Novel Resource and Energy Management for 5G Integrated Backhaul/Fronthaul (5G-Crosshaul)

Xi Li[1], Raihana Ferdous[2], Carla Fabiana Chiasserini[3], Claudio Ettore Casetti[3], Francesca Moscatelli[4], Giada Landi[4], Ramon Casellas[5], Kei Sakaguchi[6], Shahzoob Bilal Chundrigar[7], Ricard Vilalta[5], Josep Mangues[5], Andres Garcia-Saavedra[1], Xavier Costa-Pérez[1], Leonardo Goratti[2], Domenico Siracusa[2]

[1] NEC, [2] CREATE-NET, [3] Politecnico di Torino, [4] Nextworks, [5] CTTC, [6] FhG-HHI, [7] ITRI

Abstract— **The integration of both fronthaul and backhaul into a single transport network (namely, 5G-Crosshaul) is envisioned for the future 5G transport networks. This requires a fully integrated and unified management of the fronthaul and backhaul resources in a cost-efficient, scalable and flexible way through the deployment of an SDN/NFV control framework. This paper presents the designed 5G-Crosshaul architecture, two selected SDN/NFV applications targeting for cost-efficient resource and energy usage: the Resource Management Application (RMA) and the Energy Management and Monitoring Application (EMMA). The former manages 5G-Crosshaul resources (network, computing and storage resources). The latter is a special version of RMA with the focus on the objectives of optimizing the energy consumption and minimizing the energy footprint of the 5G-Crosshaul infrastructure. Besides, EMMA is applied to the mmWave mesh network and the high speed train scenarios. In particular, we present the key application design with their main components and the interactions with each other and with the control plane, and then we present the proposed application optimization algorithms along with initial results. The first results demonstrate that the proposed RMA is able to cost-efficiently utilize the Crosshaul resources of heterogeneous technologies, while EMMA can achieve significant energy savings through energy-efficient routing of traffic flows. For experiments in real system, we also set up Proof of Concepts (PoCs) for both applications in order to perform real trials in the field.**

Keywords—Fronthaul/Backhaul; resource managment; energy managment; optimization; SDN/NFV

I. INTRODUCTION

5G mobile transport networks will have to support multiple Cloud RAN functional splits in a flexible and unified manner [1]. This will allow for various degrees of Radio Access Network (RAN) centralization, varying from no centralization D-RAN (Distributed), to fully Centralized RAN (C-RAN). Thus, the 5G transport network will have to flexibly distribute and move base station functions across data centres, introducing another degree of freedom for resource management. In this context, the division between *fronthaul*, which is the interface between the Remote Radio Heads (RRH) and their associated centralized-processing units (Base Band Units, BBU), and *backhaul* will blur since varying portions of functionality of the base stations will be moved flexibly across the transport network as required for cost-efficiency/performance reasons. In order to meet these requirements, we propose an adaptive and cost-efficient solution for future 5G transport networks integrating multi-technology fronthaul and backhaul segments into a common transport infrastructure, namely 5G-Crosshaul. This solution enables a flexible and software-defined reconfiguration of all networking elements through unified data and control planes interconnecting distributed 5G radio access and core network functions, hosted on in-network cloud infrastructure.

This paper presents the key design aspects of the 5G-Crosshaul architecture [2] and its main technological building blocks. On top of this architecture, two key SDN/NFV applications, namely the **Resource Management Application (RMA)** and the **Energy Management and Monitoring Application (EMMA)**, are designed for managing the Crosshaul resources with the aim to improve energy efficiency and resource utilisation both cost-wise and performance-wise.

- **RMA**: (i) to manage Crosshaul resources including networking, computing and storage resources in a flexible and dynamic way, (ii) to cope with the level and variation of demand expected from 5G Points of Attachment (5G PoA), (iii) to maximize the resource utilization and cost-efficiency while meeting various service requirements.
- **EMMA***:* to reduce energy consumption of the different Crosshaul elements. It is a special version of RMA with special focus on optimizing energy consumption and minimize energy footprint of the Crosshaul network. It also monitors and estimates the energy usage of the fronthaul and backhaul, providing monitoring data to other applications when required.

The rest of the paper is organized as follows. Section II presents the design of the 5G-Crosshaul architecture, including control and data planes. Sections III and IV present the design of resource management and energy management application, the proposed algorithms and obtained results, and the setup of PoCs for conducting experiments in a realistic environment. In particular, we also apply EMMA to two special use cases of mmWave mesh networks and high-speed train scenarios. Finally, Section V draws our conclusions.

II. 5G-CROSSHAUL ARCHITECTURE

A. 5G-Crosshaul Architecture Concept

Fig. 1 presents the architecture of 5G-Crosshaul defined in [2]. The design follows the principles of SDN architecture laid down by Open Networking Foundation (ONF) by decoupling data and control plane. Our design leverages the state-of-the-art SDN and NFV architectures to maximize the compatibility and integration of the system design with the existing standard frameworks and reference specifications, and to allow the reuse of open source projects to facilitate its deployability while minimizing the implementation costs.

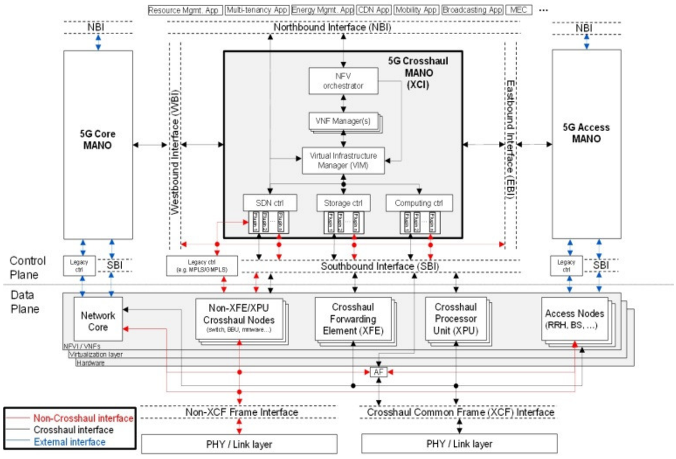

Figure 1: 5G-Crosshaul Architecture [2]

Control plane is divided into application layer at the top and 5G-Crosshaul Control Infrastructure (XCI) below. An ecosystem of applications exploits 5G-Crosshaul resource orchestration functions to support diverse functionalities such as planning, resource optimization, energy management, etc. The XCI is the 5G transport Management and Orchestration (MANO) platform, designed to integrate the SDN control in the ETSI/NFV MANO architecture [3]. SDN relies on a centralization of controllers, control and data plane separation and the specification of open and standard South Bound Interfaces (SBI), enabling hardware programmability and deployment of modular applications. NFV allows infrastructure and function virtualization. It also offers NFV services as defined by the ETSI NFV use cases, such as the deployment of Network Services (NS), through the on-demand and automated instantiation of scalable Virtualized Network Functions (VNFs) interconnected through VNF forwarding graphs.

The XCI provides an abstracted view of available resources, states and control and management functions to an ecosystem of applications, via a Northbound Interface (NBI). The XCI is connected to the data plane elements via a Southbound Interface (SBI) to execute control and management functions on the actual hardware components. From a top-down perspective, the first layer of the XCI includes the ETSI NFV MANO components such as the NFV orchestrator (NFVO), multiple VNF managers (VNFMs), and Crosshaul extended Virtual Infrastructure Manager (VIM). The second layer corresponds to the controller layer, composed of the network, computing, and storage controllers, enabling the allocation and configuration of the different types of resources in the NFV Infrastructure of a 5G-Crosshaul environment.

Specific functions of the XCI support the allocation of virtual infrastructures (VI), yielding extensions of the architecture that involve recursive approaches enabling network sharing and multi-tenancy, in which a client or tenant can operate a virtual infrastructure as if it was physical and exclusively owned. In this sense, multiple instances of the XCI can be deployed in a recursive way.

Data Plane: is comprised of Crosshaul Forwarding Elements (XFEs) and Crosshaul Processing Units (XPUs). XFEs are switching units, including a packet-switching entity (the XPFE) along with a circuit-switching entity (the XCSE) to support extreme low latency traffic. XFEs interconnect a broad set of link and PHY technologies using a common framing (Crosshaul Common Frame, XCF) to transport both backhaul and fronthaul traffic. XPUs are the computing nodes that take care of computing operations in 5G-Crosshaul, to support C-RAN related operations including BBUs, and hosting VNFs and other virtualized services (e.g. CDN).

III. RESOURCE MANGEMENT APPLICATION

A. *Introduction of RMA*

Resource management is one of key challenges considering high degree of flexibility and heterogeneity required for 5G transport networks. Though various research attempts have focused on dynamic resource allocation and NFV placement to improve resource utilization in networks [4][5][6], these issues are yet to be explored in the 5G context. To this end, the RMA takes care of optimizing 5G-Crosshaul resources in a centralized and automated fashion, in order to meet the requirements of different client applications. The RMA relies on the XCI controllers for the actual provision and allocation of resources and can operate over physical or virtual network resources, on a per-network or a per-tenant basis. Essentially, RMA has two main functional pillars: (i) dynamic resource allocation and (re-) configuration as the demand and network state change; and (ii) dynamic NFV placement.

B. *RMA high-level design*

Figure 2 shows the high-level design of the RMA. It includes the REST Client which interacts with the XCI components via REST APIs, the DB manager which is responsible for collecting the relevant information, the RM database that stores the inventory of the switching and processing elements, and the REST sever that is in charge of implementing the northbound REST API of the RMA to allow other applications or XCI modules that request for services. The main services provided by RMA are the Path Computation and Virtual Network Function Placement (*PC-VNFP*) service, for computing the optimal path and of placing the VNFs on XPUs considering the network resources and technology types available within the 5G-Croshaul network.

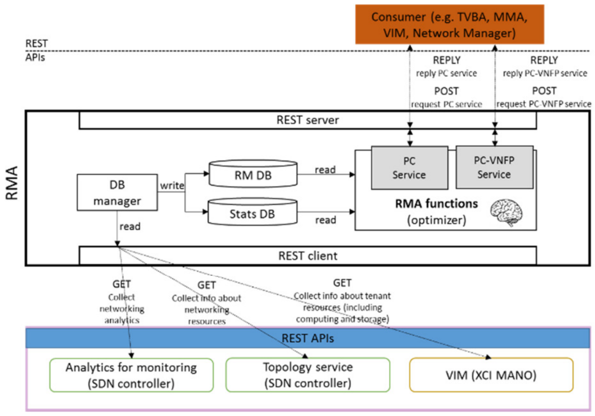

Figure 2: RMA high-level design

C. *RMA algorithm for PC-VNFP service*

To provide the *PC-VNFP* service the RMA algorithm tries to optimize the objective function $U(\cdot)$. This is done in terms of: (i) **VNF placement, i.e.,** placement of services on processing nodes in such a way that service requests are fulfilled, and (ii) **Flow allocation, i.e.,** the computation of the optimal path for a flow in such a way that the services demand is fulfilled. Since 5G-Crosshaul includes the possibility of deploying VNFs on XPU nodes and connecting XFEs through different transmission technologies, the optimization problem is formulated accordingly. In particular, the objective of RMA to perform *PC-VNFP* services consists in the following minimization:

$$U = \min\left(C_{VNF} + C_f + C_d\right) \ , \qquad (1)$$

where C_{VNF} is the cost associated with deploying a VNF over an XPU node; C_f denotes a fixed parametric cost associated with a transmission technology and C_d is a dynamic parametric cost associated with that technology. Costs are introduced as a penalty that the system incurs in case specific decisions are made. Overall cost minimization clearly yields the optimal solution. All costs are unit-less and serve the purpose of describing the differences between selected transmission technologies. The algorithm is formulated as an equivalent Integer Linear Programming (ILP) problem. The formulation focuses on minimization of the objective function defined in Eq. (1), subject to different constraints that stand for the service. The ILP formulation relies on the work in [6].

D. *Simulation Results*

The initial evaluation of the RMA algorithms for the *PC-VNFP* service is performed through Matlab simulations of a random network topology including a deployment of switching and computing nodes as generic as possible. We consider two transmission technologies in the network, connecting the switching elements: Gigabit Ethernet and mmWave. As anticipated, the fixed cost of Ethernet is chosen to be higher than that of mmWave, but this is exactly the opposite for the dynamic cost.The latter is quantified whereby the link success probability $p_s \in [0,1]$. For Ethernet it is assumed $p_s^{(eth)} = 1$, whereas $p_s^{(mmwave)} \leq 1$. The dynamic cost function is computed as $C_d = 1/p_s$ irrespective of the selected technology. The probability of success for mmWave links is obtained combining the work done in Table 1 [7] and Eq. (2) [8]. Due to the high attenuation, mm-wave links are typically confined in a relatively short-range depending on whether they are outdoor or indoor. Figure 3 shows that, as expected, the probability of success for mmWave links decreases very rapidly with the distance between the transmitter and receiver and with the increase of the central frequency. Here, the 3GPP propagation model at 2.5 GHz is assumed.

The RMA algorithm can select any of the technological options available for transmission (i.e., either Ethernet or mmWave). For evaluation, an ILP formulation in which flows are allocated in consecutive fashion is formulated. The fraction of used link resources is computed as *η=number of used links/total number of links* separately for each technology option connecting XFEs and for the total number of used links. Table 1 shows the numerical values used in simulations.

Table 1: Numerical values used to obtain initial results

Parameter	Value
Geographic area	[2000 × 2000] m
Coverage radius of a mm-Wave transmitter	≤ 200 m
Percentage of XPUs and XFEs	30%, 70%
Percentage of video & voice flows	70%, 30%
Latency constraint for video & voice traffic	<100 ms, <10ms
Fixed cost [Eth, mmwave]	[100, 1]
Capacity [Eth, mmwave]	10 Gbit/s, 2Gbit/s

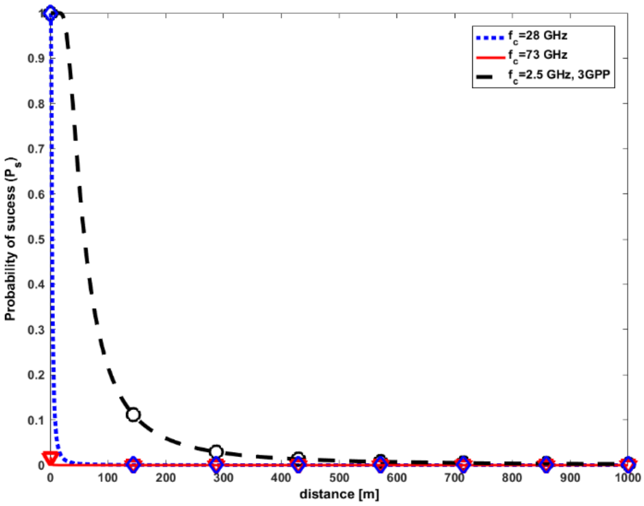

Figure 3: Probability of success for mmWave technology as a function of distance between transmitter and receiver. Curves are shown for different propagation models and central frequencies.

Figure 4 shows the utilization of various link technologies over the overall available links in the network, while increasing the total number of flows with a number of nodes in the graph equal to 30. It can be noticed that even in correspondence of 100 flows to allocate, the overall utilization of network resources remains below 50%. This result allows us to preliminary conclude that the objective of avoiding fragmentation in resources utilization has been achieved, compatibly with the compound demand of flows.

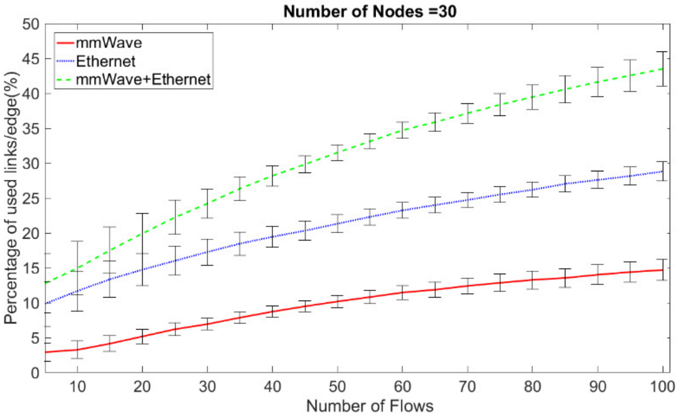

Figure 4: Percentage of the total number of links used in a network with 30 nodes (XPUs+XFEs), while varying the number of flows to be allocated in the network on a Flow-by-Flow basis.

E. *PoC for RMA*

The following PoC targets the experimental assessment of the ability of the RMA to allocate network resources within a multi-layer transport network, in which the RMA is responsible of orchestrating network resources relying on a *hierarchical multi-domain resource management*, which involves i) a data plane topology spanning multiple technology domains, ii) hierarchical SDN control plane functional elements within the XCI and iii) the RMA within the Crosshaul application plane, in order to compute optimal routes between endpoints. The RMA relies on a graph-based abstract view of the underlying topology, provided by the XCI, which gathers the topology information from the underlying physical infrastructure. In the data plane, two wireless domains are interconnected by a multilayer wired network, encompassing two Ethernet-based domains over a wavelength switched optical network or WSON (see Figure 5). One of the wireless domain features 802.11ac cards in addition to 802.11ad, which allows evaluating a heterogeneous wireless backhaul providing a rich scenario for multi-technology link and path restoration.

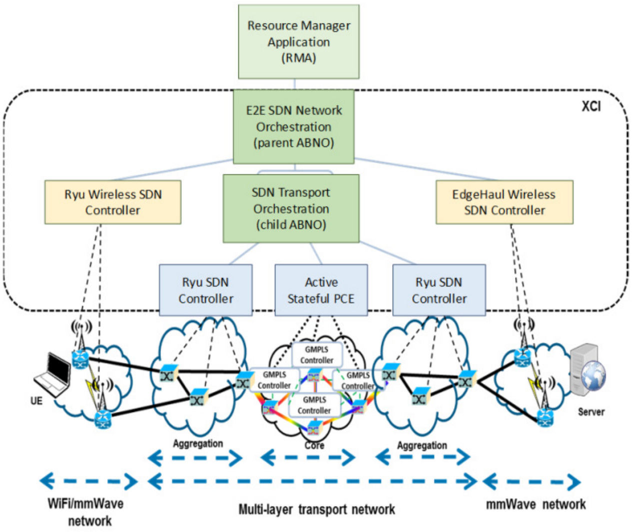

Figure 5: Hierarchical multi-domain resource management.

Within the XCI, the PoC encompasses a hierarchical structure of parent-child SDN controllers including: (i) a parent Application-Based Network Operations (ABNO)-based [9] multi-domain and (ii) three (per-domain) child controllers, two of which are deployed for the wireless transport domains and one for the multi-layer transport network. For the wireless domains, the child SDN controllers directly interact with the mmWave and Wi-Fi nodes. Within the wired transport network segment, another hierarchical level is deployed: a child ABNO orchestrator is responsible for orchestrating three additional technology-specific controllers. The WSON controller is implemented as an Active Stateful Path Computation Element (AS-PCE), which is able to drive the instantiation of optical connections across the domain, delegating to the underlying GMPLS-control plane. The technology-specific controllers use mainly OpenFlow. Alternatively, the PCE protocol can also be used, notably when abstracting an underlying GMPLS control plane. The interfaces within controllers and ABNO-based orchestrations are implemented using REST frameworks, in particular, in order to expose this multi-domain information in a homogeneous manner to RMA.

This PoC is focused on automated service provisioning, especially on the deployment of network connectivity between endpoints in a 5G-Crosshaul transport network characterized by a heterogeneous data plane and hierarchical SDN control. For performance metrics, this PoC enables the measurement of indicators related both to the control and data planes. For the former, it enables the measurement of the connectivity service provisioning delay, from the top-most application (RMA) down to the underlying control domains that combine tree-based models (SDN controllers) to chain models (GMPLS in the optical domain) including hardware configuration. Resource planning is also possible, including characterizing the optical network in terms of blocking probability and the supported offered traffic load. Relevant indicators also include control plane overhead (in terms of messages per unit time and overall throughput and the number of sessions between entities) and requirements in terms of memory and processing power. Finally, for the latter, end-to-end throughput or delay can also be measured with common measurement tools once the service provisioning is complete.

IV. ENERGY MANAGEMENT AND MONITORING APPLICATON

A. *Introduction of EMMA*

Although several works have addressed energy-efficient network management, the problem is still unsolved in SDN-based 5G networks. Among the existing studies, [10] casts the energy-efficient traffic allocation in backbone networks as an ILP. [10] also presents a heuristic that first turns off nodes with the smallest traffic load and re-routes traffic consequently, then it tries to de-activate links. An opposite approach is adopted in [11], where the least congested links are turned off first. In [12], both virtual machine (VM) placement and traffic routing are optimized. Specifically, the authors first partition VMs into sets that minimize the overall intra-group traffic volume, then they propose a greedy bin-packing based algorithm for routing and node switch-off. A similar solution is in [13], which targets a sudden surge in traffic occurring after an off-peak period. Other relevant works addressing data centers are [14][15]. The work in [16] extends [15] by introducing a monitoring module that collects networks statistics. Finally, link physical characteristics of the links are accounted for in [17][18].

Below, we present the EMMA, which has been developed for the 5G-Crosshaul and which, as highlighted later, significantly differs from previous work. The EMMA monitors the energy parameters of the fronthaul/backhaul, estimates energy consumption and triggers reactions to minimize energy footprint of the virtual network while maintaining the required QoS for each virtual network operator or end user. The energy-based optimization is achieved through several modules, each implementing a different task: routing (and re-routing) of traffic flows and regulation of network node power states (including their On/Off switching) depending on network resource demand.

The EMMA leverages the SDN technology, and enhances a controller application with new, powerful solutions.

B. EMMA high-level design

The EMMA is a compound of several software components, each with a specific role in the whole application workflow. In particular, the EMMA implements three main energy efficiency-related functionalities in the 5G Crosshaul ecosystem: (i) the correlation of energy-related information for network and IT domains, as exposed by the XCI, to provide summarized energy consumption data at the physical or virtual infrastructure level; (ii) the automated configuration of the power status of the devices (e.g., putting inactive nodes in sleeping mode); and (iii) the optimization of network path provisioning and VNFs allocation for Service Function Chains (SFCs). The optimization in network paths provisioning minimizes power consumption across end-to-end connections and, where needed, procedures for re-planning of already established network paths are automatically activated based on operator policies. On the other hand, the provisioning of VNFs and SFC implements resource allocation algorithms that minimize the power consumed by XFEs and XPUs, still guaranteeing the compliance with the service specification, (e.g., regarding disjoint VNFs placement). In terms of implementation, the EMMA operates over software-based switches (i.e., the XPFEs) and is applied to vEPC VNFs.

Figure 6 shows the design of EMMA. The interaction with the SDN controller and the NFV MANO tools is based on REST APIs used to collect power consumption monitoring data and configure devices in terms of forwarding behavior and power states. At north-bound interface, EMMA exposes REST methods to retrieve summarized power consumption data for physical/ virtual infrastructures, as well as for specific tenants and services. The network administrator can configure energy-related policies to regulate EMMA processing and algorithms for provisioning and re-planning operations.

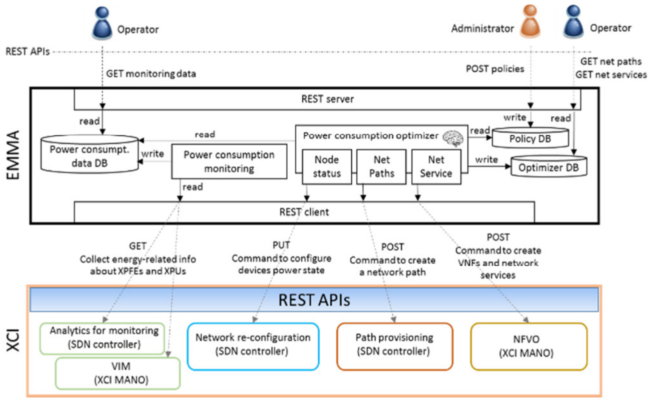

Figure 6: EMMA high-level design

C. Power consumption optimizer

The algorithm that optimizes the power consumption of network devices assumes the knowledge of the parameters of incoming new flows and of existing traffic, as well as the power states of network devices and their topology. It operates in two steps. In the first step, the algorithm takes as input the network topology and the information on the new flow to be allocated, the power state of the network devices and the traffic crossing every link. Upon the arrival of a new traffic flow, initially only nodes and links that are already active are considered for computing a suitable path. To this end, a shortest path selection is applied: if an active path meeting the flow traffic requirements is found, the flow can be successfully routed onto it. Otherwise, the algorithm looks for another suitable path considering also inactive links. Again, if, by applying a shortest path selection, a path is found, the links and nodes that need to be added are activated. The second step is executed whenever the active network topology changes, i.e., if the search for a path leads to the activation of new nodes and/or links. The flows that have started or have been re-allocated within a certain past interval are considered. For each of these flows, a path on the current topology is computed, starting with the flows with higher rate requirements. If the computed path costs less than the current path, the flow is rerouted to the new path. If some links and/or nodes become idle following the rerouting, those links and/or nodes are turned off. A similar action is taken upon the termination of a flow, leading to idle nodes and links being switched off to save energy.

We remark that, although our work draws on [10][12], the study we present significantly differs from such works. Indeed, our problem formulation resembles that in [10], but it accounts for the instantaneous power consumption and for a more realistic power consumption model for SDN switches, which changes the nature of the optimization. As far as our heuristic is concerned, we leverage [12] but design an algorithm that, unlike [12], aims to find a better route for all existing flows whenever there is a change in the active topology. In addition, our focus is on the design of a practical energy optimizer that works in synergy with the EMMA monitoring functionality and exploits the capabilities offered by the SDN technology. To this end, the definition and the implementation of the interactions between the EMMA optimizer and the monitor are of paramount importance.

D. Emulation results

Our evaluation of the EMMA is done using emulation in Mininet. We compare the EMMA performance to the optimal solution, as well as to the simple case where the network is always active (No Power Saving in the plot). The optimal solution is derived by solving the optimization problem in [19] in the same emulated network. Results assume a default number of core and edge switches equal to 12 and 6, respectively with 10 hosts connected to each edge switch.

Links between any two core switches are set with probability 0.5 and the link capacity is set to 10 Mbits/s and carry TCP traffic flows between randomly chosen source-destination pairs. Newly generated flows arrive after a negative exponential-distributed time with a default mean rate of 0.1 flows/s and last 20 s on average. Figure 7 compares the performance of the EMMA, of the optimum and of the No Power Saving scheme, as functions of the flow arrival rate and for a default number of core switches (namely, 12). The EMMA and the optimum are tightly matched, for all values of the flow arrival rate. The power saving with respect to the No. Power Saving scheme is dramatic, though the power gain diminishes with a high flow arrival rate, since more switches and links have to be used. Also, we observed that turning off nodes saves much more energy than turning off links.

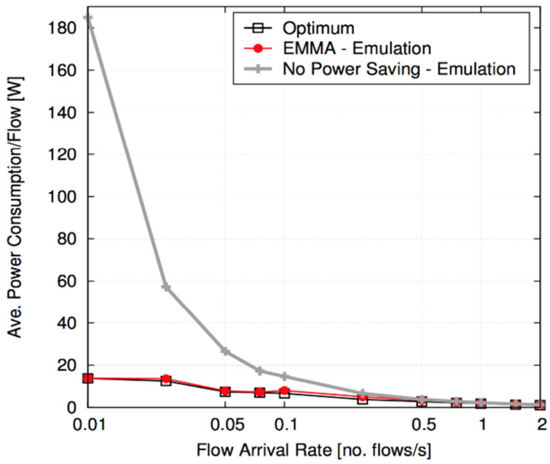

Figure 7: EMMA vs the optimum and No Power Saving.

E. PoC for EMMA

The EMMA is developed as a Java application that consumes the services provided by the XCI for the configuration and the monitoring of the 5G-Crosshaul infrastructure, in particular of XPFEs (software-based switches based on Lagopus [20]) and XPUs. Monitoring of power consumption relies on the information collected from XCI components (i.e. VIM for XPUs and SDN controller for XPFEs), in terms of traffic load and power. These data are processed and aggregated based on tenants, connections and virtual services and they are stored in an internal no-SQL database, based on the Apache Cassandra database. The Power Consumption Optimizer implements the EMMA logic and computes the optimal resource allocation based on the computed power consumption data and the policies configured by the administrator. In particular, this component makes use of the XCI services to automatically modify the power states in selected infrastructure nodes, de-activating unused devices, and to request the provisioning of the energy efficient network paths and SFCs with the resource allocation computed by the EMMA itself.

The XCI functionalities are implemented in OpenDaylight SDN controller, which has been extended with new services for network path provisioning and configuration of power states via SNMP protocol. A web-based graphical user interface, developed in the OpenDaylight framework, allows the operator to visualize the status of network nodes (e.g., nodes in sleep or active mode) and some graphs related to power consumption of single nodes, entire paths or networks, and services deployed for specific tenants.

F. Application of EMMA to mmWave Mesh Network Scenario

In dense urban information scenario, which is one of important scenarios in 5G, network densification is necessary because of the high traffic volume generated not only by smart phones and tablets but also by augmented reality information such as sensors and wirelessly connected cameras. Typical environments are shopping malls, airports, open squares, street canyons, etc., where users tend to gather and move as large and dynamic crowds while want to keep connectivity to the cloud. 5G-Crosshaul provides efficient deployment and management procedures by using mmWave meshed network with the EMMA algorithm for such densely located access networks, as shown in Figure 8.

In Figure 8, mmWave nodes are overlaid on a LTE macro cell to play a role of both XPFE (relay) and (mmWave) access with three or four sectors in both access and backhaul/fronthaul [21]. The LTE macro BS plays a role of mmWave gateway as well in the cell to accommodate time-variant and spatially non-uniform traffic by forming a mmWave meshed network. The prominent objective of the EMMA is to reduce energy consumption of mmWave mesh network by switching off as many mmWave nodes as possible in an area with small traffic demand. As it is hard to optimize ON/OFF status of mmWave nodes and backhaul/fronthaul paths all at once, the EMMA algorithm for the mmWave mesh case involves three steps. In the first step (i), the initial ON/OFF status of mmWave nodes is determined based on the traffic demands per mmWave node. In the next step (ii), initial paths of backhaul/fronthaul network are created to minimize power consumption. If isolated mmWave nodes exist even after step (ii), the final step (iii) re-activates remaining mmWave nodes in an energy efficient manner so as to transfer the traffic for the isolated mmWave nodes. Control signaling to manage ON/OFF status of mmWave nodes and to create physical paths between them are transmitted over the LTE as an out-band control plane. As such, a dynamic and energy efficient mmWave meshed network is formed.

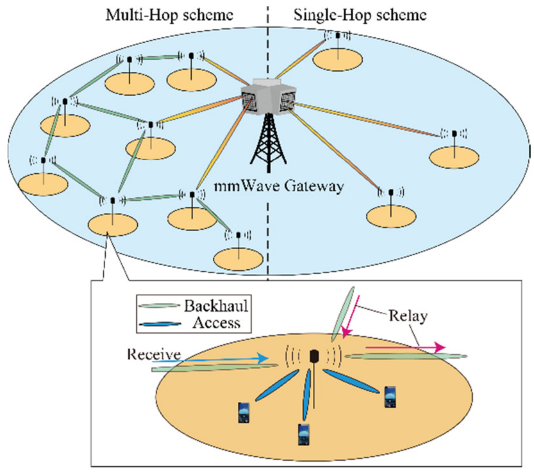

Figure 8: mmWave meshed network overlaid on a LTE macro cell.

G. Application of EMMA to High-Speed Train Scenario

Radio over Fibre (RoF) technology allows optical fibres to transmit Radio Frequency (RF) signals between base station (BS) and remote antenna unit (RAU) instead of coaxial cables to provide large transmission bandwidth, which is highly required in 5G networks. Currently RoF nodes are active throughout the day consuming 36W. Assume there are R_N north-bound and R_S south-bound trains in a day, and the serving time for each train is T_S seconds then the percentage of time a RoF node is idle in a day is:

$$1-\frac{(R_N+R_S)\cdot T_S}{86400} \quad , \tag{3}$$

The high-speed train scenario is a special use case of EMMA as a centralized energy management mechanism to control the status of a large number of RoF nodes along the train track. A typical scenario is shown in Figure 9, where each train pushes its location information to a cloud database, and a central controller utilizes the information to maintain the status of all RoF nodes along the rail track. It is assumed that the RoF nodes are connected to eNB B and C. eNB's pushes the context information (such as physical cell id and etc.) when the train is in their coverage area to the IPC (Industrial Personal Computer) server (installed on the train) via CPE (Customer Premises Equipment). IPC extracts the relevant information and posts it to the cloud database. Cloud database notifies the EMMA upon reception of new entries. After the retrieval of records, the EMMA decides based on the mapping table if the connected RoF nodes should be turned ON or OFF. Similarly, as the train approaches eNB B, the EMMA via SNMP turns ON the RoF nodes and, as it leaves eNB C, it turns them OFF. In this way, we minimise the energy footprint of the deployed distributed RoF nodes by leveraging the 5G-Crosshaul network without degrading the QoS of ground-to-train communications.

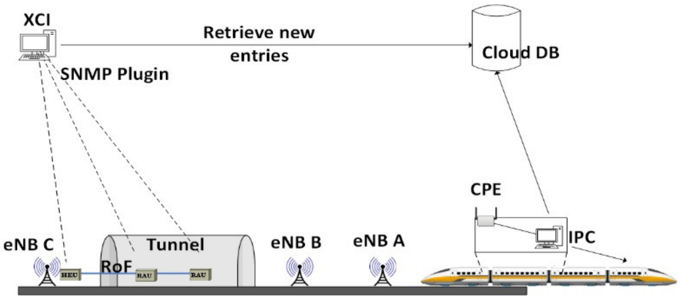

Figure 9: Scenario of EMMA-specific High-speed Train.

V. CONCLUSIONS

In this paper we presented the concept of the 5G-Crosshaul architecture, which is based on the SDN/NFV principles and composed of a unified control plane and data plane. On top of this architecture, we presented two applications developed for 5G-Crosshaul: namely, the RMA to manage the resources and the EMMA as a special version of RMA with the focus on optimizing the energy consumption and minimizing the energy footprint of the 5G-Crosshaul infrastructure. With regard to the EMMA, we also investigated the mmWave mesh network and high speed train scenarios. For implementation of the applications, a high level application design was provided, which describes the main components and required interfaces. We further presented the individual application optimization algorithms, along with preliminary results. The next step will be to perform experiments on the built PoCs. The first evaluation results demonstrate that the proposed RMA can cost-efficiently utilize the infrastructure resources in a multi-technology Crosshaul network, and the EMMA can bring significant energy savings through energy-efficient routing of traffic flows and switch off of idle nodes.

ACKNOWLEDGMENT

This work has been supported by the H2020 project "5G-Crosshaul: The 5G Integrated fronthaul/backhaul" (671598).

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