Automated Control Plane for Reconfigurable Optical Crosshaul in Next Generation RAN

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Abstract: The paper proposes a unified automated control plane of an SDN-enabled densely deployed reconfigurable optical crosshaul for future radio access networks, with tested ability to perform sub-second automated reconfiguration on low-cost and low-bandwidth control plane.

1. Introduction

The future mobile networks are expected to accommodate a massive number of devices and applications as well as their increasing demands for higher data rates, coverage, and stringent latency. This is also true for the mobile crosshaul network, which becomes an increasingly prominent network segment in the future mobile Radio Access Network (RAN) landscape to provide transport between the core network and the wireless access points. The future crosshaul network will be densely deployed, large in scale, and complex in functionality [1]. This requires scalable network solutions, that streamline deployment and promote interoperability to accommodate increased network capacity and growing data demands in a cost-effective manner.

To ensure scalability and interoperability, future networks should be fully reconfigurable and automated. This can be achieved via an automated and unified control plane, which translates to the following requirements. Firstly, network node's deployment should be fully automated, and no human intervention in the software should be required beyond the physical installation of the node. Secondly, the control plane should support the integration of multi-vendor devices in the forming of the network via abstraction and standardization of device configuration data models. On this front, openness and interoperability are considered to be two main characteristics of future network deployment including the optical crosshaul. This requires automatic exposure and unification of heterogeneous device attributes to a uniform configuration data structure. In addition, the control plane should adhere to Software-Defined Networking (SDN) paradigm which has become an obvious choice for efficient network management [2].

Automating the management of the future optical crosshaul network is a major challenge as it requires considerations on many aspects including network path provisioning, radio access network function allocation, functional split point optimization, and transport interface selection. In this work, we show how automation and unification of the control plane can be realized in a future-ready dynamic reconfigurable optical crosshaul architecture incorporating SDN-enabled control and heterogeneous data plane. Specifically, we use standardized NETCONF/YANG network configuration protocol [3] for our automated optical crosshaul implementation. The proposal is suitable for the integration of multi-vendor devices and inter-operable deployment in a disaggregated optical network ecosystem through device model abstraction and fully automatic control interface setup. The optical control plane is evaluated via a demonstrative deployment process and measurements on reconfiguration time.

2. Reconfigurable Optical Crosshaul

The SDN-enabled reconfigurable optical crosshaul architecture considered in this work conforms to the Open RAN (O-RAN) architecture where the RAN functions are split into Central Unit (CU), Distributed Unit (DU),

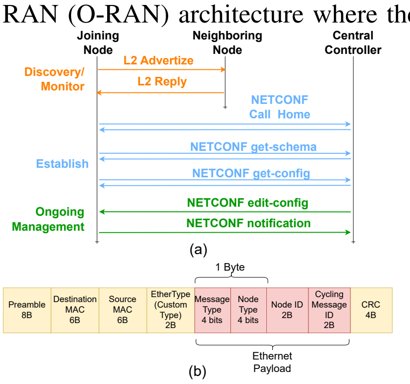

Fig. 1: Control plane signaling and Ethernet-based Advertize packet format

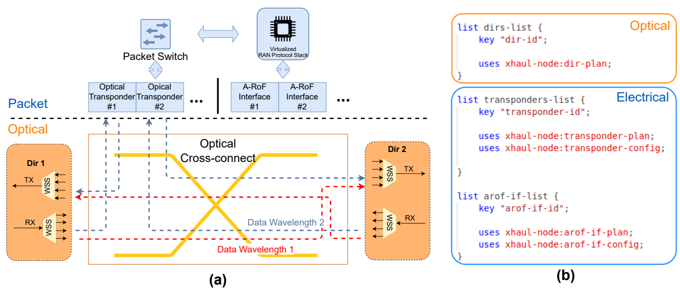

Fig. 2: (a) Multi-layer reconfigurable optical crosshaul data plane (b) YANG model abstraction of the data plane configurable attributes

and Remote Unit (RU) nodes [4]. The reconfigurable crosshaul as a future-proof architecture, will extend the O-RAN crosshauling interface definition to carry more dynamic and diverse traffic and support multiplexing in both the optical layer (optical paths and wavelengths) and the packet-switching layer. As such, a node would contain optical switching infrastructure (e.g. Reconfigurable Optical Add/Drop Multiplexer (ROADM)) as well as electronic packet switches. The configuration of the crosshaul is controlled by the Central Controller (CC). More details of this envisioned reconfigurable crosshaul architecture can be found in [5].

Following the SDN paradigm, the control plane is decoupled from the data plane in this architecture, including on the physical layer. That is, a dedicated wavelength is used for all control plane communication. On the control plane, every DU and RU host a node control agent. CC in the CU can convey crosshaul configuration requests to node agents over the control wavelength. Likewise, the node agents can alert CC about the data plane events. However, before regular control signaling can be exchanged, certain deployment steps need to be performed. For example, point-to-point logical control channels should be established between CC and node agents, and key node information such as topological information and data plane capability should be exposed to CC to update its global view. In a dense deployment scenario, the automation of these deployment steps becomes non-trivial and enables considerable cost and time savings while minimizing human errors. Such automation can be aided by the plug-and-play capability, and its composition is explained next.

3. Automated and Unified Control Plane

3.1. Automation of Control Channel Establishment

On the control plane, the control wavelength should be standardized. That is, all devices should agree upon the use of a dedicated control wavelength. When a new node is plugged into the network, it will start transmitting and listening on this control wavelength and attempt to automatically initiate a control session, via the steps listed below and shown in Fig. 1. These steps are realized via custom layer-2 ethernet frame exchange and subsequently the standardized NETCONF protocol.

Discovery Phase As soon as the new node is plugged in and powered on, it starts advertizing its presence to its neighboring nodes (those to which it has a direct fiber connection) over the control wavelength. The advertize message is composed of Ethernet packets with a special 2-byte EtherType field (e.g. 0x0fc0). The complete frame structure of advertize message is illustrated in Fig. 1. The neighbor nodes can then recognize the frame in the advertize message and reply to it with the necessary information, mainly the neighbor's node ID. This allows the joining node to collect local topological information on the optical layer. The advertize messages will be sent as broadcast Ethernet packets to obtain full scan of its vicinity. Nevertheless, to limit the layer 2 (L2) message exchange between the immediate neighbor nodes, the neighbor's switch will recognize the EtherType and withhold from broadcasting the packet further, as opposed to the handling of regular broadcast packets. For this, augmentation is made to the packet switching protocol to recognize the custom EtherType. The advertize message will be periodically broadcast after the Establishment Phase, as a means to monitor the control plane health.

Establishment Phase To establish a NETCONF control session between CC and a node agent, the NETCONF Call Home feature is leveraged [6]. As the NETCONF protocol is above the network layer, the node will need to be assigned an IP address as well as obtain the NETCONF controller's IP. In the current implementation, this is done via standardized Dynamic Host Configuration Protocol (DHCP). The DHCP server is co-hosted on the same IP as the NETCONF controller. With this, the NETCONF agent can simply invoke Call Home to the DHCP server IP to find the NETCONF controller. CC can then query the node's data plane capacity, and local topological information. CC can use this information for data plane service provisioning and orchestration. This completes the automatic establishment procedure.

Management Phase From this point onwards, a control session is established to enable central control of crosshaul nodes. The node can also alert CC to local data plane changes via NETCONF notification.

3.2. Unification of Device Configuration

The second aspect of the control plane is to enable universal handling of device configuration irrespective of the device vendor. The use of NETCONF protocol and YANG data modeling already provides a powerful framework for standardization and abstraction. By constructing appropriate high-level configuration model templates that can readily import vendor-specific YANG device models, universal control can be established from the NETCONF controller to a disaggregated, multi-vendor optical network ecosystem. In our implementation, we created a YANG model in line with the envisioned 2-layer data plane structure, as shown in Fig. 2(a). In this model, optical ports (wavelength-selective switch ports) can be paired with optical transponders for ADD/DROP operations, or paired with another optical port for wavelength routing. The electrical domain operations can be configured to 1) assign a packet flow to a packet forwarding lookup table for electrical-domain packet forwarding, or 2) assign a packet flow to a virtualized RAN function for functional split processing. Accordingly, the YANG configuration model (Fig. 2(b)) contains a `dirs-list` for encapsulating all optical port configurations. This can also include additional vendor-specific configuration attributes such as in-line amplifier gains, depending on the imported configuration data model. The electrical domain configurations are encapsulated by `transponders-list` and

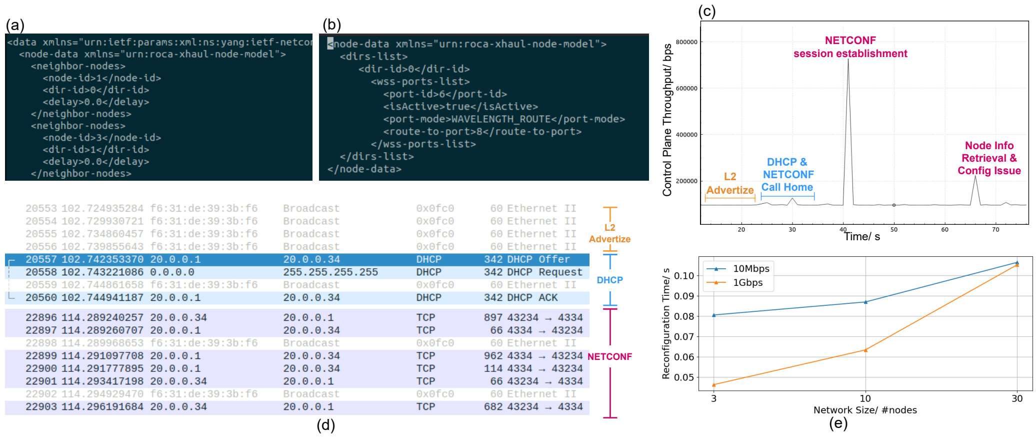

Fig. 3: (a) Sample topological information queried from a DU node (b) Sample optical wavelength routing configuration command used for reconfiguration (c) Wireshark I/O graph at the NETCONF controller (d) Wireshark packet capture at the CC (e) NETCONF reconfiguration time at varying network scales and control plane datarates

`arof-if-list` for O/E interface configuration (e.g. transponder bitrate, Analogue Radio-over-fiber (A-RoF) carrier frequencies) and electronic packet forwarding configurations such as packet forwarding lookup tables.

4. Evaluation and Results

To evaluate the proposed control plane, the reconfigurable optical crosshaul architecture is fully implemented via the NS3 simulation framework, including the dedicated control wavelength and all mentioned data plane infrastructure (optical ports, transponders, A-RoF interfaces, and packet switches). The node agents and controller are deployed as real software within Linux containers and tapped into the simulated architecture. Specifically, netopeer2 [7] is used for the NETCONF implementations. The demonstration setup deploys a 3-node linear topology (CU-DU-RU). Upon the startup of a new node (launching the Linux container of the node), the successful automatic NETCONF session connection is observed from the controller side. Fig. 3(c) and Fig. 3(d) show the controller network interface bandwidth usage and the captured packet exchange during such process, respectively. Subsequently, the new node's local topological information and configuration attributes can be queried (as shown in Fig. 3(a), and node configurations command can be issued. From there, sample reconfiguration command (as shown in Fig. 3(b)) is issued, and the reconfiguration procedure time is measured. Furthermore, the deployed topology is expanded into tree topology with more nodes, where the automated deployment procedure is validated and the reconfiguration time is measured. In addition, varying control plane data rates are tested on each topology, as shown in Fig. 3(e). The results show that the proposed control plane can perform sub-second reconfiguration even with a low-data rate control plane on a sizeable crosshaul network with 30 nodes.

5. Conclusions

In this paper, we proposed an SDN-enabled automated and unified control plane for the next-generation reconfigurable optical crosshaul, based on a L2 message advertize mechanism and NETCONF "Call Home" procedure. We demonstrated the automated node deployment procedure using real NETCONF controller and agent over an emulated optical crosshaul network. The performance of such control plane is assessed in terms of reconfiguration time over different network sizes and control plane data rates. The results show that the proposed control plane automation and unification are valid and scalable.

6. Acknowledgements

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