Towards Per-user Flexible Management in 5G

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Abstract—Flexible management is one of the key components of next-generation 5G networks. Currently, many approaches focus on network functionality (services) and translate it afterward into end-user requirements, which slightly constrains the flexibility for both management and end users. Furthermore, moving the intelligence of the network towards the edge (i.e. the users) has already proven its benefits, such as computational offloading, lower latency and higher bandwidth utilization. In this article, we try to move management as close as possible to final users, providing per-user flexibility and unique user to service paths, enabling custom paths adapted for each user requirements instead of users adapting to service requirements. To validate our ideas, we work on two different use cases, implemented as proof-of-concepts in the ONOS platform. From the results obtained we conclude that there is still work to be done regarding the integration of SDN in the radio access and evolved packet core functions to provide the desired flexibility.

Index Terms—SDN, NFV, 5G networks, fronthaul, cloud computing, flexible management

I. INTRODUCTION

On the road towards the fifth-generation mobile network (5G) [1], different challenges have been defined. The 5G Infrastructure Public Private Partnership (5G-PPP) lists various Key Performance Indicators (KPIs) that should be accomplished, where particularly network management Operating ExPenDiture (OPEX) is expected to be reduced by at least 20% compared to today.

One concept that has emerged recently together with 5G is the Mobile Edge Computing (MEC) [2], recently rebranded as Multi-Access Edge Computing, which conveys part of the network intelligence to the edge of it. The MEC framework is envisioned to leverage Software-Defined Networking (SDN) [3] and Network Functions Virtualization (NFV) [4] technologies to enhance network management. Similarly, the Central Office Re-architected as a Datacenter (CORD) initiative [5] has a branch focused on mobile networks (M-CORD) expected to procure proximity to end users as well.

Cloud technologies and flexible service management in Radio Access Network (RAN) are key towards 5G [6]. Accordingly, the network edge becomes a Cloud Radio Access Network (C-RAN) [7], where the traditional Base Station (BS) is cracked into two pieces: the Remote Radio Head (RRH) (dummy radio hardware) and the Baseband Unit (BBU) (which processes the baseband signal as part of the cloud intelligence) [8]. This separation implies establishing a high-performance network in between: the fronthaul, whose traffic is generally transported by the Common Public Radio Interface (CPRI) [9].

Although the benefits of extending the cloud to the edge [10] seem apparent, the open question is how close can network management be from final users.

In this article, we analyze how to leverage SDN to manage per-user connectivity at the fronthaul in 5G and present a Proof of Concept (PoC) implemented in Open Network Operating System (ONOS) [11] (following the principles of CORD). Section II is devoted to the analysis and definition of the approach, Section III describes the implementation, and finally Section IV examines conclusions and future work.

II. A SUPERFLUID APPROACH

The superfluid network concept originates from the architecture for 5G defined in the Superfluidity project [12]. One of its cornerstones is flexible network management. Ideally focused on supporting per-user granularity, services could be deployed at the core or at the edge (particularly, in the MEC) following end user requirements at each time. To go one step further, Superfluidity attempts to identify specific user profiles and bring them access accordingly.

To accomplish it, first we decided to design a management framework focused on users and their associated services (instead of services and the users who employ them). Second, we try to merge both fronthaul and backhaul management, to avoid defining a barrier in between. Third, we focus on two use cases: bandwidth control and traffic paths based on users. Finally, we analyse the current protocols in play for those use cases, mainly GPRS Tunnelling Protocol for User data (GTP-U) and CPRI. The following sections detail these aspects in further detail.

A. Per-user flexible management

So far, 5G architectures first focus of the services deployed and, later on, on how they affect end users. The principle we want to accomplish is the other way round: individual people connecting to the mobile network anytime, anywhere, while the network adapts to their requirements, following the principles of Human-Defined Networking (HDN) [13]. Hence
questions emerge: Would that user have all the services at all places? Could they configure what they want at any time (adjusting billing accordingly)? What if they want to hire a service at that right moment without needing to call their provider?

In line with the above questions some examples arise, such as, paying for a new service at user demand, one idea would be having a dynamic user captive portal from which end users could configure their services.

B. Backhauling the fronthaul

To accomplish per-user flexible management, the immediate question is where should the management framework be located in the network. According to the current deployment of Superfluidity (see Fig. 1), which follows the standard 5G network architecture, the edge network is divided into two pieces: fronthaul and backhaul. More specifically, the fronthaul is the closest path to the user and, ideally, per-user management should start from it. Currently, the fronthaul is just thought as a –non-cloudified– transport network. However, we believe it should also be part of the cloud and the associated management framework. The barrier between fronthaul and backhaul should be blurred, as stated in [14].

C. Two use cases: per-user bandwidth control and traffic diversion

We envision two main use cases:

1) **Per-user bandwidth control**: By leveraging SDN, we could control the fronthaul transport network, not only dynamically instantiating paths between the RRHs and BBU, but also defining the characteristics of those paths, such as bandwidth.

2) **Per-user traffic diversion**: Diverting specific user traffic could be useful for different scenarios, such as the user captive portal we mentioned in the example above, or even for security reasons, e.g. the user’s mobile is temporarily hacked and we want to drop malicious traffic as close as possible to the user.

D. The protocols in play: GTP-U and CPRI

In traditional Long Term Evolution (LTE) architectures, the data plane transport protocol on the core network is based on GPRS Tunnelling Protocol (GTP), which is the protocol carrying General Packet Radio Service (GPRS) packets. Inside GTP we can find three other sub-protocols: i) GTP-C, mainly used for signalling, session activation and QoS provisioning for users, ii) GTP-U, focused in transporting user data through the data plane, and iii) GTP', focused on billing.

Alternative approaches have been designed in order to remove the dependency with GTP tunnels. M-CORD [15] redefines the radio access, by leveraging SDN and NFV technologies, to deploy flexible networks, capable of acting as cloud platforms to deploy services. M-CORD features: i) Programmable RAN (SD-RAN), ii) Disaggregated and virtualized Evolved Packet Core (EPC), iii) MEC, and iv) End-to-end slicing from RAN to EPC. On the fronthaul ONOS controls the virtualized BBU instances deployed to serve their RRHs. With such control over the data plane and disaggregated EPC functionalities, M-CORD can progressively remove GTP connection tunnels in favor of OpenFlow tunnels. Migrating to a connectionless LTE.

On the other hand, nowadays CPRI is the preferred option to deploy the fronthaul network. Introducing this interface in the management framework would allow a new range of possibilities of control closer to end users.

III. Implementation and Evaluation

To demonstrate the feasibility of the two use cases described in the previous section, we implemented a proof-of-concept of each of them leveraging the ONOS platform as SDN controller (more specifically ONOS version 1.10.4). The network was both virtualized with the Mininet [16] platform, using Open vSwitch (OvS) [17], and also tested with the hardware SDN switch Pica8 [18] (P-3297 model), which is OvS-based as well.
A. Per-user bandwidth control

The fronthaul could be simplified as a transport network in between of two final nodes: the RRH and the BBU (as represented in Fig. 1). At the same time, ONOS provides the Intent Framework [19], which automatically deploys shortest paths between pairs of end hosts, for example. An intent is a way of expressing what functionality we want in the network, instead of focusing on how to do it. Accordingly, thanks to ONOS, we can easily build a minimum latency path between the RRH and the BBU (without worrying about the underlying network), but that path will have the same characteristics for all end users served. Thus, our objective was to implement some type of differentiation in the paths between the RRH and BBU nodes.

To start with, we decided to enhance the current intent framework in ONOS by developing a bandwidth-based intent, i.e. shortest path with an additional parameter for QoS: bandwidth control. More specifically, we implemented an ONOS app that introduces bandwidth-based intent and a REST API for control, as depicted in Fig. 2. The REST API permits dynamic instantiation of host scenarios from scratch and intent deployment afterwards.

For example, initially the network manager will be able to define the hosts that he is willing to connect. These hosts can be of type RRH (ADD host 1) or BBU (ADD host 2). An example of how an RRH node would be added is shown in Listing 1.

Once hosts and their roles are settled, we can dynamically create the shortest paths with delimited bandwidth (ADD intent bandwidth) between pairs of RRH and BBU hosts, as shown in Listing 2. This new type of intent leverages the already existing HostToHost intent in ONOS. Note the simplicity of the command, which only requires 3 parameters to set up routes: the RRH, the BBU, and the bandwidth (optional parameter).

```bash
curl --request POST \
   --url http://IP:p/superfluidity/edge/host/ \
   --header 'accept: application/json' \
   --header 'authorization: Basic <...>=' \
   --header 'content-type: application/json' \
   --data '{
      "device":"of:0000000000000001",
      "port":"1",
      "mac":"00:30:18:ce:ef:cd",
      "vlan":-1",
      "ips":["172.16.1.1"],
      "type":"RRH"
   }'
```

Listing 1. Usage sample of the ADD host command

```bash
curl --request POST \
   --url http://IP:p/superfluidity/edge/intent/ \
   --header 'accept: application/json' \
   --header 'authorization: Basic <...>=' \
   --header 'content-type: application/json' \
   --data '{
      "one":"00:00:00:00:01:01/None",
      "two":"00:00:00:00:02:01/None",
      "bandwidth":100
   }'
```

Listing 2. Usage sample of the ADD intent bandwidth command

The implemented app is composed of the following modules:

- **EdgeHost**: Edge host model.
- **EdgeIntent**: Edge intent model.
- **EdgeHostWebResource**: It implements the REST API for the hosts (add, delete, etc.).
- **EdgeIntentWebResource**: It implements the REST API for the intents (add, delete, etc.).
- **EdgePacketProcessor**: It is in charge of detecting traffic between one RRH and a BBU.
- **InternalHostProvider**: It extends the AbstractProvider class to be able to add, modify and delete hosts in ONOS.
- **EdgeComponent**: Main class. It implements the Activate and Deactivate methods and it contains the rest of the implementation.
- **EdgeService**: Class that defines the service to be implemented in EdgeComponent.

To install the different paths, the app connects to the network switches through the Open vSwitch Database (OVSDB) protocol [20]. The app installs a QoS entry and an associated queue in the ingress and egress switches (as represented in Fig. 3) which guarantees the requested bandwidth limitation when the route is created after the REST API call. Once the QoS entry and the queues are installed, the HostToHost intent is installed by specifying the two hosts we want to connect and the queue ID we want to link to the intent. Currently, HostToHost intents can only be associated to a
A single queue ID, so the queue ID of the ingress and egress switches are set to the same value.

Additionally, the app implements an extension of the ONOS GUI that is able to alert the network manager when traffic is detected between a RRH and a BBU, which potentially would require a path to connect them both. The extension of the GUI is shown in Fig. 4. To integrate this frontend web with the ONOS platform, the following modules were developed:

- **EdgeUiTableComponent**: Integration of the frontend web as a table component in ONOS.
- **EdgeUiTableMessageHandler**: Implementation of the app extended GUI.

**Fig. 4. ONOS GUI detecting a connection between RRH and BBU**

Finally, we tested the implementation in a Mininet OvS-based network. The graphical representation of the traffic is depicted in Fig. 5. However, although routes were installed correctly at every moment, after testing with ping and iPerf, we realized that bandwidth limitations was not being granted. After studying the tests carefully, we discovered that ONOS was performing correctly and the problem was related with how Mininet implements links between the OvSs.

Therefore, we repeated the tests on a network built with the P-3297 switch from Pica8. Pica8 internally implements OvSs as well, in a customized way. This time the problem was a different one, which is that ONOS raises a code=BAD_QUEUE in the logs, and flows are not installed, kept in the PENDING_ADD status.

After analyzing the Pica8 documentation, we found out that the port QoS is Pica8 specific and should be one of the following: type=PRONTO STRICT or type=PRONTO WEIGHTED ROUND ROBIN. Currently, neither of them is implemented by ONOS, according to their code in QosDescription.java.

Up to this point, we stopped the implementation, as we considered some development effort needs to be done from the communities of Mininet, Pica8 and ONOS. A relatively fair solution would be updating the QosDescription.java code, but it implies both people from Pica8 and ONOS to work together.

**B. Per-user traffic diversion**

The second use case implies processing per-user granular flows by analyzing the traffic inside GTP-U tunnels. The main objective is to divert specific user traffic before it reaches the cloud, i.e. the service location. As we mentioned in the introduction, several reasons might require this diversion, such as: securing the network from potential attacks (diverting traffic to honeypots) or directing a user to a captive portal for service hiring.

To implement this use case proof-of-concept, the first requirement is the support of GTP-U tunneling in OvS, which is the switch we are using for our tests, and also the most supported along the SDN community. Currently, OvS needs a patch to support it [21].

In this case, the app we developed leverages the previous feature to encapsulate and decapsulate GTP-U traffic. More specifically, a switch associated to the BBU is in charge of...
this task, as shown in Fig. [6]. Thanks to it, we can distinguish the owner (end user) of the traffic and act accordingly. To follow this behaviour, we install the flows in the switch via an SSH tunnel. The reason behind this is that OpenFlow does not support the installation of these flows. Thus, one alternative design would be extending the OpenFlow protocol so that it supports the use and inspection of GTP-U frames.

A very simplistic scenario would be the following: A user hired voice, but not a data service with the operator. However, she decides to start using some data services, so the first time she uses GTP-U, her traffic is diverted to a user captive portal where she can directly hire new services by adding her billing information (as depicted in Fig. [6]). This portal would communicate with the SDN platform (e.g. via REST API), which would install the corresponding paths afterwards. This minimizes the effort of the network manager, who usually activates services manually, and it also gives added control and enhances service flexibility to end users, who are capable of deciding which services they want to use anywhere at anytime.

IV. CONCLUSIONS AND FUTURE WORK

Along the article, we have described the need to move network management towards the edge. The main objective is to provide management flexibility with focus on end users, following the principles of HDN.

To prove our ideas, we have described two use cases: (1) per-user bandwidth control and (2) per-user traffic diversion, and we have implemented a proof-of-concept of each of them as an app in the ONOS SDN platform.

The first use case proves the feasibility of the approach, reducing management time (i.e. a command with just 3 parameters installs shortest path with specific QoS) while adding flexibility at the same time (nodes are easily registered via a REST API and tracked via a graphical interface). However, we could not test the QoS as Mininet does not implement bandwidth limitation, and Pica8 requires specific queues, which are not currently supported in ONOS. As future work, we consider the Pica8 and ONOS community should collaborate for integration of this feature.

The second use case adds flexible management both for the services provider and end users, who are capable of hiring their services at request. However, we had to install a patch in OvS to support GTP-U tunnelling, and flows are installed via SSH, instead of OpenFlow, which does not support it. As future work, we believe extending OpenFlow to support GTP-U should be considered, or at least new Southbound Interface protocols under research should have it in mind.

REFERENCES

[1] A. Gupta and R. K. Jha, “A Survey of 5G Network: Architecture and Emerging Technologies,” IEEE Access, vol. 3, pp. 1206–1232, 2015.
[2] ETSI, “Mobile Edge Computing (MEC) Framework and Reference Architecture,” European Telecommunications Standards Institute, GS MEC 003, Mar 2016.
[3] D. Kreutz, F. M. V. Ramos, P. E. Verissimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig, “Software-defined networking: A comprehensive survey,” Proceedings of the IEEE, vol. 103, no. 1, pp. 14–76, Oct 2015.
[4] ETSI, “Network Functions Virtualisation (NFV); Management and Orchestration; Architectural Options,” European Telecommunications Standards Institute, GS NFV-IFA 009, July 2016.
[5] L. Peterson, A. Al-Shabibi, T. Anshutz, S. Baker, A. Bavier, S. Das, J. Hart, G. Palukar, and W. Snow, “Central office re-architected as a data center,” IEEE Communications Magazine, vol. 54, no. 10, pp. 96–101, October 2016.
[6] P. Rost, C. J. Bernardos, A. D. Domenico, M. Di Girolamo, M. Lalam, A. Maeder, D. Subella, and D. Wübben, “Cloud technologies for flexible 5G radio access networks.” IEEE Communications Magazine, vol. 52, no. 5, pp. 68–76, May 2014.
[7] China Mobile, “C-RAN: the road towards green RAN,” White Paper version 2.5, vol. 2, 2011.
[8] C. L. I. J. Huang, R. Duan, C. Cui, J. Jiang, and L. Li, “Recent Progress on C-RAN Centralization and Cloudification,” IEEE Access, vol. 2, pp. 1030–1039, 2014.
[9] A. de la Oliva, J. A. Hernandez, D. Larrabeiti, and A. Azcorra, “A view of the CPRI specification and its application to C-RAN-based LTE scenarios,” IEEE Communications Magazine, vol. 54, no. 2, pp. 152–159, February 2016.
[10] R. S. Montero, E. Rojas, A. A. Carrillo, and I. M. Llorente, “Extending the Cloud to the Network Edge,” Computer, vol. 50, no. 4, pp. 91–95, 2017.
[11] P. Berde, M. Gerola, J. Hart, Y. Higuchi, M. Kobayashi, T. Koide, B. Lantz, B. O’Connor, P. Radoslavov, W. Snow, and G. Parulkar, “ONOS: Towards an Open, Distributed SDN OS,” in Proceedings of the Third Workshop on Hot Topics in Software Defined Networking, 2014.
[12] G. Bianchi, E. Biton, N. Blefari-Melazzi, I. Borges, L. Chiaraviglio, P. de la Cruz Ramos, P. Eardley, F. Fontes, M. J. McGrath, L. Natarianni, D. Niculescu, C. Parada, M. Popovici, V. Riccobene, S. Salsano, B. Sayadi, J. Thomson, C. Tselios, and G. Tsolis, “Superfluidity: a flexible functional architecture for 5G networks,” Transactions on Emerging Telecommunications Technologies, vol. 27, no. 9, pp. 1178–1186, 2016, ett.3082. [Online]. Available: http://dx.doi.org/10.1002/ett.3082
[13] E. Rojas, “From Software-Defined to Human-Defined Networking: Challenges and Opportunities,” IEEE Network, vol. PP, no. 99, pp. 1–7, 2017.
[14] A. de la Oliva, X. C. Perez, A. Azcorra, A. D. Giglio, F. Cavaliere, D. Tietelbekkers, J. Lessmann, T. Haustein, A. Mourad, and P. Iovanna, “Xhaul: toward an integrated fronthaul/backhaul architecture in 5G networks,” IEEE Wireless Communications, vol. 22, no. 5, pp. 32–40, October 2015.
[15] M-CORD: Mobile CORD. [Online]. Available: https://www.opennetworking.org/solutions/m-cord
[16] B. Lantz, B. Heller, and N. McKeown, “A Network in a Laptop: Rapid Prototyping for Software-defined Networks,” in Proceedings of the 9th ACM SIGCOMM Workshop on Hot Topics in Networks, ser. Hotnets-IX, 2010.
[17] OvS: Open vSwitch. [Online]. Available: http://openvswitch.org/
[18] Pica8: White Box SDN. [Online]. Available: http://www.pica8.com/
[19] ONOS: Intent Framework. [Online]. Available: https://wiki.onosproject.org/display/ONOS/Intent+Framework
[20] B. Pfaff and B. Davie, “The Open vSwitch Database Management Protocol,” RFC 7047, Dec. 2013. [Online]. Available: https://rfc-editor.org/display/ONOS/Intent+Framework
[21] GTP-U tunnel support: OvS kernel module extension. [Online]. Available, https://github.com/pa5h1nh0/GTP-U_Ovs-kernel-extension