, have posed new challenges for bringing down the energy costs whilst maintaining QoS. However, it is not easy to provision end-to-end QoS for such applications with the current separated control mechanisms across domains. A unified, intelligent cross domain control mechanism is needed. Under these circumstances, Software Defined Networking (SDN) [4] concepts have been considered. SDN decouples the control and data planes, allowing for an integrated control plane across domains. A programmable SDN control plane can provide flexibility in designing new functionalities and services, independent of the underlying physical infrastructure. This is discussed in detail in our previous work [5]. The proposed structure operates on the top of a translucent Generalized Multi-Protocol Label Switching (GMPLS) controlled optical core network, together with Optical Network Units (ONU) Management and Control Interface (OMCI) [6]

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controlled Gigabit Passive Optical Network (GPON) access networks. The integrated control plane enables a sharing of network information across these network domains. To support end-to-end (from access network to core network to access network) QoS control under the integrated control plane, the traffic from the access network is differentiated and the information is exchanged between the access and core networks assisted by the control plane. Furthermore, differentiated routing can be applied within path computation function in the integrated control plane. In [5] the tailored energy efficient routing algorithm is applied mainly to low priority traffic, while delay and blocking sensitive traffic is not impacted. We choose a centralized, overlay model [5,7] to design the integrated control plane. Although a centralized control requires monitoring information to be brought to a single entity, imposing a latency and communication overhead, it has the benefit of possessing global knowledge. In contrast, distributed mechanisms can suffer from inconsistencies across the network due to latency and also require information sharing to maintain converged behavior.

Traditionally, most dynamic routing algorithms, e.g. Shortest Path (SP) or Load Balancing (LB), can only evaluate one parameter at a time. By applying energy efficient routing algorithms, e.g. Least Consumption (LC) [5] on the part of network traffic that is not delay or blocking sensitive, certain energy savings can be achieved without influencing other types of traffic. However, such routing strategies are limited in that only one criterion (i.e. energy consumption, delay or blocking) is considered at a time. Our work improves performance by utilizing centralized control as well as a multi-objective routing mechanism. Instead of using hop count as the only objective for the delay sensitive traffic, energy consumption is considered as a secondary objective. A Multi-Objective Evolutionary Algorithm (MOEA) is used to improve the route selection in a dynamic network context whereby Strength Pareto Evolutionary Algorithm 2 (SPEA2) [8] is used to assign a fitness value to each candidate solution. The algorithm is tested in a dynamic simulation environment using OPNET [9]. Although a certain time is required to execute the heuristic algorithm, we assume a suitable delay tolerance exists when setting up an optical core network path. Results from the multi-objective algorithm are compared against the results obtained from the single objective dynamic routing algorithms (SP, LB and LC algorithms [5]).

2. Related work

Energy efficiency in optical networks has been widely considered. In [10], the authors compare energy efficiency with network topologies and architectures. The authors in [11] use power-aware provisioning methods to achieve energy savings in optical networks including grooming operations. There are other similar works, but few of them take QoS requirements into consideration. In order to support a differentiated service in the core network, similar to the concept in this work, the authors in [12] explored the possibilities of using MPLS Traffic Engineering (MPLS-TE). However, the method has limited use in an optical network environment. Similar to our integrated control plane, a unified control plane concept has been discussed by a number of researchers [13–15], where end-to-end QoS is the driver. Comparable concepts are developed with SDN technologies where [16,17] proposed an unified control plane to use with cloud services and optical burst switching. However, these works do not consider the impact on energy efficiency. The Internet Engineering Task Force (IETF) Internet draft proposed in 2013 [18], has defined network control functions for SDN. The concept is similar to our proposal, with a more general and broader scope. However, there is no actual implementation discussed in the work. Evolutionary Algorithms (EA) have been widely used to solve Routing and Wavelength Assignment (RWA) problems in optical networks, such as [19]. The author in [20] uses EAs to form both single and multi-objective problems. Neither of these have applied their approaches in a dynamic environment, nor tailored designs to the needs of different applications.

3. Software defined integrated control plane architecture

The control plane serves as a platform to support the differentiated routing mechanisms proposed in this work. Fig. 1 shows an overview of the network architecture including the information flow, which is distributed in both the core network and access network. An optical translucent mesh structure is considered for the core network, and a point to multi-point GPON structure is considered for the access network. As an overlay layer to the GMPLS and ONT Management and Control Interface (OMCI) control plane, the integrated control plane interacts with both of these. The traffic type information is encapsulated using GPON Encapsulation Method (GEM) [21] labels in the GPON network part, extracted to the integrated control plane, and translated to the traffic type for the core network.

Each connection request is treated as a traffic flow. The flow table is set up and maintained in the control plane, and is implemented in a centralized manner. The information stored in the flow table can be user defined, e.g. to include traffic type and duration information. To enable a flexible routing structure, traffic type information is needed in the flow table, together with the information necessary to define a traffic request, e.g. the required bandwidth, source and destination node address. Unlike a routing table lookup in an IP network, a flow table look up is performed only at the ingress router of the core network. If no entry is found in the flow table, a new request will be initiated by the GMPLS control plane to the integrated control plane and route calculation is performed based on QoS requirements of the traffic flow. Once a route is obtained, the GMPLS control plane is then invoked to perform resource reservation. If the resources are successfully reserved (i.e. there exists a possible connection to support the flow) by the GMPLS control plane, the reserved route information is returned back to the integrated control plane, and the connection ID is inserted into the corresponding flow table entry. The flow setup is then complete.

As an overlay model upon both the GMPLS and the OMCI control plane, the integrated control plane is designed to