AUTONOMIC SDN CONTROL OF MULTI-ADAPTIVE OFDM-BASED BVTs IN FULLY-DISAGGREGATED SDM/WDM FRONTHAUL NETWORKS

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Abstract

We present a multi-adaptive OFDM-based BVT controlled with YANG/NETCONF by an autonomic SDN controller for fully disaggregated SDM/WDM fronthaul networks. The autonomic SDN controller deploys a control loop that monitors the per-subcarrier SNR and computes the optimal constellation based on the actual signal degradation.

1 Introduction

Telecom operators look at the optical disaggregation approach with great interest, i.e., how white box optical hardware might replace the established incumbent aggregated model, based on single vendor systems [1]. Disaggregation aims at providing a new degree of flexibility, allowing component migration and upgrades without vendor lock-in. In the full disaggregation model, all optical network elements (i.e., transponders, ROADMs, etc.) can be provided by different vendors with open interfaces to the software defined networking (SDN) control system, exporting programmability along with unified data modelling. On the other hand, another challenge is the introduction of autonomic control in the SDN control plane to increase overall performance, efficiency and cost-effectiveness by eliminating most of the manual labour, and to cope with the ever-increasing complexity of the networks [2]. Autonomic control loops are enabled by applying data analytics to monitored data, with analysis outcomes used to recommend network reconfiguration actions.

Bandwidth/bitrates variable transceivers (BVT) are the key element for optical transmission systems [3]. BVTs implement a range of advanced functionalities, such as different bit rates and a dynamic variation and adaptation of modulation format and symbol rate. In this regards, optical orthogonal frequency division multiplexing (OFDM) is a promising candidate thanks to its superior granularity and capabilities for transmission reconfiguration [4]. OFDM allows adaptive modulation format selection at subcarrier level according to the channel profile.

In this paper we present and experimentally validate multi-adaptive OFDM-based BVTs controlled with YANG/NETCONF by an autonomic SDN controller for fully disaggregated Spatial/wavelength division multiplexing (SDM/WDM) fronthaul networks. The autonomic SDN controller deploys a control loop for adaptive subcarrier modulation based on the actual signal degradation. In particular, the SDN controller continuously monitors the

signal noise ratio (SNR) for each subcarrier, analyses the monitored data applying a bit/power loading algorithm [5] to calculate the optimal constellation, and then reconfigures the subcarriers accordingly.

2 Fully-Disaggregated SDM/WDM fronthaul scenario with multi-adaptive OFDM BVT

The considered disaggregated SDM/WDM fronthaul scenario with OFDM-based BVTs is shown in Fig.1. It is composed by a central office (CO) that serves a remote node and different cell sites. At the CO, a pool of base band units (BBUs) is attached to an array of OFDM-based BVTs connected to an optical switch [6]. The optical switch provides connectivity to either the fan-in/out for SDM transmission [7] or to one or eventually a pool of arrayed waveguide grating (AWG) for WDM transmission. The CO delivers its data signals to an optical distribution network, whose feeder stage is a multi-core fiber (MCF) that connects the CO with the remote node. At the remote node, signals are space demultiplexed by means of a fan-in/out device. After the remote node, different drop stages are envisioned, either featuring 1-core single mode fiber (SMF) bundles for continuing SDM paradigm or just an SMF with WDM. Finally, the cell sites also contain BVTs connected to the radio remote head (RRH) and eventual wavelength demultiplexing stages. The remote node is intended as a main space division demultiplexing point and eventually serving a macro-cell. The cell sites are proposed for a small cell service, using standard SMF or a bundle of them.

Fig. 1. Disaggregated SDM/WDM fronthaul scenario

Fig. 2. Autonomic SDN controller architecture

The optical switch at the CO and the different OFDM-based BVTs deploy dedicated SDN agents to interact with the SDN controller by means of NETCONF protocol. The switch is an optical switching matrix supporting cross-connection between any pair of input and output ports. The OFDM-based BVT can be configured for an optimal management of the network resources. The parameters able to be configured at the BVT are: status (active, off, standby), frequency slot (nominal central frequency and frequency slot width), FEC (hard-decision or soft-decision), equalization (zero-forcing or minimum mean square error), and constellation. Constellation is set in a per subcarrier basis by means of two vectors: one containing the bits per symbol (e.g. from $L=2$ up to $L=8$, corresponding to 2^L -QAM), and another one with the normalized power per symbol for each subcarrier. Therefore, the capacity can be set by the SDN controller by generating the suitable constellation. Also, the BVT has a couple of monitored parameters; the overall BER, giving a general view of the connection performance, and the SNR per subcarrier, in order to have an idea of the channel response for driving the adaptive modulation of the OFDM subcarriers. The defined YANG data model is available at [8].

3 Autonomic SDN control for subcarrier adaptive modulation

The proposed autonomic SDN controller architecture is depicted in Fig. 2. It is composed of the next modules:

- **Connectivity Service Orchestrator (CSO):** It handles the internal workflow between the different modules and processes the incoming requests from the Northbound Interface (NBI). NBI offers the connectivity and topology services based on the ONF Transport API (TAPI).
- **Context Manager:** It is responsible of building and managing a database that includes all the relevant information about the connections associated to the connectivity services, the multi-layer network topology, and the associated service interface points (SIPs). It is updated after the provisioning of each service.
- **Path computation Element (PCE):** It centralizes the computation of the spatial path (i.e., nodes and links) and frequency slot. It is based on a single unified multi-layer PCE which can perform a path computation accounting with the TE constraints of the SDM and WDM layers.
- **Connection Manager:** It is responsible of the management of the connections by configuring the nodes using the specific NETCONF plugins.
- **Transponder Manager:** It is responsible of the management of the transponders by configuring and monitoring the BVTs using the specific NETCONF plugin.

Fig. 3. Workflow for autonomic SDN connectivity services.

- **Multi-adaptive BVT algorithm:** It is responsible of allocating the initial OFDM-based BVT parameters (i.e., optical bandwidth, constellation, and equalization) for a requested capacity. Moreover, it also performs the processing of the monitored per-subcarrier SNR and computes the optimal constellation using the Levin-Campello bit/power loading algorithm [5].

The SDN controller provides connectivity services between pairs of OFDM-based BVTs with autonomic reconfiguration of the per-subcarrier constellation based on the monitored SNR. Fig.3 depicts an example of the workflow involved between the autonomic SDN controller and the SDN agents for the provisioning of autonomic connectivity services, involving the following steps:

- 1) A TAPI connectivity service request is sent to the SDN controller, specifying the source and destination SIPs (i.e., sip1 and sip2), the requested capacity, and the FEC.
- 2) The multi-adaptive BVT algorithm considers the worst-case scenario (i.e., without knowledge of the channel profile) and allocates the required optical bandwidth, the constellation for each subcarrier, and the equalization between the source and destination BVTs associated to sip1 and sip2 in order to meet the requested capacity.
- 3) The PCE computes the best spatial path and the frequency slot between sip1 and sip2 considering the (worst-case) optical bandwidth, and then the connection manager provisions the spatial path by sending NETCONF rpc <edit-config> (create) message with the computed node parameters to the node SDN agent.
- 4) The transponder manger configures the source and destination BVTs with the allocated frequency slot, constellation, equalization and FEC, using the BVT NETCONF plugin. It is performed by sending NETCONF rpc <edit-config> (create) to the BVT SDN agents. After that, the SDN controller can notify with the TAPI that the connectivity service is provisioned.

Fig. 4: a) Experimental setup, b) and c) measured SNR and bits x symbol, d) delay, e) Wireshark screenshot with NETCONF messages

- 5) The transponder manager is continuously monitoring the SNR per subcarrier at the receivers by sending NETCONF rpc <get> messages to the SDN agents. Then, the multi-adaptive BVT algorithm computes the optimal constellation, including arbitrary sub-carrier suppression. If there are changes, the transponder manager reconfigures the BVTs as performed in step #4, but sending NETCONF rpc <edit-config> (merge) messages to the SDN agents in order to update the constellation.

4 Experimental validation

The experimental setup used for validation is shown in Fig.4.a. It is composed of two BVTs, two BVT agents, and an SDN controller. BVTs are based on offline processing. A programmable DSP Tx module is implemented with Python and Matlab software to generate digital OFDM signals according the specified constellation. A high-speed digital to analogue converter (DAC, up to 64 GSa/s and 13 GHz) is used to convert the digital OFDM signals and provide electrical analog signals that are optically modulated using a Mach-Zehnder modulator (MZM), with the corresponding linear drivers and a C-band tunable laser source (TLS). The receiver is based on direct detection with PIN photo-diodes followed by the corresponding transimpedance amplifiers. A real-time digital oscilloscope (up to 100 GSa/s and 20 GHz bandwidth) is used for analog-to-digital conversion (ADC). The digital signal is processed with the DSP Rx module based on Python software to measure the per-subcarrier SNR and the overall BER. Both BVTs are connected with a 50-km SMF.

Two BVT agents have been implemented to configure and monitor the BVTs. Each agent is composed of a NETCONF server based on Python (pyang [9] and pyangbing [10]) that contains a modular YANG-based data store for the configuration and operational state data. The main element of the BVT agent is the agent core module that is responsible of mapping the high-level actions requested by the NETCONF server into several specific low-level actions on the involved optical sub-systems (i.e., laser and DSP TX/DAC, and DSP RX/ADC) by means of the developed function libraries.

We have experimentally validated the workflow depicted in Fig.3. In the first test, the SDN controller configures both BVTs to provision a bidirectional channel with a capacity of

40 Gb/s with the following parameters: nominal central frequency (193.4 GHz), optical bandwidth (25 GHz), FEC (hard-decision), equalization (minimum mean square error), and same constellation for all the 512 subcarriers (bits per symbol = 2, and power per symbol = 1), since the channel has not been estimated yet. Fig.4.e shows the Wireshark screenshot with the exchange of NETCONF messages between the SDN controller and the SDN agents. It can be appreciated that the overall setup delay to configure both BVTs is 433s. In the second test, the SDN controller requests to the BVT agents the monitored SNR for the 512 subcarriers through the exchange of NETCONF messages as shown in Fig.4.e. For each subcarrier, the DSP Tx performs the average of 10 measurements in order to provide a more accurate SNR. As observed from the Wireshark capture, the delay for getting the SNR values is 407s. In the third test, the SDN controller computes the new constellation for the 512 subcarriers with the bit/power loading algorithm using the monitored SNR and reconfigures both BVTs. Fig.4.b shows the monitored SNR and the new values of the constellation (bits per symbol) for each subcarrier, in comparison with the uniform values used in the provisioning phase (Fig.4.c). Significant changes are observed, including subcarrier suppression to compensate accumulated dispersion after 50 km SMF. The delay for reconfiguring the BVTs is 401s, as depicted in the Wireshark capture in Fig.4.e. Finally, in the fourth test, the SDN controller deletes the optical channel by removing the state in the BVTs with the NETCONF rpc <edit-config> (delete) messages sent to the BVT agents. The delay is 16s.

5 Conclusion

We have experimentally validated a control loop for adaptive OFDM subcarrier modulation with two multi-adaptive BVTs controlled with YANG/NETCONF. The capacity can be set by the SDN controller by generating the suitable constellation, and the SNR per subcarrier can be monitored in order to estimate the channel profile and enable adaptive modulation of the OFDM subcarriers.

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