Dynamic Virtual Network Connectivity for C-RAN Backhauling

A. Asensio*, M. Ruiz, and L. Velasco
Optical Communications Group (GCO). Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
**e-mail: aasensio@ac.upc.edu*

ABSTRACT
Aiming at satisfying in a cost-effective manner the forecast traffic growth that future mobile networks will need to support, traditional distributed Radio Access Networks (RANs) are evolving towards centralized architectures. Specifically, the Cloud-RAN (C-RAN) architecture has shown that can alleviate to some extent the ever increasing Total Cost of Ownership in mobile networks. The current trend in C-RAN is to separate Remote Radio Heads (RRH) with radio frequency (RF) functions and Baseband Units (BBU) gathering baseband processing. This functional split allows keeping RF modules close to the antennas while placing BBUs at centralized locations so they can be shared among different sites and even be virtualized. However, some issues still need to be addressed in future mobile networks, especially due to the dynamicity of services and the strict constraints imposed by the interfaces needed. Since connectivity reconfiguration for backhaul interfaces (X2 and S1) needs to be provided as an all-or-nothing request to enable mobile resources reconfiguration in a geographical area, in this paper we propose dynamic Customer Virtual Network (CVN) reconfiguration to be supported in metro and core network segments. Additionally, such CVN requests must include Quality of Service constraints to ensure specific delay constraints, as well as bitrate guarantees to avoid service interruption. An efficient algorithm is presented for the CVN reconfiguration problem and exhaustive simulation results study its performance on realistic scenarios.
Keywords: cloud services, cloud radio access network, customer virtual networks, telecom cloud.

1. INTRODUCTION

Evolution of radio access technologies to satisfy the forecast mobile traffic growth in a cost-effective manner in next generation mobile networks reveals new paradigms. Indeed, it is expected that mobile traffic will reach about 30.6 EBs per month by 2020 [1]. Centralized Radio Access Network (RAN) architectures ([2], [3]) have been demonstrated to be cost-effective RAN architectures to support cell site's demand increment [3].

Novel RAN architectures may consider different functional splitting levels. Specifically, a widely studied functional splitting in centralized RAN consists in gathering baseband processing functions in baseband units (BBU) placed in central offices (CO) and separated from Remote Radio Heads (RRH) with radio frequency (RF) functions. BBUs can be shared among different sites and can even be virtualized [4] in Cloud-RAN (C-RAN). To connect RRHs and BBUs a fronthaul network is needed, whereas to connect BBUs in distant locations and BBUs to core entities (e.g., the Mobility Management Entity, MME, or the serving Gateway, S-GW) hosted in metro and core network segments, connections supporting X2 and S1 interfaces, respectively, need to be established over the so called backhaul network.

Despite the advantages of centralized RAN to reduce Total Cost of Ownership against traditional distributed RAN architectures ([3], [5]), some issues need to be addressed to support the dynamicity related to the wide range of services that future mobile networks are expected to support. Moreover, in addition to such dynamicity, communication interfaces required in future RAN require very restrictive constraints, mainly in terms of capacity and delay, which backhaul networks need to satisfy. In fact, service-specific parameters in Service Level Agreements (SLAs) become crucial to guarantee the required Quality of Service (QoS) and a minimum bitrate guaranteed aiming at avoiding service interruption. To provide service-specific network services, network virtualization can be considered.

In this paper, from our previous work in [6], we propose dynamic Customer Virtual Network (CVN) reconfiguration (including QoS constraints to ensure specific delay constraints, as well as bitrate guarantees to avoid service interruption) to be supported in metro and core network segments. An efficient algorithm is described for the CVN reconfiguration problem and simulation results are shown to study its performance on realistic scenarios.

2. C-RAN BACKHAULING

In this section, we first summarize the C-RAN requirements considered for backhauling and describe our proposal to provide dynamic virtual network connectivity.

This work was partially supported by the EC through the METRO-HAUL (G.A. 761727) project, from the Spanish MINECO SYNERGY project (TEC2014-59995-R) and from the Catalan Institution for Research and Advanced Studies (ICREA).

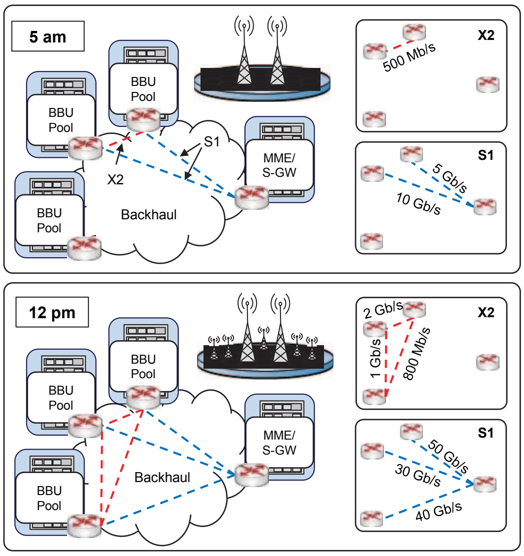

Figure 1. Example of CVN reconfiguration in C-RAN.

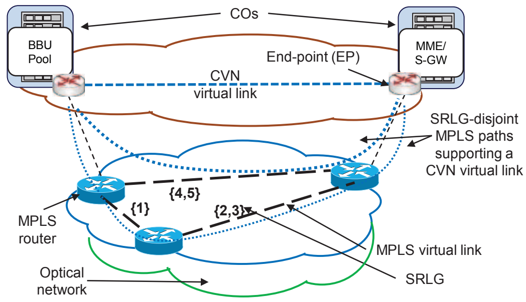

Figure 2. Layered network to support CVNs.

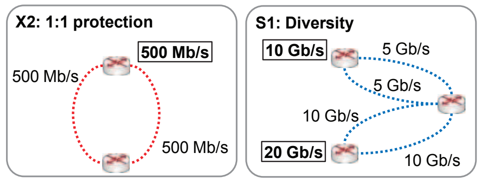

Figure 3. Bitrate guarantees for X2 and S1 interfaces.

A. Backhaul Requirements in C-RAN

From our work in [5] and [6], we summarize the considered requirements to support C-RAN backhauling:

i) *Time dependent capacity*. S1 and X2 required capacity depends not only on the site configuration but also on the load density, which varies with time.

ii) *Dynamic C-RAN topology reconfiguration*. The required network topology in the backhaul to support C-RAN can also vary with the time to adapt to the demand location and density. Connectivity reconfiguration needs to be provided as an all-or-nothing request.

iii) *QoS*. Delay constraints need to be considered in X2 and S1 interfaces.

iv) *Bitrate guarantees*. Failures in links supporting connections in the backhaul would impact several communication interfaces simultaneously in C-RAN and will potentially interrupt service for a wide range of users. Therefore, some kind of bitrate guarantees is needed for X2 and S1 interfaces.

Figure *1* shows an example with the virtual topology required from a C-RAN operator to satisfy backhaul connectivity for X2 and S1 at two different hours of the day (5 am and 12 pm).

B. Dynamic Virtual Network Connectivity

Since connectivity reconfiguration needs to be provided as an all-or-nothing request, we propose dynamic CVN reconfiguration based on the Abstraction and Control of Transport Networks (ACTN) framework [7] to be supported in metro and core network segments. Customers (C-RAN operators) can request connectivity between their end-points (EPs) to reconfigure their virtual topology, including service-specific parameters [8]. We assume that CVNs are provided on top of a multilayer MPLS network supported by an optical network. Figure 2 represents such layered network containing: *i*) the customer layer with CVNs connecting EPs in COs. Every CVN's link is supported by one or more MPLS paths; *ii*) the MPLS network layer consisting in a number of MPLS routers connected through virtual links (*vlink*) supported by optical connections; *iii*) the optical network.

Regarding bitrate guarantees in case of failures, the requested bitrate for X2 interfaces needs to be guaranteed to ensure the service; therefore 1:1 protection is required. Differently, for S1 interfaces, in the event of a failure bitrate could be reduced while keeping service active. As a result, users' data rate would be decremented. Diversity can be considered for S1 interface, where a proportion of the requested bitrate is guaranteed. Figure 3 illustrates the selected bitrate guarantees options. Note that both bitrate guarantees options are supported by the MPLS-over-optical network assumed. Figure 2 shows a CVN vlink (S1) supported by two Shared Risk Link Group (SRLG)-disjoint MPLS paths, where one of them uses SRLGs {4, 5} and the other uses SRLGs {1, 2, 3}.

3. CVN RECONFIGURATION

The CVN reconfiguration problem can be formally stated as follows:

Given:

- A multilayer optical network represented by the graph $G^O(N, L)$; being N the set of optical nodes and L the set optical of links.
- An MPLS network represented by a graph $G^V(V, E)$; being V the set of MPLS nodes and E the set of vlinks,

where each vlink can be supported by several lightpaths.

- A set of customers (C-RAN operators) C; each $c \in C$ manages its own CVN, which topology is represented by a fully meshed graph $G_c(V_c, E_c)$; being V_c the set of EPs and E_c the set of CVN links of c.
- A CVN reconfiguration request coming from customer c that is represented by the tuple $<B^r, Q^r, W^r>$; where B^r is the capacity matrix of CVN vlinks between EPs, Q^r is the QoS matrix, and W^r is the matrix with CVN links capacity to be guaranteed. We assume that $w^r \leq 0.5 * b^r$; e.g., 50% of requested bitrate to be guaranteed.

Output: the set of MPLS paths and lightpaths to be established to serve the CVN reconfiguration request.

Objective: minimize the cost of the used resources in both, the optical and the MPLS layer.

To solve the problem, we propose the randomized algorithm in Table 1, which runs a number of iterations (line 2). At every iteration the set of requested CVN links (demands) is randomly sorted and served sequentially in the resulting order. The obtained solution is compared against the best solution obtained so far and, in case the latter is improved, it is updated (line 14) and eventually returned (line 15).

The algorithm first updates those CVN links with unchanged or decreased requirements to release resources that can be reused afterwards (lines 4-6). The rest of the CVN links are de-allocated from G_c and added to the set D (lines 7-8). The set D is randomly sorted (line 9) and every CVN link is then set up (lines 10-13) using the *setupCVNLink* algorithm, which returns the set Ω with the MPLS paths and lightpaths to be established. If one of the CVN links cannot be updated, then the complete CVN reconfiguration request is blocked (line 12).

4. RESULTS

To evaluate the performance of CVNs we implemented the proposed algorithm in C++ and integrated it in an ad-hoc event driven simulator based on OMNeT++. We assume that specific CVNs are requested for X2 and S1 connectivity because of their different requirements in terms of capacity, QoS and bitrate guarantees. In addition, a case where no bitrate guarantees are requested is considered (*no guarantees*). The network topologies in Figure 4 are used here for both, metro (X2) and core (S1) segments. It is worth noting that, to capture real distances (and delays), the network diameter is scaled down to about 50 km when those topologies are used for the metro segment. Finally, each point in the results is the average of 10 runs with more than 10,000 requests.

A. C-RAN CVN Provisioning to Support X2

We consider a set of COs geographically distributed, hosting virtualized BBU pools and connected to the network through packet nodes, and an increasing number of CVNs to be reconfigured. The capacity of each link varies in the range [200 Mb/s, 5 Gb/s]. X2 CVNs are full mesh topologies, where the probability that a X2 connection between 2 specific COs is required depends on the hour of the day, being higher during daytime hours and lower during night hours thus, representing the flexible assignment between RRHs and BBUs along the day to a different number of COs [5]. Regarding delay constraints, we limited the maximum end-to-end (e2e) delay to 0.5ms; note, however, that per CVN link values can be specified in the request.

Table 1. Algorithm for CVN reconfiguration.

```
INPUT: Gc(Vc,Ec),Br,Qr,Wr,α,maxIter
OUTPUT: BestSol
 1:  BestSol← Ø
 2:  for 1..maxIter do
 3:    D ← Ø, S ← Ø
 4:    for each e ∈ Ec do
 5:      if Br(e) ≤ B(e) and Qr(e) ≤ Q(e)
         and Wr(e) ≤ W(e) then
 6:        update(e,Br(e),Qr(e),Wr(e))
 7:      else
 8:        dealloc(e,Gc); D ← D ∪ {e}
 9:    shuffle(D)
10:    for each d ∈ D do
11:      Ω ← setupCVNLink(d,Br(d),Qr(d),
         Wr(d),Gc,α)
12:      if Ω = Ø then break
13:      S ← S ∪ {Ω}
14:    if BestSol = Ø or S.fitness >
       BestSol.fitness then BestSol ← S
15:  return BestSol
```

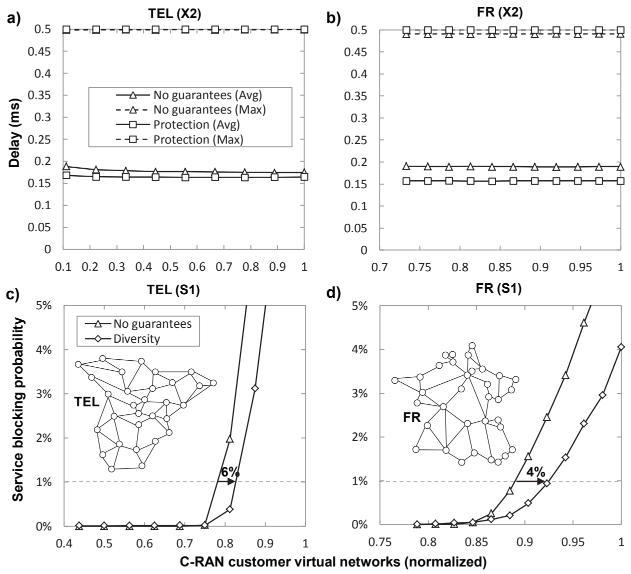

Figure 4. Delay vs. number of X2 CVNs (a and b) and service blocking vs. number of S1 CVNs (c and d).

Figure 4a and Figure 4b show average and maximum delay values for TEL and FR, respectively. Delay limit is never exceeded, being maximum values close to 0.5ms. Interestingly, focusing on the average values, the protection approach results in slightly lower times than when no bitrate guarantees are considered. The reasoning behind this is that a large number of MPLS vlinks are established to support SRGL-disjoint MPLS paths aiming at guaranteeing the whole capacity. In contrast, fewer MPLS vlinks need to be established under the no guarantees approach thus, reducing the number of routes. Although using protection resulted in slightly lower delays, the cost is in the number of transponders needed, which increases, on average, 81% for the TEL and 110% for the FR topologies, respectively, compared to no guarantees approach.

Regarding failures, results showed that the affected connections when protection is required (about 10% for TEL and 12% for FR) is lower than when no guarantees are requested (20% for TEL and 22% for FR). It is worth noting that when a failure affects the working path of a connection supported by 1:1 protection, the delay of the protected path is considered. That is, larger routes will be considered when a failure affects a connection, thus, increasing average delay (about 65 µs more for TEL and 98 µs more for FR compared to the working path), but without exceeding the 0.5 ms limit. In contrast, when no guarantees are requested, service supported by the affected connections will be disrupted thus, impacting several cells simultaneously.

B. C-RAN CVN Provisioning to Support S1

Differently from X2, S1 connections require higher capacities but less restrictive delay constraints. To reproduce S1 scenarios we consider regions, each containing 1 or more sets of COs to create star topologies. C-RAN operators require connectivity to support S1 interfaces between COs and a centralized CO hosting mobile core entities. We consider asymmetric traffic, and the capacity required from the central location to COs is in the range [5, 50] Gb/s. A given CO requires connectivity or not with a certain probability, depending on the hour of the day. In addition, we consider that the maximum allowed e2e delay is 10 ms.

Plots in Figure 4c and Figure 4d show the service blocking probability for the TEL and FR topologies, respectively. In the evaluated scenarios, the performance of the diversity approach slightly improves that of the approach without bitrate guarantees. The rationale behind that is that under the diversity approach two disjoint paths with 50% capacity (50% of bitrate to be guaranteed has been considered) are used, in contrast to the single path used when no guarantees is requested.

When failures are considered, results showed that the percentage of affected connections is higher when bitrate guarantees are required, since two MPLS paths are considered to support every single CVN vlink. Although the available capacity is reduced in affected connections, service will not be interrupted when diversity is implemented, compared to service disruption in the case that no bitrate guarantees are requested.

5. CONCLUSIONS

Based on our previous studies, dynamic virtual network connectivity has been proposed to support C-RAN backhauling (X2 and S1 interfaces). C-RAN operators request their CVNs to be reconfigured while taking into account delay constraints imposed by the interfaces and guaranteeing bitrate. To that end, a heuristic algorithm was proposed.

Simulations were carried out focusing on the X2 interface, where bitrate guarantees are implemented using 1:1 protection, and on the S1 interface, where guarantees are implemented considering diversity. Results showed that using 1:1 protection for X2 backhauling, slightly increases the average delay in the connections in scenarios with failures. Regarding S1 backhauling, diversity was considered to guarantee 50% of the requested bitrate in case of a single link failure thus, avoiding service disruption. In addition, benefits from using more than one path to support a CVN link were observed in the scenarios evaluated, resulting in the fact that the number of CVNs supported slightly increased for a given blocking probability.

REFERENCES

[1] CISCO Visual Networking Index (VNI), 2016.

[2] Y. Lin *et al*., "Wireless network cloud: Architecture and system requirements," *IBM Journal of Research and Development*, vol.54, no.1, pp.4:1-4:12, 2010.

[3] "C-RAN the road towards green RAN," *China Mobile Research*, 2011.

[4] L. Velasco *et al*., "A service-oriented hybrid access network and clouds architecture*," IEEE Communications Magazine*, vol.53, pp.159-165, 2015.

[5] A. Asensio *et al*., "Study of the centralization level of optical network-supported cloud RAN," in *Proc. IEEE International Conference on Optical Network Design and Modeling (ONDM)*, 2016.

[6] A. Asensio *et al*., "Dynamic virtual network connectivity services to support C-RAN backhauling," *IEEE/OSA Journal of Optical Communications and Networking (JOCN)*, vol. 8, pp. B93-B103, 2016.

[7] D. Ceccarelli and Y. Lee, "Framework for abstraction and control of traffic engineered networks," IETF draft, 2016.

[8] A. Asensio *et al*., "Dynamic customer virtual network reconfiguration with QoS constraints and bandwidth guarantees", in *Proc. European Conference on Optical Communication (ECOC)*, 2015.