DIGITAL COMMUNICATIONS KNOWLEDGE TRANSFER NETWORK

Energy Efficient Wireless Communications (Green Radio Access Networks)

Wireless Technology & Spectrum Working Group

The Digital Communications Knowledge Transfer Network has been established by an industry-led group of leading players, with funding from the Technology Strategy Board. We seek to bring competitive advantage to the UK by promoting collaboration and knowledge sharing between the users and providers of Digital Communications, and helping to drive innovation in the sector.
If you are involved in Digital Communications, and have not yet registered as member of the DCKTN please visit our web page and register as a member.

Digital Communications KTN
Russell Square House
10–12 Russell Square
London WC1B 5EE

Email: **info@dcktn.org.uk**
Website: **www.dcktn.org.uk**

Telephone: +44 (0) 20 7331 2056

Contact points for positioning paper

Stuart Revell DCKTN Wireless Technology & Spectrum group chair
07836 512787
stuart.revell@dcktn.org.uk

Simon Fletcher (Editor)
NEC and Industrial Chair for the MVCE Green Radio Programme
01372 381824
Simon.Fletcher@EU.NEC.COM

The opinions and views expressed within this positioning paper have been reviewed by the members of the Digital Communications Knowledge Transfer Network Wireless Technology & Spectrum working group. The views and opinions do not necessarily reflect those of the individual members of the DCKTN or the Working Group or the organisations that the members represent.

1 Contents

2 Abbreviations and definitions

Abbreviation	*Definition*
3G	3rd Generation Mobile
3GPP	3rd Generation Partnership Project
ADSL	Asymmetric Digital Subscriber Line technology
ARPU	Average Revenue Per User
BEREC	Body of European Regulators for Electronic Communications
BIS	Department of Business, Innovation and Skills
BW	Bandwidth
CAPEX	Capital expenditure
CC	Constant Current (Mobile charger)
COTS	Commercial Off The Shelf
CPRI	Common Public Radio Interface
DAS	Distributed Antenna System
DC	Direct Current
DCKTN	Digital Communications Knowledge Transfer Network
DFT	Discrete Fourier Transform
DL	Downlink
DSL	Digital Subscriber Line
E1 PDH	2.048 Mbit/s Plesiochronous Digital Hierarchy link
ECG	Energy Consumption Gain
ECR	Energy Consumption Rate
EDGE	Enhanced Data rates for GSM Evolution
EE	Energy efficiency
ETSI	European Telecommunications Standards Institute
EUP	Energy Using Equipment
FTTH	Fibre to the home
FTTP	Fibre to the premises
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSPA+	Evolved High-Speed Packet Access
ICT	Information and Communication technologies
IFFT	Inverse Fast Fourier Transform
IMT	International Mobile Telecommunications
IT	Information technology
ITU	International Telecommunication Union
LTE	3GPP Long Term Evolution
LTE Advanced	3GPP Long Term Evolution (LTE second generation)
M2M	Machine to Machine
MC	Multi-core processor
MAC	Media Access Control (Layer 2)
MD	Mobile Device

MIMO	Multiple-Input and Multiple-Output
MNO	Mobile Network Operator
MOPS	Million Operations per Second
MSAN	Multi Service Access Node
MTBF	Mean Time Between Failures
MTX	Mobile Telephone Exchange
MVCE	Mobile Virtual Centre of Excellence
MVNO	Mobile Virutal Network Operator
NLP	No load power
OBSAI	Open Base Station Architecture Initiative
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operating Expenditure
OTT	Over The Top services
PA	Power Amplifier
PAPR	Peak to Average Power Ratio
PHY	Physical layer 1
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
RBS	Radio Base Station
RDFC	Resonant Discontinuous Forward Converter
RF	Radio Frequency
ROHC	Robust Header Compression
RRH	Remote Radio Head
RRM	Radio Resource Management
Rx	Receive
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDM	Software Defined Modem
SDR	Software Defined Radio
SFBC	Space frequency block coding
SoC	System on a Chip
SOHO	Small Office Home Office
SON	Self Organising Networks
SWR	Software radio
Tx	Transmit
UE	User equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VAMOS	Voice services over Adaptive Multi-user channels on One Slot
VDSL	Very high bit rate digital subscriber line
VLSI	Very Large Scale Integration
WCDMA	Wideband Code Division Multiple Access (3G air interface)
WiFi	Wireless Local Area Network technology (WLAN)
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network technology
xDSL	Digital Subscriber Line technology (including Video, Symetric and Assymetric)

3 Executive summary

Mobile and broadband traffic continue to grow at an exponential rate resulting in further capacity investment and the requirement for new spectrum and advanced air interfaces which provide greater spectral efficiency. Installing new capacity and providing improved coverage will yield environmental savings through better use and adoption of Mobile and Wireless ICT services.

Energy use and costs continue to rise, creating the need for future network energy efficiency to be significantly improved to ensure energy usage does not increase at the same growth rate as traffic running over the networks. The introduction of new spectrally efficient air interfaces, presents new challenges in terms of energy efficiency and a key objective in developing new networks will be to drive down the energy consumption per bit transmitted, manage equipment more efficiently and leverage natural energy sources.

The introduction of new air interfaces such as LTE will provide significant benefits in terms of data rate and energy per transmitted bit used, versus older technologies like GSM. Although the new air interfaces provide a greater efficiency the expectation of the consumer means that the new higher access speeds must not come at a cost in terms of battery life for portable equipment, therefore the industry challenge is to continue to increase speed whilst keeping the period between charging at the same rate as the older technologies.

Ubiquitous broadband is also driving behaviour change in end users, meaning that the end user equipment is now a portable media and business platform with user session lengths increasing and moving towards an ‘always on and connected’ mode of usage.

In simple terms, the efficiency gained through new air interface technology and spectrum usage introduction is essential to address the growing demand for Wireless broadband services. However, the usage consumption per user continues to rise and therefore industry must embrace these changes to ensure energy efficiency is not blocking or restricting the growth of essential services and markets.

The diagram below is an overview of the three key areas, where energy efficiency improvement opportunities exist to address these challenges:

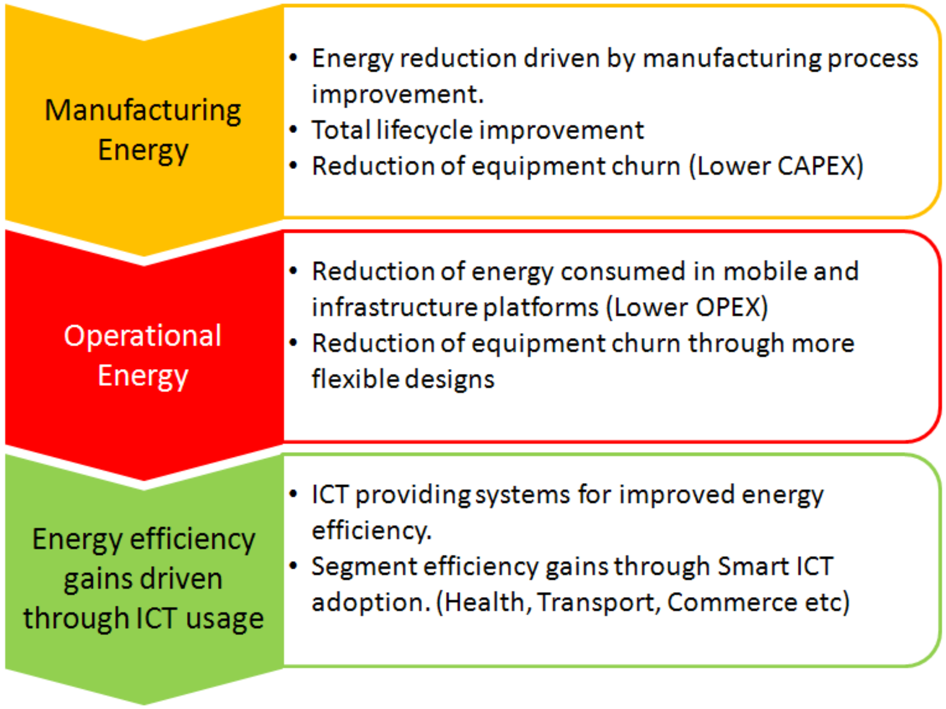

Figure 1: Three key areas for energy efficiency innovation

There is now recognition in the communications industry that there is a need to address the sustainability agenda [1] and specifically to address the efficiency of the energy consumed to create a sustainable business through the reduction of operational expense (OPEX), to which energy costs for powering networks are a significant contributor.

The DCKTN Wireless Technology and Spectrum working group recognises these challenges as significant to the industry and prioritised this topic through 2010; establishing the platform for dialogue with stakeholders through 2011. The 2010 focus of our work concentrated on the technology and innovation associated with **Operational Energy** which will drive benefits into the manufacturing cycle and help the wider adoption of ICT platforms.

During this activity we have discovered significant opportunities for innovation associated with **Operational energy** and we have identified a strong UK eco-system to address these challenges. To follow are the high level operational energy challenges which will be addressed in this paper:

- Radio Base Station and Mobile common technology innovation opportunities (equipment level)
- Optimising energy at cell sites (site level)
- Physical network topology optimisation (overall network level)
- Service and end to end systems (including virtual networks)

Manufacturing energy is also critical and is addressed in the paper by identifying how the industry may reduce churn, which also enables CAPEX reduction. The incremental benefits through wider adoption of ICT and improved network capability are not addressed in the paper as it is now widely recognised that significant benefits exist through the adoption of Wireless ICT platforms for emerging ‘connected’ applications such as healthcare applications, intelligent transport, smart grids, smart cities etc.

4 Purpose of this Positioning Paper

This paper will highlight some of the key issues identified by the Working Group that we believe present significant opportunities for innovation to improve Operational Energy Efficiency; highlighting potential for the UK R&D community to address with commercial impact in a 5+ year event horizon.

In recognition of one of the core values of the DCKTN working group of seeking to promote UK based R&D; this paper highlights companies that are known to have UK based R&D operations and that may offer a viable solution to a challenge identified in the paper. This paper provides an overarching view of the systems and technology platform challenges and highlights the eco-system of companies within that context.

The positioning paper and associated presentations will be used at appropriate Knowledge Transfer events to engage the DCKTN membership and the wider industry, and as a mechanism to help stimulate discussion with Government bodies.

5 Energy efficiency improvement focus areas

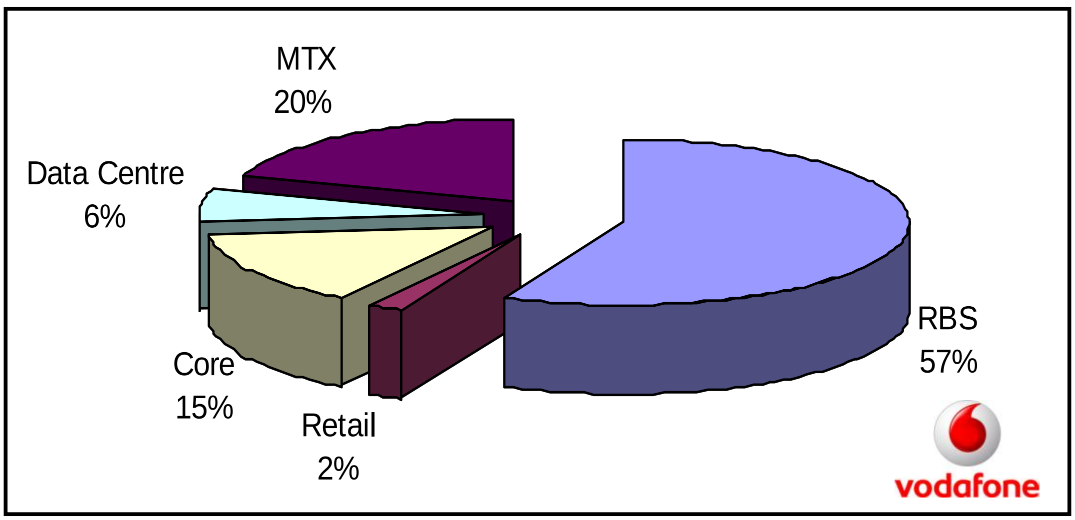

Figure 2: Breakdown of Power consumption in Vodafone UK network

The paper explores different architectural perspectives of wireless networks first highlighting the technology platform looking at Radio Base Station (RBS), which is the current dominant energy usage area and the mobile devices that connect at the access edge (see Figure 3).

When installing the RBS there are ancillary functions on the cell site that may be optimised for energy efficient operation. Wireless connectivity is increasingly ubiquitous and will only continue to become more so over the passing of time so we explore some aspects relating to multiple radio access and cell topologies. The service perspective is explored to determine benefits that may be uncovered from sharing of network resource and how traffic demands impact on the energy consumption of networks.

Taking a broader perspective, the opportunities that may be observed from a regulatory and standards perspective are necessary to consider. Finally we will highlight data centre efficiency issues and aspects relating to content/services where energy consumption should be considered.

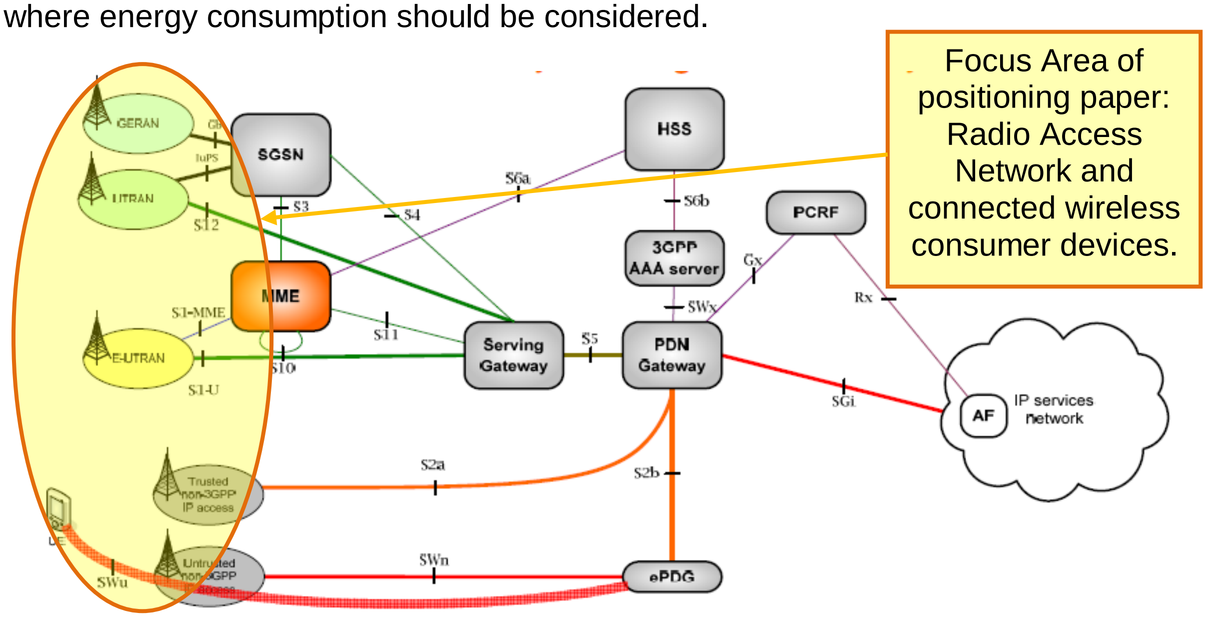

Figure 3: Radio access network – highest network energy usage

The diagram below (Figure 4) represents a logical flow of how the work and content of this paper has been derived and provides the reader with a logical flow from the network / industry view on the left of the diagram through to the ICT user based benefits, Network operators OPEX reduction and CAPEX savings through reduced churn of equipment (right of the diagram). The centre of the diagram provides the identified priorities and opportunities for innovation; these are not ranked, all of these will need to be addressed to meet long term energy reduction and efficiency targets. Section numbers have been added to assist navigation through the document.

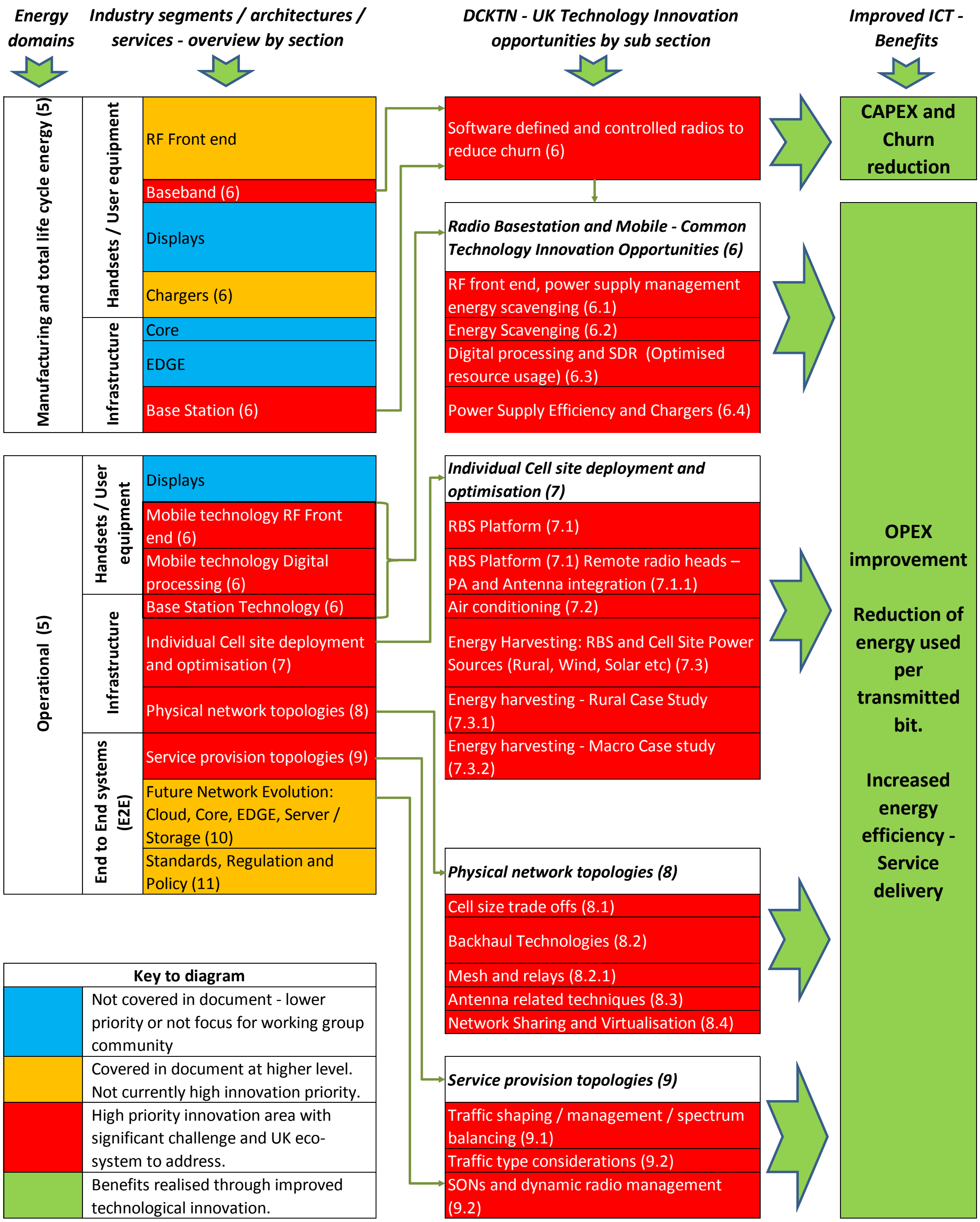

Figure 4: Positioning focus areas

5.1 Total cost of ownership and embodied energy

ETSI and other standards bodies are driven to some extent by the trends in the consumer electronics and white goods markets and are now taking a significant interest in the management of energy taking into account CO2 footprint of the technology deployed to create the wireless networks. This has resulted in studies [5] of methods to account for energy consumed during manufacture and deployment of technologies, referred to here as embodied energy.

The trend in bodies such as ETSI is to consider four key lifecycle phases; Raw material acquisition, Production, Use, and End of Life treatment. In general the approach is each of these phases has features that are to be recognised and characterised to derive appropriate control points for the development of equipment and standards.

There is yet to be consensus in the Industry on the best way to determine and manage embodied energy. It is clear that the legislators at Global, European and national level are now taking action to consider these aspects and the ICT industry must take a lead to assure agreeable or at least not detrimental legislation is imposed. It is expected that these considerations will challenge existing approaches to manufacture and logistics. In particular smart and low energy manufacturing capabilities are likely to be beneficial to stay globally competitive.

This paper will not consider these issues in any further depth, where enabling technologies are identified that are beneficial to TCO/embodied energy aspects it will be noted.

6 Radio Base Station and Mobile devices common technology innovation opportunities

An RBS comes in a multitude of form factors. Generally RBS platforms are formed of proprietary sub-systems and architectures, certainly more so than is the case for typical switching/core network equipment that tends to be integrated from Commercial of the Shelf (COTS) components with a mixture of standardised protocols and proprietary software. For an RBS there are however some core entities that we should highlight for potential energy efficiency improvements.

The cycle for industry to introduce a new air interface starts with the deployment of infrastructure and therefore this equipment is developed in advance of the user platforms that will run on the new networks. Historically, the infrastructure and mobile platforms were developed by the same companies, therefore techniques developed where adopted, tested and leveraged across the different segments. In recent times this has diverged and a distinct partition has occurred where user platforms and infrastructure are now developed by different companies. **The DCKTN Wireless Technology and Spectrum working group recognises this and the importance of knowledge transfer across different companies and segments. Techniques developed in the Radio Base Station segment can be applied to the Mobile segment and vice versa, therefore in this section all of the innovation challenges and opportunities identified can be applied in both areas.**

The potential for energy efficient platform core technologies, initially developed for a particular application, but portable with minor modifications to other product lines may give rise to significant opportunities for growth.

6.1 RF front end and Power Supply Management

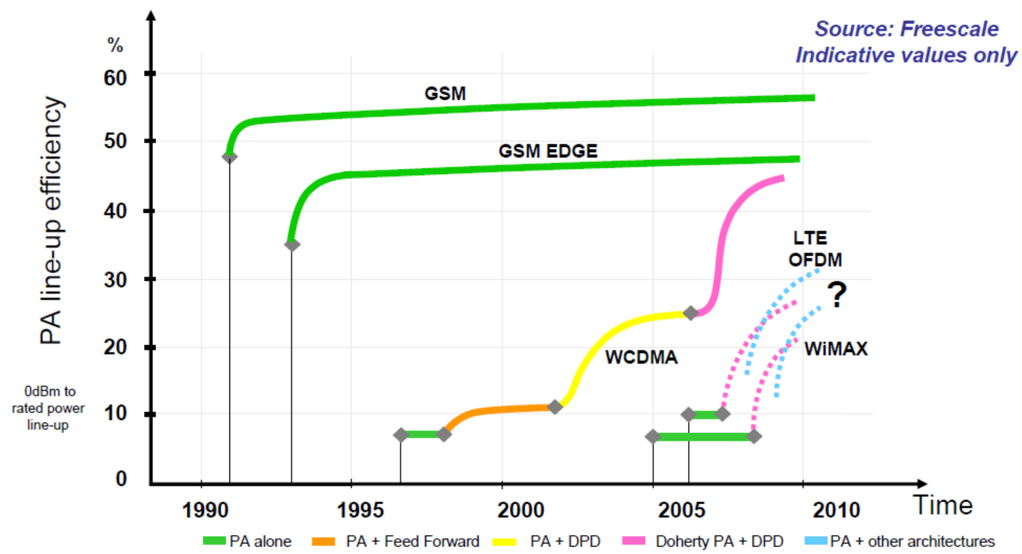

Figure 5 : Typical RF PA efficiency figures for wireless technologies (source OPERANet project)

Figure 5 illustrates the consequence of the challenge that the industry encounters each time systems are developed to support new radio access technologies. Typically there is a step change reduction in efficiency of the amplifier stage brought about by the characteristic of the transmitted signal, in particular the Peak to Average Power Ratio (PAPR).

For uplink (UL) in LTE the standards have developed a single carrier like signal (SC-FDMA) to help limit the power consumption of handsets. However in the downlink (DL) the OFDMA signal presents a greater PAPR (see Figure 6). As a consequence new techniques need to be applied to move the efficiency of the power amplifier stages (DC in to RF out) back to the level achieved by previous technologies. The industry having now gone through several generations of PA is in a good position to understand the appropriate optimisation techniques to raise the line efficiency, the trends in the industry towards site sharing and multi-technology base stations raise the bar again.

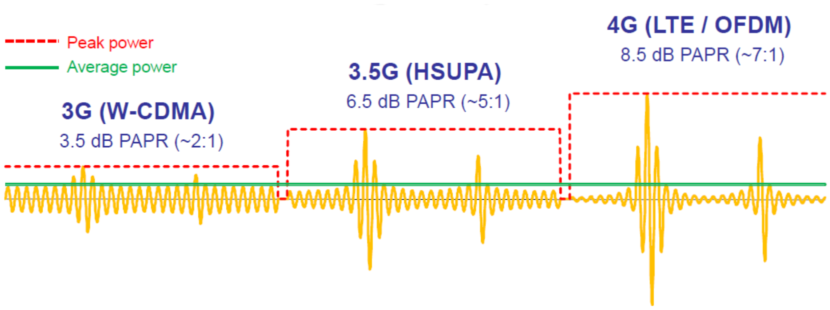

Figure 6 : The increase in Peak to Average Power across generations of wireless access technologies (source Nujira)

Technologies such as Doherty show a good efficiency of 45% [9] and are now relatively common in Base station Power Amplifier stages. As wireless standards continue to seek higher peak user and system throughput rates (but with little increase in link spectral efficiency) the systems are becoming wider band. Nujira has been pioneering the commercialisation of Envelope Tracking technologies [Figure 7] showing performance in excess of 45% efficiency; in some cases even claiming 60% efficiency for broadcast like systems whilst also enabling wider system bandwidth.

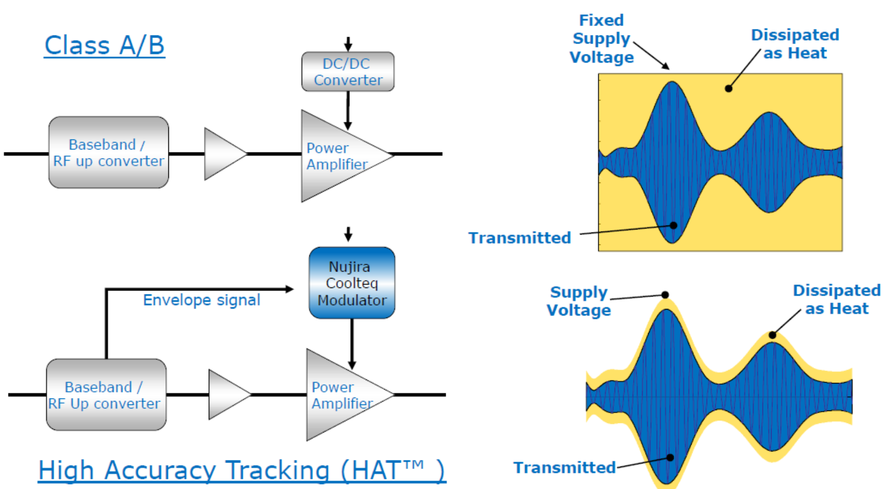

Figure 7 : The envelope tracking concept (source Nujira)

Network sharing trends along with the possibility of broadcast and cellular networks infrastructure sharing with the convergence on OFDM (see section9) may well lead to common solutions in the PA across both broadcast and cellular systems.

6.1.1 New Air interfaces: EE performance increase?

Previous sections of the chapter have primarily highlighted key components based on semiconductor component platforms. With wireless systems one can consider the air interface to be a component of the system indeed a mandatory component. Whilst global wireless standards address and assure the inter-operability of RBS and Mobile device typically the receiver component is vendor specific allowing for performance differentiation.

Even when not considering final processing solutions and taking the standardised aspects of the wireless interfaces into account it is possible to draw some conclusions about the link energy efficiency when considering a metric such as Joules per bit (J/bit). Spectral Efficiency is a measure of the utility of the spectrum available for delivery of information. Metrics derived to measure spectral efficiency have been used for several years by those researching and developing Standards. This focus has now taken us very close to the theoretic limit (Shannon Bound) for a radio link. This realisation is leading to the focus on optimisation of systems based on system metrics bounded by multiple links and co-operative processing of nodes.

When standards bodies develop specifications for wireless links for cellular, enterprise and SOHO it has not in general been a high priority to consider the energy efficiency characteristics of the system. Features of the link are normally driven by issues such as link spectral efficiency, available bandwidth, peak rates etc. When considering the energy efficiency of wireless technologies one needs to take into account both the power consumption of the mobile devices that are connected to the network and the network infrastructure itself. From the perspective of the mobile device the introduction of SC-FDMA in LTE for the uplink is to avoid the high PAPR of a standard multi-carrier OFDM radio link and thus provide a radio link that should not excessively drain the power of the mobile device battery.

When comparing an OFDM based system (LTE) with WCDMA (3G) there are some features of the radio link that give some additional flexibility for tuning system performance between Energy Efficiency and Spectral Efficiency. If both LTE and WCDMA links are fully loaded with a system tuned to maximise spectral efficiency there may be little observable EE improvement. However, LTE by virtue of its frequency selective scheduling may on average provide a more efficient link. The resource block based physical layer can be used for selective power levels towards different users, although in practice such approaches may cause complications for the amplifier stage as the envelope of the signal may not be optimal for the PA. Other features such as blanking sub-frames also offer the opportunity for the powering off of PA elements; although again the challenges for the PA stages of such a signal should not be overlooked.

The table below provides a comparison of spectrum efficiency for various mobile data technologies.

Table 1 Comparison of data throughput and spectrum efficiency for various mobile data technologies[1]

Technology	Throughput	RF bandwidth	Freq Re-use	Efficiency
GPRS*	115 kbps	200 kHz	12	48 kbps/MHz
EDGE*	240 kbps	200 kHz	12	100 kbps/MHz
UMTS R99*	750 kbps	5 MHz	1	150 kbps/MHz
HSDPA**	1.7 Mbps	5 MHz	1	340 kbps/MHz
HSPA+ **	4.2 Mbps	5 MHz	1	840 kbps/MHz
WiMAX**	11.3 Mbps	10 MHz	1	1.13Mbps/MHz
LTE**	15 Mbps	10 MHz	1	1.5 Mbps/MHz

Sources: *Qualcomm[2] **Vodafone[3]

Note that the assumed efficiency figures are typical and likely to depend on traffic being uniformly distributed around the cell. In comparing these technologies it must be noted that various studies and results vary on exactly how the measurements are taken and the conclusions drawn.

For the purposes of demonstrating and comparing efficiency, GPRS is noted as delivering 48 kbps/MHz and LTE is 15Mbps/MHz, which shows that LTE is >30x more efficient than GPRS.

The typical DC to RF out efficiency in the older technologies have gone through several generations to achieve a high DC to RF out efficiency and the new interfaces will also need to go through several iterations to achieve optimum performance. Comparing, old and new, it can be shown that a poor efficiency first generation new air interface such as LTE will still offer a much better Energy per transmitted bit due to the significant spectral efficiency gain.

The conclusion drawn is that if Industry can apply the DC to RF efficiency seen in mature air interfaces to the new LTE variants then a significant energy per bit saving can be achieved. (>30X when comparing GPRS and LTE)

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1 DCKTN Optimising use of available Mobile Radio Spectrum positioning paper Sep 2009, https://ktn.innovateuk.org/web/spectrum/document-library?p_p_id=20&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&ns_20_struts_action=%2Fdocument_library%2Fview&ns_20_folderId=865485

2 "HSDPA for Improved Downlink Data Transfer", white paper, 2004

3 "Broadband through Wireless – the unfolding story of the mobile web", presentation by Prof. Michael Walker OBE FREng to Silicon South West Wireless 2.0 Conference, 2009

6.1.2 MIMO and Radio Resource management techniques

For MIMO configurations; generally, more transmission energy is required as the number of transmit antennas increase. This is expected as intra-cell interference increases with the number of transmit antennas, resulting in higher transmission energy to maintain the same SINR. However, by appropriate [7] application of MIMO techniques energy savings can be seen. When the number of mobile users is large enough, performance evaluation results show that a five-fold energy reduction can be achieved by multi-user MIMO through employing appropriate link adaptation and resource scheduling approaches compared to a SFBC system.

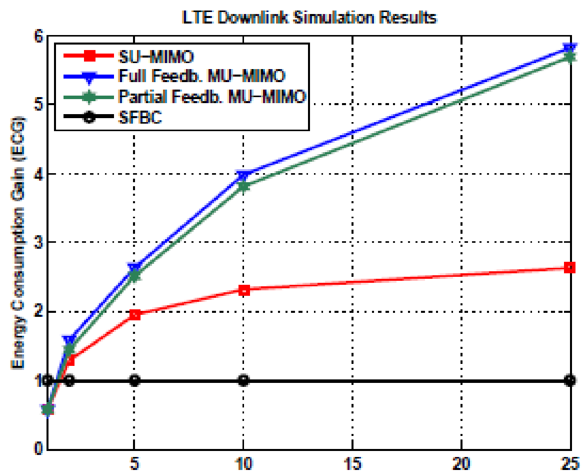


Figure 8 : LTE Downlink Simulation Results[7]

In the last 5 years the standardisation of 3GPP and IEEE technologies has continued to adopt MIMO techniques primarily driven by the need for System and Area spectral efficiency gains; LTE Advanced is now adopting 8x8 configurations. The new frontier that is yet to be fully explored in the standards is network-MIMO techniques (generally called Co-operative multi-point process; CoMP) that move beyond base station to mobile techniques to encompass co-operative paradigms. Whilst these techniques look promising it is already apparent that to achieve system gains will require reduced delays in passing of lower layer MAC/PHY data between RBS.

Radio Resource Management (RRM) is a system level approach, controlling parameters such as transmit power, channel allocation, data rates, handover criteria, modulation schemes, error coding scheme, etc. The objective is to utilise the limited radio spectrum resources and radio network infrastructure as efficiently as possible; traditionally RRM does not consider system energy efficiency but it can be enhanced to encompass this aspect.

From an energy saving point of view, a low order modulation scheme generally requires less transmit power, to maintain a specific link quality requirement, power-aware link adaptation strategies can help to improve energy efficiency by adapting the most energy-saving transmission mode according to the current quality of a channel.

Both MIMO and RRM techniques offer potential for energy saving that is worthy of further consideration and are assigned as priority for further consideration in 2011 in the Wireless Technologies and Spectrum working group.

6.2 Energy scavenging technologies

A proportion of the energy of a system is expended in the provision of the functionality to transmit the information. However, there is a significant proportion of energy “wasted” as heat. Projects, such as OperaNET, have explored the possibilities of recovering and recycling that heat energy. Results [8] have shown that through the Peltier effect and the appropriate temperature gradient electrical power is generated. Energy scavenging is now quite common place in the powering of wireless sensor nodes for industrial and commercial applications.

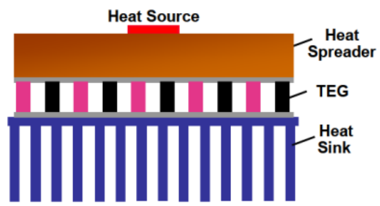


Figure 9: Thermoelectric energy scavenging module [8]

6.3 Digital Processing and Software Defined Radio

6.3.1 Baseband: Moore’s law no longer giving the same gains

The evolution of radio access standard continues to increase the requirements for processing power on both the Mobile Device and RBS.

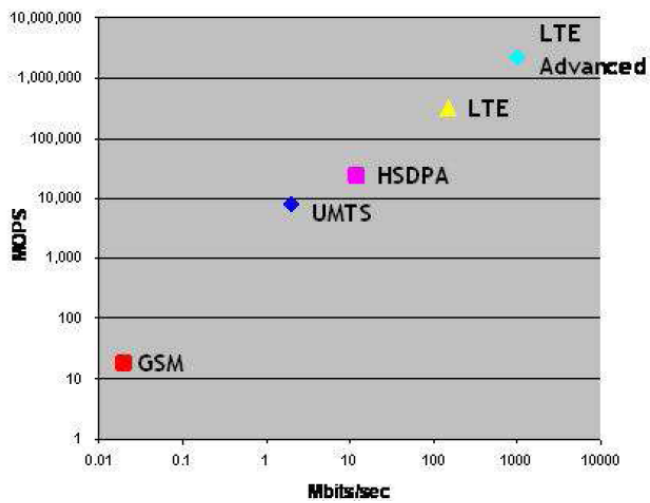


Figure 10: The continued growth in MOPS to realise new Radio Technologies (source Tensilica)

These increases can be attributed to a number of factors; increased throughput, higher algorithmic complexity due to MIMO and interference management techniques, the consequent trend is shown in Figure 10. A typical processing chain is shown in Figure 11.

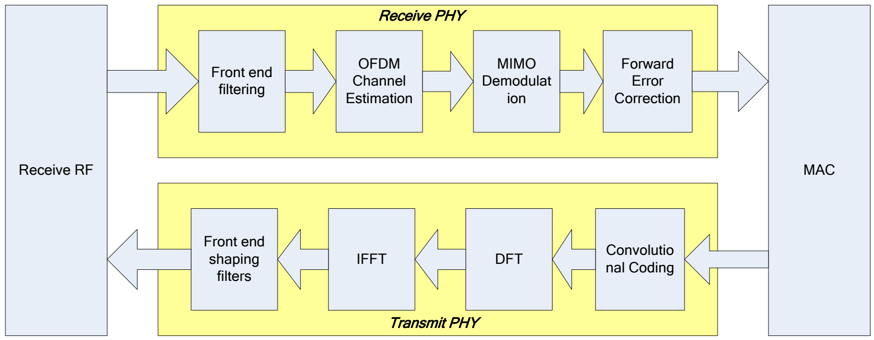


Figure 11: Typical BB processing chain

Meeting higher computation requirements by increase of processor clock speed alone is not feasible. The trend has been for the reduction in the node geometry of semi-conductors to enable higher clock speeds and also lower power consumption. However current technologies are pushing the limits and effects such as leakage and switching uncertainty are increasing the demand for an alternative approach of multi-core processing solutions.

Industry leaders such as Ottelini of Intel made statements in the early 2000s that signalled a trend towards multi-core processors, projections [2] show that future generations may offer thousands of cores. Not only in the classic x86 architecture, but also in the more typical architectures used in baseband processing of RBS; companies such as picoChip, TI and Freescale increase their multi-core offerings. SIMD and vector processing architectures are now common place in handsets with Tensilica, Infineon. Multi-core architectures provide a challenge in terms of development of software that can fully utilise their potential. There are a number of techniques to design parallel software; extracting parallelism from the code or starting from a parallel description of the code at the start of development.

The R&D groups of Freescale Europe, working in partnership with Criticalblue, are developing single chip base station solutions leveraging the latest multi-core processors platforms. It is now possible to implement a significant part of the signal and control processing of an RBS on a single System on a chip (SoC). Such a level of gate integration in combination with smart multi-core programming continues to push the envelope of lower power components that are available to Systems developers.

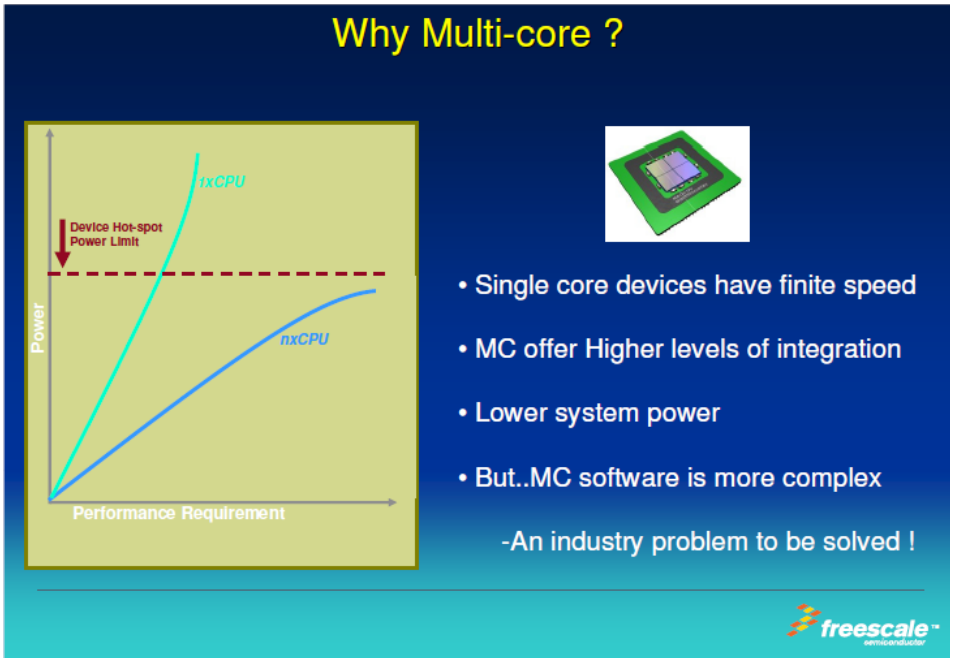


Figure 12: The need for multi-core solutions [12] (source Freescale Europe)

6.3.2 Software Defined Radio

SDR is an attractive technique for new baseband designs for both handsets and base stations. Many base stations already use techniques on the SDR[4] scale for implemented in silicon platforms such as the picoChip "picoarray" but until recently processor platforms and VLSI technology have not provided the right combination of "power / performance / silicon area" to be suitable for handsets. As VLSI geometry has shrunk, clock speeds increased, and with new multi- and parallel-processing techniques, fully-programmable baseband processor systems are now viable for handsets. (Though all the numeric baseband processing can be undertaken in software however, the radio front-end still requires analogue processing, so it is perhaps more appropriate to use the term "software-defined modem (SDM)" rather than SDR.)

SDM can potentially save power compared to conventional ASIC solutions, for two reasons. First, hardware processing solutions tend to be somewhat inflexible and are designed for the worst-case modulation and coding complexity and channel conditions. Often a much less complex modulation and coding scheme may be in use; and channel conditions may be much more benign (for example close to a base station). A software-implemented process can take advantage of these situations, taking fewer processor cycles to demodulate and decode a

[4] The Wireless Innovation Forum has defined five tiers of solutions; hardware radio, software-controlled radio, software-defined radio (SDR), ideal SWR, and ultimate SWR [http://www.wirelessinnovation.org/page/Cognitive_Radio_Architecture].

given amount of data and so saving power. Second, all handset baseband circuits today have to be multi-mode and support not just the latest version of the most complex standard but all the legacy standards still in use in the networks. Where hardware implementations are used all the legacy hardware uses extra silicon area and consumes leakage current – with SDM though, multiple modes re-use the same computing hardware running alternate software.

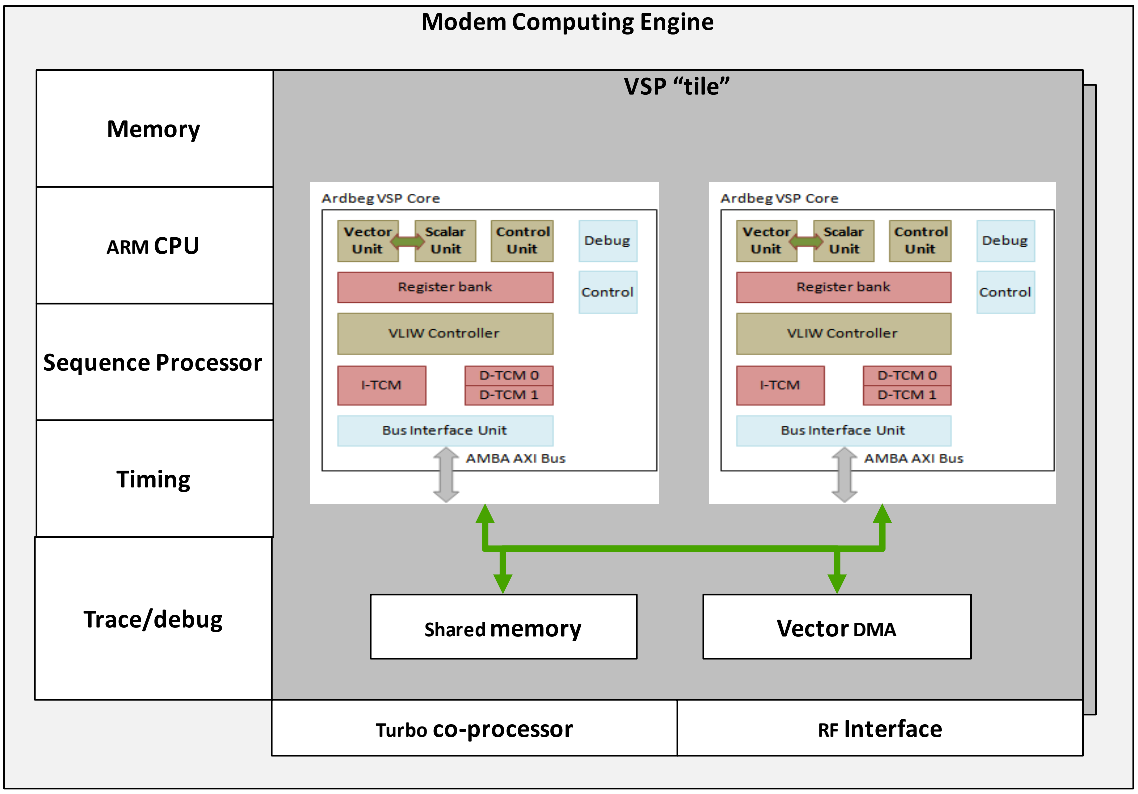


Figure 13: SDM architecture (source Cognovo)

Cognovo is an example of a UK company taking to market through IP licensing a vector processor technology, originally developed in ARM (a Cognovo investor), which the company is augmenting with specific hardware and software to produce a platform for Software Defined Modems. The product is aimed initially at wireless user equipment (though also applicable in small base stations).

Figure 13 shows the architecture of the Cognovo system, which combines a variable number of processing "tiles" each with two vector cores, with control and scheduling fabric. The number of tiles can be increased for more complex standards, from a single tile for LTE through 3 tiles for LTE-Advance.

Another benefit of SDM for future devices is the flexibility it will bring to realise many radio standards in several bands in the same device (given that the radio front-end technology can be provided). One can envisage a tablet-style device that could use any combination of for example, white-space, LTE, HSPA, GSM, WiFi, WiMax, and broadcast technologies, over a wide frequency band, depending on the use case and location from time to time, using only a single radio communications adapter that can switch mode almost instantaneously.

An important class of wireless device in future will be the modem embedded in another piece of equipment to support "M2M" communications. The industry forecasts 50 billion connected devices by 2020, and many of their applications will be fundamental to saving energy through applications such as smart metering and energy control. Compared with today's cellular handset these modems will have a very long life – up to 20 years or more compared to 12 – 18 months. SDM may also play a key role here, allowing the devices to be initially configured for a variety of wireless interfaces and upgraded during their operating life by downloading appropriate software. Extending the life of radio platforms will lead to a reduction of Embodied Energy.

Ultimately solutions that tend towards Software Radio (SWR) may emerge; however this requires integration of RF processing, in the meantime RF front end filtering is necessary. RF front end filtering can introduce significant insertion loss; as a consequence of the requirement to reject unwanted signal energy on the receive path and to preserve the spectral mask on the transmit path. Requirements for new band allocations, for example the 700 and 800 MHz bands are particularly onerous.

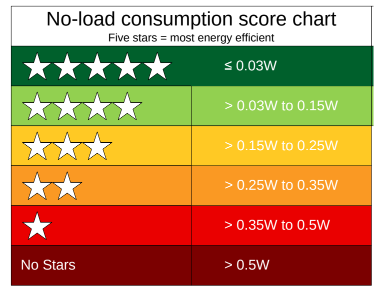
KTN supported studies of the impact of insertion loss, impact on energy efficiency of systems and feasible solutions would be beneficial.

6.4 Power supply efficiency and chargers

Mobile phones spend the vast majority of their life in our pockets or on our desks, far away from the charger that is used to re-charge the battery. Whilst cost is a prerequisite, users want phones charged as quickly and safely as possible whilst maintaining battery life, so the charger has to provide a well controlled charging current often described as Constant Current Charge mode (CC).

To meet the tight CC requirement with a Switched Mode Power Supply is generally achieved by the use of secondary feedback techniques using optocouplers and references; however, now we see the introduction of Primary Side Sensing controllers that eliminate secondary side components while maintaining the required CC performance.

When a charger remains connected to the mains whilst not utilised it enters a 'No Load condition'. The power supply however is still running as it needs to be providing a small amount of output voltage so it can detect the connection to a phone to enable it to rapidly enter its CC mode of operation. In this 'No Load 'condition the input power, referred to as No Load Power (NLP) is wasted and should be kept to a minimum. A score chart has been developed where the number of stars indicates how low the NLP of a charger is.



Cambridge Semiconductor offers a number of devices that achieve 5-star performance, by slowing down the controller's switching frequency. If the switching frequency becomes too slow then the time to detect and react to the re-connection of a phone becomes too long (seconds perhaps) and the voltage dip falls too low, the charge control IC within the battery pack detects a fault and shuts down, leading to failure to charge the battery.

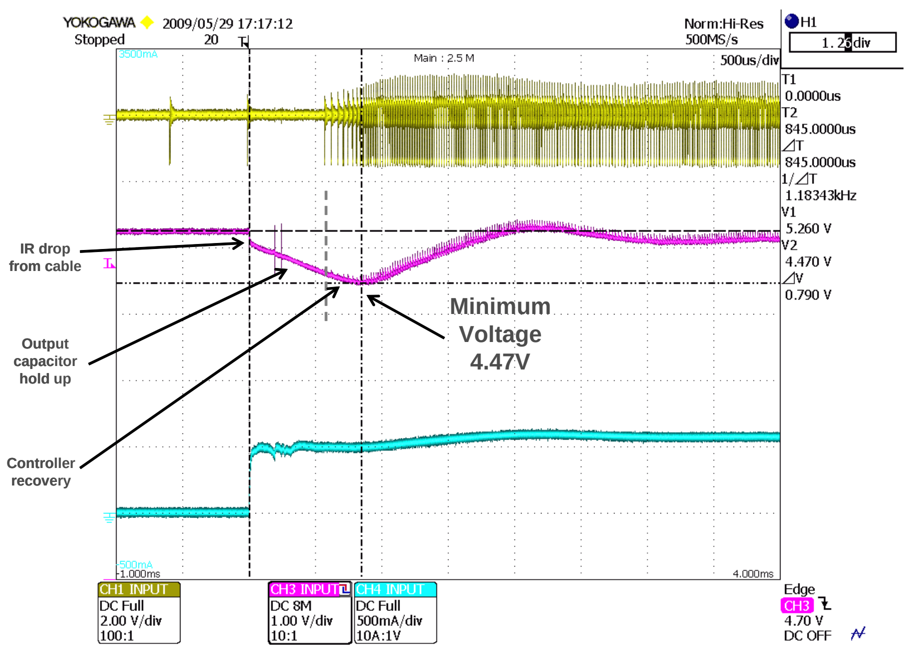


Figure 14: Transient Performance of a Power supply with a CamSemi controller (source Cambridge Semiconductor)

The figure shows an oscilloscope trace of the waveforms that describe the Transient Performance of a power supply using such a controller technique. The top trace is the switching frequency of the power supply and as can be seen to the left of the trace the distance between pulses is long. This ensures good NLP. The bottom trace is the current drawn from the supply when the phone with a discharged battery is connected, the increase in demand being instant. The middle trace shows the effect on voltage and this kept to a minimum.

Whilst the charger techniques described are specific to the charger domain there is in fact an analogous situation with the femtocell or any other small cell radio equipment. When users are not using the services of the femtocell (or the charger) they expect the device to sleep and consume no background power, solutions will have to emerge with these consumer expectations in mind.

7 Individual cell site deployment and optimisation

The classic RBS is deployed for operation in a location where it will be integrated with power supply, climate control, mast, antenna systems. The term cell site refers to the locality of installation of Radio Base station equipment and ancillary equipment, a logical depiction of which is shown below.

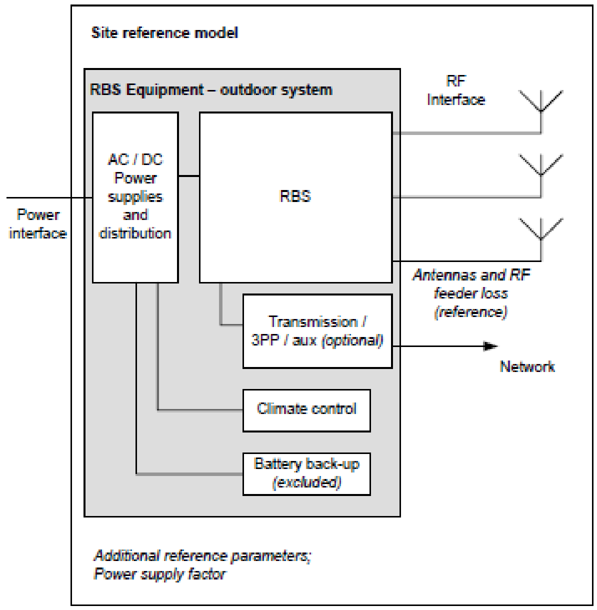


Figure 15: Base station Site Model (source ETSI EE)

7.1 RBS platforms

There are numerous platforms that are offered by the RBS vendor community to support the evolution of networks. The RBS platforms may be loosely classified as Macro (classic and distributed) and small cell (femtocell, micro, pico). The Macro classic generally comprises of the complete base station along with mast and high power amplifier and antennas. However, the RBS component of a Cell site may be modified in such a way to effectively distribute the cell site components over a wider geographic location. Distributed Antenna Systems (DAS) utilising Radio over Fibre have been deployed in the US and Japan since the deployments of 2nd generation systems. During the development of 3rd Generation systems there has been the development of standardised digital IQ sample transport interfaces between power amplifier stages and the Baseband with interfaces such as CPRI and OBSAI. Common Public Radio Interface (CPRI) [http://www.cpri.info/]. CPRI has been adopted by the recently established ETSI ORI technical group. Such approaches enable distributed RBS architectures. By virtue of the removal of RF feeder cables losses are removed. The opportunity to distribute the RRH optimally to achieve more energy efficient deployments by placing the RRH closer to high traffic areas is available.

7.1.1 Remote radio heads – PA and Antenna integration

One further integration step is to include the PA stages within the antenna enclosure itself. These concepts have been under development for some time now. The challenge of engineering such components to tolerate typical environmental conditions and achieve the expected MTBF should not be under estimated. Retrofitting RRH and heavier antenna arrays (for features such as MIMO) on existing cell site towers may not be mechanically or economically feasible if significant site/mast CAPEX is required. However, as the pressure increases to deploy high capacity solutions in dense urban environments, where less exposed antenna deployments can be envisaged these architectural features will find a larger market. Figure 16 shows a prototype developed by ACE WTL R&D groups based in the UK[5].

Figure 16: Prototype of antenna with integrated PA elements

The small cell platforms that typically support 5 to 10s of users in single cell deployments are micro/pico. Femtocell integrates some higher layer protocol functionality into the platform and may be deployed in homes and now increasingly in dense urban like environments with typical user capacity in the order of 8 to 30. Whilst from a capacity perspective small cell platforms may be similar, there are a multitude of backhaul options.

7.2 Air conditioning

One of the key challenges when deploying highly integrated technology RBS platforms is the management of heat generated by the technology. Although there is a trend towards base stations that are smaller [9] and therefore may not

[5] Formerly part of Nortel R&D, the group based in Harlow now trades as Wireless Technology Laboratories Limited (WTL), a subsidiary of Ace Technologies Corporation, demonstrating a recognised R&D competence in the UK that is sustained despite the change of parent company.

require complex cooling solutions there are still a significant proportion of cell site deployments where innovation in cooling solutions can save significant amounts of energy that may be required for forced air/air conditioning. Companies such as 4Energy offer solutions addressing this area.

7.3 Energy Harvesting: RBS and cell site power sources

The supply of power to the RBS in particular in off-grid scenarios may be a significant challenge. As the user base become increasingly accustomed to mobile phone usage there is less tolerance for loss of service; even in rural Africa regions there are now good examples of mobile phones starting to facilitate financial transactions (replacing cash), as such services penetrate the market, loss of service becomes far less acceptable.

Traditionally base stations in off-grid deployments have been powered by diesel generators. The incidents of generator failure and fuel theft have driven an increased level of development of solutions to this problem in recent years.

When positioning a cell site there is a micro-climate around the location that once appropriately characterised lends itself to an optimal blend of generator, photovoltaic and wind sources. These sources need to be blended together and managed to provide constant source of power to the RBS. Companies such as PowerOasis provide such solutions.

Recently the GSM Association has announced projects to provide off-grid solution cell sites in developing country rural areas and provision power to the local community using the cell site infrastructure as a micro-generation facility.

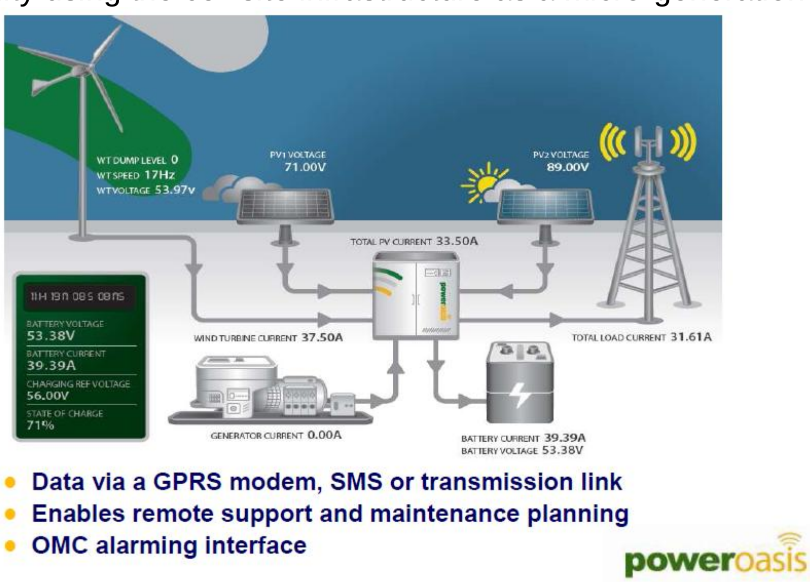


Figure 17: Power source blending (source PowerOasis)

The market interest in alternative energy sources for cell sites is resulting in the creation of solutions such as the powercube from Diverse Energy that generates power from readily-available anhydrous ammonia, a bulk agricultural feedstock.

As the trend of cell deployment moves towards small cells wireless access points, small hubs and routers for connectivity will increase. Without careful attention to the efficiency of such solutions the ambient power levels of networks are in danger of increasing significantly. As such equipment is generally 'static', the input voltage is determined by which country the modem is going to be used in and therefore are commonly known as 'single rail' ie, 110 Vac or 230 Vac input and during use, the power supply as powering the system.

Traditionally these devices have been powered by Linear 'Iron Cored' power supplies which have a high copper and steel content, weigh a considerable amount and from an electrical standpoint are hugely inefficient, indeed more than half the power transferred through these types of power supplies can be lost in the form of heat generation alone. Linear power supplies however have for some time been the cheapest solution but due to rising commodity prices and a more aware public, the market has been pushing for a more efficient solution. Technologies such as Resonant Discontinuous Forward Converter (RDFC) (developed by Cambridge Semiconductor) enable a compact, highly efficient, light weight alternative to the typical Linear power supply approach.

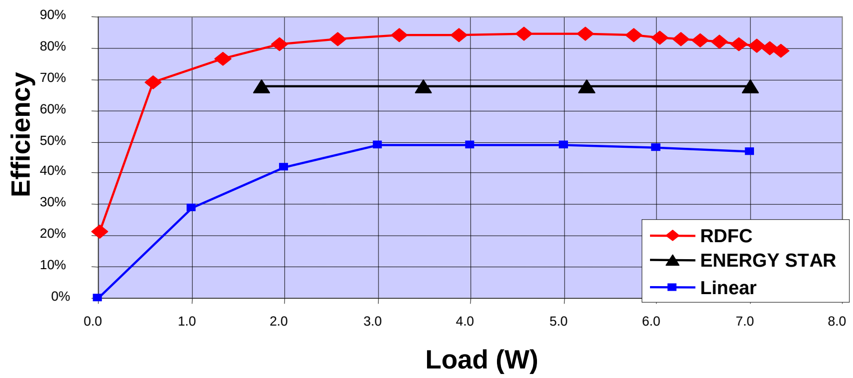


Figure 18: Linear and RDFC efficiency comparison (Cambridge Semiconductors)

Figure 18 shows a comparison of power supply efficiency across the whole operating range of the equipment for both the Linear and RDFC solutions against the Energy Star recommendations.

7.3.1 Case Study: Energy harvesting for reduced CAPEX payback duration

A good example of innovative approaches at the boundary between energy generation and energy consumption for service provision is the trials and subsequent commercial rollout of solutions in Telefonica/O2 Ireland.

Figure 19: O2 Telefonica energy harvesting example

By fitting smart metering technology that enables the locally generated power to be fed into the grid the cell site owner is in a position to balance the economics of the site. Studies have shown that a payback of 3 years is feasible for such deployments.

7.3.2 Case Study: Energy Harvesting for Rural Broadband

There is significant opportunity to bring broadband connectivity not only to developing markets through Energy harvesting but even closer to home in the UK the deployment flexibility offered by not having to be tied to installed power grid can enable both backhaul and access provision. Steepest Ascent has deployed connectivity to the Island of Bute through such techniques.

Figure 20: Steepest Ascent, energy harvesting for rural broadband

8 Physical network topologies

The opportunities for improvement of energy efficiency afforded by considering optimal deployment of cell sites and appropriate selection of technologies are significant. The trend towards small cell platforms to address area spectral efficiency is a promising trend that if managed appropriately should also result in more efficient delivery of data.

8.1 Small 'vs' Large cell trade offs

Regardless of the radio access technology it is still possible to derive some network design guidelines that should be followed to optimise for energy efficiency. An aspect that is intuitively necessary is the shrinkage of cell size as this reduces the wireless link hop length and thus reduces RF energy per bit.

The results of a short study [16] to demonstrate that the Energy Consumption Rate (ECR - Joules per bit carried) is indeed a function of the cell size and analysed an architecture that only reduced the cell sizes and an architecture that reduced cell sizes and introduced **sleep modes**. Sleep modes as a term are used to describe any partial or complete switching off of equipment. The area Spectral Efficiency is increased by the reduction of cell size i.e. increased number of small cells. The Energy Consumption Gain (ECG) applies to the RAN and measures the relative RAN energy consumption between two deployments for the same user density and service area. Introduction of the capability to sleep cells reduces the ECR and increases the ECG, at the expense of area Spectral Efficiency.

The trade off between spectral efficiency and energy efficiency is not a simple matter and will challenge network optimisation automation. Previous work in the DCKTN has articulated some benefits of deploying more spectrally efficient wireless technologies. Studies [17] have shown that by appropriate tuning of network cell sizes a 200 times improvement in the capacity density (Mbps/km^2) can be achieved, but could we also see net energy efficiency gains.

The analysis [18] of small cell deployments in a heterogeneous environment indicates that an optimum point for energy efficiency of a network can be determined. Combining of the macro for area coverage and small cell where the capacity demand exists (typically residential or enterprise) may show a power consumption reduction by up to 60% compared to a network with macro-cells only, this point is reached when around 20% of all customers have picocells deployed.

This analysis has been extended to broaden the definition of the energy system under consideration to encompass embodied energy of mobile devices and access nodes [19]. Consideration of operational life of macro, handset and femto along with optimisation for an expected QoS requirement shows 20% to 60% optimal deployment of small cell. Sensitivity analysis of the results show significant influences by operator market share, spectrum allocation, femtocell uptake, the capacity of femtocells, operational and embodied energy.

Whilst these studies show small cells may benefit an operator in both capacity and energy efficiency the approach to interference management and backhaul is critical [20]. The research and standards community can be seen to be addressing the heterogeneous network interference management challenges today; there is opportunity here for further work to deliver on optimisation of QoS, capacity density and energy efficiency benefits. Approaches to backhaul are already understood to be critical to the success of small cell; bringing energy efficiency as criteria, for network design adds to the challenge.

8.2 Backhaul technologies

There are a large number of backhaul options available for connecting the RBS to the core.

Technology	E1 PDH	Fibre Ethernet	Copper Ethernet	ADSL	VDSL	FTTP
Typical rate (Mbit/s)	2	>100	10	8	15	>100

The approach that has been adopted by Ethernet IEEE 802.3az (or Energy Efficient Ethernet) is worth noting. There are primarily two techniques that have been employed.

- A detection of link status, this allows each port on the switch to power down into a standby or ‘sleep’ mode when a connected device is not active.
- A detection of cable length and appropriate adjustment of power.

8.2.1 Mesh and relay technologies

Whilst it is highly likely that backhaul will continue to evolve to improve energy efficiency the options for wireless backhaul are of particular interest. Both relay and mesh like topologies should be considered.

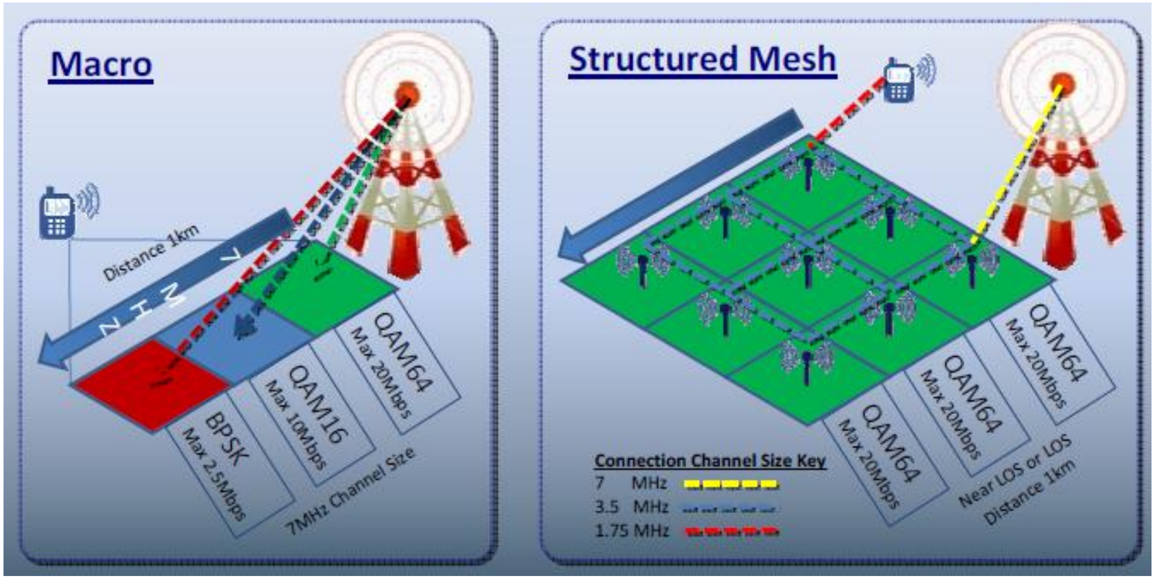


Figure 21: Structured Mesh compared to classic macro (source Airbourne Networks)

The mesh employs the basic principles that are inherent in small cell topologies. Placing access points physically closer to the end user reducing transmit and receive power. In studies and proof of concept activities Airbourne Networks claim to have demonstrated that for a small city with a population of 10,000 and a mesh coverage area of 1-2sqkm, 5000 people are connected to the network using lower power than would be the case with typical macro RBS deployments, resulting in a 40% reduction in CO2 footprint.

8.3 Antenna related techniques

Having established the energy efficiency advantages of small cell, studies have moved on to address how antenna tilt may further improve efficiency [22]. The conclusions of the study were that excessive downward tilt will increase the transmission power while increasing the average throughput in the cell. The shallower antenna tilts decrease the transmission power significantly; however, pointing of the antenna beam towards the cell edge leads to significant average throughput losses.

The above findings illustrate the principles that should be observed for the saving of RF power. However the mechanisms for tilt of antenna may introduce power consumption elsewhere in the system. Solutions from companies such as Quintel offer a platform that requires no moving or active parts and thus in the antenna component of the system we may not see increased power. There is potentially increased processing in the Baseband.

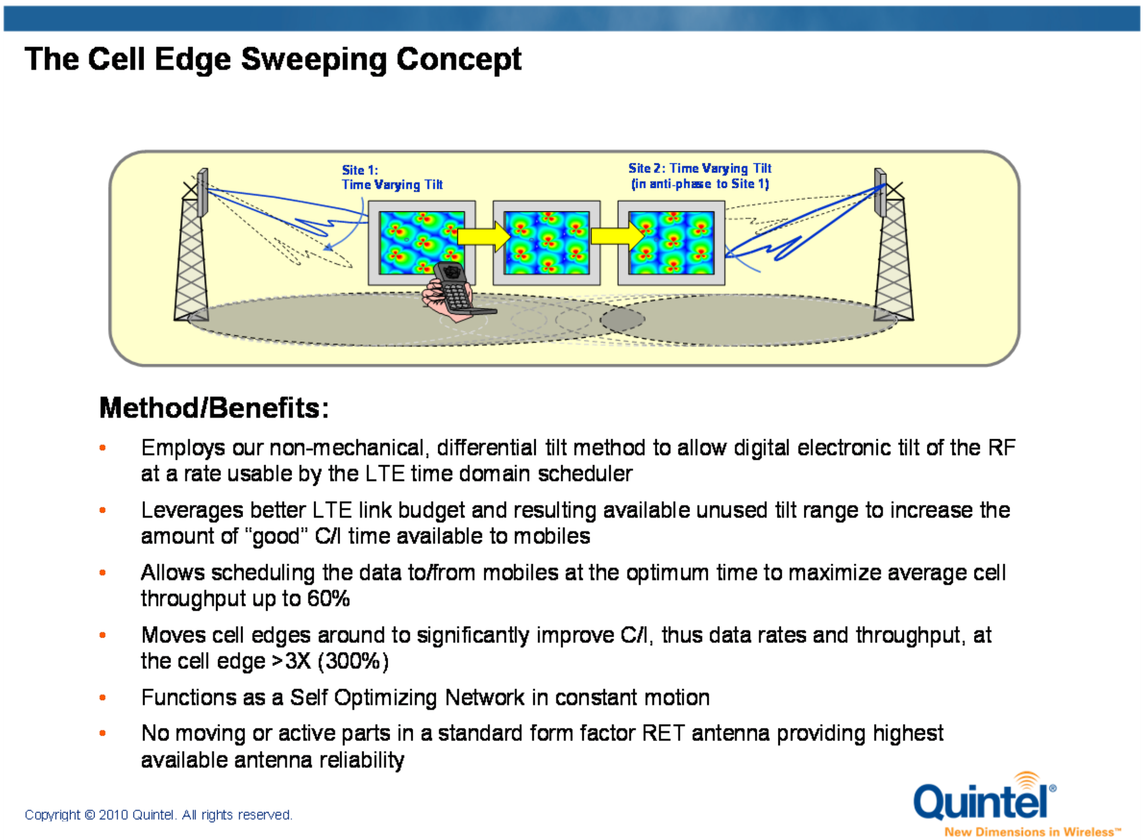


Figure 22: Antenna beam tilt technology (source Quintel) [23]

Considering the relay or mobile device perspective the ability to steer a higher gain beam again offers the potential to have an energy efficient wireless connectivity. Deltenna has developed a device that can significantly extend the reach of cellular wireless networks towards rural areas, however it may also be used in more dense deployments to provide indoor coverage and is potentially more energy efficient than an ADSL connected device.

Figure 23: Base station selection through high gain intelligent antenna (source Deltenna) [24]

8.4 Network sharing and virtualisation

Mobile Broadband Networks Ltd (MBNL) recently announced the completion of the network sharing project across Everything Everywhere and 3UK networks. This project is the largest of its type globally; with the MBNL network consisting of over 12,000 sites. The belief that sharing of network infrastructure is an energy efficient approach prevails within the Green lobby [6], the merits of such approaches can be acknowledged; however, they should not be over emphasised at the expense of other considerations.

A key enabling component of the MBNL sharing mechanism was the combiner (supplied by Radio Design). The combiner allowed each operator to have their own RF module but then combined onto a common antenna system. The combiner is low loss in both UL and DL minimising wasted energy and allows for compact shared site designs where some RBS modules are shared and all of the air conditioning is shared. Alternatives to the combiner are 3dB hybrid combiners that will waste at least half the input power

Technology sharing is also enabled by such approaches (Figure 24) allowing the overlay of a new technology on a existing site; therefore the life of the existing RBS is extended and new antennas are not required for the new technology.

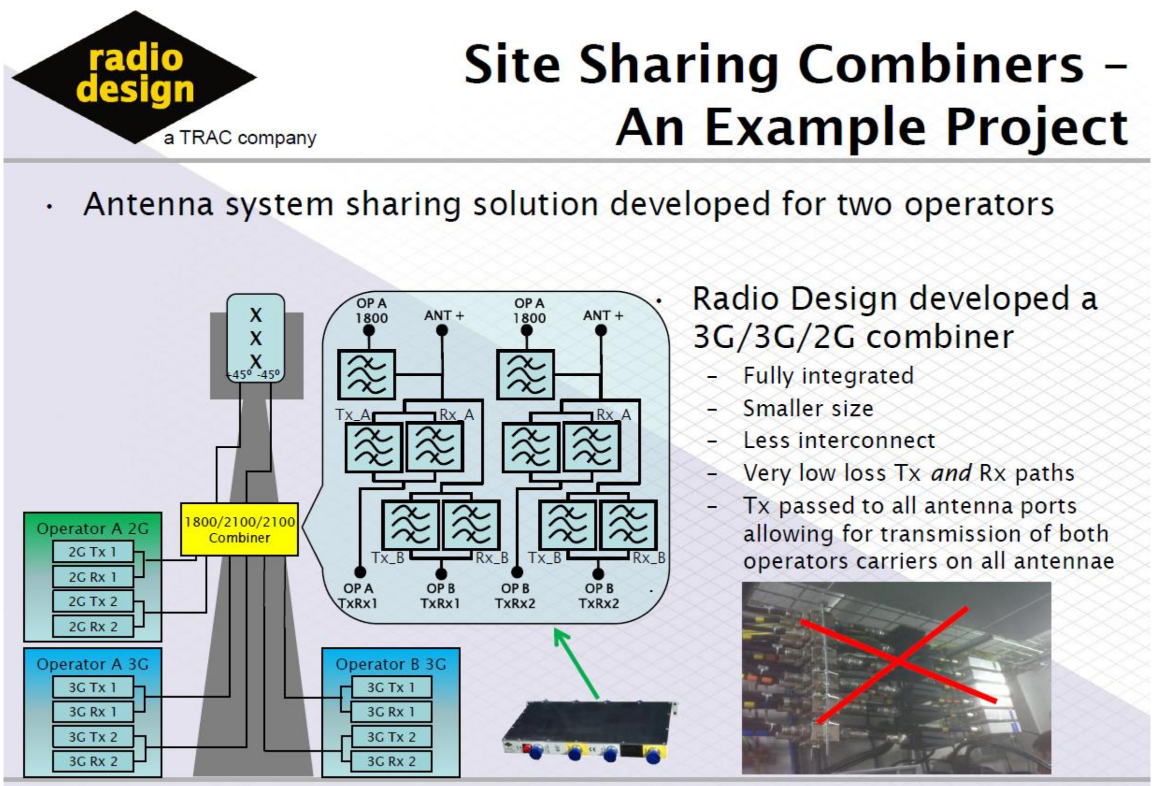


Figure 24: An illustration of cell site sharing (Source Radio Design)

The criteria for network sharing are far broader than energy efficiency. To achieve truly optimal energy efficient network sharing the planning should aim to achieve the optimal balance between coverage, capacity and energy efficiency.

9 Service provision topologies

The paradigm of sharing offers an increased profile to the concept of wholesale networks, where the network infrastructure offers a service to both mobile device and multiple service providers (MVNOs). The roadmap towards wideband systems is apparent through the IMT-Advanced activities with in parallel a continuing pressure for Operators to divest their costs for management of network equipment.

9.1 Traffic shaping / management / spectrum balancing: delivery decision on bandwidth and energy

The drive to wideband Systems to meet the ITU requirements for IMT-Advanced has resulted in standards such as 3GPP Rel10 (LTE-Advanced) having a highly scalable approach to spectrum allocation across a total system bandwidth of 100MHz. There are now concepts of multiple component carriers (20MHz) that are sub-dividable into different bandwidths, and non-contiguous spectrum band component carriers meaning an LTE-Advanced system could span a significant chunk of spectrum. Taken in combination with the re-allocation of GSM, UMTS, and LTE over time the opportunity to optimise the spectrum utilisation seems significant.

By applying spectrum balancing techniques significant improvements in the energy efficiency of the system can be expected, these techniques are particularly effective at reducing energy consumption when the network is experiencing lower traffic load as an inverse of Load Balancing can be executed to optimally load cells at appropriate frequencies.

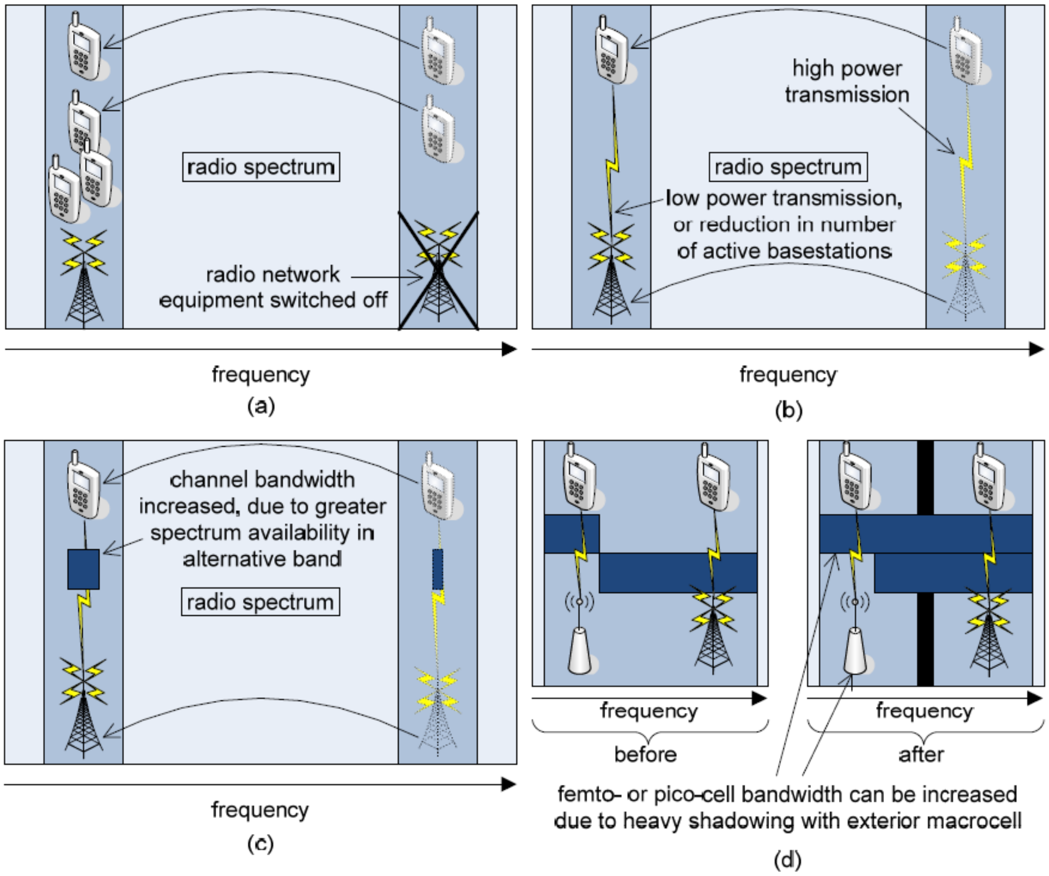


Figure 25: Spectrum Balancing Technique (source MVCE) [25]

Whilst these concepts show a potentially significant power saving, some practicalities should be considered.

In some regions requirements are emerging to support seamless voice inter RAT handovers. To achieve such functionality channel quality information may need to be acquired from at least two and potentially multiple channels, which could be any mix of GSM, HSPA, LTE. Each of these standards has a different modulation and spectral shape, leading to the need to have TX/RX exchange with multiple physical layers in multiple bands. The difficulty of achieving such a requirement should not be underestimated. **A multi band multi mode power amplifier that is also power efficiency is a significant challenge.**

Wider band channels, for example 10 or 20 MHz may create more inter-modulation products than narrow band channels. This may be a symptom of the signal shaping performed at base band, possibly less optimum in the wider channel leading to a less disciplined spectral mask once the signal is amplified by the mobile device PA.

9.2 Traffic type considerations

Whilst the need to provide technologies to address the high growth in data for mobile internet/broadband applications are clear, the need to support legacy systems and use cases and the ability to continue to evolve them towards more energy efficient techniques is necessary. An example of this would be VAMOS [10] for GSM; GSM still carries a majority of mobile voice. VAMOS (Voice services over Adaptive Multi-user channels on One Slot) is an evolution of GSM that allows the same capacity with fewer RF carriers being exercised. Legacy terminals will operate with a VAMOS solution however once VAMOS enabled terminals are available, halving of the number of RF carriers is possible thus reducing power consumption. VAMOS is a good example of where a combined approach at component and system levels is likely to lead to more efficient networks and extended life of equipment for reductions in embodied energy in the industry.

The trend now however is towards broadband IP based systems. If a system were to transport uncompressed IP packets the link efficiency would be poor, potentially 60% sub-optimal in the case of IPv6. To cater for this, 3GPP has developed techniques such as Robust Header Compression (ROHC) that are employed to strip out information surplus to requirements when transporting IP packets over the wireless link. Unfortunately although efficient hardware can be employed to support ROHC this does consume more power.

Processing of a narrow band signal (~12 kbps for voice) within a wide band (10 or 20 MHz) channel potentially introduces inefficiencies. A base band processor may have to work disproportionately harder in the wider band channel. Typically techniques are employed to narrow the radio resource over which such narrow band signals are carried. Nevertheless, **future generation parallel processors and sound cross layer design are required to achieve an optimal performance.**

In the Over-The-Top (OTT) applications domain companies such as Skype and Facebook, embed voice within their web-based applications. These services are not using voice transport native to the radio standard. As these applications go mobile the inefficiencies will impact on energy efficiency.

9.3 SONs and dynamic radio management

Automation of networks continues to be adopted and at a growing pace as Operators drive down their Operations costs in the face of increasingly complex networks.

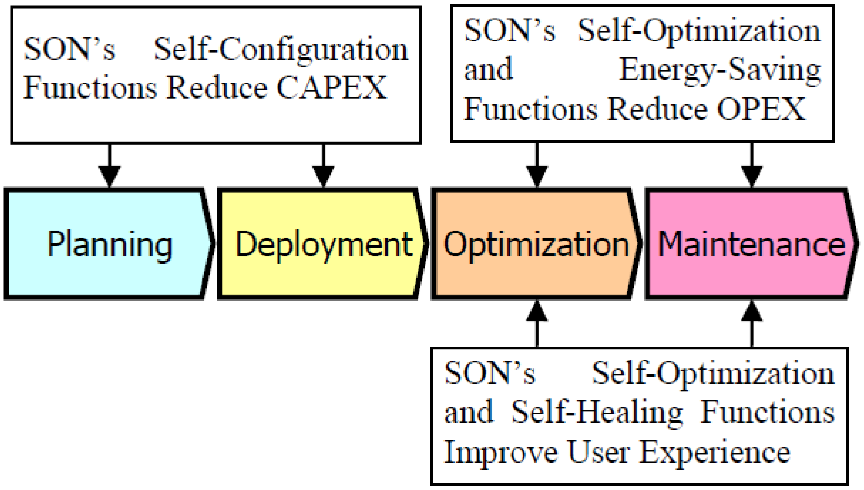


Figure 26: SON impact at key stages of network introduction (Source NEC)

Appropriate modelling of expected power consumption at the time of deployment along with the standard coverage/link budget related considerations will grow in popularity.

When considering the Optimisation of networks and the introduction of overlay/heterogeneous scenarios the possibility to leverage data gathered by mobile devices to build an intelligent picture is beneficial.

A study by Arieso to determine the optimal placement of small cell platforms for improved in-building coverage demonstrates the value of gathering geo-location data of the users to determine the mobile device location when experiencing performance loss. Leveraging this data enables optimisation of the network including improving the siting of new cell sites.

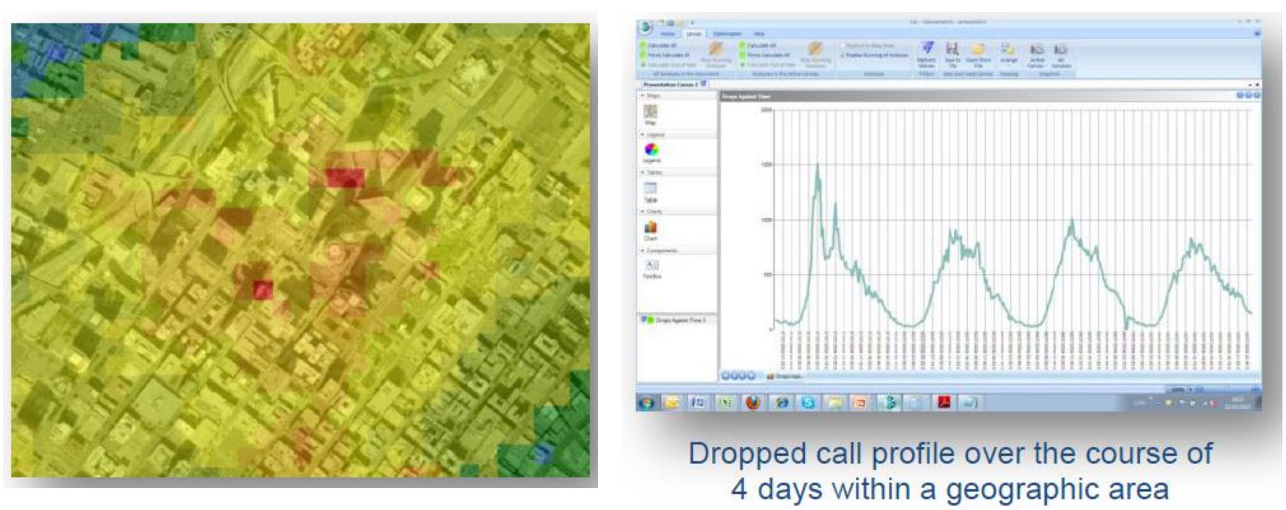


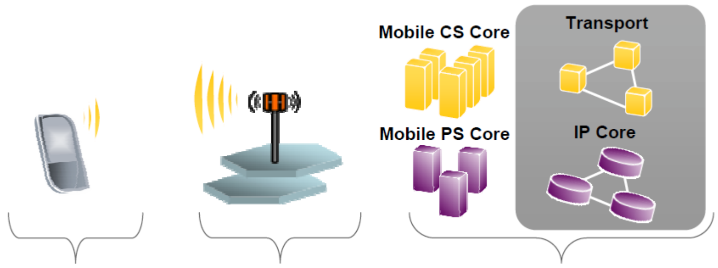
Figure 27: Hot spot mapping though geo-location and call drops (source Arieso)

This mobile device centric network optimisation paradigm can offer several potential benefits:

- Drive testing reduction of 50% over what typically would be required.
- Determining the optimal location for smaller cells as a result of knowing where the users are when they access services.
- Once Operators know where small cells are most needed the possibility of pushing (subsidised) deployments is a realistic prospect rather than expecting users to pull (=buy) small cell platforms.

10 Future network evolution

The majority of this paper has focussed on the Radio Access Network, studies have shown that today it is still the case that the number of RBS deployed (and the number deployed is only set to increase as small cell sizes are introduced) consume the majority of the power per user when considering such services as voice.



Typical power consumption per active element	1 W	500-1500 W	11000 W
Typical power consumption during a voice call	1 W	3-30 W	1 W

- The high number of base stations compared to core elements make them by far the largest energy consumer in mobile networks.

Figure 28 : Nokia Siemens Network study result for typical power consumption

However if we were to dig deeper into the network and consider some of the purely IP based services that are emerging that may draw on Cloud based services how does this balance change? The component of the systems that is likely to play increasing part in future wireless networks energy consumption is backhaul.

10.1 Data centres and cloud services

There are several innovations that have emerged through the need to reduce the energy consumption of data centres to stay within power supply capacity from the grid to the data centre. Now there is another wave of innovation as the awareness of the inefficient nature of typical data centres increases.

It is generally the case that communications systems are designed to maximise the utility of the processing platforms that are available. Studies have shown that in the case of typical server utilisation they operate in the 20% to 40% utilisation zone for a vast majority of the time. When considering the utilisation of a network of data centres it is quite common to spread user data across many databases to eliminate bottlenecks. At the semi-conductor technology level there are similar techniques applied as there are in the communications systems platforms; clock gating, dynamic voltage-frequency scaling.

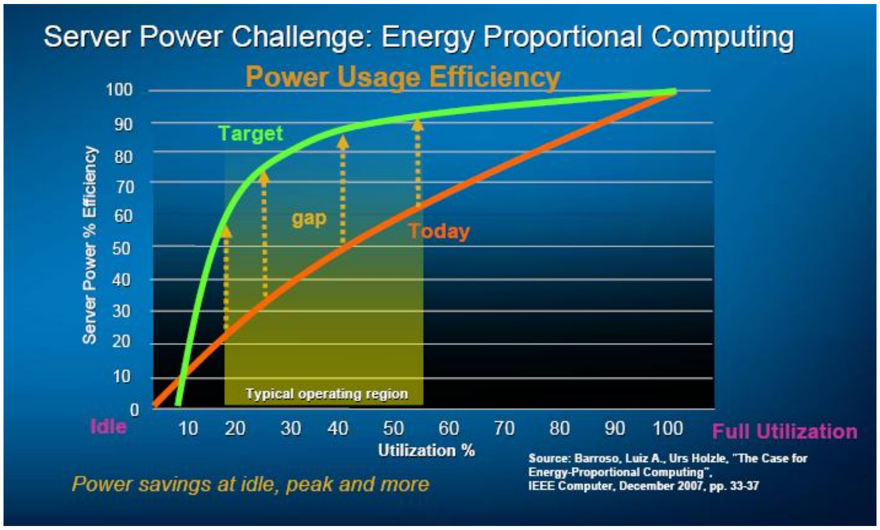


Figure 29: The typical server utilisation and power efficiency [13]

Research has shown [13] that there is a need for energy-proportional machines; where the power consumption is proportional to the activity level. It is now the case that the processor may consume only ~25% of the overall server power. In the age of concepts such as Wireless Network Cloud (WNC) where cloud based acceleration of wireless based services are available, components in the network such as memory (DRAM) and disks (solid state and standard) and their efficiency will play an increasing part.

11 Standards, regulation and policy

We can expect the regulatory framework to develop as a result of increasing interest in the Energy Efficiency of technology. Figure 30 shows the interaction of a number of bodies within the EU context; the European Commission provision of mandates to ETSI with national regulators interacting with the development of standards.

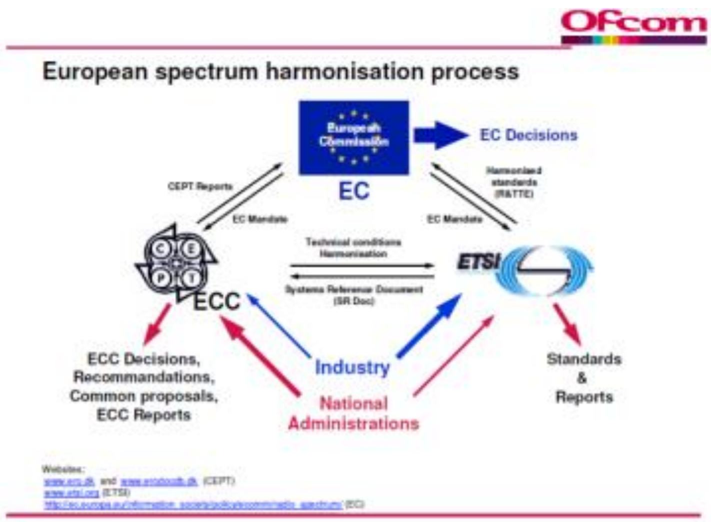
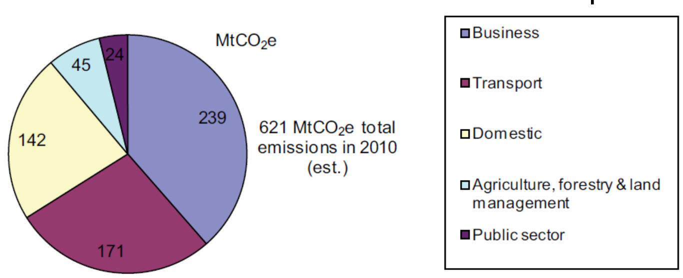


Figure 30: European Spectrum Harmonisation Process

Ofcom's interest in the energy agenda is evident through the commissioning of a comprehensive report [28], which was prompted to some extent by the need for exploration in government of the expect CO2 footprint of the UK. The figure below is reproduced from the introduction section of the report.



UK Greenhouse Gas Emissions by end-user (2010)

(Source: UK Climate Change Programme, HM Government, 2006)

Figure 31: UK Greenhouse gas emissions by end user 2010

Ofcom are not permitted to regulate usage of spectrum on the basis of the energy efficiency of systems. The report highlights the significant benefits of utilising wireless connectivity in end application segments; this may be interpreted as an additional justification for releasing more Radio Spectrum for the wider adoption of wireless platform based services.

The Body of European Regulators for Electronic Communications (BEREC) held its first meeting in Brussels in January 2010. This body, created under the EU telecoms reform legislation passed in 2009, is uniting national telecom regulators of EU member states in a more formal successor to the European Regulators Group. BEREC provides a platform for the regulators to coordinate cross-border policies, share best practices for local markets, study new market developments and advise the European Commission and other EU bodies. BEREC gives opinions on national regulatory measures notified to the EC.

EU directives that are considered significant in the ongoing development of the Energy Efficiency area are M441 (development of an open architecture for utility meters) and M462 (enable efficient energy use in fixed and mobile information and communication networks). M462 is of primary importance. Within the Environmental Engineering Technical Committee which was established over two years ago, well before these mandates, there is already some progress on establishing functional entities of the cell site that need to have power consumption quantification. This is still some way from addressing the energy efficiency networks agenda though.

In preparation for and as a continuing response to the EC Mandates ETSI has established a number of technical groups that seek to create a standards framework for the approach to equipment power management. Starting over 2 years ago the ETSI Environmental Engineering group has published static models [15] of cell sites and the methods that should be used for verification of the power consumption based on traffic load. The same groups now consider a more dynamic model of measurements of traffic giving a more accurate representation of an operational RBS and shall publish requirements in due course.

11.1 Policy to drive technology deployment

The regulatory drivers for Green Radio are directed more by its contribution to overall green policy agendas than any specific initiative. They can be broadly grouped as benefits for the user; benefits for industry and benefits for the wider society.

The drivers for the user space are limited to addressing the energy consumption of consumer equipment; currently this is regulated by means of the Energy Using Equipment (EUP) Directive. The directive, which has been phased in to effect since 2007, provides EU-wide rules for the design of electrical and electronic devices that are intended to significantly improve their energy efficiency, reduce use of hazardous substances and increase ease of recycling. Power supplies and device chargers are included within the scope of the Directive, which sets limits for the power consumption of devices whilst in operation and on standby. Additional to this regulatory approach the Commission has sponsored work in standards and research areas to reduce energy consumption.

Green Radio can benefit industry by making a contribution to reduction in the overall energy budget for companies. There are a number of energy saving schemes that may affect individual companies and sectors. Schemes such as the UK Carbon Reduction Commitment Energy Efficiency Scheme require companies to make significant energy savings commitments. For parts of the Telecommunications industry such as the Mobile Network Operators the use of Green Radio technology and products can make a significant contribution to any energy saving measures.

Overall, the use of Green Radio can make a contribution to any reduction in overall energy usage achieved by the increased use of telecommunications. This has the possibility of delivering real benefits to society as a whole in addition to the primary goal of reducing energy usage. Examples include reducing the numbers of journeys undertaken for business and more locating of businesses more locally as the use of high-bandwidth reliable telecommunications reduces the need for businesses to aggregate in larger towns and cities. Allowing people to work from home more effectively will have an impact in reducing our overall carbon footprint. The major telecommunications tool to help implement this will be fixed broadband but there undoubtedly be a role for radio (mobile, broadband wireless, satellite etc) provided broadband too.

12 Funding green innovation

Companies and entrepreneurs developing novel energy or low carbon technologies in the telecoms space are increasingly being backed by 'Cleantech' venture capitalists that recognise the growing opportunity in this space. This is driven partly by the ICT industry's recent initiatives to address the climate change challenge and partly as a clear recognition that energy is now becoming a material business constraint in expanding the core business of many ICT-related companies.

Investors sometimes categorise potential energy related ICT investments as falling either 1) within the 'direct' energy reduction space (e.g. more efficient rectifiers or cooling technology for a RBS), or 2) as an enabling technology that allows the optimisation of a broad range of systems (e.g. a novel Smart Grid technology that uses wireless communication technologies to allow fridges to shed load at certain times in response to stresses on the national grid). The first category provides a direct opportunity to reduce OPEX for an infrastructure owner although the investment case needs to take into account of potential premium costs on CAPEX. The second category allows intelligence and responsiveness to be brought to systems that historically have been highly inefficient and inflexible in their energy use (Home energy management systems, the electricity grid networks, some logistics chains, data centre rooms etc.). Whilst investor excitement exists for both of these categories, it is probably the second that is currently experiencing the most investor exuberance. This is based on a perceived convergence between ICT and energy efficiency technologies which offer the potential for investments with relatively low capital intensity, but with material scalability and pricing power in large international markets.

The environment for raising venture capital funding for early stage opportunities remains extremely difficult in 2011 for propositions that are still at the pre-revenue or early revenue stage. Specialist Cleantech or energy efficiency investors who have a broad network of industry and technology specific expertise should be the first port of call. Leading investors in this space include Carbon Trust Investments, ETF, Good Energies, or Wheb Ventures. The BVCA (British Venture Capital Association) website also provides a high level list of venture investors and their particular areas of interest as well as guidance documents on how venture capital works.

13 Summary – driving innovation through collaboration

The DCKTN Wireless Technology and Spectrum working group believe we can act as the catalyst for collaboration. The diagram below illustrates the concept of the UK eco-system working together to address major challenges. During the overall activities of the working group in 2010 it has been become clear that new disruptive innovation in RF platforms of Wireless systems, locally and globally, have not progressed for a number of years. The higher level systems and applications have progressed at a far higher rate and therefore it is a key recommendation that significant research effort is put in place to address this balance and provide the opportunity for UK Industry and Academia to take advantage of this opportunity to take a leadership position.

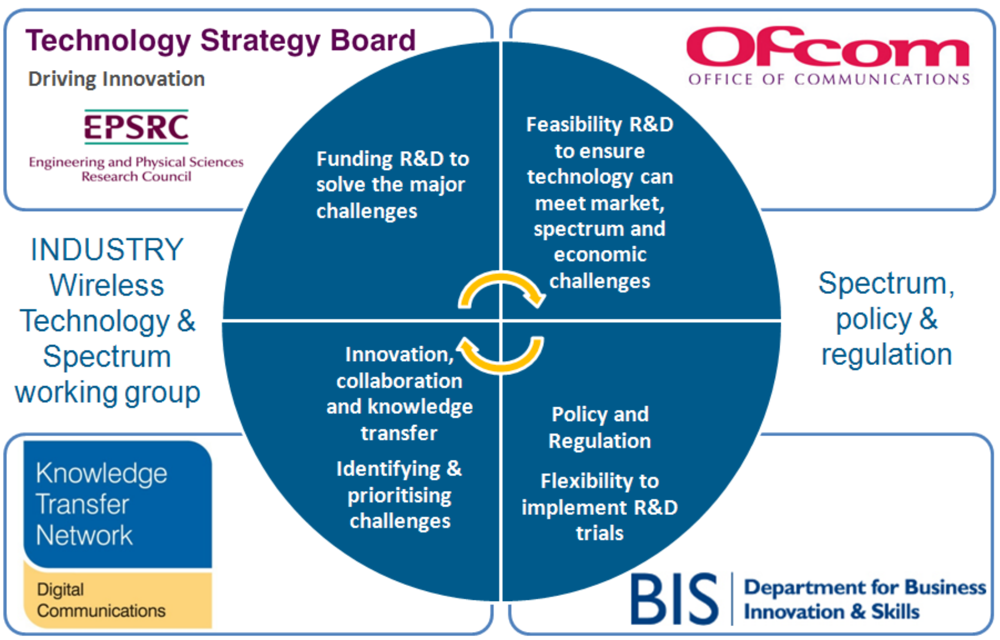


Figure 32: Collaboration enabling innovation

Wireless technology development is a major opportunity for the UK to lead the way globally in deployment, technology innovation, policy and regulation. The key to unlocking this potential is collaboration at all levels. If this can be achieved we will be able to realise significant societal benefits whilst enabling our industry to benefit across the whole of the value chain.

This paper has highlighted a number of challenges that the communications industry must continue to address on the theme of energy efficiency to achieve sustainable development; thus effectively contributing to the global trend toward business development against the backdrop of sustainability.

In several areas it is already evident that the UK technology development eco-system offers significant capabilities to supply components that may be utilised in energy efficient communications systems. Most of the technologies are still relatively recent to market and the maturing phase is yet to be entered. The technology solutions that have been identified are clearly viable solutions but unlikely to be the exclusive solution to a challenge and as such this is still a rich area for further innovation.

The power consumption of radio technology equipment is the right area to focus upon to achieve shorter term beneficial innovations. In the longer term deeper R&D, taking into account Systems / Network level thinking, may well be necessary to make significant in-roads into the energy efficiency of both wireless and wired communications systems.

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- Companies listed in section 16

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