SooGREEN: Service-oriented optimization of Green mobile networks

Invited paper

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Abstract— Today, mobile networks are witnessing an exponential growth of traffic volumes, linked to new services, especially for smart cities and smart-grid.
The European Celtic-Plus SooGREEN project, started mid 2015, is targeting to reduce the energy consumption of the services in different mobile architectures in interaction with smart-grid.
SooGREEN is focused on the services energy consumption modelling and measurement, the dynamic optimization of the mobile access network and of the content delivery, the design of an Energy Efficient Virtualized and Centralized Radio Access Network (RAN), and the bi-directional interaction of the mobile network with the smart-grid.
This paper presents insight into the project after its first year, and discusses research trends in green communication networks for the future.

Keywords—Services; Radio access network; Virtualisation; Smart-grid; Energy efficiency

I. Introduction

Mobile networks are witnessing an exponential growth of traffic volumes, associated with the emergence of new services. In particular, video services constitute a major part of the traffic and their share is expected to increase. At the same time, Internet of Things (IoT) is gaining importance with the explosion of the number of connected objects. This situation pushes towards an evolution of network architectures (e.g. LTE-A features on centralized/virtual RAN) and of content delivery solutions (e.g. in network caching) [1].

SooGREEN is built around the need of reducing the energy consumption of services in light of the traffic evolutions and exploiting the new network architectures, while looking at potential economical interaction with smart grids services. The main objectives of this project are:

- modeling the energy consumption of services in different mobile network architectures and taking into account the end-to-end path

- definition of KPIs for energy efficiency of services and adequate measurement and reporting methods (for energy efficiency standard evolutions)

- joint dynamic optimization of the mobile access network and the content delivery solutions

- definition of service-specific offload solutions that reduce the energy consumption

- proposal of bidirectional electrical interaction of the mobile network and the smart grid through flexibility of some services and the energy storage capabilities in the network.

While focusing on services, SooGREEN investigates the improvement of the power&cooling facilities in order to improve the overall Energy Efficiency including:

- efficient passive cooling solution for central offices hosting centralized base stations (BS)

- optimized energy storage and power conversion in BS sites of mobile access network, thanks to an innovative Battery Management System (BMS) and a new concept of integrated local H2 production and storage from solar energy with fuel cell generator associated to innovative battery.

SooGREEN is an industry-driven project where practical solutions and demonstrators are privileged, in addition to theoretical and simulation studies [1].

This paper is organized as follows. In section II, we discuss the first assessment of service energy efficiency. In section III it will be discriminated new levers to achieve energy savings. Next in section IV we describe demonstrators and prototypes. Section V shows the clarification of smart-grid and mobile network dependence. Finally, in section VI we describe the high level of dissemination of the project. In the last section we have some conclusions and next steps.

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II. First assessment of service energy efficiency

A. How to assess the energy consumed by a service

The energy consumption of a mobile network can be divided into two components. One is the variable energy consumption component, which varies with the network load, and the other is the fixed energy consumption component, which is constant over short periods of time, but varies with network load over longer time periods.

The innovation consists on sharing these two components among the services. The variable energy consumption of the network is shared among the service categories proportionally to their traffic proportions since this energy component varies with traffic load. The new proposition concerns the fixed component, where we consider the cooperative game theory concept. Shapley value is used to elaborate a fair sharing model representing the best compromise for all the service categories.

We apply our modeling to realistic current scenarios with a comparison to old legacy networks and future networks corresponding to new usages and increased part of data and OTT services. Up to our knowledge, this is the first theoretical assessment of the energy consumption of all the services delivered by a mobile network.

Figure 1 shows the results of our model on a yearly real dataset extracted from an operational network in Europe. Results show that our model is an optimal compromise. It is fairer both towards small services in that it reduces their shares in comparison to the uniform approach and towards larger services as it reduces their shares in comparison with the proportional one. The mathematical proof and more results are available in [2, 3].

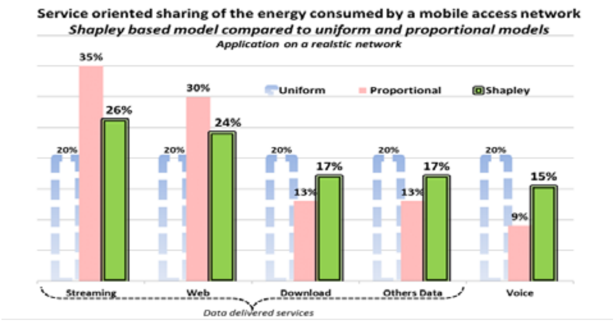

Fig. 1. Service energy consumption

B. New KPI: service energy efficiency KPI

Several energy efficiency KPIs have been proposed in literature. ETSI has created standards to measure power consumption and efficiency of BS [4] and mobile networks [5].

As more and more services are available on the mobile network and are often used for free, the assessment of the energy efficiency per service at the network level becomes crucial. We hence propose to extend a network KPI defined by ETSI in [ES 203 228] given in (bits/J) to introduce a new metric able to measure the energy efficiency of a service given in (bit/J per service) dividing the traffic corresponding to a service by its estimated consumed energy. To do that, we should make use of the traffic monitoring tools, the energy consumed at the network level measured thanks smart metering and of our modeling proposal detailed in [2, 3] to share it among the delivered services. Preliminary results are given in [6].

III. New levers to achieve energy savings

A. Offload of data among cellular networks

As around 90% of the total energy consumed by mobile network operators (MNOs) is wasted in order to ensure coverage [7], three to six MNOs covering the same geographical area results in enormous energy waste. We propose a double auction based dynamic energy saving market where MNOs participate willingly if they see profit and without revealing private information. The clearinghouse makes the offloading decisions that minimize overall energy consumption. We propose two modes of energy saving market, i.e., a) total offloading with spectrum aggregation b) total or partial offloading without sharing spectrum.

Total offloading with spectrum aggregation

In this market mechanism, each MNO submits both bids and asks to an independent auctioneer simultaneously. The bid is the offer to offload its total traffic to other MNO(s) along with releasing its own spectrum to be used by the latter. Similarly, the asks are the offer by an MNO to accept excess load along with the spectrum. The auctioneer matches the bids and asks, determines the trading price, and make the offloading decisions that minimize total energy consumptions. We show that the saving potential is around 50%, 66.7%, 75% if 2, 3 or 4 MNOs participate. Additionally, this mechanism improves QoS significantly at any load [8].

Total or partial offloading without spectrum aggregation

In this market mechanism, each operator uses its own spectrum. At very low load, one or two MNO will carry the total traffic of all MNOs. At very high load, all cells of all MNOs are on. However, cell edge users are offloaded to the other MNOs which have a cell closer to that user or under loaded than the current serving cell.

In this market an MNO offers bid for each user equal to the energy it can save by offloading that user. On the other hand, accepting the MNO offer corresponds to an ask which is equal to the excess energy the receiving MNO requires to serve that user. In our setting, one of the MNO is always kept ON so that there is no coverage issue and no cell serves a user outside its coverage area. Under these assumptions, the significant energy saving comes from the total offloading of MNOs at low to medium load. On the other hand, at very high load, significant energy saving comes from the users being re-assigned to the closest BS of any MNO because of the market mechanism [9].

Even though the customers of one MNO can already roam seamlessly in the other MNOs network [10], several other technical challenges need to be addressed to reap the benefit of this multi-MNO energy saving scheme, e.g., hiding the identity of the users, hardware and backhauling capacity constraints. However BSs are already capable of resource sharing , software defined radio (SDR) techniques, and equipped with broadband RF and BB analog components [11] [12].

B. *D2D greens the network*

We propose exploiting direct communication between mobile devices, D2D communication, as a solution to greener 5G mobile networks. This technique is able to compensate for coverage loss maintaining high levels of quality of service (QoS) and respecting energy consumption requirements. D2D communication is based on the direct communication between nearby devices bypassing traditional cellular network. We switch off BS to save energy and we compensate the coverage holes created by sleeping BS using D2D communication. We do not take a preconfigured spectrum dedicated to D2D but we consider neighboring active BS allocating resources from their own uplink pools according to user requests, as advocated in 3GPP [13].

Partial and Deep Sleep Mode

We consider a multi-layer cellular network where each macro cell is structured in two layers, each with a given frequency and bandwidth. In particular, the following LTE configuration is considered: 20 MHz band and 2600 MHz carrier in cell center and 800 MHz band with 10 MHz carrier in cell edge. We consider two sleep mode mechanisms: a) Partial sleep mode (PSM): frequency carrier 800 MHz in cell edge is turned off and cell edge users are served by D2D communications. Moreover, since 2600 MHz is more energy consuming, we re-assign frequency carrier 800 MHz to serve cell center users; b) Deep sleep mode (DSM): BS is completely turned off and all users in the sleeping cell are served by D2D communication.

Device Battery Consumption

We consider consumer perspective by taking into account the device battery lifetime. We define how much time we could guarantee D2D activity, and consequently how much time we can keep BS on sleep mode. Table 1 shows how long we could keep BS on partial sleep mode for a given level of thedevice battery. We suppose to split the day time in Night (6 hours), Day (12 hours) and Peak (6 hours) accordingly to daily traffic intensity that generates loads of 0.1, 0.3 and 0.6, respectively. Each table's row represents how long D2D activity could be guaranteed during Night, Day and Peak hours consuming x% of the device battery during the entire day. We observe that using 50% device battery D2D could replace BS activity during the whole day..

Table 1: D2D Time Activity

	Night (6h)	Day (12h)	Peak (6h)
10% Battery	100%	27%	0%
20% Battery	100%	70%	0%
30% Battery	100%	100%	13%
40% Battery	100%	100%	57%
50% Battery	100%	100%	100%

Numerical Results

We consider a network with hexagonal cells, each of them with omni-directional antennas and draw devices, randomly and uniformly, in the target cell and its neighboring cells. The percentage γ of sleeping BS and the strategy (sleep or partial) depends on D2D activity and on D2D loads. Active BS and D2D loads depend on their capacity estimated by evaluating throughputs of cellular and D2D links using technical specifications in ([14],[15]) for the channel model. We underline that when sleep mode techniques are applied active BS are more loaded with respect to the baseline case since they help sleeping cells sharing their spectrum and taking in charge a portion of traffic. We use a combined analytical/simulation approach, in particular a static full buffer system level simulator to derive the capacities of the different links. We then inject these capacities in a queuing theoretical model that takes into account the dynamics of arrivals/departures of call requests. More information on this hybrid evaluation approach can be found in [16], and the simulation parameters in [17]. Moreover, once established the strategies feasible according to D2D activity, energy savings are evaluated using the classical BS power consumption model given by the sum of power consumption at zero load and a term proportional to traffic load. In Figure 2, we plot the daily energy saving when sleep mode strategies are applied to a 49-cells network. The gains are plotted against the constraint on the maximal device battery energy consumption. In particular, we consider different strategies: static PSM (γ=1/7) during Night, Day and Peak hours (dashed-dot line); static DSM (γ=1/7) during Night and PSM (γ=1/7) during Day and Peak hours (continuous line); dynamic DSM (γ=1/7) during Night and PSM (γ=1/7) during Day and Peak hours (dashed line); optimal dynamic DSM (γ=1/4) during Night and PSM (γ=1/7) during Day and Peak hours (dashed-marker line). Dynamic means that the considered strategy is applied alternating the sleeping cells. We observe that sleeping mode strategies and D2D communications enhance energy efficient networks achieving maximum energy saving (~ 10%) using only 20% device battery consumption.

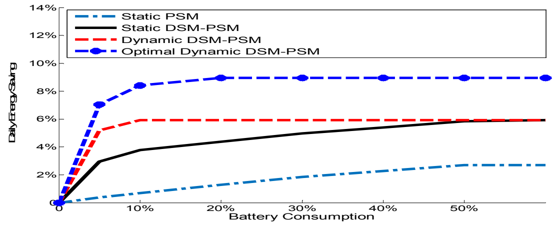

Fig. 2. Daily network energy saving evaluated in a 49-cells network for different sleep mode strategies

C. *Energy saving potential by RF channel shutdown*

In this section, we provide the measurement from a real network that quantify the energy saving potential by BS symbol power saving (SPS), i.e. powering off the PA at empty symbol and RF channel shutdown (RFCS), i.e., forcing SISO to MIMO system when load is low. As both features can deteriorate QoS, there are control mechanisms in place while implementing these features.

Four sites, eNodeB's, all of traditional macro type have been selected for the registrations; see Table 2 for site configuration.

Table 2: The configuration of chosen BSs

eNodeB	Load	Band	Cells
T314428	Low	800, 900, 2600	9
T314799	Low	800, 900, 2600	9
T315326	Medium to high	800, 900	6
T315429	Medium to high	800, 900	6

All the cells have 2x2 MIMO configuration. The bandwidth in 800 and 900 band is 10 MHz and in 2600 band 20 MHz. SPS has been implemented in all the frequency bands while for RFCS has only been implemented in 800 and 2600 MHz bands.

The five week long measurement schedule along with activated feature variants is provided in Table 3. The measurement was carried out between the hours 00:00-06:00 where time granularity for averaging was hourly measurements.

Table 3: Measurement schedule with feature details

Week	Date (Y2016)	Feature
1	18.10 – 24.10	No feature
2	25.10 – 01.11	SPS
3	02.11 – 08.11	SPS + RFCS (setting 1)
4	09.11 – 15.11	SPS + RFCS (setting 2)
5	16.11 – 22.11	SPS + RFCS (setting 3)

The measurements parameters for RFCS at different weeks have been provided in table 4.

Table 4: Measurement setup for RFCS

Parameter name	Setting 1 (week 3)	Setting 2 (week 4)	Setting 3 (Week 5)
Ref. signal power adjust offset (dB)	3	3	3
Downlink PRB threshold	40	20	0
Uplink PRB Threshold (%)	40	20	0
Downlink PRB offset (%)	10	10	0
Uplink PRB offset (%)	10	10	0
RRC connected user threshold	20	10	0

Measurement results

Figure 4 and Figure 5 compare the energy saving properties throughout the five scenarios during the five weeks. The total power consumption has been measured for the two highly loaded eNodeB's as shown in Figure 4. We observe that the power saving is negligible, especially compared to the low load case as shown in Figure 5. Site T315429 shows some deviation in energy saving during test week four and five, however, this is rather related to the reduced load.

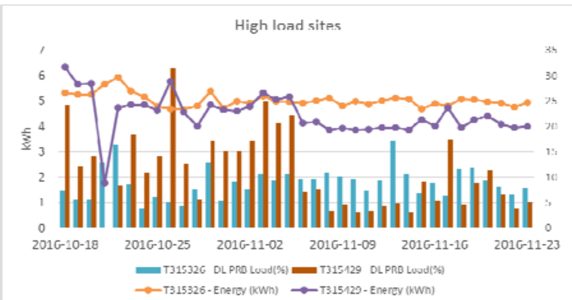

Fig. 4. Energy saving comparison for different setting for high load sites

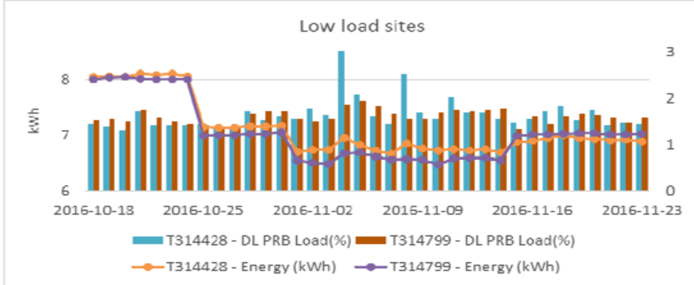

Fig. 5. Energy saving comparison for different setting for low load sites

Figure5 shows significant energy saving starting from test week 2, when only SPS was implemented. The energy saving from SPS is around 10%. When the SPS has been combined with RFCS, the maximum energy saving is around 20%. Note that for low load cases, the energy saving potential is not fully capitalized as the energy saving features do not work for 900 band as the PAs are shared between LTE and GSM radios.

Also notice that the difference in energy saving between test week three (setting 1) and week four (setting 2) is negligible for low load sites. However, settings do not have much impact if the load is high, see Figure 4. Different quality metrics have been scrutinized during the measurements and no visible compromise in QoS has been observed.

IV. Demonstrators and Prototypes

A. First demo on RAN as a service

The mobile traffic is expected to rise at a compound annual growth rate (CAGR) of around 45 % [18].

This growth forces the Telco Operators to invest in elastic network infrastructures as C-RAN that could be built with the new Cloud-native technologies & open-source NFVs. A way to leverage these investments is infrastructure sharing (multitenancy).

The tenants could buy mobile LTE and 5G connectivity on-demand, on a specific location and time with guaranteed QoS. Mobile Cloud Operators will combine open technologies on generic platforms with in-house development.

The RANaaS demonstrator targets to build a cloud-based architecture to provide mobile connectivity on-demand for multiple tenants.

The overall architecture of this demonstrator is illustrated in Figure 6:

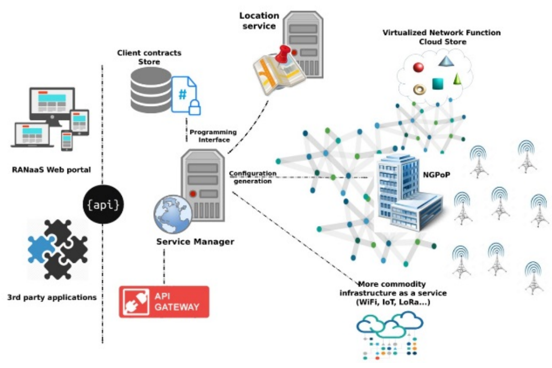

Fig. 6. RANaaS overall architecture

While Multitenancy in IT infrastructure is a common feature (e.g. Openstack), RANaaS could tackle the challenge of sharing a Telco Infrastructure using cloud principles.

We present a real software RAN testbed based on an open-source LTE implementation, Eurecom's Open Air Interface (OAI) [19], using in real-time container-cloud, using Docker's [20] rich ecosystem to manage its lifecycle and run the different features as Service Manager and NFVs.

The prototype is built around a micro-services architecture (REST API, stateless/stateful, atomic and composable, scalable) using open-source technologies. Our on-demand RAN service requires Software-Defined Network (SDN) principles to install a per-client fronthaul-to-backhaul network forwarding plan with guaranteed SLA. Docker's ecosystem is also used here to manage the lifecycle of the controller, statistics database and more SDN-related components.

The RANaaS testbed serves as a proof of concept. Next section presents an evolution integrating real-time energy monitoring.

B. *Energy-Aware Cloud RAN+EPC proof of the concept*

The evolution of mobile networks toward cloud-based architectures is an opportunity to rethink the energy awareness of the system by integrating from the beginning the consumption monitoring, control and optimization. In this section, we present an evolution of the RANaaS prototype demonstrating native integration of real-time energy monitoring.

First, we benchmarked different energy monitoring tools and solutions. We analyzed both commercial power meters and software-based solutions. The latter promise process level granularity, in theory more adapted to our needs, bust resulted difficult to install and use. Thus, we decided to use commercial power meters interfaced with Kwapi [21], a solution enabling to collect, visualize and report their measurement to the virtual infrastructure manager (Openstack [22]).

The monitoring solution has been integrated onto an experimental 4G cloud platform (Figure 7) derived from RANaaS, with RAN and EPC in the form of Virtualized Network Functions (VNFs). The RAN is composed of virtualized BBU, based on OAI [19], and RRHs, based on Ettus Research USRP B210 cards [23]. The virtualized EPC (S/PGW, MME and HLR) has been developed by Nokia. The infrastructure is architected around the three domains defined by [32]: central cloud for EPC, edge cloud BBU and radio access for RRHs (Figure 12). The infrastructure is managed as-a-Service (IaaS) by Openstack: semi-static virtual machines are created, on which the 4G VNFs are dynamically deployed on-demand. The entire deployment phase is extremely fast: the 4G network is operational in about 10s.

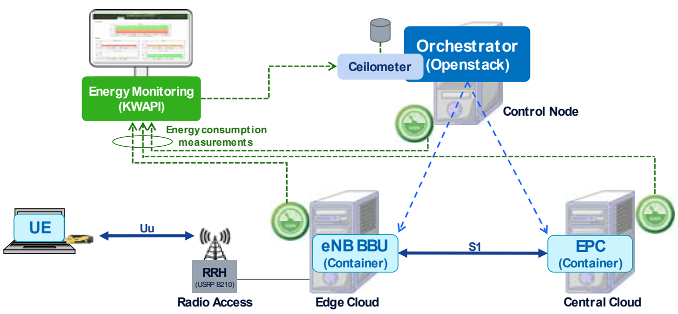

Fig. 7. Energy-aware Cloud-RAN/EPC platform

Energy monitoring is integrated by connecting a power meter to each compute node. Each power meter is managed by a local Kwapi Driver that collects and sends the measurements to the centralized Energy Monitoring unit, in charge of:

- offering a graphical visualization of the real-time energy consumption of each monitored node
- providing to Openstack the energy consumption values of each node

Through the energy-aware platform we could validate our energy monitoring chain in a virtualized Openstack environment. As a practical example, we observed that starting a software eNB on a given node increases its energy consumption from 20% to 80%.

In future, thanks to data analytics, energy monitoring will allow to derive useful insights and correlations between telecom events, IT events and the energy consumption. Moreover, it will allow runtime decisions aiming at optimizing the energy consumption of the system dynamically. All these points merit to be studied in further research work.

V. Clarification of Smart-Grid and Mobile Network Dependence

A. *Technical economic study for developing regions and emerging markets*

With the advent of smart grids, new players are entering the grid value chain. They are active in grid connected renewable energy generation, energy storage, demand-response services and connectivity services [24]. There are synergies between the telecom and energy provisioning worlds. Based on the analysis of the activities in the smart grid and on the real life examples, we developed the position of the MNO (Mobile Network Operator) with regards to the four main activities. We found that the MNO, besides his strong position in the connectivity and IoT (Internet of Things) domain, can play an important role in the distributed energy generation and storage and not only grid connected. Indeed, the MNO can act as consumer of renewable energy (REN), and deploy REN sources on the BS on sites possibly associated to energy storage capabilities,. Moreover , the MNO can act as a VPP (Virtual Power Plant), exploiting his customer database and his communication infrastructure.

In the case where the MNO invests into REN generation, as in the case in the sub-Saharan Africa, then it would be interesting for him to investigate the business opportunity of an enhanced VPP aggregator, assuming the commercialization of its own-generated REN, (selling surplus production) and buying electricity from clients able to produce REN all that depending on predicted needs.

In most African countries, where the electric grid is neither ubiquitous nor reliable in time, MNO have invested in fossil and mostly REN equipment to generate necessary energy for BS towers. People living in the vicinity of the tower installations became interested in getting access to electricity, both in order to charge their mobile phones and for their domestic use. Therefore an ecosystem has been developed around mobile BS installations, where it is not only the mobile communications but essentially the access to electricity that matters.

In this context, electrification can become an asset that can eventually help the business grow. We propose to get inspired from the electric vehicle aggregator model, as described in [25]. This model can be transposed to one where batteries for charging electric cars are replaced by batteries for charging mobile BS. This requires a change of paradigm, where electric production turns from necessity into a key resource. In such an advent, extension to current licenses per country would be required (license to provide telecom services versus providing electricity services).

B. *Energy storage new findings*

In Soogreen project, there are study on the interaction between service delivery in mobile networks and smart grid services such as demands-response, peak shaving, use of renewable energy, etc. These new uses require improved energy storage solutions in term of performance, service life and cost as the common Lead Acid solution (LA) used at more than 95% in Telecom/IT has several limitations. The charge/discharge cycles at hot temperature are reduced. It is not adapted to partial charge state common with intermittent energy. Its low energy density leads to high weight on floors or roof of buildings or on top of radio masts. Another difficulty is to know preventively the battery state of health as lead-acid can suffer from sudden death. And finally, as lead is easy to melt at low temperature and lead-acid batteries easy to reuse, theft can be also an important issue to solve in some countries.

As a consequence, Orange has carried out investigations on other battery technologies able to solve these issues among a vast choice of technologies. It was also critical not to lose the advantages of lead-acid technology such as ease of operation and maintenance, safety. The panorama shown in Figure 8 in general and Figure 9 for Lithium rechargeable batteries are clarifying the positioning of different technologies according to the main criteria enumerated above. This first approach has outlined that the Lithium Iron Phosphate (LiFePO4 or LFP) technology appears today as being a more adapted technology than the other due to intrinsic material stability and safety while keeping a good energy density, within an acceptable operation temperature range, cycling ability and ease to maintain. This is true also for lithium Titanate, but their cost and weight are still much higher. This is not excluding possible interest of new Nickel based batteries as they are easier to manufacture and greener than Lithium having no organic electrolytes inside. This can be the new NiMH (Nickel Metal Hydride) chemistry improved with less rare earths in hydride metal It can be also the new high cycling Nickel-Zinc (NiZn) under SCPS patents that should come in near future with the advantage of no rare earths inside and 1,65 Volt per cell compared to 1,2V for other Nickel batteries. More can be found in [26], [27], [28].

The LFP battery has a somewhat lower energy density than other Lithium technologies used for portable ICT or cars due to a lower cell voltage of 3,2V compared to 3,7 V, but for stationary application, compared to Lead-Acid it brings a significant improvement of factor 3 to 5 in weight and volume. Considering the global system installation, this bring a global advantage in total cost ownership on 5 to 10 years e.g. by reducing cabinet's size and enabling installation on mast.

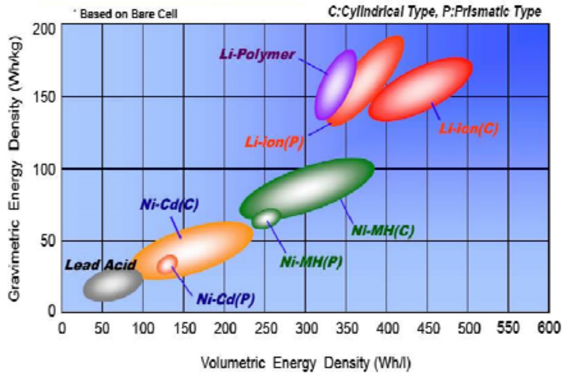

Fig. 6. General view of battery technology in term of energy density (based on DoE approach) – Note : NiZn is similar to NiMH in density)

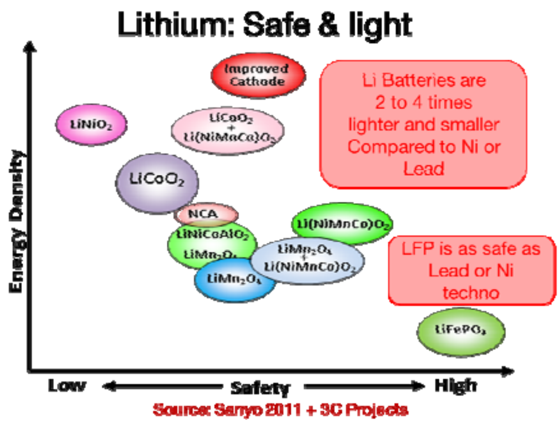

Fig. 7. Lithium technologies pre-selection in energy density and safety

Based on this technological preselection, the real performance of LFP cells and then batteries were tested. Many different suppliers of LFP cells were investigated in the world and among about 80, three have been pre-selected The existing Orange testing system was adapted to test Lithium cells in safe, accurate and reproducible conditions considering site constraints. Safety is obtained by precisely limiting each cell voltage below high charge and above low discharge voltage thresholds.

Major technical lessons were learnt in this research phase

on cell performances and behaviours:

- Deep cycling operation: >1200 deep cycles at 3 h charge/discharge rate at 100% capacity defined by voltage and at medium temperature of 30-35°C (see Figure 10). This is 2 to 5 times more than Lead-acid batteries (LA)
- LFP is not fully mature (e.g. charge parameters changes by vendors during our tests) as seen for other lithium's.
- Ageing curve of LFP cell is linear showing no sudden death which is much better than LA
- Energy efficiency is around 95% at any state of charge i.e. about 10% to 20% more than for LA
- Careful Lithium cell charging procedure is critical for safety but also for life time.
- After long shelves storage period at high temperature an important charge unbalance from cell to cell appear. Lithium cells are not affected in state of health and lifetime by unbalance as they admit partial state of charge at the opposite of LA cells [29].

on batteries made of many cells in series :

- There is a critical need of cell balancing to keep the global battery performance. This is done in general by a device named BMS Battery Management System
- Additional requirement appears when using parallel strings of cells as required in field operation to increase energy storage capacity and reliability.

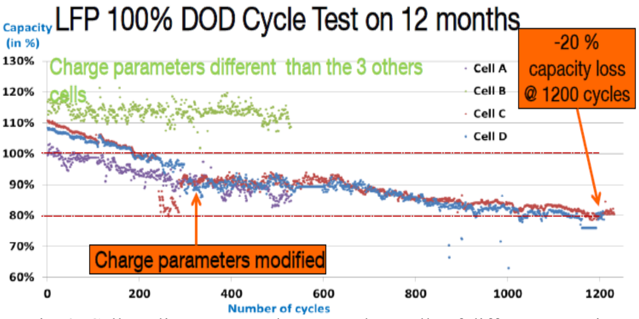

Fig. 8. Cell cycling tests results on vendors cells of different capacity

on BMS

Common low current BMS cannot recover from relatively small charge difference on LFP at the site commissioning after long shelf storage. No high current BMS was available from the identified LFP vendors or from 3rd party vendors. Some papers are pointing the need of some more research to build these efficient BMS at low cost [30], [31].

As a consequence an adapted and accurate battery management system (BMS) integrating innovative points such as high balancing current with minimum heat dissipation and ability to equalize the cell charge in a limited time is required and has specified. The balancing principle is based on active dynamic management of cells in addition to mandatory safety alarms and protections of each cell. A Lab tester was built by Orange Labs and Figure 9 is showing the major balancing effect measured:

- the overall capacity of the battery pack is not limited by the weak cell capacity. The BMS can help to be closer to average capacity.
- the cells voltages are more homogeneous.
- the weak cell is detected enabling a preventive replacement before losing too much battery autonomy and losses of system services
- Two major information, State of Charge level and State of Health value should be issued from the developed prototype in next study phase.

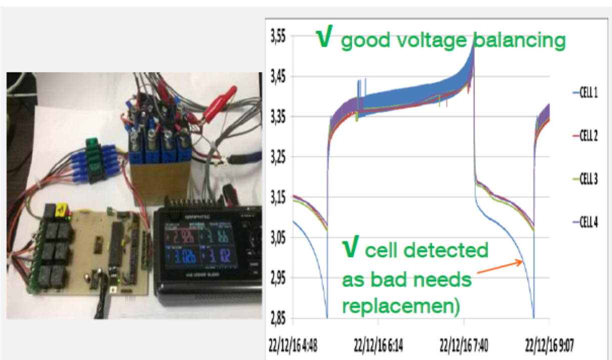

Fig. 9. New Lithium-iron charge balancing strategy under test on a four 8 Ah cells in Orange Labs

VI. High Level of Dissemination

SooGreen provided high level definitions and principles to be used for the assessment of energy efficiency of Cloud RAN networks. These definitions and principles were included as an informative annex into ES203228 [32]. The generic CRAN architecture consists of three parts:

- The Radio Access (RA) domain is consisting of the Remote Access Points (RAP) dedicated to the CRAN
- The Edge Cloud (EDC) domain is consisting of small datacenters dedicated to telecom functions, including Virtualized Network Functions (VNF) Servers (VNFS) used by the CRAN
- The Central Cloud (CC) domain is consisting of a multi-server datacenter (DC) including Central Servers (CS), Switching Equipment (SE) and other Telco Equipment (TE) if needed.

These principles will be further developed to support the new EN 303 471 (Energy efficiency measurement method and KPIs of Network Function Virtualization (NFV) applications in ICT networks).

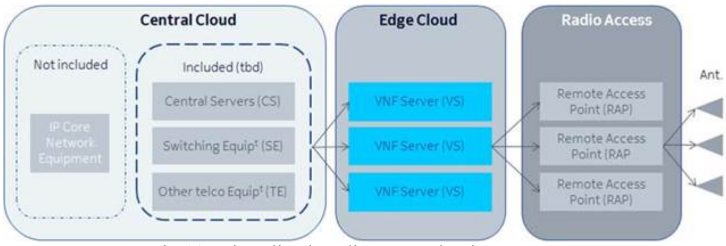

Fig 10: Virtualized Radio Network Diagram

VII. Conclusions

The approaches and initial results of the SooGREEN project have been presented. SooGREEN project tasks are going-on until mid-2018. Modeling and measurement of services energy consumption is extending to end-to-end scenarios. Integration activity is including Wifi Offloading demo on multiple traffic profiles, energy efficient orchestration for RAN, and network self-organized with services and energy balancing. Energy efficient access network is providing E2E mobile networks, in-door distributed antenna system, IoT distributed architecture versus centralized and DVB2 broadcasting. Service delivery in c/vRAN is delivering a vRAN hardware accelerated platform, passive cooling for Central Office, and ASIC design for Polar code. Interaction between service delivery and smart-grid is demonstrated through tech-eco analysis, BMS prototype for high-efficiency batteries with fine balancing current and reduced footprint hydrogen prototype.

The strength of the project lies in the fact that a wide range of important topics is tackled by a single task force. This is enabling a strong impact on green communications via standardization, together with new solutions and products.

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