SAVING THE PLANET

- The rationale, realities and research of Green Radio

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Why is Green Radio so important and where has it come from ? Wireless telecoms is a major contributor to global economic development. It also offers huge potential when it comes to reducing CO_2 emissions in other industries. To fulfil this potential, growth and opportunity, however, systems must become more efficient.

Ten years ago, the realities of global warming were not seriously on the public or political radar. Today, however, the necessity of major reductions in CO_2 emissions is acknowledged. Major focus has been on reducing dependency on oil – largely from perspectives of energy security and, more recently, of reducing risks of environmental damage. However, reductions not just in oil dependency but also in energy consumption are in reality needed – an area where telecoms has the potential to make a major contribution, by reducing the need for travel, by allowing greater electronic delivery of goods and services, and by enabling transformative business models in other industries.

Ten years ago there were circa 700m mobile phone subscribers worldwide, mostly located in the developed world; by July 2010 that figure had reached 5bn, with the majority, and fastest growth, in the developing regions of Asia, mainly India and China. The technology has evolved from voice services to today's wireless broadband, which provides an increasingly feasible alternative to digital subscriber line and cable Internet connections. However, as mass adoption of wireless internet has begun in developed markets, the associated energy implications have been recognised. To deliver wireless internet globally and profitably – the next major growth opportunity for the industry – energy consumption per bit and network operating costs will need to see substantial reductions.

This timely emergence and recognition of these changes has offered the industry a unique opportunity to deliver a major contribution to the widely recognised mega-trend of global sustainability [1]. Whilst this requires investment, it surely also offers major commercial potential. Consideration of these drivers by many of the major telecom operators and vendor companies from around the world began around five years ago for many within the context of Mobile Virtual Centre of Excellence (VCE)'s Industrial Vision Group. Since that time the industry has seen a range of initiatives, ranging from immediate steps aimed at energy reduction in existing infrastructure, medium term initiatives (both product and service related) and longer term research (aimed at delivering 2-3 orders of magnitude improvement in energy efficiency). The announcement in November 2009 of the mobile industry's 'Green Manifesto' at the GSM Association's conference in Asia perhaps represented the most important public statement to date by the industry as a whole, affirming its commitment to address both the challenge and the opportunity.

In the technology-intensive communications industry, significant change takes time. Longer term innovations need to be multi-faceted, addressing not only appropriate energy-reduced realisations of wireless techniques and technologies but also the broader context of appropriate choice of radio cell and equipment architecture to support ubiquitous wireless connectivity. Holistic consideration of both perspectives can deliver an approach to energy efficiency and an infrastructure capability that will benefit other industries and contribute to a sustainable global future.

Here, we survey the rationale, realities and research of Green Radio – explaining why it is important and where it has emerged from, summarising what is already happening today, in terms of industry and product change, and outlining how the industry is participating in and responding to Mobile VCE's "Green Radio" research initiative. An overview of the longer term technology challenges, priority areas, and insights from early results are included.

THE RATIONALE FOR GREEN RADIO

Three years ago, the term Green Radio did not exist – except perhaps (according to a Google search) in reference to military radios, where it referred to the colour of the equipment, or to a radio station broadcasting about environmental issues. The theme of Green Radio, as a vital enabler of wireless communications, has emerged rapidly and very prominently as three key drivers have converged.

The role of wireless in economic development

The vital role of telecoms as an enabler of economic development was well documented by International Telecommunications Union (ITU) and World Bank studies as far back as the 1990s and even the 1980s.

Until the 1990s, telecoms was dominated by wire-line, with wireless a more expensive and less functional cousin. However, the advent of GSM, its subsequent global proliferation and cost reduction together represented a sea change. Increasingly, low cost wireless telephony enabled countries with previously low teledensity to achieve rapid and cost-effective roll-out of telephony services. Globally, between 2003 and end 2009, mobile cellular penetration rose from 20% to 67% [2]. In high growth regions, the change was far more marked. In China, for example, telephony penetration rose from 0.5% in 1990 (almost entirely wire-line), to circa 18% in 2000, to ~80% by early 2010. Of circa 1.1bn phone lines in China today, over 75% are mobile phones, with wire-line subscription decreasing each quarter.

The economic impact of mobile telephony in Africa was accessibly documented in late 2009 by the Economist [3], in a set of articles which cited a variety of examples not only of how mobile telephony had already impacted the economy, but also

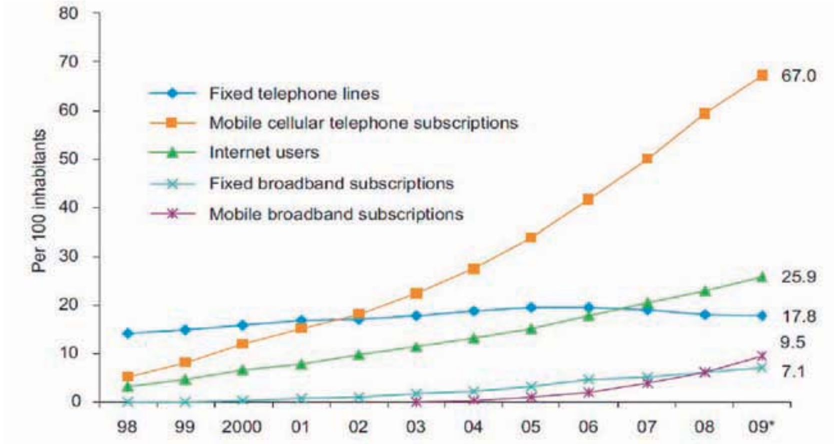

Figure 1: *Global ICT development over the past decade. Image reproduced courtesy of the ITU [2].*

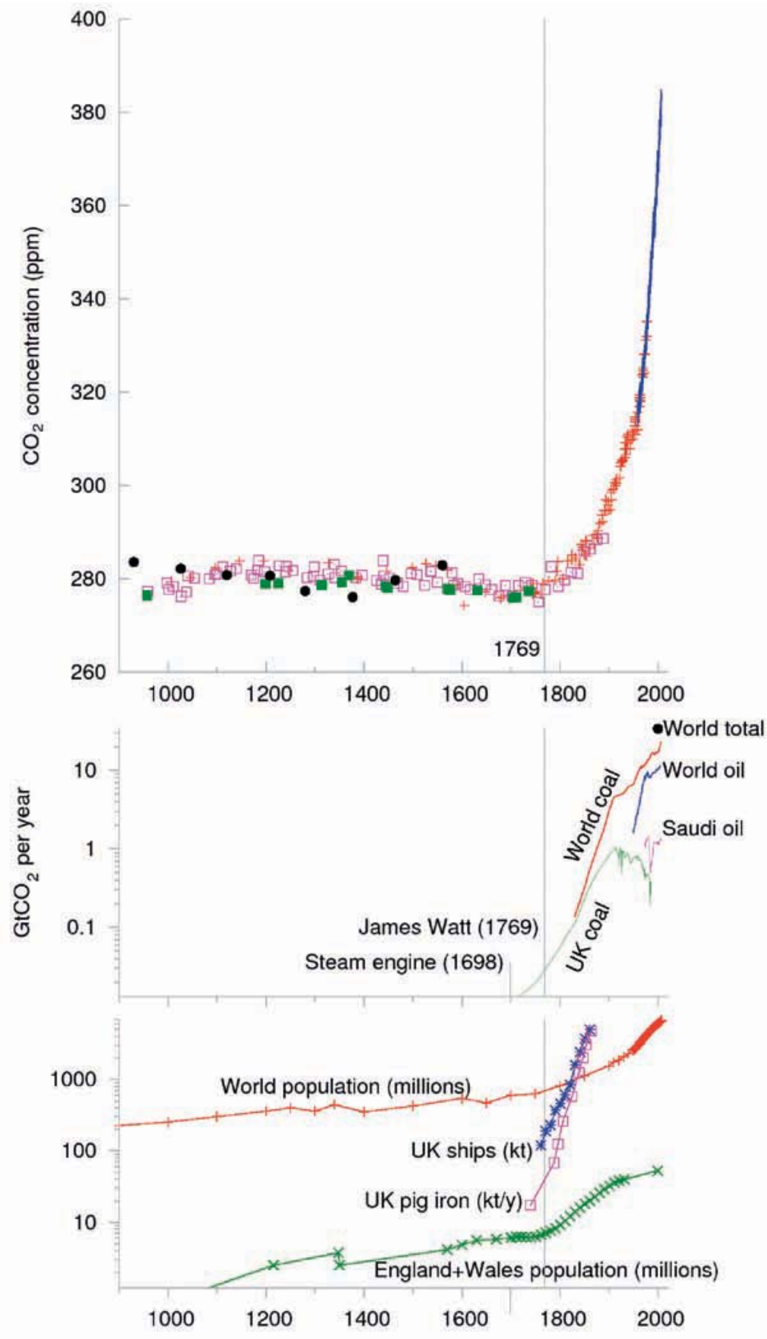

Figure 2: *Atmospheric CO_2 concentration and carbon extraction over the past 1000 years. Image reproduced under the Creative Commons licence [4].*

anticipating future impact, enabled by the transition from simple voice and text to wireless internet.

This importance of telecoms was formally acknowledged in a set of development targets, to be achieved by 2015, agreed by governments in Geneva at the World Summit on the Information Society in 2003. Progress is monitored by the ITU and most recently documented in their 2010 report [2]. Key trends to note from this report, see Figure 1, are the high growth of mobile lines, the stagnation of fixed lines and the potential remaining for internet; of the existing internet usage penetration in the developed world of >70% contrasts with circa10% in the (much larger) developing world. It is evident that as we move forward, for the majority of the planet, access to the internet will be wireless, mostly on mobile devices, not PCs.

Saving the planet

It is only in the past decade that the true cost of two centuries of industrialisation has begun to be appreciated. An excellent source for those wishing to understand these issues is the book "*Sustainable Energy – without the hot air*", available as a free pdf download [4]. Figure 2, taken from this book, illustrates the change in atmospheric CO_2 over the past 1000 years, and its correlation with fossil fuel extraction.

The impact of CO_2 on global temperatures is now well understood; studies on "possibly safe trajectories" in emissions reduction indicate a need for global emissions to fall by 70-85% by 2050 and explain the reason that the UK has established a legally binding commitment to reduce emissions by 80% (relative to 1990 levels) by that date [5].

The contribution of telecoms, in fact of all ICT, to global CO_2 emissions is small – of the order of a 2% [6] – so at first glance the role of this industry could be thought to be small; the reality is, however, different for two reasons.

Firstly, a major contributor to CO_2 emissions is transportation and, whilst we are beginning to see a major shift towards electric vehicles, it is clearly much less energy intensive to transport information than people. Research at UC Berkeley in

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2004 showed that "a company that converts 100 meetings a month to wireless teleconferences would reduce its CO_2 emissions by 720,000kg per year", indicating the major positive contribution that telecoms could make to sustainability.

The second factor however reflects the fact that wireless broadband usage is only just at its beginning, the implications of which are explained below.

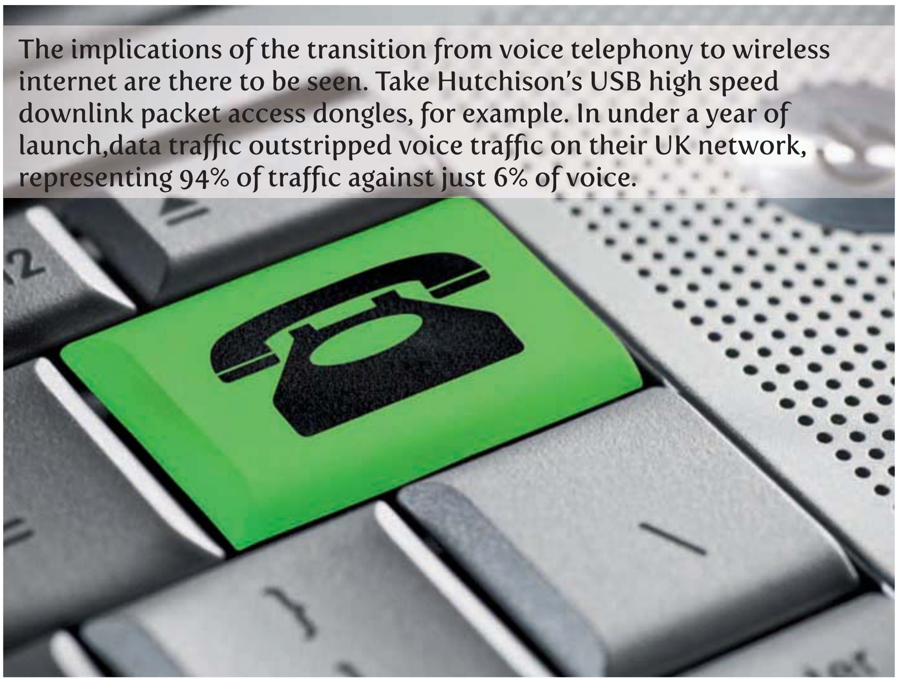
Energy and OpEx implications of wireless Internet

Wireless telecoms will play an increasingly important role over the coming decade - as a vital enabler of development and of large energy savings in other industries. However, the trend from simple voice to wireless internet has major consequences, in terms of both energy consumption and a network operator's operational costs.

A typical mobile phone network in the UK today may consume around 50 MW, excluding the power consumed by the users' handsets. From an operator perspective, energy consumption translates directly to operating expenditure (OpEx). What then are the implications of this ongoing, and accelerating, transition from voice telephony to wireless internet ?

A first implication for traffic is well illustrated by operator trends in developed markets, where wireless internet usage is most advanced. As an example, when Hutchison launched its USB high speed downlink packet access dongles , it found that within a less than a year (by autumn 2009) data traffic had exceeded voice traffic on their UK network by 94% to 6% [7] (and this before availability of the iPhone). Other operators have reported similar trends [8, 9].

Alongside this trend, the rate of revenue growth is lagging the rate of growth of data [10]. To encourage users to adopt mobile broadband, operators introduced 'all-you-can-eat' unlimited packages. Today the industry has begun to back-pedal, as networks have struggled to support rapidly increasing traffic demands. In the US and the UK operators such as AT&T and O_2 have used the introduction of the iPhone 4 in summer 2010 as a breakpoint to re-introduce metered pricing; others plan to use the transition to the Long Term Evolution (LTE) standard in the same way.



Even allowing for this, however, the price-per-bit for data is much lower to the end user than for voice, with a resulting trend of increased energy and OpEx as the internet goes mobile. Wireless data traffic is forecast to grow by a factor of x40 between 2009 and 2014, implying a major increase in energy consumption and OpEx, unless energy (and hence cost) per bit can be significantly reduced.

Given that wireless internet has yet to reach the vast majority of the planet, and that pricing in developing regions are lower than the West, the potential OpEx implications are not a pleasant prospect for the wireless operator, and are a reason for the recent re-emergence of metropolitan WiFi, and the advent of femtocells, both of which provide mechanisms to offload data traffic from the cellular to wired network.

Rationale

Continued development demands widespread global availability of the internet, which can only be done practically by wireless. Cost expectations have been set by low cost mobile telephony – thus, profitable low cost wireless internet demands major reductions in cost-per-bit. Also, if data volumes of networks are to rise by factors of 20 (as seen already in the Hutchison example), or more likely much more, with no changes in energy efficiency, not only would OpEx rise unacceptably, but so would CO_2 emissions. Compound these drivers with the opportunity of wireless to save energy in other industries and the imperative for Green Radio becomes very clear.

> The synergy between reduction of CO_2 emissions and reduction of OpEx costs for wireless networks was quickly recognised by the industry, with many Telcos now having their own operational targets for energy and CO_2

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THE REALITIES OF GREEN RADIO

The rapid emergence of Green Radio

The term Green Radio first emerged within the Mobile VCE community in late 2006 / early 2007 in discussions amongst its Industrial Visions Group which at that time was seeking to identify key drivers for its new research programme. An Industry Futures Day was followed by White Papers, and then by detailed planning of Mobile VCE's Green Radio programme, which formally launched in October 2008, the first industry-wide research initiative in the field.

Mobile VCE is a not-for-profit open innovation organisation which seeks to identify and address strategic research which can make a major impact upon the industry and deliver growth opportunities to its industry members. Past research programmes have been followed, a year or two later, by European Framework programmes involving its member companies. Its 'seed and feed' approach, whereby member companies leverage VCE research to initiate new internal R&D, is also well established. Thus, with broad industrial participation, the rapid pace with which the Green Radio ideas diffused throughout the industry was, with hindsight, not surprising.

During 2009, Board members of Mobile VCE visited and spoke about Green Radio in America and China. Subsequent initiatives were proposed to National Science Foundation (USA), Ministry of Science and Technology (China) and the EC (Europe) during that year. In January 2010 a global initiative, GreenTouch, coordinated by Alcatel-Lucent (a member company of Mobile VCE), was announced, with partners from Asia, America, Australia and Europe. The high profile arrival of these activities has strengthened the motivation of Mobile VCE's industrial leadership team and academic researchers to deliver timely, high quality, industrially relevant outcomes that others can complement. Links with these other initiatives are being actively encouraged and developed.

The recognition of the need for Green Radio however has given rise to more than just research – whilst this will address the important long term requirements of global wireless internet, the industry has also recognised the implications for the 'here and now' and this is taking several forms.

The fortunate synergy between reduction of CO_2 emissions and reduction of OpEx costs for wireless networks was quickly recognised by the industry, with many Telcos now having their own operational targets for energy and CO_2. Two member companies of Mobile VCE, Orange and Vodafone, were early players in declaring intentions to deliver substantial reductions in energy usage and CO_2 emissions [11, 12]; many others have followed. Purchasing energy from renewable sources has been a simple first step – however, whilst reducing the company CO_2 footprint, this does not actually reduce energy consumption. To deliver such reductions has required initiatives to save energy with minimal changes to existing infrastructure and to target such savings requires an understanding of where the energy is consumed.

Where is the energy consumed ?

The typical power consumption of different elements of a current cellular network is shown in Figure 3, which illustrates the major power consumption of radio base station as the primary element of energy usage, exceeding the sum of all other energy consumed by a Telco, including that of their retail outlets, switching, transmission and data centres.

Other studies have ascertained that the mobile handset energy usage per subscriber is much lower than the base station component – this is illustrated in Figure 4, which also shows that the energy used to manufacture the product (referred to as the 'embodied energy') is a much larger proportion for the mobile handset than the radio base station.

Short term developments

In looking to identify early energy and OpEx savings, operators and equipment vendors have understandably sought to identify 'short term wins'. Indeed, in establishing the Mobile VCE Green Radio programme, as described in the following section, a framework was quickly established for evaluation of the effectiveness of the research thinking and to facilitate effective steering. The process of deriving this framework contributed to identification of 'low hanging fruit' for energy saving, capable of being pulled through by industry in a relatively short time. It is important therefore to note what has already been achieved by the industry. Examples include the following:

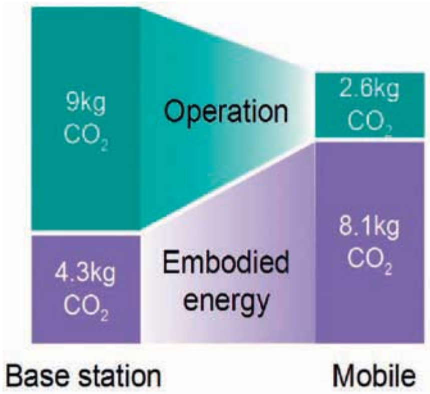

Figure 4: *CO_2 emissions per subscriber per year as derived for the base-station component and mobile handset. Embodied energy comprises that consumed in the manufacturing process, rather than in subsequent operation. Image reproduced courtesy of Vodafone [10].*

- **Network modernisation** – Reductions in power consumption are obtained by deploying single access network base stations which combine multiple standards, eg 2G and 3G. Functionality in such equipment often includes the ability to automatically switch off radio components (transceivers) when traffic load is low. Further savings are obtained by installing the active components close to the top of the mast which reduces the power losses associated with feeder cables.
- **Best practice** – In developing markets a large contributor to CO_2 emissions arises through the operation of diesel generators to support sites that are off-grid (or have access to an unreliable grid). By running a generator in a hybrid manner with batteries fuel savings of 40% can be obtained [13]. Further significant savings are achieved by simply ensuring components such as rectifiers are dimensioned for the correct load as historically such elements may have been over dimensioned and hence operated at low efficiencies.
- **Improved cooling solutions** – It is essential to ensure electronics and batteries are operated within defined temperature ranges and traditionally this would have been solved through the use of air conditioning units that could consume 50% of the total energy load of a base station [14]. Energy saving features using free cooling (which forces filtered fresh air across the base station) and solar insulation paint are now becoming widespread.
- **Alternative power sources** – Renewable energy is now an effective and economic solution, particularly for developing markets where the electricity grid is poor and solar and/or wind resource is high. 'No Frills' base stations that deliver basic wireless connectivity in rural locations may consume less than 200W [13] and can now be powered completely by photovoltaic panels and/or wind turbines. A solar powered base station developed by Huawei and Vodaphone is shown in Figure 5 (overleaf).
- **Efficient architectures** - Whilst these solutions apply for individual sites, operators are also pursuing more fundamental architectural changes to the network driven by a desire to reduce cost and energy. For example, centralised architectures as promoted by China Mobile [15] group the radio baseband units at fewer centralised locations and distribute digital information to remote radio heads

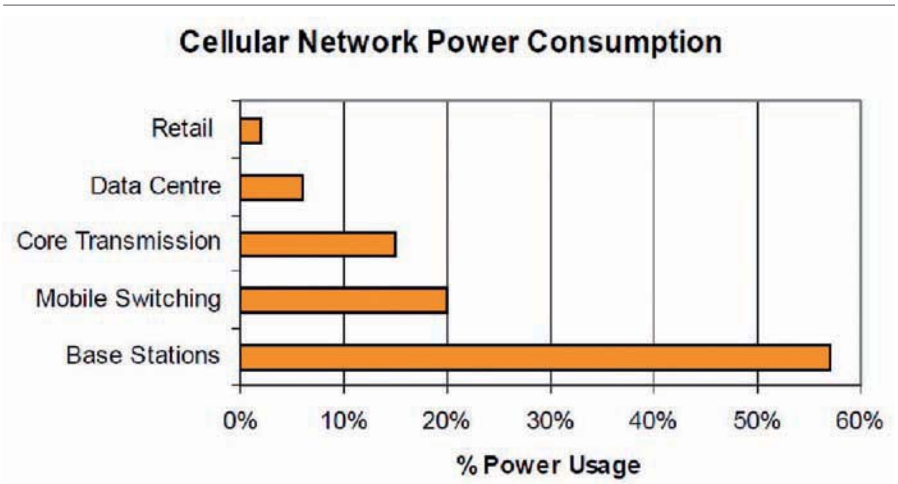

Figure 3: *Power consumption of a typical cellular operator. Image reproduced courtesy of Vodafone [10].*

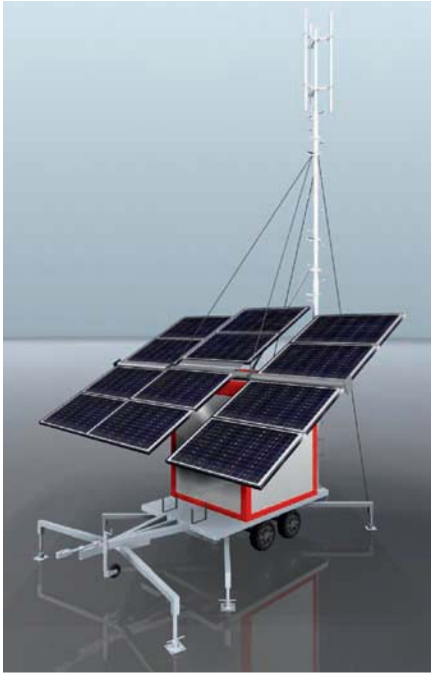

Figure 5: *Huawei and Vodafone green mobile BTS Image reproduced courtesy of Huawei.*

– this ensures efficient utilisation of equipment, a reduction in radio cabinets and introduction of more efficient cooling solutions.

- **Resource sharing** - Where fibre is not so accessible, consolidation of physical assets in the form of network sharing, or mergers, is another route available to operators. Again such solutions lead to more efficient utilisation of existing equipment including masts, antennas and possibly active radio elements. Agreements of this type can be found in markets as diverse as Australia (Vodafone and Hutchinson) and the UK (Vodafone and O_2).

Solutions described above are not just good for the planet, but they make good economic sense for operators, offering financial return within normal investment cycles.

Medium term developments

In parallel with in-house, short term, initiatives, cellular operators have already begun to give energy requirements a much higher priority when preparing requests for proposals for new equipment, of all types. Prescient vendors have similarly incorporated energy saving mechanisms in new product designs looking at not just the design of base stations but now taking into account system-wide energy efficiency.

- **Software defined radio platforms** – In markets where 2G has been deployed for several years some operators are nearing end of service life on old base station assets, whilst their business models require long term support for 2G standards such as GSM in their networks. In addition the operators have to deploy 3G and now emerging technologies such as LTE. To address these operator needs, base station vendors are offering base stations incorporating Software Defined Radio (SDR) platforms that support multiple radio access technologies. Whilst this approach may not achieve the most energy efficient solution for a single access technology, SDR enables base station developers to further integrate common components of radio base stations leading to a commensurate improvement in system energy efficiency:
- **Wireless network topologies** – In the mid-term, as a result of the drive towards spectral efficiency and ever faster wireless access speeds, smaller cell topologies will naturally be deployed. Studies show that significant energy efficiency gains can be achieved by deploying smaller cell size radio networks [16]. There are a number of base station platforms that will provide flexibility to operators for smaller cell deployments; femtocell, picocell and, emerging now from the latest standards, relays. An example of a small cell platform designed by NEC is shown in Figure 6.

Deploying small cell topology networks requires that backhaul to/from the base stations into the Core Network is deployed to more locations. Such a variety of platforms will inevitably create a complex heterogeneous network radio environment, which poses fresh management challenges for network operators. A great deal of industry effort is therefore now focussed on automation (also referred to as self organising networks) to tune the performance of the network to an optimal operating point capable of delivering optimal user experience with minimal OpEx.

- **Energy efficiency in platform technologies** – Whilst system level innovations will play a significant role over the coming years there are still significant savings to be made by considering optimisation of the technology platform of commercial systems. Two areas that are receiving significant attention are the efficiency of power amplifier stages of base stations and effective utilisation of multi-core processor architectures in both general purpose and signal processing variants.

With techniques such as Doherty (hybrid class B, class C amplifier) it is now possible to achieve 45 % efficiency of the power amplifier stages. Alternative approaches using envelope tracking are also achieving similar gains. Envelope tracking follows the amplitude of the signal being amplified and modulates the power supply to track this signal to reduce wasted energy. Each technique has an evolutionary path and base station vendors are seeking to push to > 60 % efficiency in the near future.

Multi-core processors enable base station designers to enhance approaches such as switching off amplifier stages of base stations when not needed, to creating scalable or virtualised systems that optimally use processor cores. Optimal loading of processors and switching off those

Figure 6: *An example of a small cell platform Image reproduced courtesy of NEC.*

that are not required leads to a variety of sleep mode techniques that show significant advantages, especially in dense small cell deployments where not all cells will have active or even connected subscribers [17].

- **Regulatory framework** – When considering sustainability of an industry, total cost of ownership concepts play a significant part in the engineering of products. Regulators are now seeking appropriate mechanisms to qualify all technology products with energy efficiency ratings. In the wireless industry these considerations are coming first to base stations that are deployed in homes (femtocell/wifi access points), followed by base stations that are purchased and deployed by operators. Regulators are also considering the environmental impact of manufacture and disposal of technology and investigating appropriate mechanisms to account for this impact on the environment. Over time these forces will introduce additional constraints that will surely change the way base station products are designed and manufactured; smart vendors are already incorporating such trends in their product roadmaps.

RESEARCH INTO GREEN RADIO

The VCE context

In understanding the context, goals and approach of Mobile VCE's own Green Radio research programme, described below, an appreciation of its unique industry-academic interplay is important. Without the unique contributions of these two parties, and the mechanisms employed, it would not deliver as it does:

- **Industry steering, academic research** - The Green Radio programme is jointly funded by the Industrial Companies who are members of Mobile VCE and by the UK's Engineering & Physical Sciences Research Council, and is being undertaken by an integrated research team from the Universities of Bristol, Edinburgh, Kings College London, Swansea, and Southampton under the guidance of an Industrial Steering Group, chaired by Simon Fletcher of NEC. This Industrial Steering Group, with vice chairmen David Lister of Vodafone and Terence Dodgson representing Nokia Siemens Networks, has worked with these Universities to define the programme challenges and agree technical approaches and is now co-ordinating its delivery, using Mobile VCE's time-proven management approaches and tools – including quarterly Industrial Technical Steering Group meetings, monthly web-based reporting and teleconferencing for issue management, et al.

The industrial team is supported by an Academic Coordinator, Tim O'Farrell from the University of Swansea, with responsibility for ensuring effective coordination across the academic research team. The Universities involved were selected for their complementary and internationally-leading skills and facilities, to form the broad team necessary to tackle the varied challenges addressed by the programme.

> "Mobile VCE's Green Radio programme set the aspiration of achieving a 100-fold reduction in energy consumption over current designs for wireless communication networks."

- **Energy Focus Group** - The programme also maintains an industrially-led think tank charged with relating the research outcomes to real world costs, constraints, metrics and expectations; the Energy Focus Group (EFG). The EFG plays a significant part in monitoring and helping the research team to stay aware of the rapid progress in industry and to target maximum impact for the research. The group maintains a "Book of Assumptions" which provides background reference material to abstract, define and bound the research programme. As research results evolve, these are investigated by the EFG, to assess their practical relevance in enhancing next generation system designs. The EFG also feeds back observations to further refine the problems, providing targeted questions which the researchers address and resolve.

RESEARCH OBJECTIVES

Mobile VCE's Green Radio programme set the aspiration of achieving a 100-fold reduction in energy consumption over current designs for wireless communication networks. This challenge is rendered non-trivial by the requirement to achieve this reduction without significantly compromising the Quality of Experience

(QoE) of the network customers. The research must be cognisant of the costs of deployment and operation of equipment to manufacturers, network operators and content providers. In order to meaningfully measure success in pursuit of this overarching goal, appropriate and consistent measures of energy consumption must be applied. For example, a reduction in radiated power is of no benefit if it is achieved at the expense of a greater increase in power consumed in signal processing - a holistic view of power consumption is required.

The goal of reducing energy consumption in future wireless networks is addressed by studying energy issues in two complementary domains:

- **Architectural aspects of Green Radio** – To examine alternatives to the existing network topologies (principally cellular and WiFi) to offer the potential to reduce energy and power consumption. Moving the access network closer to the user enables a reduction in the radio frequency transmit power. The growth of interest in femtocell and other small cell base station platforms to achieve significant coverage and capacity advantages may well be hastened by the need to reduce energy consumption. However reduced coverage areas with such approaches results in increased complexity in the backhaul requirements to achieve optimal connectivity to the core network, as well as increasing the handover signalling load. Suitable architectures and topologies that trade off these factors to achieve a net gain must be identified. An increased base station density also demands effective spectrum utilisation in order to ensure that the overall interference situation is not altered in a detrimental fashion. Similarly, incorporation of relay technologies into the network architecture has the potential to extend the base station reach to a mobile terminal to achieve energy savings. Detailed study of the energy efficiency of different architectural approaches can identify the best deployment options.
- **Techniques across the protocol stack for power reduction** – These may be employed either to reduce the required radiated power to achieve the required QoE or to achieve the required radiated power using less overall power (noting that the overall power consumption of a device is always greater than the radiated power). Effective Radio Resource Management and Signal Processing can reduce the radiated power requirement to maintain the required QoE, whilst energy efficient hardware implementation of necessary functionality can facilitate a reduction in total energy consumed relative to the radiated power.

> “Adoption of appropriate energy metrics is essential to ensure accurate and effective comparisons, and hence selection of the more energy efficient network architectures.”

Measuring energy gains in Green Radio

Adoption of appropriate energy metrics is essential to ensure accurate and effective comparisons, and hence selection of the more energy efficient network architectures. The importance and need for common energy metric definitions has been addressed by several standardisation institutions such as the European Telecommunications Standards Institute, Alliance for Telecommunications Industry Solutions, Energy Consumption Rating Initiative and the ITU. However, the energy metrics under development in standards bodies are usually focused on achieving equipment compliance.

From a research perspective, one important absolute metric is the energy consumption ratio (ECR) [18]. This is measured in Joules per data bit and conveys an impression of the efficiency with which data is communicated over the network. This metric needs to be defined carefully so that it is clear how and where the energy is measured. In addition, it is helpful if the ECR is measured for each data bit that is successfully delivered to its destination, rather than simply for each data bit transmitted.

A second metric adopted in the project is the energy consumption gain (ECG). This compares the energy efficiency of two different radio systems. For example it could be computed as the ratio of the ECR metrics for a baseline reference system and a system that is supposed to use a more energy efficient approach. The ECG metric provides a means to quantify the potential benefit of different architectures and of novel technology options.

Optimising the architecture

Minimising energy consumption can benefit from a wide range of architectural approaches, which have recently come to the forefront in communications. In this section, three of the most promising options for reducing the energy consumption of future networks are discussed.

- **Small cells and femtocells** - The use of smaller cell sizes has been identified as a medium term goal for industrial deployment. The potential gains are readily apparent from the obvious reduction in radio base station transmit power, which scales as the cell radius raised to the power η, which is the radio propagation path-loss exponent. This gives rise to an important research question: can such offerings be extended to the end-to-end network level such that the total energy consumption of the cellular network is reduced? To this end, the energy consumption characteristics of femtocell deployments in a macrocellular network from a system-wide perspective are being evaluated. Initial results on mixed macrocell/femtocell networks in Figure 7 show that deploying femtocells can reduce the power consumption per user in the network. More detailed studies are ongoing to confirm how these results translate to a range of different operational scenarios.
- **Relay techniques** - In a similar manner to the small cell techniques described above, the use of relays to exchange information between a base station and mobile

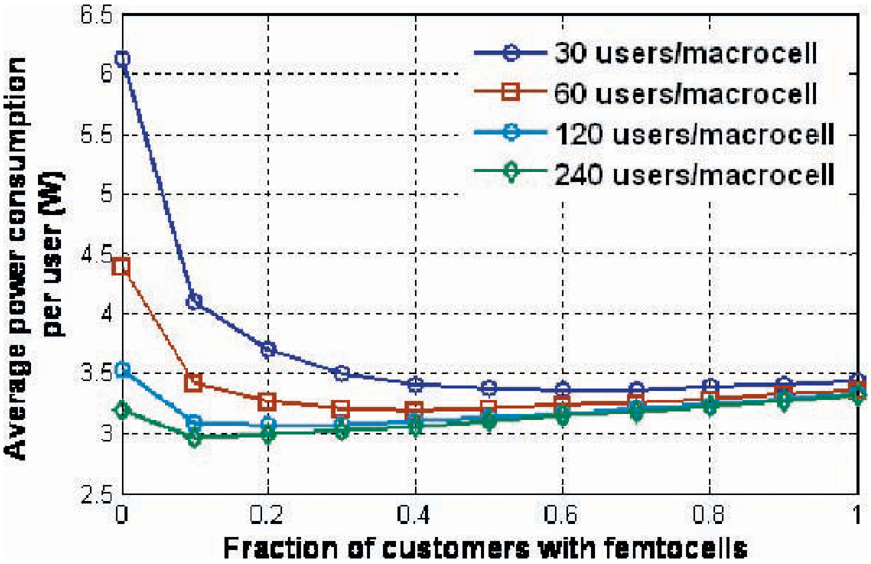

Figure 7: Power consumption per user results as a function of the number of deployed femtocells in a mixed network of macrocells and femtocells [26].

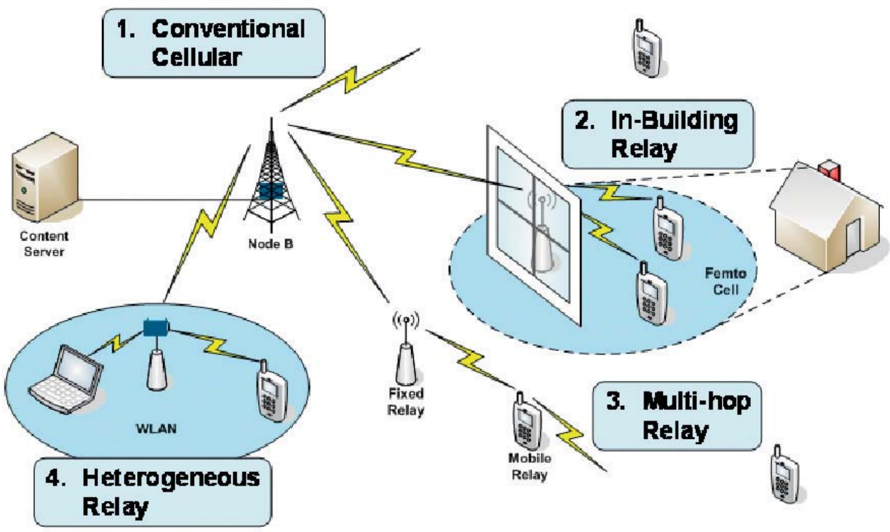

Figure 8: Four techniques to reduce power consumption through introduction of delay tolerant networking Image reproduced courtesy of Mobile VCE.

terminal may be an effective way to improve base station energy efficiency. This is because the transmission distance to the relay is reduced compared to the destination, increasing data rates or permitting reductions in transmission energy. Relays can enable important reductions of the network energy consumption without complicated infrastructure modifications. These may be deployed in streets or in buildings to provide improved signal quality to locations which might otherwise experience poor QoE. Figure 8 shows different types of relay technology that can be utilized in an existing wireless network. One interesting approach that is being studied in the project is the store carry forward concept, which can be used to trade energy efficiency for extra delays in data delivery. This is building on work of the Delay Tolerant Network Research (working) Group of the Internet Research Task Force [19].

- **Advanced spectrum management** - Statistical differences between traffic loads in two or more spectrum bands can be used to allow users to be dynamically moved between the networks servicing these bands [20], thereby allowing unused radio equipment to be switched off. Voice and data traffic varies significantly over a 24 hour period and also across different networks, eg 900MHz an 1800MHz. With many operators now having access to multiple spectrum allocations, this concept has practical applicability.

Radio techniques and technology

As well as considering future architectural options, it is also important to address radio based techniques that can be used to improve the efficiency of the technology deployed in future wireless networks. Such techniques span all of the protocol layers from modifications of the physical layer and radio frequency circuitry to high level techniques supporting the services that run over the networks. Three promising approaches to improving the energy efficiency of radio base station devices are briefly discussed:

- **Efficient power amplifier and antenna technologies** – Analysis shows that the greatest potential for increasing the overall base station efficiency comes from improving the efficiency of the power amplifier and antenna, as well as optimising the power transfer between them. Work underway in the programme is seeking to push beyond current industry goals in this area to, achieve efficiency figures of 85% and 90% respectively for these two components. In the case of the power amplifier, one possible approach uses the Class J amplifier [21], which relies on fundamental and second harmonic tuning to achieve high efficiencies.

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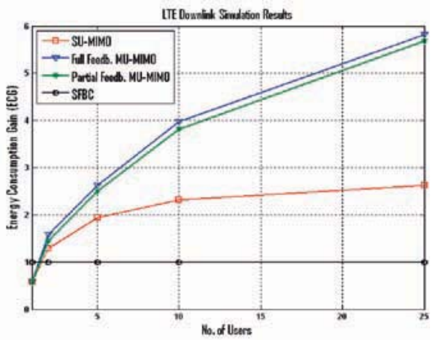

Figure 9: *Simulated Energy Consumption Gain of various multiple antenna scheduling schemes, relative to space frequency block coding (SFBC), all at 3bit/s/Hz spectral efficiency. Image reproduced courtesy of Mobile VCE [23].*

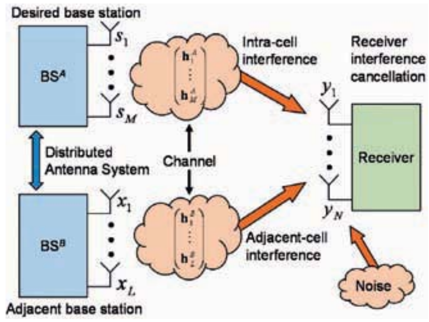

Figure 10: *Example scenario for transmitter and/or receiver interference cancellation showing multiple base stations transmitting to a multiple antenna receiver. Image reproduced courtesy of Mobile VCE [25].*

Further efficiencies may be gained by locating the power amplifier next to, or indeed integral with, the antennas, thereby eliminating power loss in the feeder cables of current designs. This approach inherently also reduces cooling requirements, compared with amplifiers installed in cabinets in an equipment room.

- **Resource allocation techniques** - Complementing efficient power amplifier and antenna technology, resource allocation techniques that make the most efficient use of these elements to transmit data to users in the network have the potential to deliver further significant enhancement in overall energy efficiency.

Analysis of data traffic in wireless networks show that the traffic load is typically very uneven across the cells. For radio base stations in low traffic load conditions, more bandwidth may be available to transmit data to users than is actually required at that point in time. One frequency domain approach that is being studied in the project exploits such spare bandwidth resources to reduce energy consumption [22].

Alternatively, under high traffic load conditions, the base station may be transmitting data to many users simultaneously, possibly using multiple input multiple output (MIMO) techniques. In [23], it is shown that this so-called multiuser diversity effect can reduce energy requirements [23]. Figure 9 shows one example result where significant energy consumption gains are obtained for multiple user MIMO as the number of users in the cell increases.

- **Interference cancellation** - Interference cancellation schemes can be used to combat interference in any practical communication system where multiple base stations share the same spectrum. The impact of interference is more severe as users move closer to the cell edge, leading to significant data rate reductions in such regions. Most existing interference cancellation schemes have been designed to increase the spectral efficiency and data rate, while overlooking the energy efficiency. If, instead, the level of interference can be reduced at the mobile terminals, this can permit base stations to reduce the wireless transmission energy without compromising the QoE of the wireless link. Two complementary strategies are being explored to deliver such an outcome, shown in Figure 10, namely distributed antenna systems [24] and receiver interference cancellation [25].

ABBREVIATIONS

ECG	Energy Consumption Gain	LTE	Long Term Evolution
ECR	Energy Consumption Ratio	MIMO	Multiple Input Multiple Output
EFG	Energy Focus Group	QoE	Quality of Experience
ITU	International Telecommunications Union	SDR	Software Defined Radio
		VCE	Virtual Centre of Excellence

CONCLUSIONS

Even three years ago, few in the industry had heard of the concept of Green Radio. Yet, in a very short space of time, Green Radio has emerged as an industry imperative, driven by three self-reinforcing drivers – the potential of wireless internet to drive economic growth in the developing world, the potential to deliver CO_2 reductions in other industries, and the need for profitable wireless broadband at scale.

Working within the open innovation framework of Mobile VCE, operators and vendors from across the value chain and global geography together identified this theme as an essential area of focus where VCE research could make a difference, as well as initiating a range of shorter term responses, some of which are already beginning to make real business impact.

Given the projections for wireless internet growth, rapid advances are needed. Mobile VCE's industry-led programme enables member companies to leverage intellectual horsepower, explore a wide range of technical approaches, and thereby to 'seed and feed' their own in-house activities with research ideas and concepts as they emerge, shortcutting traditional research methods.

Looking forward, an important next step beyond Green Radio is likely to be network virtualisation, also identified as a key part of Mobile VCE's "2020 Vision". New research to address this is anticipated in 2011, as well as a further phase of Vision's activity. Mobile VCE's work is open to all industrial companies worldwide – operators, vendors and others wishing to participate in these initiatives are welcome.

FOOTNOTES

[1] Industry members of Mobile VCE include Alcatel-Lucent, BBC, BT, Fujitsu, Huawei Technologies, NEC, Nokia Siemens Networks, Orange (France Telecom), Samsung, Thales, Toshiba, Turner & Vodafone

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