Green 5G Mobile Networks: A Survey

Sumant Kumar Mohapatra, Sukant Behera, Sushil Kumar Mahapatra, Sujit Khandai
Dept. Of ETC, TAT, Bhubaneswar

***Abstract*— In 2020, mobile access networks will experience significant challenges as compared to the situation of today. Traffic volumes are expected to increase 1000 times, and the number of connected devices will be 10-100 times higher than today in a networked society with unconstrained access to information and sharing of data available anywhere and anytime to anyone and anything. One of the big challenges is to provide this 1000-fold capacity increase to billions of devices in an affordable and sustainable way. Low energy consumption is the key to achieve this. This paper takes as starting point the situation of today, and tries to pinpoint important focus areas and potential solutions when designing an energy efficient 5G mobile network architecture. These include system architecture, where a logical separation of data and control planes is seen as a promising solution; network deployment, where (heterogeneous) ultra dense layouts will have a positive effect; radio transmission, where the introduction of massive antenna configurations is identified as an important enabler; and, finally, backhauling solutions that need to be more energy efficient than today.**

***Index Terms*—5G, green, energy efficiency, mobile network, radio access, system architecture**

I. INTRODUCTION

MOBILE COMMUNICATIONS have experienced a tremendous journey since its introduction in the late 1970s. At that time analog voice calls were the main application, while today we have mobile broadband services capable of providing end user data rates of tens, or even hundreds, megabits per second. Due to the introduction of new devices such as smartphones and tablets and associated applications and use cases, the data traffic volumes in the networks have in principle exploded during the last few years [1]. This trend is expected to continue in the coming years [2]. In addition, future visions such as the Internet-of-Things [3] are more and more becoming a reality. We are moving towards a networked society with unconstrained access to information and sharing of data available anywhere and anytime to anyone and anything.

Hence, a common conclusion is that mobile systems in the future will need to cope with vastly different challenges and expectations than today. Current 3G and 4G technologies such as high speed packet access (HSPA) and long term evolution (LTE) will evolve in that direction, but there are also initiatives starting up focusing on new, 5G, technologies. One example is the EU-funded FP7 project METIS [4], an industry-wide consortium with the target to explore mobile and wireless enablers for the 2020 information society.

One of the big challenges is to meet the future requirements and expectations in an affordable and sustainable way. Low energy consumption is the key to achieve this. Already today, the mobile operator's energy bill is an increasing part of their OPEX (operational expenditure), and with the future requirements and expectations there is a clear risk that this may increase even further if nothing is done. This is also important from a sustainability perspective; even though mobile communications today only contribute to a fraction of a percent of the global CO2 footprint [5], it is important to maintain or even reduce this in the future. Hence, low energy consumption is an important design target for mobile communication systems in the future.

5GrEEn [6] is a joint effort of partners tightly connected to the METIS project representing the telecom vendor perspective, the mobile operator view, and leading academic institutions. 5GrEEn will specifically focus on energy efficiency aspects of 5G mobile networks, and will hence contribute significantly to the important design target of low energy consumption.

This paper takes as starting point the situation of today, and tries to pinpoint important focus areas when designing an energy efficient 5G mobile network architecture. The outline is as follows: After a more in depth discussion on major challenges for mobile networks in the future, the important focus areas and some potential solutions are outlined. Finally, a summary and concluding remarks are provided.

II. MAJOR CHALLENGES

As already touched upon in the introduction above, there are a number of different challenges and requirements that mobile networks need to be able to handle in the future. Some of the most important ones from a green design perspective will be discussed in the following subsections.

A. Data Traffic Volumes

Today, there are over 2 billion mobile broadband subscriptions worldwide, a figure that has grown 40% annually over the last six years, making mobile broadband the most dynamic market in the entire ICT sector [1]. Furthermore, forecasts predict that data traffic volumes will experience an exponential growth in the coming years [2], as illustrated in Fig. 1. For example, it can be seen that the data traffic volumes are expected to increase approximately 10 times between 2012 and 2018. By extrapolation of this, one easily realizes that a several hundred-fold, or even a thousand-fold, increase can be expected somewhere beyond 2020. This is well in line with other forecasts [7][8]. For example, [7] predicts that per-user data rates are expected to grow by a factor of up to 50-100; on the other hand the density of mobile Internet users is expected to increase by a factor of up to 10, implying a factor of 1000x capacity demand in the 2020 time frame.

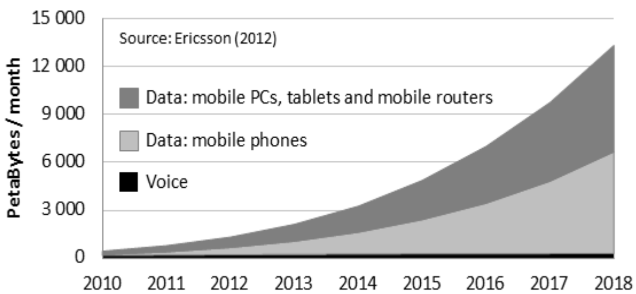

Fig. 1. Evolution of mobile data traffic per month up to 2018

Hence, it is obvious that mobile systems in the future need to be capable of delivering significantly more capacity than today. This trend is important also from a green design perspective, since the mobile network evolution (additional deployment of legacy 2G-3G-4G equipment and installation of new and efficient 5G technology) should be performed by avoiding the risk of an unreasonable over-provisioning of the network that in this scenario will become more and more unsustainable in terms of costs. In fact, up to now mobile networks were dimensioned by taking into account the peak capacity. With this approach, exponential grow rate will imply a costly network deployment. Instead, evolved mobile networks should satisfy the increasing traffic demand by a flexible availability of capacity (in time and space) in order to sustain the data rate development that has been observed during recent decades.

B. *Number of Connected Devices*

Today, there are almost 7 billion mobile subscriptions, and thereby wireless connected devices, worldwide. Most of them are devices used by humans such as mobile phones, laptop computers, or tablets. However, in the future this is predicted to change, as different kinds of machines such as smart grid devices, sensors and surveillance cameras will be connected to the networks. This is usually referred to as Internet-of-things [3] or machine-to-machine (M2M) communication, and means that everything that can benefit from a wireless connection will have a wireless connection. Just by considering the number of devices in a normal home, one realizes that the number of connected devices in the future will be 10-100 times higher than today [9].

This kind of evolution will also introduce new characteristics of the traffic in the networks, e.g. due to the presence of a large number of M2M devices requiring small amount of bits, but requiring a relatively high overhead in terms of signaling. In this sense, the need of an efficient signaling management will be crucial also in terms of offering to the network nodes the possibility to be de-activated during no traffic periods. From this point of view the M2M traffic will introduce additional challenges for a green network design.

C. *Diverse Requirements*

In the evolutionary scenario discussed in the present paper, 5G will include a myriad of applications with a wide range of requirements and characteristics, some of them vastly different than what is the case in mobile systems of today. Some applications may require low latency, for example time-critical control functions in industrial applications. The same type of applications typically also require very high reliability, while others such as simple sensors can have lower reliability requirements. Certain applications such as surveillance cameras may have to convey enormous amounts of data while others have very small data amounts to send.

This challenge need to be taken care of in the system design, as this sets up new and varying quality-of-service (QoS) requirements. This may have a significant impact on the green design, as the minimization of network power consumption should not have impacts on the correct and efficient management of the QoS in the system.

D. *Energy Consumption*

Perhaps the most important challenge is to meet the above mentioned challenges and requirements in an affordable and sustainable way. Cost is an important issue to consider, and will be so also in the future. CAPEX and OPEX need to be at a level where services can be provided at a reasonable end user price and with attractive business cases for the mobile operators.

Already today, the mobile operator’s energy bill is a substantial and increasing part of their OPEX, and with the future requirements and expectations there is a clear risk that this may increase even further if nothing is done. Hence, low energy consumption is very important, and we have above discussed the impact of the other challenges on this.

The energy consumption should at least be kept at the same level as today (despite the traffic growth, the massive amount of devices, and new requirements), but we believe that it is possible to go further than that. The EARTH project showed that it is possible to cut the energy consumption of LTE by a factor of 4 with a 2012 baseline [10], and recently the GreenTouch consortium issued a press release [11] saying that they could cut the energy consumption of current systems by a factor of 10 with a 2010 baseline. 5GrEEn will target a factor of 10 lower energy consumption compared to today, while fulfilling the requirements stated in the previous subsections.

most dynamic market in the entire ICT sector [1].

A. System Architecture

The system architecture constitutes a fundamental limit on how low energy consumption that is possible to achieve. An energy efficient system needs to be efficient both when transmitting data as well as when we are not transmitting data. The system architecture in particular affects the latter, as it (explicitly or implicitly) mandates a certain amount of mandatory idle mode network functionalities. In current cellular systems these by far dominate energy consumption, and hence this is an important area to address. When the network is in idle mode we need to improve e.g. the distribution of access information, paging, and idle mode mobility.

To do this, we will assume a logical separation between idle mode functions (such as transmission of system information) and user plane data transmission and reception, see Fig. 2. Such an architecture was first proposed in the EARTH project [12][13], and will in 5GrEEn be further developed into a more mature state.

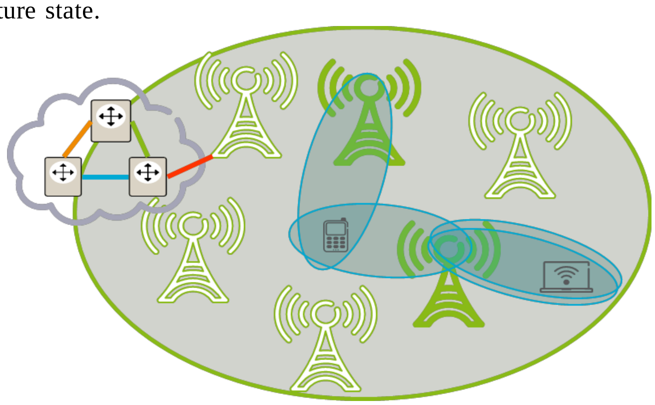

Fig. 2. Logical separation between idle mode and active mode network functionalities enable very efficient use of DTX and DRX in the network nodes as well as very high gain antenna beam-forming to active UEs.

In this architectural design, cells can be viewed as UE specific resources for data transfer that are dynamically created and configured to support only the currently active UEs. The use of dynamic cells very efficiently enables the use of DTX/DRX in the network nodes as well as very high gain antenna beam-forming. In current cellular systems there is a fixed relationship between the "cell", "physical cell identity" and "access point". By a decoupling of the access point and "cell" the "cell" becomes more flexible. For example, the same physical cell identity may be used in several adjacent access points, in other words, the area covered by the cell is the union of the coverage of all the access points that uses the physical cell identity used by this cell. Moreover, an access point may be utilized by more than one cell. Also, a dynamic cell may fully utilize reconfigurable antenna system (using e.g. beam-width and tilt optimization) at the access point(s) in order to shape the coverage in the best way. This makes it easier to allow that the number of access points turned on is dynamically adapted to the traffic condition.

In telecommunication systems we usually talk about the control plane, user plane and management plane. The control

This kind of evolution will also introduce new

the user plane carries the network's users' traffic; the management plane carries the operations and administration traffic required for network management. Broadcast of system information also belongs to the management plane. By separation of the network into these planes we facilitate e.g. independent utilization of access points by the planes, i.e. a given access point may be used by a subset of the planes. For example, we may have an access point which is exclusively used for broadcast of system information. Such separation allows for independent scaling of control/user/management plane entities. Hence independent deployment of the different plane entities can be done at the most energy efficient location.

B. Network Deployment

Energy efficiency improvements through network deployment strategies have been touched upon in several projects for state-of-art technologies [14][15]. Example of these deployment strategies are different topologies of cells, distributed antenna systems and base station cooperation. Especially heterogeneous network deployments, where small cells are deployed under an umbrella macro cellular coverage, have gained great interest and have been presented as a promising solution for improving energy efficiency of LTE [13]. This is due to the fact that if correctly placed the small cells can significantly offload the macro cells with an overall energy saving as result.

In order to handle the future capacity demands and the massive amounts of different devices, it is expected that even denser deployments, so-called ultra dense deployments (see Fig. 3), will be necessary. These deployments are of particular interest in areas where extremely high data rates and capacity are needed, for example in offices, shopping malls, and subway stations. As these typically are located indoor, we can expect this to be beneficial from an energy consumption perspective due to the avoidance of power consuming wall penetration. Despite this rather obvious expectation, an important question from an energy perspective is how to design the ultra-dense network deployments in order to minimize the energy consumption, and at the same time considering the vastly different challenges and expectations of today with a new system architecture. For example, if care is not taken in the design a small cell deployment can even result in increased energy consumption [16]. The new system architecture will relax the constraints established by the state-of-art standards designed without any energy concern and thus provide more degrees of freedom.

The architectural solution with a logical separation between the ability to establish availability of the network (transmission of system information) and the ability to provide functionality or service will have impact on how to design an energy efficient network deployment. This new system architecture will enable network-wide traffic adaptation with DTX and DRX functionality as well as high gain antenna beam forming to active users. The former will change base station power consumption, and the latter will increase the link-level energy efficiency. New energy-optimized network deployment solutions need to consider these new features due to the foreseen changes in node power consumption (different level of sleep modes) and network performance assessment.

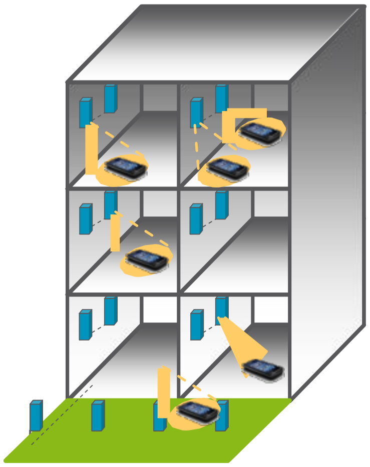

Fig. 3. Ultra dense deployment.

5GrEEn will develop energy-optimized heterogeneous network deployment strategies for different traffic distributions and environments that will provide capacity where it is actually needed and will bring maximum benefit from the additional flexibility created by the new system architecture. The most significant difference in deployment level will arise from the fact that future network dimensioning will not only consider the busy hour traffic and aim to minimize the total power consumption for the worst case scenario -as is currently being applied- but it will take the daily traffic variation into account to minimize the overall energy consumption. New network deployment solutions need to be developed that minimize the energy consumption through long- and short-term sleep opportunities by exploiting the flexibility in the new system architecture. This includes how to distribute the control- management- and user-planes among the access points, as discussed in the system architecture section above.

C. Radio Transmission

As already mentioned in the system architecture section above, an energy efficient system needs to be efficient both when transmitting data as well as when we are not transmitting data. In order to be energy efficient when transmitting data, all we need to do is to "send the packet to the receiver". We should do it quickly and we should try to avoid sending signals in directions that does not reach the receiver.

State-of-the-art mobile communication systems of today are already very efficient in this discipline; they employ adaptive modulation and coding, and also precoded multiple-input multiple-output (MIMO) transmission which allows both multi-layer transmission for increased data rates, and beamforming to certain extent. The result is high spectral efficiency which also is good from an energy efficiency perspective as it means high data rates and more time for potential node sleep.

We believe that the MIMO technology has further potential. Recently, massive antenna configurations, or very large MIMO, have gained increased interest [17]. Proper use of such technology will further boost peak data rates and system capacity, which can benefit energy efficiency in two ways; higher peak data rates means more time for sleep, higher system capacity means that a future traffic demand can be served without a corresponding densification of the network. The large number of antenna elements can also be used for very selective beamformed transmission to a recipient while reducing interference to others, which means that the transmission power in the network is reduced. Such high gain beamforming, in combination with the system architecture solutions mentioned above, can allow increased inter-site distances with maintained system capacity, which of course is beneficial from an energy efficiency point of view.

However, there are some issues that need to be considered. The first is to make sure that the energy consumption of the baseband processing does not explode, and the other is to make sure that data transmission protocols are improved. Today we spend a lot of energy of preparing the channel for optimum transmissions, and here we need to improve.

D. Backhauling Solutions

Despite the relative scarce attention paid to the role of backhaul in optimizing the overall power budget of mobile radio networks, recent studies have highlighted its remarkable impact especially when heterogeneous deployments are considered [18]. The results showed that there is a tradeoff between the power saved by using small and low power base stations and the baseline power that has to be spent to backhaul their traffic. This is mainly due to the fact that the power consumption for the backhaul becomes almost comparable with the small cells consumption itself [18]. Therefore, with a potential evolution towards even more heterogeneous network deployments (i.e., where a massive number of ultra dense nodes will be used to meet the increased need for coverage and capacity envisioned for 2020) the power consumption of backhaul may become one of the bottlenecks for future green wireless access networks. In this regard, there are a series of questions that need to be answered to get a holistic understanding of how to achieve a green backhaul solution.

In 5GrEEn, we will tackle these questions and study various existing and future backhaul technologies. We will consider the advantages/disadvantages of different backhaul technologies, e.g., microwave, fiber, copper, for different deployment scenarios as shown in Fig. 4. For example fiber-based backhaul has higher CAPEX and longer deployment time but offer long-term support with respect to increasing capacity requirements. Microwave is an appealing solution due to its quick and relatively cheap deployment potential. On the other hand, there is still a great interest on copper based solution in order to increase their capacity so that the existing infrastructure can still be exploited at its maximum. Therefore, a "one solution fits all" may not be viable. A good backhaul architecture may not necessarily have to rely on one single technology but it may be the result of a mix of fiber, microwave and copper, depending on several factors, e.g., existing infrastructure, spectrum and licence costs, availability of equipment, operator business modeling, and QoS level to be provided. In this regard, we will assess the power consumption of some hybrid backhauling solutions that can cope with the massive demand in 2020. This will be done for different heterogeneous network layouts considering their limitations with respect to capacity, distance, availability etc. These properties will be used to define which technology is the most suitable candidate at different aggregation levels in the backhaul network, thus enabling us to identify the most energy efficient backhaul solution for different scenarios. With this knowledge it will also be possible to define new and holistic wireless deployment strategies tailored for specific backhaul architectures to avoid the bottleneck in the backhaul power consumption.

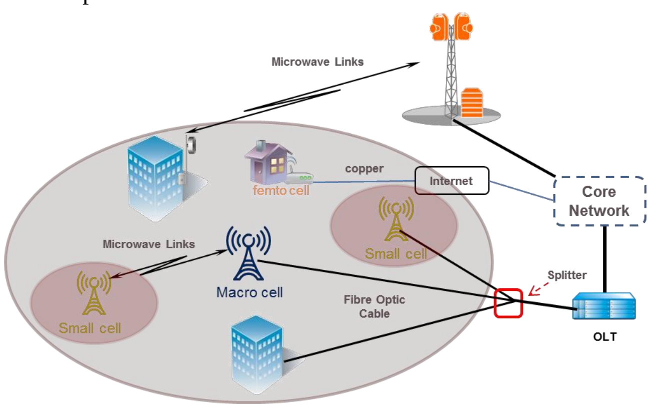

Fig. 4. Illustration of possible backhauling solutions.

IV. CONCLUDING REMARKS

This paper has provided an outlook on green aspects and solutions for 5G mobile network design that will be worked on in the 5GrEEn project.

In 2020, mobile access networks will experience significant challenges as compared to the situation of today. Traffic volumes are expected to increase 1000 times, and the number of connected devices will be 10-100 times higher than today in a networked society with unconstrained access to information and sharing of data available anywhere and anytime to anyone and anything. One of the big challenges is to provide this 1000-fold capacity increase to billions of devices in an affordable and sustainable way. Low energy consumption is the key to achieve this. Important focus areas to achieve this include system architecture, where a logical separation of data and control planes is seen as a promising solution; network deployment, where (heterogeneous) ultra dense layouts will have a positive effect; radio transmission, where the introduction of massive antenna configurations is identified as a promising enabler; and, finally, backhauling solutions that need to be more energy efficient than today.

All these areas are important in order to meet the future challenges and requirements with a green 5G network design. Due to the partners' tight connection to the METIS project, 5GrEEn will influence the work in METIS which will take benefits from the guidelines and recommendations provided by 5GrEEn in their overall design of future mobile technologies.

Furthermore, some of the focus areas and solutions are also relevant and applicable in current mobile network technologies, and when possible 5GrEEn partners will contribute to relevant standard bodies such as the ETSI EE technical committee and 3GPP in order to make sure that all future mobile networks will be as green as possible.

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