Access-aware Backhaul Optimization in 5G

Rakibul Islam Rony
Universitat Politècnica de Catalunya
Barcelona, Spain
rakibul.islam.rony@upc.edu

Elena Lopez-Aguilera
Universitat Politècnica de Catalunya
Barcelona, Spain
elopez@entel.upc.edu

Eduard Garcia-Villegas
Universitat Politècnica de Catalunya
Barcelona, Spain
eduardg@entel.upc.edu

ABSTRACT

Aggressive demand of future access network services is being translated into the stringent requirement on future backhaul infrastructure. It is not possible to take the backhaul resources for granted anymore; rather, more focused research is required to tackle the challenge of limited resources. It is also anticipated that, to meet the expectation of 5G, access and backhaul networks will work closely and therefore, total separation of their resources may not be possible anymore and joint operation is required. In this paper, we argue that, joint access-backhaul mechanisms is becoming necessary to ensure the best use of the scarce resources. We introduce the problem of statically assigning resources to capacity-limited backhaul links and we provide preliminary results to show the potential benefits of an intelligent access-aware backhaul capacity optimization scheme, where a central controller optimizes backhaul capacity according to corresponding access network requirements. Simulation results show that, with this approach, we are able to carry more traffic in a network limited by its backhaul capacity.

ACM Reference Format:
Rakibul Islam Rony, Elena Lopez-Aguilera, and Eduard Garcia-Villegas. 2018. Access-aware Backhaul Optimization in 5G. In *16th ACM International Symposium on Mobility Management and Wireless Access (MobiWac'18), October 28-November 2, 2018, Montreal, QC, Canada.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3265863.3265881

1 INTRODUCTION

Capacity demand of mobile networks is exponentially increasing throughout the years with evolution of Radio Access Networks (RAN). With the increased demand of data rich applications (video call, online streaming) and data rich devices (smart phones, tablets, etc.) future wireless communications system will ask for 1000 times capacity and 100 times the data rates of Long Term Evolution (LTE) [1]. To meet the aforementioned expectations, 5G is likely to employ a CRAN approach, which proposes full centralization of functions, employing only Remote Radio Head (RRH) at the edge of the network (i.e. placed very close to the User Equipment (UE)). In CRAN, RRH performs only the Radio Frequency (RF) function and all other RAN functionalities are centralized in Base Band Units (BBU). In this scenario, the links connecting RRH to BBU and intra-connecting

MobiWac'18, October 28-November 2, 2018, Montreal, QC, Canada

ACM ISBN 978-1-4503-5962-7/18/10…$15.00
https://doi.org/10.1145/3265863.3265881

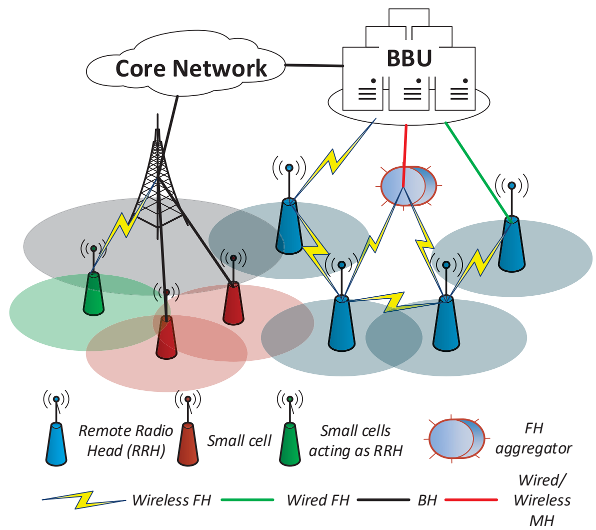

Figure 1: Complex heterogeneous backhaul in 5G networks..

different RRHs are refereed to as fronthaul (FH). Additionally, connecting links between Macro Base Stations (MBS) and the Small cells (SCs) acting as RRH, with some functionalities of the SCs centralized into a co-located processing unit with MBS, can also be considered as FH. The links connecting BBU to the Core Network (CN) is refereed to as Backhaul (BH). Additionally, few nearby FH links can be aggregated to an aggregation point to benefit from multiplexing gain, and the links connecting such FH aggregation point to the CN is referred to as Midhaul (MH). On the other hand, current deployments, such as LTE, are based on the concept of Distributed RAN (DRAN), where Evolved-NodeB (eNB) perform all the RAN functionalities and connect to the CN utilizing BH network. Additionally, the links connecting SCs to the eNBs are also referred to as BH. However, it is anticipated that, in 5G, traditional DRAN, will co-exist along with densely populated low cost SCs (deployed to improve coverage, spectral efficiency and area capacity). Thus, in 5G, the transport network will be heterogeneous (i.e. a combination of wired and wireless technologies), very complex, composed of FH, BH and MH, performing a strenuous job of connecting many different types of Access Points (APs) both among each other and to the subsequent part (e.g. BBU, CN) of the network. Figure 1 depicts this vision of an heterogeneous transport network in 5G. At this point, we would like to note that the term BH is used hereafter to refer to the entire transport network (including fronthaul and midhaul) although, in few cases, they are also used separately when required.

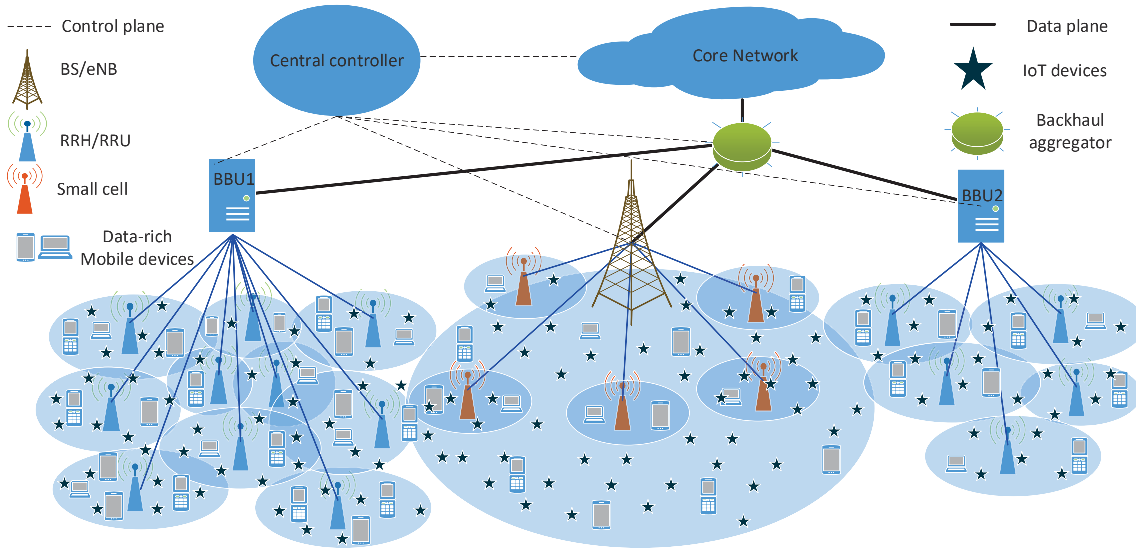

Figure 2: Heterogeneous 5G scenario with 2 BBUs and 1 eNB covering 1km^2 area.

In order to transport the anticipated dense access network traffic, the BH needs to have compatible capacity, which is really challenging, especially when utilizing wireless BH options, as is the case of the architecture envisioned by current 5G projects such as 5G-XHaul [2]. Moreover, with the multiple use cases (e.g. coverage expansion, indoor coverage, SC deployed on lamp posts, roof-top, walls mounted to buildings, etc.) that the 5G APs will serve, a purely wired BH network will be unfeasible. Thus, due to the benefit of cost and faster deployment, capacity-limited wireless options are more alluring solutions in many scenarios. Hence, to ensure the best use of the limited BH resources, it is foreseen that access and BH networks will become dependent on each other, pushing towards their joint design and management. For example, in future ultra-dense networks, considering a scenario where the UE receives service from several APs, a large collection of parameters characterizing both access and BH (i.e. state of access and BH portions of the network) should be considered to ensure the best possible experience, thus encouraging its joint operation. Additionally, in 5G, access and BH may employ similar radio technologies and operate using a common spectrum pool [3]. Hence, solo optimization should be abandoned in favor of joint optimization.

RAN-BH awareness, an approach to perfrom the aforementioned joint optimization, was discussed in [4], where joint routing and scheduling is implemented to select the best path according to access network requirements. Moreover, both cell load and BH capacity are considered for cell selection. Work in [5] is also a fair example of joint optimization, where access network is re-designed according to individual purpose of each AP, and subsequently fed with required BH resources. Reference [6] proposes a novel approach for optimizing the joint deployment of SC and wireless BH links by finding the optimal number of small cells that can be served by the constrained BH link. Other works, such as [7], present BH-aware resource allocation in the access network, while also analysing total BH power consumption. BH-aware cell association was discussed in [8], where both access and BH network power consumption are considered to associate UEs in an energy-efficient way. In [9], authors propose a centralized optimization technique to adjust Cell Range Extension Offset (CREO) to associate BSs in a two-tier cellular network, where SCs are deployed overlaid with macro cells (MC)/BSs. Reference [10] balances the network load through a BH-aware user association technique. Additionally, [11] proposes user centric BH, where CREO is also associated with BH network information such as, latency, capacity and resilience showing results validate the user centric BH proposal.

In the following, we propose a mechanism supported by preliminary results for flexible BH capacity allocation according to access network's current requirements.

2 ACCESS-AWARE BACKHAUL CAPACITY OPTIMIZATION

In current deployments, all BH links are commonly offered equal and highest available capacity, which is agnostic to current access network's requirements making use of all available resources. In such approach, some links may be overprovisioned and, thus, wasting valuable resources while, at the same time, it might create congestion due to insufficient resource allocation in other parts of the network. Moreover, in future dense network, higher user density and mobility will create very unpredictable scenarios, where different APs will serve a varying number of users and, consequently, each processing unit might serve different amount of APs and the users attached to them. Therefore, BH links are expected to carry different amount of data and, thus, require different link capacity, provided in the form of resources, which sometimes are shared with the RAN (e.g. frequency channels, time slots, etc. in

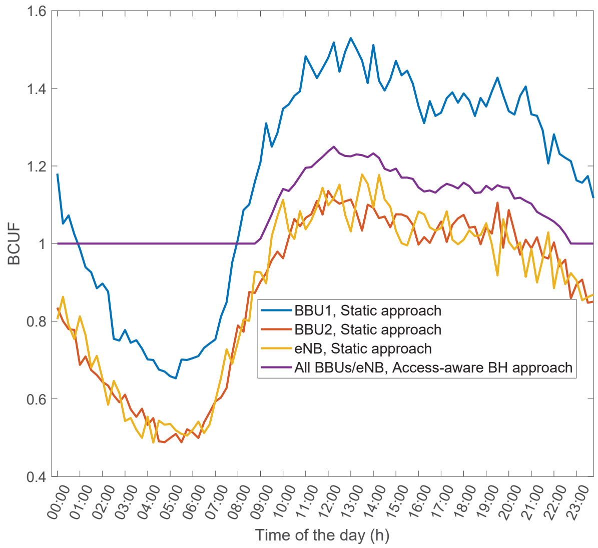

Figure 3: System BCUF during 24 hours with 80% system backhaul capacity.

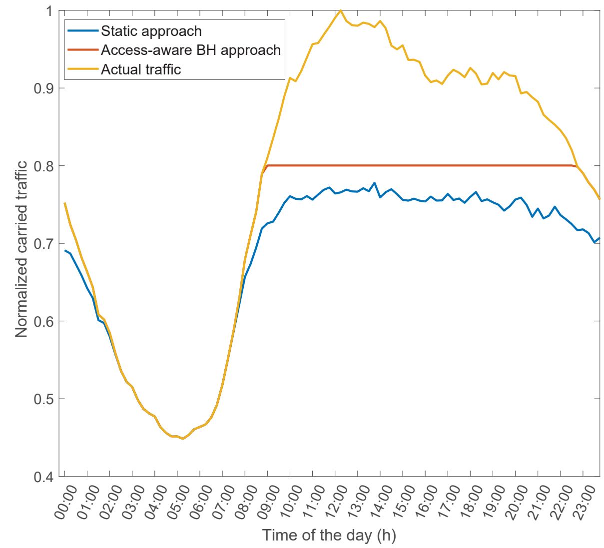

Figure 4: Normalized carried traffic for different approaches during 24 hours with 80% system backhaul capacity.

the case of wireless-based BH). The aforementioned idea of access-BH awareness is validated in the following discussion towards an access-aware BH capacity allocation scheme for different BH links under a common central controller.

In the envisioned system, capacity allocation of different BH links depends on the current requirements of respective served RAN. That is, access level requirements are calculated first, and corresponding BH link capacity is allocated accordingly. Let us consider an urban area of $1km^2$ in what we think represents a realistic future dense network, where eNBs co-exist with CRANs. We assume the scenario illustrated in Figure 2, where three BH links (black solid lines) serve three heterogeneous RAN with different capacity constraints.

For the considered system, in current deployments, total available BH capacity provided is static, being equally distributed among the different links. On the contrary, in our proposed scheme, control plane and data plane are decoupled and all the BBUs/eNBs are connected to the central controller via control plane, whereas data planes are aggregated into a BH aggregator, whereby BH resources are provisioned dynamically according to the varying demands of the different links (Figure 2). The central controller, which is aware of the traffic per RAN is capable of distributing BH capacity accordingly, through the aggregation point. However, when congestion arrives to the BH, i.e. total BH capacity is not sufficient anymore, the available BH capacity is distributed in a proportional fairness basis.

3 SIMULATION RESULTS

According to the International Mobile Telecommunications for 2020 (IMT-2020) [12], in 5G, support for connection density up to 10^6 is expected, and hence, we consider 10^6 active devices within our considered area. Among those devices, we assume[1] 100,000 are

[1] As a reference, Manila has the highest density of population, 41,514 habitants/km^2; each of them having 2.4 devices on average would make 100,000 devices.

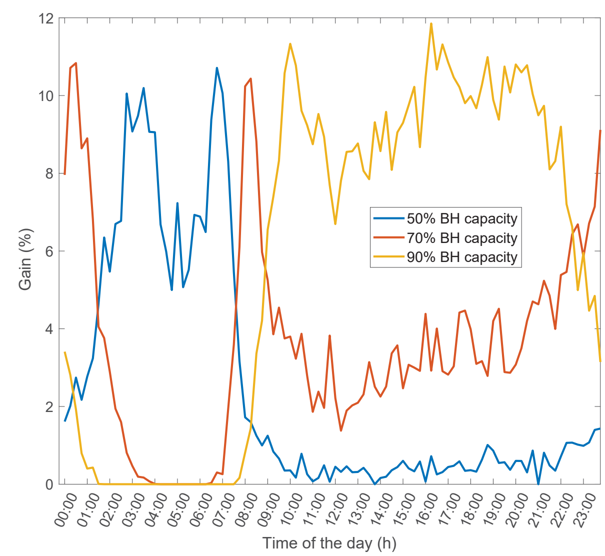

Figure 5: Gain of access-aware BH approach during 24 hours for different backhaul capacity conditions.

data-rich mobile devices expecting data rates between 0 to 10Gbps, whereas other 900,000 are IoT devices expecting data rates between 0 to 250Kbps [13] . We also consider different user density for each BBU/eNB: one BBU (BBU1) covers an area with larger device density (serving 30% to 50% of device population), a second BBU (BBU2) with medium density (20% to 40%) and an eNB serving the rest of the devices. This assumption ensures that corresponding BH links have different requirements. Finally, in order to be consistent in the capacity-limited BH premise discussed in the previous sections, we consider the system has 80% BH capacity available, that is, the system can serve, on average, 80% of maximum possible offered traffic.

Figure 3 depicts the simulation results of the system during 24 hours, in terms of Backhaul Capacity Utilization Factor (BCUF), which is the ratio of **required** versus **provisioned** BH capacity for a particular BH link. Thus, BCUF below 1 denotes that the BH capacity is not fully utilized, i.e. it is overprovisioned, whereas BCUF above 1 denotes BH link is congested, i.e. it would require more capacity. A large number of random simulations were generated using Matlab tool, where the pattern of traffic demands and simultaneously active users follows that of real traces. Said network traces were collected in a current LTE deployment in a European city over a period of two weeks; measured parameters (e.g. number of active UEs) have been scaled up to match the future 5G scenario described previously, following [12]. Results are averaged over a 24h period to ease its visualization. From Figure 3, in a static approach, all the BH links are overprovisioned during off-peak hours (i.e. from 02:00h to 08:15h). After that, BH link corresponding to BBU1 experiences congestion, since it belongs to the RAN with largest user density, while BH links corresponding to BBU2 and eNB reach the congestion point later on (i.e around 09:45h). On the other hand, in the proposed access-aware BH scheme, provided that the load does not exceed the BH capacity, BCUF is 1 for each BH link (overlapping purple line), since BH capacity is distributed according to the current requirements, resulting in an efficient utilization until the congestion point arrives. Note that here we assume that the network controller has a perfect knowledge of the actual load at each AP; in practice, a central controller would act based on predictions obtained from the constant monitoring of the network (e.g. [14]). In this approach, the unused or saved capacity by those links carrying less load can be distributed to other BH or access links by the central controller, if required.

Figure 4 depicts the normalized carried traffic (the ratio between carried traffic and maximum offered traffic) for both approaches. Evidently, access-aware BH approach is able to carry more traffic than the static approach considering the same BH capacity condition, i.e. 80% in this case. While BH capacity is enough during off-peak hour for both the approaches, access-aware BH approach shows better performance in terms of carried traffic during the congestion period, i.e. peak hours.

Figure 5 represents gain of access-aware BH approach over the static approach (in %) during 24 hours for different BH capacity conditions. When BH capacity condition is high (e.g. 70% to 90%), access-aware BH uses the whole available capacity and distributes it intelligently (i.e. according to the current requirement of each link), while the static approach may have links wasting capacity. During off-peak hours both the approaches provide enough capacity to serve the required traffic, and thus, no gain is observed. On the other hand, during the peak hours, gain of access-aware BH approach increases, becoming more significative for higher the BH (i.e. 90%). Conversely, when BH capacity is more restricted (e.g. 50%), the maximum gain is observed during off-peak hours. Both the approaches are out of capacity during peak hours, hence showing similar performance (i.e. 0% gain). Also note that, when BH resources are really scarce, even during off-peak hours, some links may reach the saturation point following the static approach, while access-aware BH approach has the means to overcome this circumstance, thus showing high gain performance. Therefore, access-aware BH approach gets the most when system works close to the saturation point. In case the system is extremely overloaded or really underutilized, both approaches provide similar performance.

We also observed that the benefits of the dynamic access-aware BH approach increased as the traffic supported by the different BH links becomes more unbalanced. Obviously, when the users are evenly distributed over the different areas, a static approach based on equal distribution of resources shows the same performance as the dynamic approach.

4 CONCLUSION

This paper discusses the future RAN architecture and the complexity of BH networks. The presence of a capacity-limited BH seems a realistic assumption, which brings new challenges and requires best usage of scarce resources. Joint access-backhaul optimization validates the dependency between both the networks and facilitates the efficient utilization of resources. Presented preliminary results support the statement, in which access-aware BH optimization technique brings benefits over the static approach in terms of resource efficiency.

ACKNOWLEDGMENTS

This work has been supported by the EU Horizon 2020 research and innovation programme under grants No. 675806 (5GAuRA) and 762057 (5G-PICTURE).

REFERENCES

[1] P. K. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design considerations for a 5g network architecture," *IEEE Communications Magazine*, vol. 52, no. 11, pp. 65–75, Nov 2014.

[2] 5G-XHaul, "System Architecture Definition," *Deliverable D2.2*, no. January, p. 73, 2016. [Online]. Available: https://www.5g-xhaul-project.eu/download/5G-XHaul_D2_2.pdf

[3] Ericsson, "5G Radio Access What is 5G ?" *White Pap.*, no. February, p. 10, 2015. [Online]. Available: http://www.ericsson.com/res/docs/whitepapers/wp-5g.pdf

[4] E. Pateromichelakis, A. Maeder, A. D. Domenico, R. Fritzsche, P. D. Kerret, and J. Bartelt, "Joint RAN / Backhaul Optimization in Centralized 5G," *EuCNC 2015*, pp. 386–390.

[5] C. Ran, S. Wang, and C. Wang, "Balancing backhaul load in heterogeneous cloud radio access networks," *IEEE Wirel. Commun.*, vol. 22, no. 3, pp. 42–48, 2015.

[6] X. Xu, W. Saad, X. Zhang, X. Xu, and S. Zhou, "Joint deployment of small cells and wireless backhaul links in next-generation networks," *IEEE Commun. Lett.*, vol. 19, no. 12, pp. 2250–2253, 2015.

[7] K. M. S. Huq, S. Mumtaz, J. Bachmatiuk, J. Rodriguez, X. Wang, and R. L. Aguiar, "Green hetnet comp: Energy efficiency analysis and optimization," *IEEE TVT*, vol. 64, no. 10, pp. 4670–4683, Oct 2015.

[8] A. Mesodiakaki, F. Adelantado, L. Alonso, and C. Verikoukis, "Energy-efficient context-aware user association for outdoor small cell heterogeneous networks," in *ICC*, June 2014, pp. 1614–1619.

[9] G. Zhang, T. Q. S. Quek, A. Huang, M. Kountouris, and H. Shan, "Backhaul-aware base station association in two-tier heterogeneous cellular networks," in *SPAWC*, June 2015, pp. 390–394.

[10] H. Beyranvand, W. Lim, M. Maier, C. Verikoukis, and J. A. Salehi, "Backhaul-aware user association in fiwi enhanced lte-a heterogeneous networks," *IEEE TWC*, vol. 14, no. 6, pp. 2992–3003, June 2015.

[11] M. Jaber, M. A. Imran, R. Tafazolli, and A. Tukmanov, "A multiple attribute user-centric backhaul provisioning scheme using distributed son," in *IEEE GLOBECOM*. IEEE, 2016, pp. 1–6.

[12] ITU, "IMT Vision âĂŞ Framework and overall objectives of the future development of IMT for 2020 and beyond, M Series, Recommendation ITU-R M.2083-0," vol. 0, p. 21, 2015. [Online]. Available: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

[13] V. Baños-gonzalez, M. S. Afaqui, E. Lopez-aguilera, and E. Garcia-villegas, "IEEE 802.11 ah: a technology to face the IoT challenge," Sensors 2016, 16(11).

[14] J. Pérez-Romero, J. Sánchez-González, O. Sallent, and R. Agustí, "On learning and exploiting time domain traffic patterns in cellular radio access networks," in *Machine Learning and Data Mining in Pattern Recognition*. Springer, 2016, pp. 501–515.