Green communications in 5G

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Introduction

- In the next decade, the number of connected devices is expected to increase 100 times and the data volume by 1000 times
- Operators are already facing significant power bills
- Moving towards green communications is important both for **environmental** and **economic** reasons

One of the big challenges is to meet 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)

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 5GrEEn [6] is a joint effort of partners tightly connected to the METIS project representing the telecom vendor Perspective.

This paper takes as a 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.

Network planning and deployment

Intro:
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Challenges

- Data traffic Volumes
- The number of connected devices
- Diverse requirements
- Energy consumption

Challenges: green design perspective will be discussed in the following subsections

Data traffic Volumes

- Today: 2 billion mobile broadband subscriptions
- Exponential growth in the following years
- A factor of 1000x capacity demand in 2020 vs 2012
-

Data traffic volumes: Today, there are over 2 billion mobile broadband subscriptions worldwide, a figure that has grown by 40 percent annually over the last six years.

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 Predictions are made 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 Hence, it is obvious that mobile systems in the future need to be capable of delivering significantly more capacity than today.

In fact, up to now mobile networks were dimensioned by taking into account the peak capacity. With this approach, the exponential growth 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

The number of connected devices

- Today: 7 billion mobile devices
- Future: Smart devices (smart grid, sensors and surveilence camera's)
- Internet of things (IoT)
-

Today, there are almost 7 billion mobile subscriptions, and thereby wireless connected devices, worldwide.
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

Diverse requirements

- Different applications of 5G
- Low latency
- Different data sizes
-

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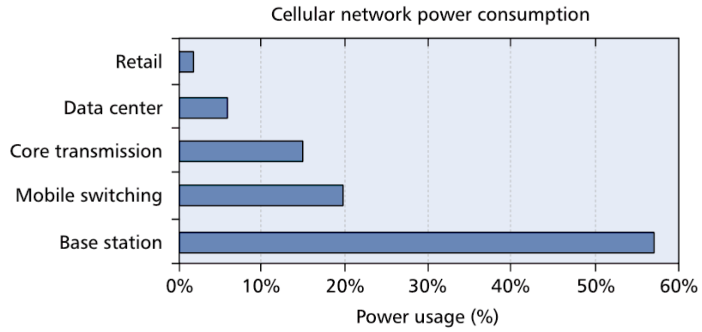
Reducing power consumption [181]



- The base station is the most power intensive element (more than 50%).
- Also the usual lifetime is around 10–15 years, while smartphones is only 2.
- By reducing the power consumption of the largest element, the whole consumption is reduced.

Harvesting renewable energy resources

In order to power the Base Stations (BS), energy can be obtained from renewable sources:

- Natural sources: Sun, wind, vibration
- External: Batteries, fuel cells

Solar energy has been studied in UK cities, in order to power BS installed in road lamps, with a solar panel on top [175]. It has been observed that it can run fully autonomous, with the exception of the January month, where external power was needed.

Other sources of energy may not be so profitable, as sun is the source with the highest amount of power, about $100\,\mathrm{mW\,cm^{-2}}$, followed by the wind with $12\,\mathrm{mW\,cm^{-2}}$.

User-centric designs

Smaller frame overhead [1]

- Bursty traffic cause devices to change state between idle and connected with the associate **power consumption**
- Significant **overhead** with small packets
- Contention based method have been proposed

[1]Following [178] paper in depth: Uplink Contention Based Multiple Access for 5G Cellular IoT

Expand based on reference 178

Uplink contention based methods

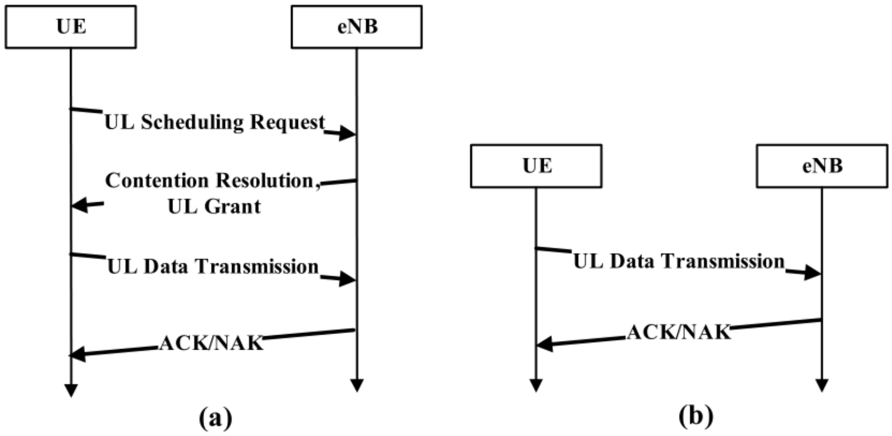


Figure 2: Data reporting via optimized Random Access procedure.

- Small signalling payload
- Direct small data packet

Results of simulation

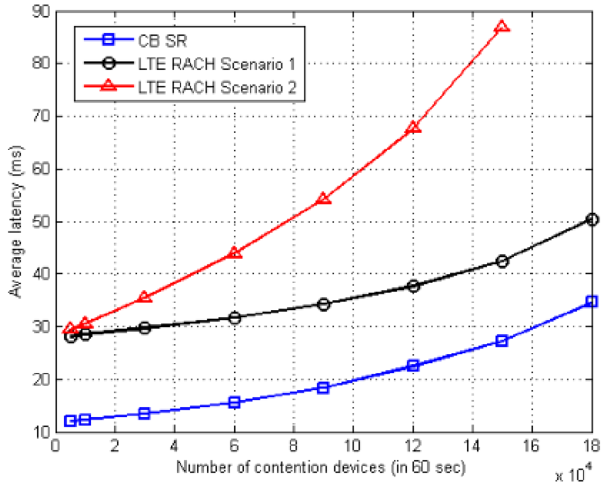


Figure 6. Latency performance improvement by proposed CB SR

Open problems

- Power control: max power BS, sunlight.
- Energy efficient hardware: transceivers
- Energy efficient network architecture: SDN, NFV, data/control plane
- New battery technologies: sugar bio-batteries[2], photo-MFC

[2] Following [183] paper in depth: *A high-energy-density sugar biobattery based on a synthetic enzymatic pathway*

There are some challenges to be resolved.

- Power control
  - In multi-tiered networks, the user is not connected to the BS with maximum power.
  - Solar and wind energy harvesting can be unfeasible in dense localities and where sunlight is not available.
- Energy efficient hardware
  - Current transceivers are energy costly, as they are designed for good throughput.
- Energy efficient network architecture
  - Multiple technologies as MIMO, SDN, NFV, D2D, cloud computing...
  - Separation of control and data planes
- New battery technologies: sugar bio-batteries, photo-MFC
  - Based on enzymes that extract energy from sugar, similar to humans.
  - Moss can also be used to harvest solar power
  - Still with a low efficiency to be used.

Sugar bio-batteries [183]

- The typical density of energy of a Lithium cell is around $0.54\,\mathrm{MJ\,kg^{-1}}$
- But the combustion energy of glucose can release up to $15.5\,\mathrm{MJ\,kg^{-1}}$
- Sugars are non toxic, safe and carbon neutral

The energy per Kilogram stored in a lithium cell is about 2 orders of magnitude below the available energy in an equivalent sized glucose cell. Those cells are able to work for long periods with a suitable flow of glucose-like input stream. The enzymes used for the transformation of sugar are non toxic, an easy to obtain, they don't need any exotic metal nor element. Experiments with bio-batteries seem to have a suitable position as power cells.
The cells consist of some enzymes placed close to an electrode. A

Sugar bio-batteries [183]

- Maltodextrin (food additive), produced from starch.
- Sugars are non toxic, safe and carbon neutral
- The lifetime of enzymes is very short (weeks)
- They have to be recharged regularly.

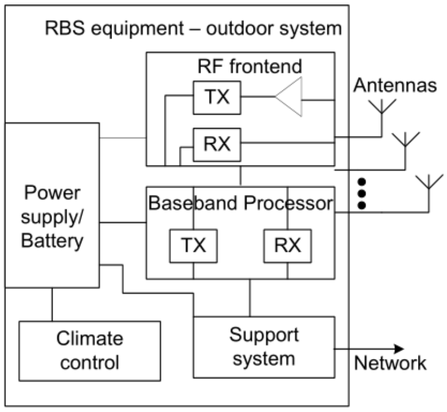
Energy efficiency metrics [179]

- We need some way to compare energy efficiency (EE), but which metric is more suitable?
- Output energy/input energy?
- Performance/energy consumption?
- What load should we use for the measurement?
- Accuracy?

In order to obtain an meaningful comparison of different technologies used in electronic communications, some metrics should be established so we can compare the energy efficiency.
Some candidates as the output power by the input power are useful when we can measure the power, but some times other measurements are more interesting. For example if we look at a processing unit, we may be interested in the performance per watt.
The base stations can operate at different loads, and the metric should include information of the load to be compared. Also the accuracy of the metric should be taken into consideration, as it may include information of fluctuations when the system is under operation.

We will focus on the metricss used at different levels of abstraction, starting from the lowest part, the component level, to the uppermost, the network level.

EE at component level



- The components are analyzed by parts
- Example: The efficiency of the antenna as the input power that it receives compared with the irradiated power.
- On the baseband processor, EE is measured as performance per unit of energy consumption.
- For the power supply, output power/input power, often higher than 85%

A general model us commonly used, as the one in the figure, to understand the different parts of a system. In each part we can identify and measure the efficiency based on specific metrics.
In the case of a radio base station, which may includo one or more antennas, the efficiency can be expressed as the ratio of the radiated power P_r to the input power P_i,

$$\eta = P_r/P_i$$

Whereas, in a baseband processor we are interested in the performance per watt, which can be meassured by means of MFLOPS or MIPS which often can be expressed in equivalent MOPS (millions of operations per second). The power supply is normally measured in terms of electrical effiency, with the ration of output power by input power, often higher than 85%.

EE at equipment level

- Power is computed by the average power level (high, med, low).
- Power supply correction factor and cooling factor.
- Energy consumption rating: Power/effective throughput.

EE at network level

- Rural, cellular: Coverage area/average power consumption
- Urban: Suscribers/average power consumption
- Error correction: transmitter power/bit rate