WiBACK: A Back-haul network architecture for 5G networks

Christian Niephaus*†, Osianoh Glenn Aliu*, Mathias Kretschmer*, Senka Hadzic*, Gheorghita Ghinea†
*Fraunhofer FOKUS
Email: {christian.niephaus, mathias.kretschmer, osianoh.glenn.aliu}@fokus.fraunhofer.de,
senka.hadzic@fokus-extern.fraunhofer.de
†Brunel University
Email: george.ghinea@brunel.ac.uk

***Abstract*—Recently both academic and industry world has started to define the successor of Long Term Evolution (LTE), so-called 5G networks, which will most likely appear by the end of the decade. It is widely accepted that those 5G networks will have to deal with significantly more challenging requirements in terms of provided bandwidth, latency and supported services. This will lead to not only modifications in access and parts of core networks, but will trigger changes throughout the whole network, including the Back-haul segment. In this work we present our vision of a 5G Back-haul network and identify the associated challenges. We then describe our Wireless Back-haul (WiBACK) architecture, which implements Software Defined Network (SDN) concepts and further extends them into the wireless domain. Finally we present a brief overview of our pilot installations before we conclude.**

***Index Terms*—QoS, 5G Back-haul , SDN, hardware abstraction**

I. Introduction

It is widely accepted that future 5G networks, which will appear by the end of the decade, have to cope with a huge variety of existing and novel services and applications, such as cloud-based applications, ultra-HD television and online conferencing, Machine-Type-Communication (MTC) as well as augmented reality [1]. First and foremost, this leads to a tremendous increase in the required capacity [2] for future networks. Besides that, 5G networks also need to provide high reliability and a very low latency in order to support those novel applications and allow for a good Quality-of-Experience (QoE) perceived by the user. Precisely, 5G networks are supposed to provide 10x higher throughput per Mobile Terminal (MT) and 1000x more traffic the aggregation- or Back-haul network [3] while reducing the service level latency to 5ms and mainting a reliability of 99.999% [4].

A lot of effort is made to investigate novel technologies and mechanisms for the access networks, such as mmWave, ultra dense deployments or massive multiple-input and multiple-output (MIMO), in order to cope with the aforementioned requirements, yet the implications on the Back-haul segment of the network are often silently ignored. However, the increasing number of cells, each of which supporting a significantly higher throughput, needs to be adequately connected to transport the traffic to the core segment and eventually the Internet. In existing 4G networks this is usually not an issue, since Evolved Node Bs(eNodeBs) are either connected with a high speed wired connection, e.g. optical fiber, or with a high capacity micro-wave link so that the Back-haul network does not present a bottleneck. With the advent of network densification and small cells, which are deployed also at non-conventional locations, more complex Back-haul network structures relying often on heterogeneous wireless technologies will appear. For example, cells might be located on traffic lights, distributed in- and outdoor on large campuses, etc., where a wired infrastructure and high capacity line of sight (LOS) microwave links are either impractical or too costly to deploy everywhere. Instead, more cost-effective wireless connections might be used, most likely even in a multihop fashion. Hence, an over-provisioned Back-haul network, as it is the usual case in 4G networks, becomes rather the exception and capacity constraints will occur. In order to mitigate those intelligent and self-organizing Back-haul techniques are required, which utilize the available spectrum most effectively by avoiding interferences with each other and the Radio Access Network (RAN).

Moreover, in order to provide sufficient bandwidth virtually everywhere including rural and remote areas, even satellite overlay networks will be used in future 5G networks. Satellite networks have evolved heavily recently to a terrabit per second communication system, leading to a significant decrease in costs per bit [5]. They are primed for broadcast and multicast type services covering large areas and thus, are particularly suited to provide additional capacity wherever it is needed.

In this paper we present our WiBACK technology, which provides a self-managing, Quality-of-Service (QoS)-aware network management architecture supporting heterogeneous technologies. WiBACK exploits and extends novel SDN concepts to allow for a centralized optimization of the network suitable to be used in future 5G networks. The remainder of the paper is structured as follows: First we present our vision of future 5G Back-haul networks in detail and identify the challenges associated with them. Afterwards, we review the related work before we present our WiBACK architecture. Finally we briefly present our pilot installation followed by a conclusion and an outlook on the future work.

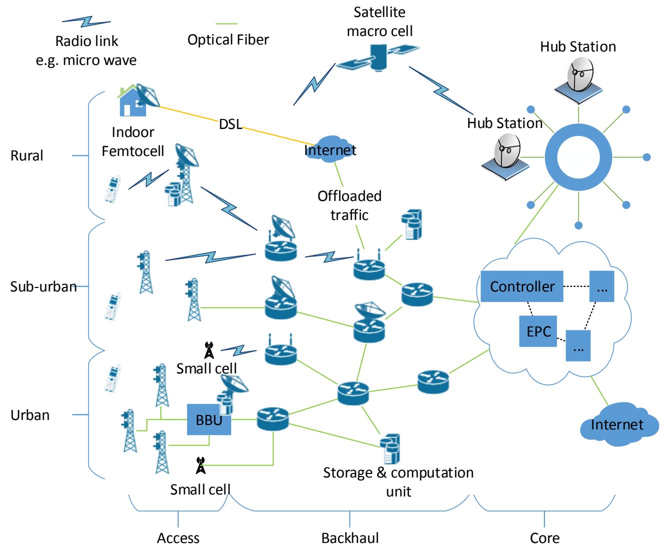

Fig. 1. Example of a 5G Back-haul network

II. 5G Back-haul vision

Fig. 1 depicts our vision of future Back-haul networks considered in this work: Base stations, i.e. eNodeBs++[1], which are providing access to MTs, are connected via a Back-haul network, utilizing heterogeneous technologies, with the core network and eventually with the Internet. The terrestrial Back-haul network relies upon optical fiber, microwave and other wireless network technologies to establish connections among the nodes within the Back-haul as well as the core network and the RAN. It is complemented with an additional satellite overlay network, i.e. some of the eNodeBs++ as well as some intermediate nodes in the Back-haul are equipped with bi-directional satellite equipment [1]. Even individual households are connected via a terrestrial and an additional satellite connection. The counterpart of those nodes in the satellite domain is a ring of hub stations connected to the core network. The RAN is potentially much denser compared to current 4G networks and consists of cells of different sizes, i.e. ranging from macro to femto cells. It should also be noted, that Back-haul networks, similar to the RAN, will also rely on massive MIMO technologies in order to increase the capacity but also to dynamically change links. On the higher layers, both core and Back-haul segment will heavily rely on SDN and Network Function Visualization (NFV) concepts to allow for virtualization and standardized management of networks components

Given this vision, several new challenges arise or become much more important compared to current Back-haul structures in 4G networks. These can be classified into physical layer and higher layer issues.

The first is primarily important for wireless connections and encompasses the configuration of links in terms of frequency, Modulation and Coding Scheme (MCS), Transmission power (TX-Power), etc. in order to minimize interferences while optimizing the available capacity on each links. This so-called *spectrum management* also includes dealing with exploiting temporarily free frequencies, i.e. secondary usage of spectrum, as well as configuration of MIMO antennae in order to decide which node can 'talk' to which other node. It should be noted that in future denser networks, this physical configuration of interfaces is expected to take place autonomously by the network itself, without the need of an administrator to e.g. manually assign frequencies.

In contrast to that, the higher layer challenges are focusing on capacity planing and traffic engineering issues. Since in 5G networks capacity constraints might occur virtually everywhere in both RAN and Back-haul network while the latency demands increase, the routing processes will become highly complex. Current routing protocols, such as Open Shortest Path First (OSPF) [6] or Border Gateway Protocol (BGP) [7], usually operate in a decentralized manner and are a monolithic block performing multiple tasks. These include the following: First, detecting the network topology and forming a network graph. Second, to calculate least cost path for each (IP) destination and to populate the routing table of a router running the routing protocol and finally, to monitor the network in order to react on e.g. link failures. However, in very heterogeneous (5G) Back-haul environments, in particular if satellite networks are included, these features are not sufficient anymore. For instance, since satellite networks can usually bridge long distances, the amount of hops required to reach a certain destination from a source might be small compared to terrestrial links. This leads to a routing decision in favor of the satellite, without taking into account the comparatively high delay on satellite connections, which causes problems for real-time and interactive services. Instead, intelligent traffic steering is required, which considers both the traffic's QoS demands as well as the capabilities and properties of the potential links in order to avoid congestions and a bad QoE perceived by the user. This includes a potentially centralized capacity management, which has a global view on the network, and a continuous monitoring process immediately or even proactively detecting problems.

Furthermore, the Back-haul network might be equipped with additional storing capabilities, i.e. caches, or even computational units. This is required to bring content and services closer to the user in oder to achieve the demanded low latency. Thus, the Back-haul network needs to become highly flexible in terms of traffic controlling and capacity management.

III. Related work

It is generally believed that extended SDN approaches increase the flexibility of networks and enable novel concepts to address the aforementioned challenges. With the advent of SDN [8] a paradigm change in networking architecture has started, shifting from monolithic network devices, which combines control-, monitoring-, management- and data-forwarding functions in a single entity, towards a clear separation of

[1]5G equivalent of an eNodeB

control- and data planes. That is, the decision making processes, such as routing of traffic, firewalling, spanning-tree protocols, etc., are clearly separated from the pure data forwarding methods. This allows for a more flexible management of the network, as the control functions can be run centralized. [9] presents further details on the differences between traditional networking and SDN.

SDN enabled networks are characterized mainly by two things, first the decoupling of control- and data-plane and second, programmability [10]. Fig. 2 shows the general SDN architecture [10]. On the lowest layer, the infrastructure layer, the actual data forwarding devices are located. Their main task is to perform any kind or packet processing based on the rules the SDN-controller, which is located in the middle layer, provides. The most commonly used protocol between the SDN controller and the devices on the infrastructure layer is currently OpenFlow [11]. This interface is also often referred to as Southbound interface. It is used to push rules to the infrastructure layer, to request monitoring information and statistics or to transmit packets, for which none of the rules apply to, back to the controller. Furthermore, the control layer provides an application programming interface (API), the so-called Northbound interface, to the application layer, which contains to so-called network applications. An application might be something simple such as a centralized Dynamic Host Configuration Protocol (DHCP) server or more complex services like parental control for certain MTs or seamless mobility. It should be noted that so far there is no standardized Northbound interface.

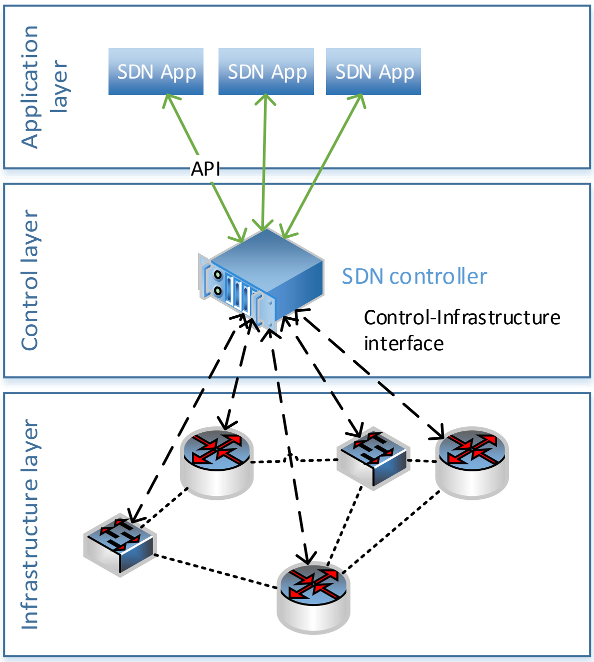

Fig. 2. SDN architecture

While most of the SDN related work so far is focusing on wired environments, recently the advantages of SDN are also recognized in the wireless world, particularly in the Back-haul segments of the network. As described in [12], given the more complex control- and management plane for wireless devices, introducing SDN concepts here can even bring more advantages than for the wired world.

Focussing on the dataplane, authors in [13] first present key conceptual contributions for realization of a software defined cellular infrastructure. In order to achieve this, a reconsideration of the binding of wireless protocols to the processing and decision planes is proposed. A step towards achieving this is having a programmable data plane. The authors thus present OpenRadio: a programmable wireless data plane that also achieves a tradeoff between flexibility and performance. This tradeoff is a key challenge and still an open problem when considering cost constraints. The unique feature of OpenRadio is the software abstraction layer that enables a modular and declarative interface to program the physical and MAC layers. The concept of utilizing an abstract and technology agnostic interface to program the lower layers was also presented in [14].

However, based on the frameworks reviewed, there is a clear lack of generic framework for SDN in the wireless domain, which we refer to as Software Defined Wireless Network (SDWN). It must be understood that no single architecture would provide the best performance and address all challenges associated. A generic framework is thus a valid option where different architectures can be developed (while keeping to the fundamental SDN principles) to suit unique or special set of use cases.

One of the major assumptions in SDN-enabled networks is that always a communication channel between the data forwarding devices and the SDN controller exists. However, for networks consisting of devices which only have wireless network interfaces this might not be true. For example, nodes deployed in the field that can only be connected to a central SDN controller located in the operator's office via a multi-hop connection and not via a direct link. Especially during a bootstrap phase, in which one or multiple nodes start-up, this becomes easily a chicken-and-egg problem given that the routing information is calculated on the SDN-controller and pushed to the data forwarding devices, which in turn cannot contact the SDN-controller without this information.

Concluding, extensions of SDN concepts to allow managing wireless networks still needs to be defined. Moreover, the specific challenges in a typical heterogeneous, wired and wireless Back-haul network require additional functionalities on the control layer, such as spectrum and capacity management or intelligent routing.

IV. WiBACK Architecture

After analyzing the challenges of Back-haul segment in 5G networks and evaluating the related work we now present our WiBACK approach, which addresses the aforementioned challenges. As we described in [15], WiBACK aims at providing a holistic cross-layer solution for wireless Back-haul networks. It implements the concepts of SDN for data forwarding

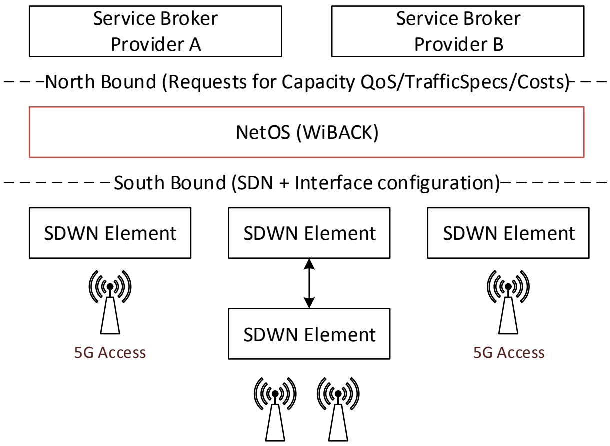

Fig. 3. WiBACK architecture

and also includes extensions compared with typical SDN to controll wireless interfaces. Thus, the WiBACK architecture can be seen as a realization of SDWN.

Fig. 3 gives an overview of the general WiBACK architecture. The key parts of WiBACK are located in the control layer and enable the operation of a wireless Back-haul network. Furthermore, WiBACK provides a simple Northbound interface allowing applications to request capacity with certain QoS parameters as well as a unified interface control functionalities on the Southbound interface. In the following sections we describe the different layers and their functions in details.

A. Infrastructure layer

The main enhancement of WiBACK on the infrastructure layer is the definition of messages that allow for configuring the physical parameters of the wireless interfaces, such as configuring cell membership, spectrum scanning or TX-Power regulatory management. As discussed in [16] it is worthwhile that the entities in the control layer can operate in a technology independent manner and, thus, those additional messages are defined technology agnostically. In order to do that, WiBACK defines a Unified Technology Interface (UTI), which provides a mapping to technology specific primitives. For instance, a `scan` command, which performs a neighborhood scanning, is mapped onto a `MLME-SCAN.request` for IEEE 802.11 Wireless Local Area Network (WLAN). Furthermore, it is intended that the UTI is designed generically so that it can be standardized and implemented in future devices.

Fig. 4 shows the extended infrastructure layer in WiBACK, which is integrated in each device. Similar to typical SDN devices the envisioned data forwarding devices also rely on one or multiple flow tables, which contain the packet handling instructions. However, the interfaces, or ports in OpenFlowterminology, can be configured and monitored by using the UTI. This extends the SDN concepts to manage interfaces and not just flows.

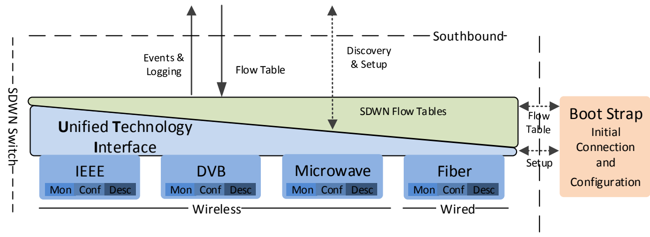

Fig. 4. SDWN extended infrastructure layer

B. Control layer and Northbound interface

In addition to the extended Southbound interface, WiBACK defines an SDWN control layer and a generic Northbound interface to the application layer. Both are designed having the Back-haul scenario in mind and are not supposed to cover all potential use cases for SDWN, since a universal Northbound API seems not useful, given the huge field of applications [17].

The main task of the control layer in the Back-haul use case is to configure and maintain the topology of the network as well as to allocate capacity. While the first is usually not a challenge in wired networks, it becomes more complex once wireless links are considered due to the additional configuration dimension of frequency and channel bandwidth. Thus, the WiBACK controller includes a Spectrum Management module. Its goal is to gain a global view on the physical network topology by highly utilizing the `scan` command provided by the UTI that identifies which interface on which node is physically able to communicate with which other interfaces of different devices. That is, it identifies which interfaces are of the same technology, can be tuned on the same frequency and are in communication range of each other. Moreover, the ambient spectrum usage is assessed as well. Based on this global knowledge the Spectrum Management module centrally assigns optimized frequencies and channel bandwidths to minimize interferences within the network and with other networks. Based on this knowledge it selects out of the physically possible connections the most optimal links and creates a logical topology by configuring the wireless interfaces properly. The algorithms of the Spectrum Management are explained in detail in [18]. It should be noted that the Spectrum Management module runs continuously in order to react on events in the network, such as new interferences, link failures, etc.

The Spectrum Management module is complemented by a Capacity Management module. This also operates centralized, following the SDN approach and performs the task of path calculation and resource, i.e. capacity, allocation. The required information, such as the network topology or the capacity on the individual links, is provided by the Spectrum Management. Since the Spectrum Management has created a logical topology, which consists only of the links that are already configured and whose capacity is determined, the Capacity Management can operate without being aware of actual technology, frequency or other physical layer parameter.

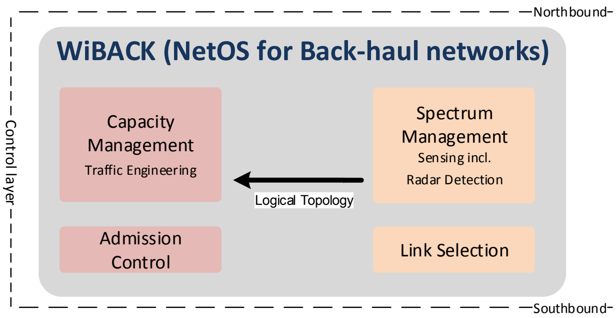

Fig. 5. WiBACK Control Layer

The Capacity Management itself is based on the concept of a centralized stateful Path Computation Element (PCE) [19]. For each link, the stateful Capacity Management module keeps track of the available resources as well as the currently allocated resources. We have provided a more detailed discussion on management of the available capacity in WiBACK in [20].

Capacity is allocated based upon request from an application via the Northbound interface. Therefore WiBACK provides an Extensible Markup Language (XML) interface, which allows an application to request capacity between two arbitrary nodes. If not just best-effort (BE) traffic should be transported explicit QoS requirements, i.e. max. latency, jitter, packet loss ratio, can be added to the request. Upon reception of such a request at the control layer the Capacity Management module validates it and checks if it can be admitted taking into account the requested bandwidth and other QoS parameters. Failure or success message of the request execution is sent back to the application. Furthermore, the XML-based Northbound interface allows for providing current topology information to the applications and services running on the application layer.

Applications that utilizes the WiBACK SDN-based architecture may include 5G enabled evolved Packet Core (EPC), which requested capacity to establish dedicated evolved Packet System (EPS) or end-to-end bearers with a certain bandwidth and QoS class of identifier (QCI).

C. Bootstrapping

Of particular interest for the aforementioned (wireless) Back-haul use case is the bootstrap phase when nodes are trying to (re-)join the network due to power failures or new nodes, which are being installed. As mentioned in Section II, in 5G Back-haul networks it is expected that nodes are working autonomously with no or only limited amount of configuration and interaction with an administrator required. Moreover, current SDN approaches also assume an always existing or fixed pre-configured connection between the data path devices and the SDN controller, which might be an invalid assumption for future Back-haul networks that highly rely on wireless links. Hence, wireless channels need to be configured properly in order to allow a node to establish an initial contact to its controller(s). Given that, we introduce a Boot Strap module on the infrastructure layer (see Fig. 4) existing in every data forwarding device. This module acts like a minimalistic controller. It also utilizes the UTI as a regular controller to initiate connectivity to an adjacent node and provides required entries in the flow table to allow for communication between the actual controller and the data path device. Once this connection is established the Boot Strap module stops and the spectrum and capacity management of the controller takes over until the connection is lost. A detailed description of the bootstrapping mechanism can be found in [18].

V. Pilot Installations

All core components of the presented WiBACK architecture have been implemented from scratch in C++ using our SENF library[2] and are evaluated in a number of pilot installations in Europe and Africa, e.g. [15]. Fig. 6 depicts an exemplary screenshot of the WiBACK management system. It shows the current capacity allocations in our Wirless Backhaul testbed[3] requested via the Northbound interface. The path marked in orange represents a BE capacity allocation between the `Controller` node and the Theishohn node. It should be noted that the `Controller` node, which is running the centralized WiBACK NetOS, for convenience reasons is also the gateway to external networks. The table on the right side of the figure shows the established dedicated data paths and its associated guaranteed QoS parameters.

It should also be noted that the individual components of the WiBACK controller, i.e. the Spectrum Management and the Capacity Management module, have been validated individually. The results of these validations can be found in the references mentioned throughout this work. Due to the lack of space we do not present a full system evaluation here.

VI. Conclusions and Future Work

We have presented our vision of future Back-haul networks in a 5G environment and the challenges that need to be solved in order to cope with requirements of future traffic and services. We acknowledge that future networks needs to be highly flexible and, thus, should follow the SDN concepts and extend them even further to also control (wireless) interfaces to become a SDWN. Furthermore, we have presented our WiBACK architecture, and have shown that it can already be seen as a SDWN implementation for wireless Back-haul networks.

The future work will focus on a close integration with the EPC and other potential applications for our SDWN controller.

Acknowledgment

This work has been supported by the BATS research project which is funded by the European Union Seventh Framework Programme under contract n317533. The views and conclusions contained here are those of the authors and should not be interpreted as necessarily representing the official policies

[2]http://senf.fokus.fraunhofer.de

[3]http://net4dc.fokus.fraunhofer.de/en/projects/solarmesh_testbed.html

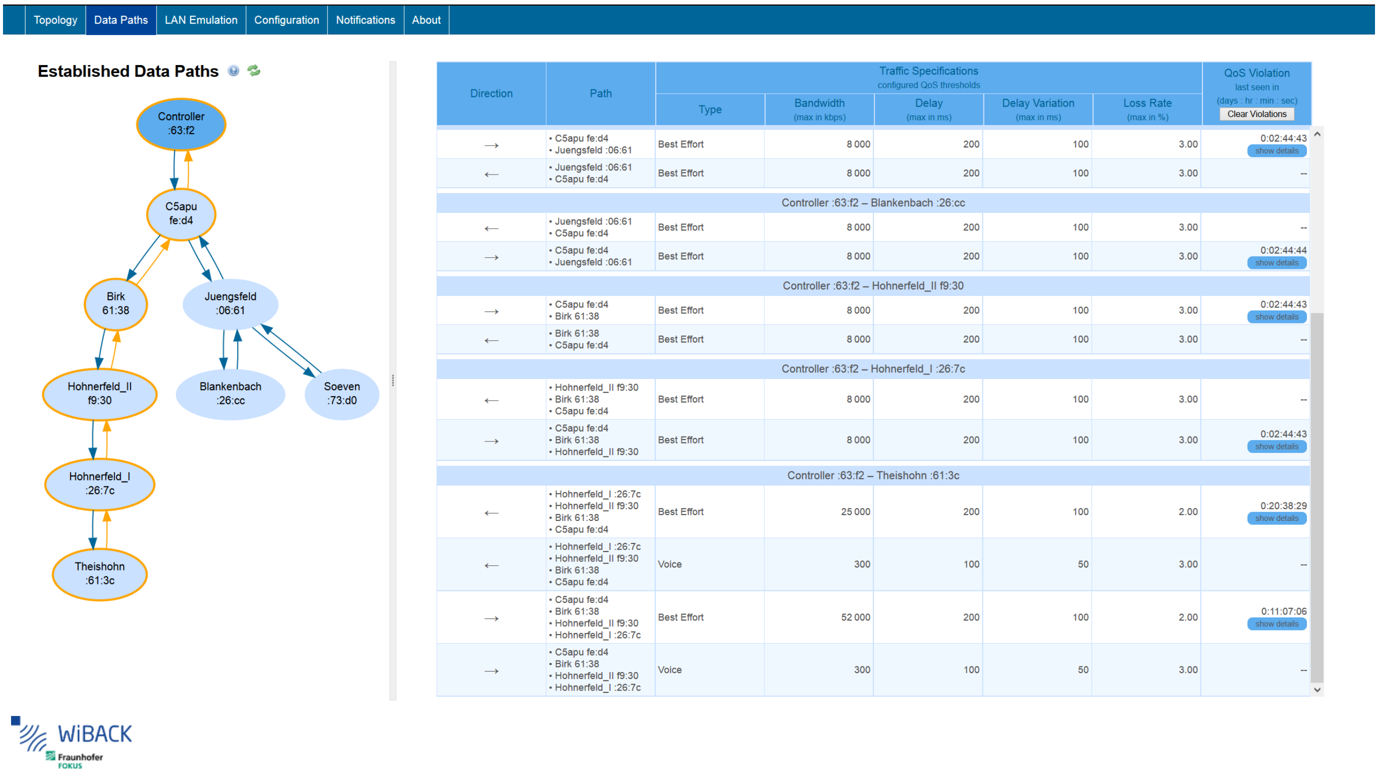

Fig. 6. Active capacity allocations requested via Northbound interface

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References

[1] Network2020 ETP, "5g: Challenges, research priorities, and recommendations," European Technology Platform for Communication Networks and Services, Draft, 2014.
[2] Cisco Cooperation, "The zettabyte era-trends and analysis," 2013.
[3] Radio Access and Spectrum FP7 Future Networks Cluster, "5g radio network architecture," March 2014.
[4] A. Osseiran *et al.*, "Scenarios for 5g mobile and wireless communications: the vision of the metis project," *Communications Magazine, IEEE*, vol. 52, no. 5, pp. 26–35, May 2014.
[5] B. Evans *et al.*, "Concepts and technologies for a terabit/s satellite," in *SPACOMM-2011*, Budapest, Hungary, 2011.
[6] J. Moy, "OSPF Version 2," RFC 2328 (Standard), Internet Engineering Task Force, Apr. 1998, updated by RFC 5709. [Online]. Available: http://www.ietf.org/rfc/rfc2328.txt
[7] Y. Rekhter, T. Li, and S. Hares, "A Border Gateway Protocol 4 (BGP-4)," RFC 4271 (Draft Standard), Internet Engineering Task Force, Jan. 2006, updated by RFC 6286. [Online]. Available: http://www.ietf.org/rfc/rfc4271.txt
[8] Open Networking Foundation, "Software-Defined networking: The new norm for networks," Open Networking Foundation, Palo Alto, CA, USA, White paper, Apr. 2012. [Online]. Available: http://www.opennetworking.org/images/stories/downloads/sdn-resources/white-papers/wp-sdn-newnorm.pdf
[9] B. A. A. Nunes *et al.*, "A survey of software-defined networking: Past, present, and future of programmable networks," *Communications Surveys Tutorials, IEEE*, vol. 16, no. 3, pp. 1617–1634, Third 2014.
[10] W. Xia *et al.*, "A survey on software-defined networking," *Communications Surveys Tutorials, IEEE*, vol. PP, no. 99, pp. 1–1, 2014.
[11] *OpenFlow Switch Specification*, ONF Std., Rev. Version 1.3.2, April 2013.
[12] C. Bernardos *et al.*, "An architecture for software defined wireless networking," *Wireless Communications, IEEE*, vol. 21, no. 3, pp. 52–61, June 2014.
[13] M. Bansal *et al.*, "Openradio: A programmable wireless dataplane," in *Proceedings of the First Workshop on Hot Topics in Software Defined Networks*, ser. HotSDN '12. New York, NY, USA: ACM, 2012, pp. 109–114. [Online]. Available: http://doi.acm.org/10.1145/2342441.2342464
[14] M. Kretschmer *et al.*, "Link calibration and property estimation in self-managed wireless back-haul networks," in *Communications (APCC), 2012 18th Asia-Pacific Conference on*, Oct 2012, pp. 232–237.
[15] C. Niephaus, M. Kretschmer, and K. Jonas, "Qos-aware wireless back-haul network for rural areas in practice," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, Dec 2012, pp. 24–29.
[16] A. de la Oliva *et al.*, "IEEE 802.21: Media independence beyond handover," *Computer Standards & Interfaces*, vol. 33, no. 6, pp. 556 – 564, 2011. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0920548911000213
[17] M. Jarschel *et al.*, "Interfaces, attributes, and use cases: A compass for sdn," *Communications Magazine, IEEE*, vol. 52, no. 6, pp. 210–217, June 2014.
[18] M. Kretschmer *et al.*, "Topology discovery and maintenance for heterogeneous wireless back-haul networks supporting unidirectional technologies," in *Communications (MICC), 2011 IEEE 10th Malaysia International Conference on*, Oct 2011, pp. 1–6.
[19] A. Farrel, J.-P. Vasseur, and J. Ash, "A Path Computation Element (PCE)-Based Architecture," RFC 4655 (Informational), Internet Engineering Task Force, Aug. 2006. [Online]. Available: http://www.ietf.org/rfc/rfc4655.txt
[20] M. Kretschmer, C. Niephaus, and G. Ghinea, "Qos-aware flow monitoring and event creation in heterogeneous mpls-based wireless mesh networks supporting unidirectional links," in *Communications (MICC), 2009 IEEE 9th Malaysia International Conference on*, Dec 2009, pp. 680–685.