K. Kondepu, N. Sambo, F. Giannone, P. Castoldi, and L. Valcarenghi. (march, 2018). *Orchestrating Lightpath Adaptation and Flexible Functional Split to Recover Virtualized RAN Connectivity*. Paper submitted in Optical Fiber Communication Conference, San Diego.

DOI: 10.1364/OFC.2018.Th2A.30

Orchestrating Lightpath Adaptation and Flexible Functional Split to Recover Virtualized RAN Connectivity

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Abstract: This study shows that a two-step recovery scheme orchestrating lightpath transmission adaptation and evolved NodeB (eNB) functional split reconfiguration preserves the Virtualized RAN fronthaul connectivity even when network capacity is scarce.

1. Introduction

In the next years, the design, the control, and the management of metro networks [1] will be driven by the maximum latency and capacity required by emerging 5G services (e.g., eMBB — enhanced Mobile Broadband; mMTC — massive Machine Type Communications; URLLC — Ultra-Reliable and Low Latency Communications) and architectures (e.g., the New Radio Access Network — RAN). To support such requirements, metro networks will likely have to employ transponders based on spectrally efficient modulation formats (e.g., PM-16QAM). At the same time, operators are working to reduce costs and make networks more scalable, for example, by reducing margins [2]. Margin reduction can increase the probability of experiencing *soft failures* [3] (i.e., degradations resulting in bit error rate —BER— increase over acceptable thresholds) that can be overcome by transmission adaptation: for example by changing the modulation format (e.g., from PM-16QAM to the more robust PM-QPSK) or by increasing the code redundancy along the same path. Transmission adaptations can be fast (e.g., in the order of microseconds for baud rate adaptation [4]). However, the change of transmission parameters may imply a rate reduction (e.g., 50% from PM-16QAM to PM-QPSK at fixed baud rate) [3]. If this not acceptable by specific services, re-routing is applied to save the whole rate.

In parallel, the envisioned 5G network architecture, including the New RAN, will be heavily based on virtual network functions (VNFs) [5]. In the New RAN the evolved eNB functions are split into two new, most likely virtualized, network entities [6,7]: the Central Unit (CU) deployed in centralized locations and the Distributed Unit (DU) deployed near the antennas. The function distribution is based on the chosen functional split. Several functional splits have been considered [7], demanding different requirements in terms of latency and capacity to the fronthaul network [8].

In this paper, we propose a two-step scheme to recover DU-CU connectivity in Virtualized RAN fronthaul upon lightpath soft failure. The scheme is based on the combination of lightpath transmission adaptation and eNB functional split reconfiguration. The scheme complements the fast recovery of physical layer resilient schemes with the capability, through functional split reconfiguration, of recovering DU-CU connectivity even when optical network resources are scarce and lightpath rerouting is not possible.

2. Scenario and Proposed Architecture

In a metropolitan city, the most likely fronthaul architecture is an optical metro ring [9]. As depicted in Fig. 1 antennas are connected to the optical metro ring switches by either point to point links or next generation passive optical networks (NG-PON2). DUs and CUs are virtualized and placed, respectively, either at the antenna sites or in their vicinity (connected to the same metro switch) and in a centralized data center connected to one of the metro ring switches. Connectivity between CU and DU is implemented by means of lightpaths routed in the optical metro ring.

The proposed two-step recovery scheme architecture, depicted in Fig. 1, is based on the ETSI NFV-MANO architecture [10]. The working lightpath (i.e., red solid line) connecting DU and CU is monitored by a *Network Monitor*. Such monitor reveals or even anticipate degradation in the quality of transmission of the working lightpath and it notifies the Virtual Network Function Manager (VNFM)/Virtual Infrastructure Manager (VIM). The VNFM/VIM triggers the modification of the lightpath modulation format or the code redundancy increase (i.e., green dashed line). If the re-sulting lightpath rate is not capable of carrying the original functional split (i.e., DU1s1 and CU1s1), the VNFM/VIM notifies the NFV Orchestrator (NFVO) that triggers the reconfiguration of the functional split to the one that can be supported by the lower lightpath data rate (i.e., DU1s2 and CU1s2). To speed up recovery operation, in this study, sev-eral DUs and CUs featuring different functional splits are already deployed and they are activated upon VNFM/VIM request.

3. Performance Evaluation

The proposed two-step recovery scheme performance is evaluated through both simulations and a testbed experiment.

Simulations are conducted to evaluate the amount of traffic recovered by transmission adaptation (thus, without re-routing) in an optical metro network when link degradation occurs. A five-node ring topology with 10-km links is considered. Optical amplifiers are assumed as boosters. Poisson traffic is assumed (e.g., emulating small cell on-off), with exponentially distributed holding time with average $1/\mu = 5000$s. The offered traffic load is λ/μ, where $1/\lambda$ is the request mean inter-arrival time. Transponders support 200 Gb/s PM-16QAM and 100 Gb/s PM-QPSK. Lightpath BER is computed through optical signal to noise ratio (OSNR) and by assuming negligible the non-linear effects because of the limited distances of the topology [11, 12]. A BER lower than 10^{-3} is assumed as acceptable: 200 Gb/s PM-16QAM is considered acceptable with an OSNR higher than 20.5 dB, while the model in [12] is adopted for 100 Gb/s PM-QPSK. Soft failures are randomly generated on a single link.

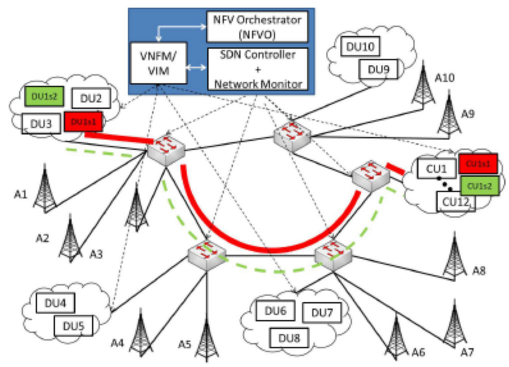

Fig. 1. Two-step recovery scheme architecture

Fig. 2a shows the recovered rate through transmission adaptation as a function of the offered traffic load, assuming that each soft failure introduces an OSNR penalty of 2dB. The overall rate impacted by soft failures increases with traffic load since more connections are active. The figure shows that 50% of the impacted traffic can be recovered with format adaptation. Indeed, with the considered link length and OSNR penalty of 2 dB, 100 Gb/s PM-QPSK is acceptable in any path. Fig. 2b shows the recovered rate versus OSNR penalty with a load of 100 Erlang. The overall rate impacted by soft failures increases with OSNR penalty because the larger the penalty the higher the probability of exceeding the BER of 10^{-3}. When OSNR penalty is higher than 4 dB, the recovered traffic through format adaptation is not exactly 50% because for some connections also PM-QPSK presents unacceptable BER (typically the longest ones). Thus, in the considered scenario, after soft failure only half of the capacity originally offered by lightpaths is available for carrying DU-CU connections.

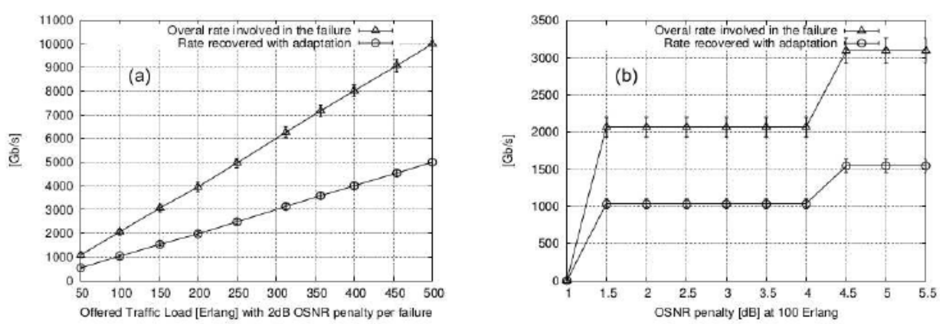

Fig. 2. Overall rate recovered through format adaptation at: (a) varying the offered traffic load with 2-dB-OSNR-penalty soft failures; (b) the OSNR penalty with 100 Erlang of traffic load

Experiments are conducted to evaluate the performance of functional split reconfiguration that is triggered if the residual lightpath capacity is not sufficient to carry all the CU-DU connections. The considered experimental evaluation scenario is shown in Fig. 3a. The Evolved Packet Core (EPC) is deployed in *Host Machine 1* by utilizing *Openair-cn* from OpenAirInterface (OAI) (*http://www.openairinterface.org/*). For the DUs and the CUs, two functional splits are considered: Option 8 and Option 7a in the 3GPP terminology [7] (i.e., IF5 and IF4.5 in OAI terminology). Even in this case the OAI platform is utilized to implement DUs and CUs. As shown in Fig. 3a, *Host Machine 2* contains a Docker with two containers (i.e., *container-CU1* and *container-CU2*) to deploy the two CUs. Similarly, the DU functions are hosted in *Host Machine 3* (i.e., *container-DU1* and *container-DU2*). *Host Machine 2* and *Host Machine 3* are directly connected by a 1 GbE link. The Ettus Universal Software Radio Peripheral (USRP) B210 acts as radio front-end and it is attached to *Host Machine 3*. The Huawei E3372 dongle, attached to *Host Machine 4*, is utilized as UE. Dongle and USRP are connected through coaxial cables with a 20 dB attenuation in the middle of the link. The VNFM/VIM and the NFVO are emulated by a shell script running in *Host Machine 5*.

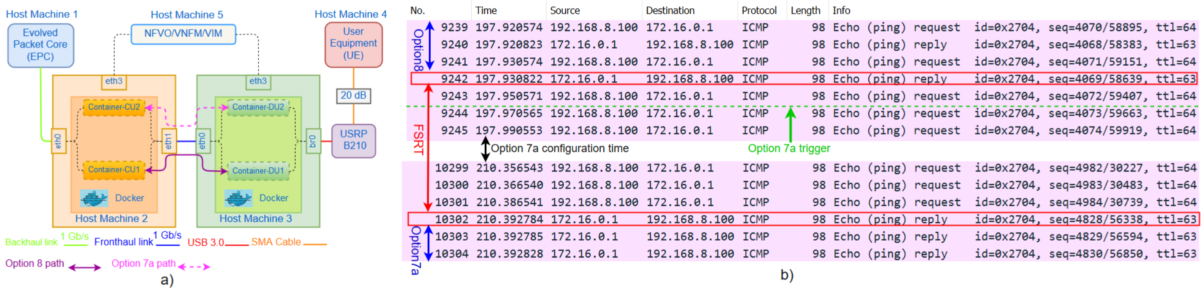

Fig. 3. (a) Scenario considered for the experimental evaluation; (b) Capture (at the UE) of ICMP messages exchanged between the EPC and the UE.

The considered performance evaluation parameter is the *eNB functional split reconfiguration time (FSRT)*, defined as the time elapsing between the last *ping* reply sent by the EPC to the UE before functional split reconfiguration and the detection of the first successive *ping* reply after functional split reconfiguration. The FSRT measurement is performed by continuously (i.e., every 1ms) sending ping messages from the UE to the EPC.

Fig. 3b contains the wireshark capture at the UE (192.168.8.100) of the *ping* messages exchanged by UE and EPC (GTP interface address 172.16.0.1) during the eNB functional split reconfiguration from Option 8 to Option 7a. The timestamp of the wireshark is measured in *seconds*. As shown in the Fig. 3b, once the functional split reconfiguration is undergoing, only ICMP request messages at the UE can be observed. The measured FSRT is about 12s. It includes a 2s sleep time to start first the DU and the CU and synchronize the fronthaul interface during Option 7a activation. The shell-based VNFM/VIM contributes about 1s to enter into the containers and run the requested functional split option.

4. Conclusions

This paper proposed a two-step recovery scheme orchestrating lightpath transmission adaptation and evolved NodeB (eNB) functional split reconfiguration. Results showed that the proposed scheme not only maintains the fast recovery of optical layer resilience but it allows to recover distributed unit and central unit connectivity even when optical resources are scarce and lightpath rerouting is not possible.

Acknowledgment

This work has been partially funded by the EU H2020 “5G-Transformer” Project (grant no. 761536).

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