RTT TECHNOLOGY TOPIC
July 2016

5G Energy

5G Energy Efficiency

3G and 4G standards focussed substantially on improved spectral efficiency, an understandable prioritization determined by the escalating cost of spectrum.

However the 5G business model is targeting specific vertical markets, for example Internet of Things (IOT) connectivity and machine type communication (MTC), where power efficiency is more important than spectral efficiency.

In parallel, new spectrum could potentially be available at higher frequencies/shorter wavelengths at lower cost making spectral efficiency less cost effective for developed economy markets.

Similarly, emerging economy mobile broadband markets remain unserved or underserved due to high energy costs, a product of the high number of off grid sites and poor quality electricity supply.

The present standards approach, reflected in the NB-CIoT and NB LTE work groups, is producing a separate set of narrow band physical layer proposals to meet perceived IOT and MTC market requirements.

However mainstream mobile broadband applications also have an emerging power problem. If energy consumption continues to increase at the same rate as bit throughput then network energy consumption will become unsustainably expensive. In mature markets, energy costs account for 10-15% of total network operating expenses. In developing markets this can reach 50%.

Improved energy efficiency across all potential applications both at network and device level is therefore a pre-condition for a sustainable 5G business model but hard to deliver without compromising spectral efficiency. Allocation of substantial bandwidth in the centimetre and millimetre band would make spectral efficiency a lower design priority but is it possible to make this shorter wavelength spectrum energy efficient (and cost efficient) for wide area mobile?

Read on

There are at least three ‘wish list’ energy targets in present 5G standards discussion documents.

The European METIS[1] ‘wish list’ for example specifies ten times longer battery life for low power battery life for low power massive machine communications where machines such as sensors or pager are assumed to need a battery life of a decade. For general mobile communication, METIS suggests a need for *’similar cost and energy dissipation per area as existing cellular systems’.*

Ericsson suggests the need for a 10X battery life extension for low power devices. 5GPPP suggest an order of magnitude decrease in energy consumption compared to 2010.

[1] **M**obile and wireless communication **E**nablers of the **T**wenty–twenty **I**nformation **S**ociety
www.metis.com

A European METIS definition of 5G Mobile and wireless communications Enablers for the Twenty-twenty Information Society	A vendor definition of 5G (Ericsson)	A 5G PPP definition of 5G
Ten times longer battery life for low-power massive machine communications where machines such as sensors or pagers will have a battery life of a decade	10X battery life extension for low power devices	1/10x decrease in energy consumption compared to 2010

There are two useful and relevant White papers on present and future network and device energy consumption and *'Lean Carrier'* concepts, a Nokia White Paper, *'Technology Vision 2020- Flatten Network Energy Consumption'* and a White Paper from Ericsson.

http://info.networks.nokia.com/Technology-Vision-2020-Flatten-Network-Energy-LP.html
www.ericsson.com/res/docs/2015/energy-performance-of-5g-nx.pdf

The Ericsson White Paper highlights how the deployment of small cells increases network performance (throughput and capacity) but potentially uses three times more power than an equivalent macro network due to increased signalling overhead.

The Nokia paper points out that the radio access network accounts for 80% of all mobile network energy use with consumption increasing by between 15 and 35% every year. At the physical layer, only 15% of this energy is used for forwarding bits, the rest disappears into fans and cooling systems, heating and lighting, uninterruptible and other power supplies and running idle resources.

A (partial) solution is to dynamically reduce reference signalling to reduce inter cell interference. This allows higher order modulation including the 256 level QAM now supported in LTE to be used in larger cells including areas with cell overlap.

However there is also a need to focus on base station baseband and RF efficiency improvements including site optimisation (reduced cooling and feeder losses), the use of higher voltage DC or AC, RF power amplifier linearization and dormancy concepts in which unused radio channels are taken off line in low traffic loading.

Beam forming is referenced as a mechanism for improving RF efficiency but the cost is additional baseband consumption. The general assumption is that DSP performance improvements can keep pace with these increased baseband requirements but digital signal processing is increasingly constrained by gate capacity and input voltage reduction rather than Moore's law.

Brute force DSP is not a long term answer.

The argument is that LTE can be made more efficient than GSM in terms of traffic per watt. In practice GSM coverage is still much better in many rural areas so the link budget difference will be a dominant factor. What is probably more important is that LTE is significantly more power efficient than 3G CDMA with up to six times as much throughput per cell for an equivalent energy consumption. Pragmatically the best approach from an energy efficiency (and cost efficiency) perspective is to decommission all 3G hardware and run one or two GSM carriers alongside an LTE carrier.

There is of course a legacy issue here. Operator CFO's quite rightly expect telco equipment to last for 10 to 15 years and it can be expensive to decommission legacy hardware with an associated engineering opportunity cost that can outweigh energy cost savings. Given that 50% of traffic is delivered through 15% of sites there are opportunities to focus upgrades where they deliver maximum cost benefit but this has to be managed in the context of meeting vertical market requirements.

The automotive industry for example makes a compelling technical case for better geographic coverage and a 1 in 10^5 packet loss threshold.

Delivering one or the other would require a 4G link budget increase of 15 dB. This is now included in the Release 13 standard documents. Delivering both implies another 15 dB. This is being discussed for 5G as part of Release 14.

A link budget increase of this order of magnitude is presently economically unimaginable. Increasing the link budget by 10 dB implies a site density increase of 273% assuming no change in present power outputs and sensitivity thresholds. Increasing power output to 10 watts on the uplink would help but would introduce inter and intra system co-existence issues as would an equivalent increase in downlink power, 200 watt base stations for example.

An alternative is to improve sensitivity. One of the ways to do this apart from reducing transmit power (which doesn't solve the directional link budget issue) is to use a narrow band radio channel. NB-CIoT and NB-LTE for example both support 200 KHz channel bandwidth with uplink sub carrier spacing of 15 KHz (NB=LTE) or 3.75 KHz (NB-CIoT) and downlink sub carrier spacing of 15 KHz or 3.75 KHz.

The use of simple constant envelope modulation, either BPSK or GMSK, means that power efficient (>50% system efficiency) Class C amplifiers can be used so the net result is lower power consumption but with constrained peak data rates. You also miss out on the multiplexing gain achievable from wider bandwidth channels so there is an associated capacity hit. At system level there is also an issue of how to implement narrow band channels directly adjacent to the wider band channels in LTE, for example 5 and 10 or 20 MHz.

However it is not just an issue of channel bandwidth but the width of the pass band, many of which are becoming wider. Band 5 for example, the US 850 band, can now theoretically be replaced with Band 26 increasing the pass band from 25+25 MHz to 35+35 MHz with an additional extension possible by consolidating the new 'super band' with the SMR sub band (Band 27). This also has the effect of reducing the duplex gap and guard bands. Consolidating Band 4, Band 10 and Band 25 creates a matching wider pass band AWS super set at 1800 MHz.

These wider super set pass bands make it easier to re-farm existing spectrum from narrower band legacy CDMA or GSM to 5 or 10 MHz or aggregated carrier LTE but the related impact is a softening of the filter band edges. This can be addressed by adding extra filters, for example roofing filters, but these introduce additional insertion loss (and cost).

This begs the question as to how improvements in spectral efficiency have been achieved. The answer from 2G onwards has been improvements in speech coding and channel coding which allows the networks to work at a lower C to I or in other words to have a radio interface that is more tolerant to inter system and intra system interference.

Theoretical gains have also been achieved in 3G and more effectively in 4G by implementing higher level non constant envelope modulation but the additional amplitude components have required additional signal processing to recover RF power amplifier system efficiency. This whole generation of adaptive modulation and coding and error detection and correction schemes work well in theory but introduce additional coding and signalling overheads which absorb bandwidth and lower the energy per bit so have an impact on the link budget. The 'lean carrier' solution, referenced earlier, reduces coding and signalling overhead but the higher order modulation projects more power into adjacent channels. Essentially there is always going to be a trade-off between in band and out of band performance.

So what are the other possibilities for 5G and how do these correlate with present spectrum thinking?

In last month's technology topic, *'Guided Media- where next?'* we discussed how beam width and bandwidth are a proxy for power. A narrow beam concentrates RF energy where it is needed but bandwidth ratios of 10% or less are needed to achieve sufficient linearity to enable adaptive beam forming and to allow for optimum RF matching reducing component to component return loss.

The wavelength spacing needed between antenna elements in base station and user device antenna arrays means that this RF efficiency can only be realised at centimetre or millimetre wavelengths.

Similarly the 500 MHz of channel bandwidth needed for high bit rate 5G with optimum multiplexing gain requires a centre frequency of at least 50GHz to meet the linearity and matching needs of high bit rate high throughput wide area mobile networks.

Present thinking in the industry suggests that spectrum in the metre band below 6 GHz and 3 GHz (refarmed 4G spectrum) will be needed to deliver low cost energy efficient 5G. In the centimetre band, there is vendor and operator support for 28 GHz. However this assumption is based on propagation models that become progressively less accurate at shorter wavelengths (and quite honestly are not useful beyond 2 GHz).

A one degree beam width adaptive antenna in the millimetre band can deliver 40 dB of isotropic gain which more than off sets any potential propagation loss. Note that the longer wavelengths at 700 MHz often result in negative antenna gains of the order of -7 dB or more which adds to this 40 dB difference.

However RF efficiency also depends on interference management and mitigation.

There are many opportunities in a narrow beam network to manager RF interference more effectively but the cost will be additional baseband processing load and intra system and intersystem timing will need to improve.

Similarly there are many opportunities to improve power down modes both in base stations and user and IOT and MTC devices but only if timing is more aggressively managed (a topic to which we return in future technology topics).

Summary

Power efficiency in 5G is discussed in standards meetings in an IoT and MTC context but the broader issue of high bit rate mobile broadband power consumption gets less attention.

RF and baseband consumption in user devices and base stations is presently increasing both in relative and actual terms. There are marginal improvements being made and proposed which will reduce energy per bit but essentially these reduce rather than resolve the longer term energy consumption conundrum.

At network level it can also be observed that backhaul energy consumption is increasing. The combined traffic per watt trend is not going in the right direction. It is hard to see how that can change without a wider recognition that the centimetre and millimetre bands offer a potentially major improvement in RF link budget, lower intra and inter system interference (delivering a coverage and capacity and energy efficiency gain) and the opportunity to deploy energy efficient in band point to point backhaul.

It would be useful if this was more fully reflected in present 5G spectral policy and industry band plan advocacy.

Ends

Learn more about these topics - resources for 5G engineering, marketing and policy teams

5G STUDY - 5G and its vertical markets: challenges and opportunities 2015-2030
Co-authored by Geoff Varrall, published and researched by Policy Tracker.

Based on in depth interviews and online surveys with over 40 industry professionals and covering 50 companies, the study analyses the costs and opportunities of 5G vertical markets and their relative value. The 5G business model depends on increasing speed, decreasing latency and dealing with massively increased network density. Which of these is the most challenging and how will that affect deployment?

£999 + VAT for up to five users within a single organisation.
Order a copy here

5G BOOK – 5G Spectrum and Standards – Geoff Varrall
Published by Artech House

The spectrum, band plan and standards choices for 5G radio systems and the relative technology and economic impact of these choices on the industry supply chain, operator community and end users.

£117.00 available to pre-order at a discounted price of £87.00
Order a copy here

Geoff Varrall is also presenting two ninety minute modules on the final day of the Policy Tracker 5 day Training Course ***Understanding Modern Spectrum Management*** *at Harris Manchester College, Oxford* (***September 19- 23 2016)*** – to book a place follow the link

About RTT Technology Topics

RTT Technology Topics reflect areas of research that we are presently working on. We aim to introduce new terminology and new ideas to help inform present and future technology, engineering, market and business decisions. The first technology topic (on GPRS design) was produced in August 1998.

18 years on there are over 200 technology topics **archived on the RTT web site**.

Do pass these Technology Topics and related links on to your colleagues, encourage them to join our **Subscriber List** and respond with comments.

Contact RTT
RTT, **Policy Tracker** and **The Mobile World** are presently working on a number of research and forecasting projects in the mobile broadband, two way radio, satellite and broadcasting industry.

If you would like more information on this work then please contact **geoff@rttonline.com**
00 44 208 744 3163