Improving Call Admission Control in 5G for Smart Cities applications

A. Slalmi
M.I.S.C
Ibn Tofail University
Kenitra, Morocco
aslalmi@gmail.com

R. Saadane, H. Chaibi
SIRC-LaGeS
EHTP
Km 7, Ouasis Route El Jadida
Morocco
Saadane@ehtp.ac.ma

H. Kharraz Aroussi
M.I.S.C
Ibn Tofail University
Kenitra, Morocco
kharraz@yahoo.com

ABSTRACT

In this paper, we discuss the Call admission control (CAC) issue in 5G network and the state of the art in this field. Which study will be conducted to suggest and develop an algorithm of admission control modeling in the case of New Radio access namely NR 5G. It will also tackle the issue of handover and more generally mobility management, power control and interference. All this will be done taking into consideration and ensuring acceptable QoS and QoE as well as an energy saving and power efficiency. We focus, in our study, on the development of an algorithm for the improvement of call admission control based essentially on a minimal consumption of energy. In the algorithm we consider one base station (RRH) in ultra dense network environment by considering Heterogeneous network and CRAN systems (H-CRAN).

Keywords

Call admission control (CAC); Power efficiency; Mobility management in 5G; Handover; Smart cities

1. INTRODUCTION

Generations of mobile systems have been running at a new generation per every 10 years (Figure 1). The transitions from 1G to 2G and from 2G to 3G were rather technological breakthroughs (analogue to digital, low-speed voice and data service to high-speed multimedia services). The transition from 3G to 4G was necessary, although 3G has introduced new techniques such as MIMO (Multiple Input Multiple Output) and achieved even greater theoretical data rates and thus reducing the phenomenon of fading (slow and fast) signals due to multipath [1]. The transition to 4G based on LTE (Long Term Evolution) technology has allowed for a significant increase in throughput (exceeding 100 Mbps, under certain circumstances) based on a significant improvement in the architecture and significantly improved voice over IP (VoIP).

ACM ISBN 978-1-4503-6289-4/19/10…$15.00
https://doi.org/10.1145/ 3368756.3369031

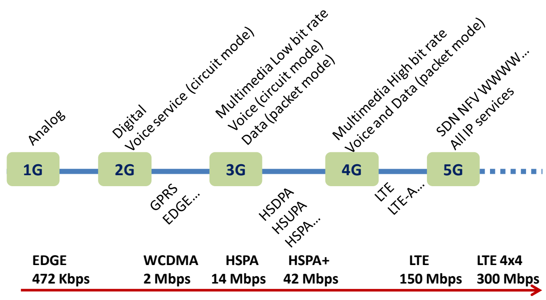

Figure 1. Theoretical peak data rate (3GPP technologies)

Currently, with 5G technology, the concern is not always focused on the only increase of high speed rate, like the generations that preceded it, but especially interested in answering a certain number of constraints and necessities of the number in phenomenal growth of users (ranging from mobile phones to different connected objects) and their needs in terms of reduction of latency, increase of indoor coverage by including small cells as well as outdoor coverage, cost reduction, increase spectral efficiency, bit rates, while guaranteeing a good quality of service (QoS) and a good quality of experience (QoE) and especially with energy saving. This will facilitate the implementation of Smart cities in the best conditions. Indeed, the latter require very important connections, fast, efficient and reliable with considerable energy savings. 5G technology will have to cope with a large number of connected devices, which is expected to reach almost 50 billion by 2020, according to both Cisco and Ericsson, and therefore recognized that bit/Joule energy efficiency is a central design principle of 5G. In the NGMN white paper for 5G [2], energy efficiency is identified as a key performance indicator (KPI) of 5G, and is defined as the number of bits that can be transmitted per Joule of energy, where the energy is computed over the whole network, including potentially legacy cellular technologies, radio access and core networks and data centers. Also, we can cite the connections trend 5G network to electric power network, the type called "smart grid". The interaction between the smart grid, regularly showing the needs and indications of the energy supplier, and the 5G cellular network, a big consumer of energy with a wide range of user-side services, leads to important improvements. The use of renewable energies (in particular wind turbine or solar), clean energy, but presenting in return the new problem of unsecured availability, is another interesting track for 5G. In this paper, we present evolutions of access networks in different generations of mobile networks from 2G to 5G and then different methods used in CAC. Finally, we end by presenting a CAC method based on optimal energy consumption in an ultra-dense architecture such as H-CRAN.

2. CALL ADMISSION CONTROL (CAC) IN MOBILE NETWORKS

2.1 CAC evolution in mobile networks

In this section, we will review the different principles used in different generations of cellular mobile networks in terms of call admission control (CAC). First of all, the main task of the CAC is to decide whether a new call request can be accepted without causing an unacceptable loss of QoS to the users already connected or not. It should be noted that the interruption of a communication in progress (dropping call) is more troublesome than the blocking call from the point of view of the users. Call Admission Control (CAC) is a technique that controls the admittance or otherwise of new or handover calls [3].

Basically, the CAC needs to respond to QoS requests in terms of fresh and new calls, despite the insufficient capacity of the network. In general, there are two categories of CAC systems in cellular mobile networks namely deterministic CAC and stochastic CAC [4]:

1- *Deterministic CAC*: in this system, the QoS parameters are well determined. In general, these schemes require a thorough knowledge of system parameters, such as the mobility of users for instance, which is not always practical, or to sacrifice radio resources to meet the limits of the defined quality of service;

2- *Stochastic CAC*: QoS parameters are guaranteed with some probability. By relaxing quality of service guarantees, these systems may allow greater use than deterministic approaches.

In a second generation mobile network (2G, FDMA / TDMA), frequencies and time slots are managed. For admission control, the network allocates a frequency and a time slot to each new user who requests to connect to the network, within the limit of the radio resources (in terms of time and frequencies).

In a third-generation network (3G, WCDMA), powers are managed because the user equipments use the same frequency and are differentiated by codes. Admission control is very much related to power control. Indeed, the decision on admission must respect the following constraints:

-a mobile whose admission would lead to a network of which the power is impossible to control must be refused. A network is said to be impossible to control in power when there is no distributed power distribution in a way that all quality objectives are achieved. If this mobile was busy, it would then be necessary, to reduce the overall interference, to interrupt a communication, possibly different from that of the new entrant;

-a mobile whose admission would lead to a network which can always be controlled in power should not be refused.

Several admission control algorithms have been proposed for CDMA networks. They are divided into three groups: those based on the level of interference, those based on the estimate of the maximum number of simultaneous communications and finally those based on the forecast of the possibility of carrying out the admission control after possible admission of the newcomer users. For a mobile who wishes to initiate a call, a power control must be defined for the period of time during which the call is being set up, in addition to that occurring during the call when a new request is presented, the system calculates the overall load of the affected cell and compares this load with the maximum permitted load or, depending on the configuration, calculates the overall noise rise and compares it with the allowed noise rise value at the cell. If exceeded, there will be refusal of the admission of this new request by the system.

As part of the admission control, the data rate must be selected. In the case where the network cannot provide the desired data rate, a lower rate will be selected. It may be necessary to verify that this imposed bit rate is not lower than the minimum bit rate of the mobile or the service concerned. A lower rate allows a lower target SINR.

4G LTE user can demand and run simultaneously different services, such as web browsing, real-time gaming, and streaming video. Each service has its different quality requirement. Therefore, a number of media are associated with differentiated quality specifications in the LTE core network (EPS). For 4G LTE technology, the main criteria is that the total number of Physical Resource Block (PRB) per transmit time interval (TTI) required by the new user (or also handover user) and the active users in the eNodeB must not exceed the number of PRBs in the system.

Two attributes of bearers have been defined so that the network differentiates them and applies the quality of service: QCI (QoS Class Identifier) and ARP (Allocation and Retention Priority). At the radio access network level, the bearers are associated with QCI and ARP. QCI is an indicator of the state of the channel measured by the EU in downlink. It is determined by the UE and returned to eNodeB to allow planning for the downlink. The QCI defines how a medium (and its associated services) are processed in the base station. The ARP is used for CAC decision in the face of constrained network resources. ARP is only used during admission control and does not influence the processing of data once the bearer is established. The scheduling or flow control mechanisms implemented in eNodeB doesn't include this parameter. Finally, ARP is an internal parameter of the operator's network and is not communicated to UE.

The International Telecommunications Union (ITU) identifies three main categories of uses for 5G technologies [5], as shown in Figure 2:

- mMTC (massive Machine Type Communications): communications between a large number of objects (devices) with various quality of service needs. The goal of this category is to respond to the exponential increase in the density of connected objects. Connected objects such as portable objects, heart monitors, devices connected to the smart home and the smart city, as well as communications between cars and infrastructure. The density of connected objects will grow exponentially; 5G will allow these objects to communicate without a saturated network;

- eMBB (Enhanced Mobile Broadband): ultra-high speed connection both in outdoor and indoor with uniform quality of service, even at the edge of the cell. The fact that the network offers a higher throughput of greater capacity will allow the flows to be larger. We obviously think of the Ultra HD video format. Features related to virtual and augmented realities, as well as those related to live video (video calls) will benefit from these technological advances;

- uRLLC (Ultra-reliable and Low Latency Communications): ultra-reliable communications for critical needs with very low latency, for increased responsiveness. Many uses will be made possible thanks to the reliability and responsiveness of the 5G network, such as autonomous cars, which must react quickly, in real time, to the situations encountered. Medicine (e-health) and industry (professional applications of connected devices) will also be impacted.

It goes without saying that considering each service type separately and building a 5G network accordingly, we would likely end up with very different radio access network (RAN) designs and architectures [6].

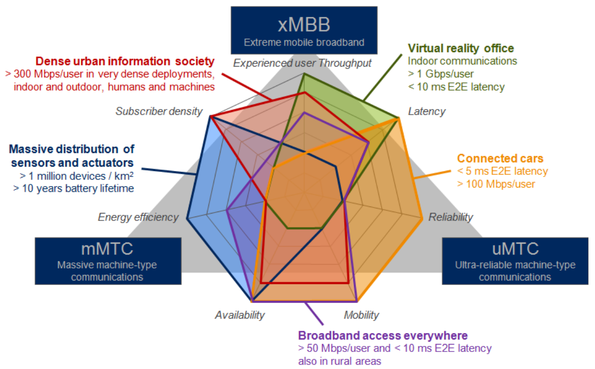

Figure 2. New services supported by 5G technology

2.2 A new RRC state is introduced in 5G

Radio Resource Control (RRC) states are a solution for system access, energy saving and mobility optimization. 5G technology must support eMBB, uRLLC and mMTC services with the same cost and energy dissipation per day and per zone.

The access to the 5G system and the services requested have different characteristics compared to previous generation for mobile technologies. Connectivity control in 5G for future services needs to be flexible and programmable. To meet the characteristics of these new services, a new RRC service state must be introduced for the following main reasons:

- To support uRLLC services those transmit small packets requiring very low latency with high reliability;

- Massive IoT devices rarely wake up in power saving mode to transmit and receive a small payload;

- The equipment must be placed in a low-activity state and sporadically transmit uplink data and status reports with a small payload on the network;

- Equipment needs periodic and sporadic downlink packet transmission;

- When the user equipment (UE) is in the RRC connected state and sporadically transmits uplink data and status reports with a small payload to the network;

- Smartphones and consumer devices with embedded electronic equipment (eMBB UE) issue periodically and sporadically small uplink and downlink packets and high data rates.

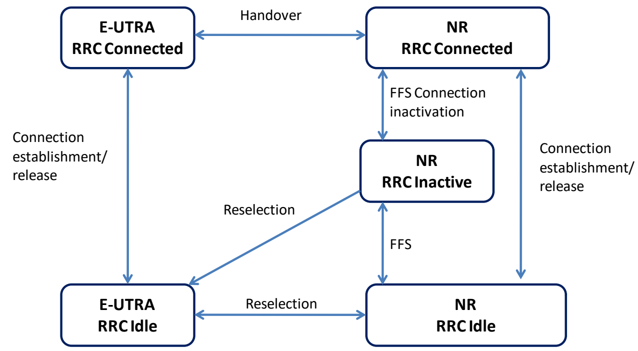

Figure 3. RRC states transition in 5G NR

As shown in Figure 3, NR 5G technology is supposed to interact with previous technologies such as LTE (E-UTRA), UMTS (UTRA) and GSM / GPRS (GERAN). New-Radio (NR) introduced a new RRC condition called "RRC Inactive" to meet the 5G service requirement.

3. POWER CONSUMED IN THE MACROCELL IN A UDN

Energy consumption of a wireless network is dominated by the Base Stations (BS), which currently consume around 80% of the total power [7]. A sleep model for future 5G base stations has been proposed in [8]. Every day, we encounter an increasing demand for wireless data use due to a growing number of broadband-capable devices, such as 3G and 4G mobile telephones. To satisfy a higher demand for data rates, service providers and mobile operators expect upgrades and expansion of the existing network, but the required capital expenditure (CAPEX) and operational expenditure (OPEX) are superior to the revenue growth. The high upgrade and maintenance costs are mainly caused by the current architecture of mobile broadband networks, in which the radio access network is built upon the included base station architecture [9]. Only about 15-20% of base stations operating in the current RAN architecture are loaded more than 50% (with respect to the maximum capacity), which makes the current RAN architecture energy inefficient [10].

As part of the virtualization of the 5G network, in particular that of the access network NR 5G, the Cloud Radio Access Network (CRAN) technology has been introduced. This technology, promoted by China Mobile initially is today recognized by several other operators and equipment manufacturers. Introducing a CRAN has the potential for several new advantages, in terms of high-speed connectivity to network-deployed small cells, as well as a means for mitigating interference. However, there are still several challenges to overcome in terms of interference management, fronthaul design, and mobility [11]. The first benefits with the implementation of CRAN are improved energy efficiency and cost reduction. The starting point of the CRAN is the separation (before the CRAN but pushed to the extreme) of the base station between BBU (Base Band Unit), a basic unit regrouping all the "intelligence" and RRH (Remote Radio Head), simple transmitting / receiving antenna, mainly transposing into frequencies. A first advantage of this separation is the possibility of grouping the BBUs in one place, the BBU pool or "BBU hotels", and / or owning unmarked calculation machines. In the case of a HetNet (heterogeneous network) and dense networks (UDN), H-CRAN technology has been introduced which combines CRAN with these high density networks [12].

In this paper, we consider in ultra dense network (UDN), a macrocell (MRRH) and (M-1) small cells (RRHk) (such as $0 \le k \le M-1$) as shown in the Figure 4.

The consumed power, P_{BS}, by a base station BS (macro or small cell) is given by the following formula (1):

$$P_{BS} = N_{TX}.N_{Sect}.N_C.(P_0 + P_{TX} + P_{fL} + P_{PA}).(1 - G_{DTX}) \quad (1)$$

Where

P_{BS}: Power consumed by a BS (MRRH or RRH_k)

N_{TX}: : Number of transceivers (antennas employed)

N_{Sect} : Number of sectors

N_C : Number of carriers

P_0 : Static power consumption caused by the cooling and signal process

P_{TX} : Transmission power consumption

P_{fL} , P_{PA}:Power consumption dependent on the transmitted power, due to feeder losses and the power amplifiers respectively

G_{TDX} : Gain due to discontinuous transmission (DTX) mechanism.

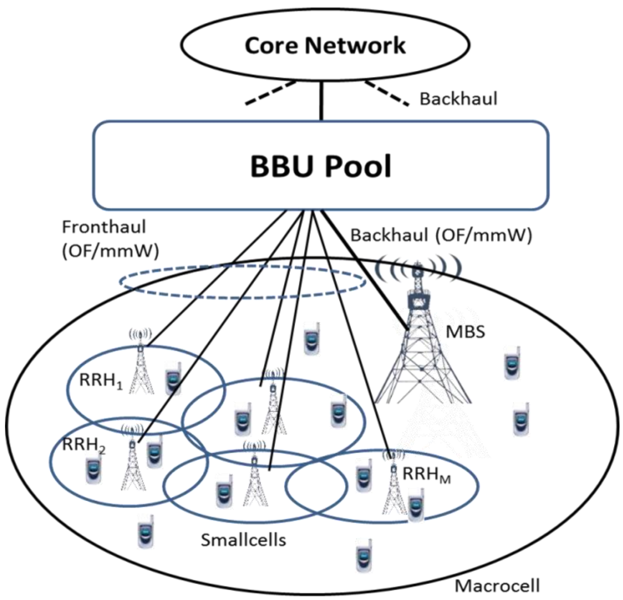

Figure 4: Macrocell in H-CRAN 5G environment

The mode DTX (Discontinuous Transmission) is used in order to reduce the energy consumption of a base station by switching into sleep mode during small periods in each frame. In this matter, the BS transmits only when there is a need, and otherwise put the transmitter in a low power state. If applied we can obtain a gain due to this mode, noted G_{DTX} in (1).

On the physical and medium access layers, the transmission related energy is consumed for RF transceiver chains including power amplifiers, low noise amplifiers, coding and decoding algorithms and signal processing, as well as channel coding and decoding [13].

We denote by:

$$\gamma_1 = P_0 + P_{TX} + P_{fL} + P_{PA} \text{ with } 0 \le P_{TX} < P_{\max} \text{ for active mode} \quad (2)$$

$$\gamma_2 = P_{SM} \text{ ,for sleep mode (SM)} \quad (3)$$

$$\gamma_3 = \mu P_{SM} \text{ , for deep-sleep mode} \quad (4)$$

$$\text{and } \lambda = N_{TX}.N_{Sect}.N_C.(1 - G_{DTX}) \quad (5)$$

Where

P_{max}: The maximal transmission Power consumed by a BS (MRRH or RRH_k)

P_{SM}: Power consumed by a BS (MRRH or RRH_k) in sleep mode

μ : Part of P_{SM}, with $0 < \mu < 1$

Hence, the total power consumed by each BS (MRRH or RRH_k) is :

$$P_T^{BS} = \alpha_1 \lambda \gamma_1 + \alpha_2 \gamma_2 + \alpha_3 \gamma_3 \text{ with } \sum_{i+1}^{3} \alpha_i = 1 \quad (6)$$

Where,

P_T^{BS} denotes the total power consumed by a BS (MRRH or RRH_k)

$\alpha_1, \alpha_2, \alpha_3$: binary numbers that take the value 1, respectively if the BS is in active mode, or sleep mode or deep-sleep mode (advanced sleep mode), otherwise they take the value 0.

Hence, if we denote P_T^{MRRH}, the total power consumed by the MRRH in the macrocell, and $P_T^{RRH_k}$, the total power consumed by each RRH_k in small cell, we can deduce the total power, P_T, consumed by the macrocell :

$$P_T = P_T^{MRRH} + \sum_{K=1}^{M-1} P_T^{RRH_k} \quad (7)$$

4. CALL ADMISSION CONTROL WITH LOWER ENERGY CONSUMPTION IN 5G

In this section, we study call admission control (CAC) at the level of a RRH belonging to a macrocell in an H-CRAN environment.

We consider a RRH serving K user equipments UE. Each UE has a different service and a different bit rate with an acceptable QoS. In this section, we propose an algorithm for handling new demand while taking into consideration energy consumption constraints as a prime requirement for this new user. We denote, in the following, $P_{\max}^{RRH}$ the total maximal power in the cell and P_T^{RRH} the total power consumed by serving the K users.

If a new request for a (K+1)th user occurs, the cell resource management system calculates the possibility of admitting it in the cell according to the rate of the service $D_{K+1}$and the requested QoS. The system must therefore be able to deduce the additional power that must be consumed P_{K+1}, if the cell accepts to introduce this new user. If this additional power added to the total power does not exceed the total power of the RRH, then this new user is admitted, otherwise he is refused.

For this, we are interested in the radio part between the RRH and the user equipment. It is necessary to estimate the minimum power that a RRH must bear to allow the guaranteed bit rate to users.

By using the Shannon's formula, we calculate the bit rate, D_i, required by a UE_i (0<i<K+1) in the cell, as the following:

$$D_i = B_i . \log_2 (1 + SINR_{ij}) \tag{8}$$

Where,

D_i: Bit Rate required by a UE_i

B_i : Bandwidth of a UE_i

$SINR_{ij}$ denotes the Signal to Interference plus Noise Radio between transmitter i and receiver j.

$SINR_{ij}$ can be obtained as [14]:

$$SINR_{ij} = \frac{\frac{P_{TX}}{PL_{ij}}}{\sum_{k \neq i} \frac{P_{TX}}{PL_{kj}} G_{kj} + B_i . N_0} \tag{9}$$

Where,

k : Each interfering link

P_{TX} : Transmitted power

PL_{ij}: Path Loss between the receiver UE and the BS

G_{ij} : Beamforming gain

B_i : Total Bandwidth for UE_i

N_0 : Thermal noise

We have,

$$SINR_{ij} = \frac{\frac{P_{TX}}{PL_{ij}}}{I + B_i N_0}$$

Where

$I = \sum_{k \neq i} \frac{P_{TX}}{PL_{kj}} G_{kj}$ is the total interference caused by other UEs in the cell.

Then,

$$\frac{D_i}{B_i} = \log_2 (1 + SINR_{ij})$$

$$1 + SINR_{ij} = 2^{\frac{D_i}{B_i}}$$

$$SINR_{ij} = 2^{\frac{D_i}{B_i}} - 1 = \frac{\frac{P_{TX}}{PL_{ij}}}{I + B_i N_0}$$

Hence, we deduce the value of P_{TX} as the following:

$$P_{TX} = (2^{\frac{D_i}{B_i}} - 1).(I + B_i N_0).PL_{ij} \tag{10}$$

We can therefore conclude that to serve a UE who requires a minimum bit rate $(D_i)_{min}$, with the required QoS, the cell must consume a minimum transmission power $(P_{TX})_{min}$, with :

$$(P_{TX})_{\min} = (2^{\frac{(D_i)_{\min}}{B_i}} - 1).(I + B_i N_0).PL_{ij} \tag{11}$$

PL_{ij} is determined according mainly to the propagation model considered and used frequency in the cell.

So, the total power consumed, in case of the new use is accepted, will be:

$$(P_T^{BS})_{new} = P_T^{BS} + (P_{TX})_{\min} \tag{12}$$

This new UE will be only if $(P_T^{BS})_{new}$ does not exceed the maximum power consumed by the relevant BS. Otherwise, this new user will be denied access to the cell.

For instance, the maximum power of a MRRH is 20 W and for a small cell RRH 200 mW. These values depend on the type of BS deployed in the cell. It can be considered that almost 50% of the energy is consumed by the computation power at 5G small cell base stations. This computation power of 5G small base station (RRH) can reach 800 W when a massive MIMO (eg 128 antennas) is deployed to transmit high volume traffic [15].

5. ALGORITHM OF CALL ADMISSION CONTROL WITH LOWER ENERGY CONSUMPTION IN 5G

Algorithm: Admission Algorithm of new call

INITIALIZATION:

$(D_i)_{min}$, B_i #minimum bit rate required and the bandwidth of a new UE_i#

P_T^{BS} #Current total power consumed in the cell#

$(P_T^{BS})_{\max}$ #BS Maximum Power#

K #Current number of UEs served by the BS#

PL_{kj}# PathLoss between k (UE_k) and j (BS)#

BEGIN:

#Calculus of Total interference caused by other UEs in the cell#

$I := 0;$

FOR $k := 1$ **TO** $(K+1)$ EXCEPT I **DO**

$I := I + P_{TX} / PL_{kj}$

END FOR

#Calculus of minimum transmission Power in the cell#

$$(P_{TX})_{\min} := (2^{\frac{(D_i)_{\min}}{B_i}} - 1) * (I + B_i * N_0) * PL_{ij}$$

#Calculus of total power consumed by BS if a new UE is admitted#

$$(P_T^{BS})_{new} := P_T^{BS} + (P_{TX})_{\min}$$

#Decision of Admission#

IF $(P_T^{BS})_{new} < (P_T^{BS})_{\max}$ **THEN** **“** New UE Accepted”

ELSE “New UE Not Accepted”

END IF

END

We denote here that, due to the lack of real data concerning parameters required for this algorithm (e.g. power consumption of different equipments of BS) and given the different propagation models that can be used to calculate each path loss, which depends on different frequency bands that are used in 5G mobile networks (frequency bands will be determined in World Radiocommunication Conference 2019 (WRC-19), which will be held in Geneva from 28 October to 22 November 2019), a suitable simulation will be carried out in a further paper, once these data are available [16].

6. CONCLUSION

A cost-effective radio access network solution that responds to the growing volumes of mobile data traffic meets a set of requirements. First of all, the new CRAN radio access network must adapt quickly and automatically to the variable amount of mobile traffic. In addition, it needs to consume less energy while offering more capacity and network coverage. Finally, it should allow mobile network operators (MNOs) to upgrade and exploit the service frequently over multiple radio / heterogeneous interfaces. It should be noted here, that thanks to the new state of service "inactive state" introduced by 5G, much service goes in saving energy, as exploited in this paper. Only about 15-20% of base stations operating in the current RAN architecture are loaded more than 50% (with respect to the maximum capacity), which makes the current RAN architecture energy inefficient.

In an ultra-dense network such as 5G, where the need to connect a phenomenal number of objects and devices, requires the deployment of a large number of cells (RRH) to respond to increasing bit rates, with a QoE reasonable, the energy consumption will also increase dramatically. Therefore, it is necessary to think of suitable methods and processes that minimize this consumption. The purpose of this paper is to show that this energy wastage can be avoided by limiting the access to the network according to the constraints on the total power consumed. This can contribute to consume at least the energy deployed in the mobile access networks and without degrading the QoS.

7. REFERENCES

[1] E. Dahlam, S. Parkval, J.Sköld. 4G LTE-Advanced Pro and The Road to 5G, Third Edition, Elsevier, February 2016

[2] A deliverable by the MGMN Alliance, 2015, https://www.ngmn.org/fileadmin/ngmn/content/images/news/ngmn_news/NGMN_5G_White_Paper_V1_0.pdf

[3] Modibbo Adama et al. Call admission control techniques for 3GPP LTE: A survey, July 2016, DOI: 10.1109/SAI.2016.7556057

[4] Call Admission Control in Mobile Cellular Networks: A comprehensive Survey, Feb. 2006, DOI: 10.1002/wcm.246 https://www.researchgate.net/publication/220098821_Call_admission_control_in_mobile_cellular_networks_A_comprehensive_survey

[5] ITU-T Y.3101. Requirements of the IMT-2020 network, 2018, https://www.itu.int/rec/T-REC-Y.3101-201801-I/en

[6] 5G PPP METIS White Paper on 5G RAN Architecture and Functional Design, March 4th 2016, https://metis-ii.5g-ppp.eu/wp-content/uploads/white_papers/5G-RAN-Architecture-and-Functional-Design.pdf

[7] L. Saker and S. E. Elayoubi.”Sleep mode implementation issues in green base stations,”in IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC, 2010, pp. 1683-1688. DOI: 10.1109/PIMRC.2010.5671926.

[8] B. Debaillie, C. Desset, and F. Louagie, “A flexible and future-proof power model for cellular base stations,” IEEE Vehicular Technology Conference, 2015, DOI: 10.1109/VTCSpring.2015.7145603

[9] C.X. Mavromoustakis, G.Mastorakis, C.Dobre. Advances in Mobile Cloud Computing and Big Data in the 5G Era, Springer, 2017, DOI. 10.1007/978-3-319-45145-9, ISBN 978-3-319-45143-5

[10] C.Perez, X. Swetina. Radio access network virtualization for future mobile carrier network. IEEE Communications Magazine (Volume: 51 , Issue: 7 , July 2013), DOI: 10.1109/MCOM.2013.6553675

[11] Fei Hu. Opportunities in 5G Networks. A Research and Development Perspective, CRC Press, April 2016, ISBN 9781498739542

[12] J. Rodriguez. Fundamentals of 5G mobile networks, Wiley 2015, ISBN: 9781118867525

[13] Fa-long Luo, Charlie, Zhang, Signal Processing for 5G, Algorithms and implementations, Wiley, 2016 ISBN: 9781119116479

[14] Mattia Rebato et al. Understanding Noise and Interference Regimes in 5G Millimeter wave cellular networks, May 2016, European Wireless 2016; 22th European Wireless Conference, https://ieeexplore.ieee.org/document/7499308

[15] M.S. Swetha, G.N. Anil, Raman Shah, Shreejwol Disti, A Survey on Energy Efficiency Techniques in 5G Networks, Vol. 7, Issue 4, April 2019, DOI: 10.15680/IJIRCCE.2019.0704022, http://www.ijircce.com

[16] Report of the CPM on technical, operational and regulatory/procedural matters to be considered by the World Radiocommunication Conference 2019,Radiocommunication Bureau, https://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-CPM-2019-PDF-E.pdf