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# Radio network energy performance: Shifting focus from power to precision

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# Radio network energy performance: Shifting focus from power to precision

**Building energy-efficient radio networks is about prioritizing energy performance throughout the entire system, where a wide range of products and solutions need to work together. Adopting such a holistic approach will help operators meet their energy-efficiency commitments.**

PÅL FRENGER, CHRISTER FRIBERG, YLVA JADING, MAGNUS OLSSON, AND OVE PERSSON

**In recent years, rising and volatile energy prices have had a profound effect on all industries, not least the telecoms sector, which is also being challenged by rapidly rising traffic volumes and massive subscriber uptake.**

When building high performing networks telecom operators have many design aspects to consider, including how to achieve top user performance as traffic continues to grow, as well as the best possible energy performance. Energy concerns coupled with the fact that telecom operators are among the largest electricity consumers in many countries are adding to the importance of improved energy performance and putting traditional network designs to the test.

In recent years, the number of mobile subscriptions globally has risen dramatically, and the service quality supported by mobile networks in terms of user bit rate and QoE has improved tremendously, yet the energy consumption of mobile network infrastructure per subscription has remained more or less constant[1]. Despite this, the concerns about energy related opex and network energy consumption among operators and vendors are growing steadily. Energy consumption is high on the political agenda, and the spotlight is on the ICT industry to halt the escalation of its collective energy consumption.

With this in mind, operators of all sizes are now looking for innovative solutions to reduce energy consumption in all aspects of their business, which makes developing scalable and adaptable energy-efficient solutions an important focus area.

*From power to precision*

By installing the most advanced and powerful products at each site, a network can deliver top user performance. However, more precise solutions are needed to build a network that delivers both best user performance and best energy performance. Network architecture needs to fit the specific traffic situation at each site, rather than being designed for maximum capacity only.

As network dimensioning shifts from power to precision, choosing the right products for each site is a crucial part of the design process, and will result in networks that can provide excellent user performance as well as outstanding energy performance.

### Economy, environment and engineering

Reducing energy consumption has several benefits – a drop in network opex being the most apparent. Capex can be reduced through the use of cost-efficient solutions in, for example, battery backup and cooling systems, and lowering energy consumption results in a smaller $CO_2$ footprint – a goal for many operators and governments.

In the Networked Society, connectivity is the starting point for new ways of innovating, collaborating and socializing. In both high growth and emerging markets, smartphones have pushed up the demand for capacity. Providing network coverage for the next billion subscribers brings a new set of challenges, such as delivering coverage in remote areas with poorly developed infrastructure, where investment and operational costs need to drop significantly. Reducing the energy consumption of base stations is a key enabler for on-site energy solutions in remote areas. Solutions such as solar panels need to be available at cost levels suitable for mass deployment. Without coverage

**BOX A Terms and abbreviations**

| | | | |
|---|---|---|---|
| AIR | Antenna Integrated Radio | RF | radio frequency |
| DTX | discontinuous transmission | RBS | radio base station |
| DUW | Digital Unit WCDMA | RRU | remote radio unit |
| EARTH | Energy Aware Radio and neTwork tecHnologies | RSC | Remote Site Controller |
| | | TCO | total cost of ownership |
| QoE | quality of experience | TMF | tower-mounted amplifiers with frequency shifting |
| RAT | radio-access technology | | |

there can be no Networked Society, and improving energy performance of radio networks is therefore a fundamental enabler for a future society where everything that can benefit from being connected will be connected.

Lower energy consumption also reduces the amount of heat generated inside cabinets and enclosures, which has a direct impact on the form factors for both radio and digital parts. Reducing energy consumption is consequently a fundamental part of developing compact, lightweight, and yet highly capable radio base stations. It is also an enabler of modern RBS solutions, where for example hardware is mounted in the tower or inside the antenna, such as in the Ericsson Antenna Integrated Radio (AIR) products.

**Network reality**

Over the past three decades, vendors, operators, and academia have successfully worked together to improve radio network capacity. The main focus of this joint effort has been to provide top performance in high load scenarios. This strategy has been successful, resulting in good user and system performance not just for peak scenarios, but also for low load and off-peak hours.

A crucial part of this success has been the joint industry effort in 3GPP to develop radio-access network specifications that result in low signaling overhead in relation to the peak load. But despite this focus, system-signaling overhead (including pilots or reference signals, synchronization signals, and system information) is still quite substantial at low load, as it does not scale proportionally with traffic. Consequently, networks that are energy-efficient at heavy load are less efficient – for instance in terms of energy consumption per bit – at low load. As it turns out though, it is more common for the load in cellular networks to be low rather than high. As shown in the top part of Figure 1, load distribution is highly uneven. Typically, half of the network sites carry only 15 percent of the total traffic, while 5 percent of sites carry 20 percent of the traffic. In addition to this, traffic growth tends to increase most at times and locations where it is already high, while growth is much slower in places

**FIGURE 1** **Top: capacity demand varies significantly across the network; middle: traffic growth is significantly lower in low capacity sites; bottom: low capacity sites exist over the entire network**

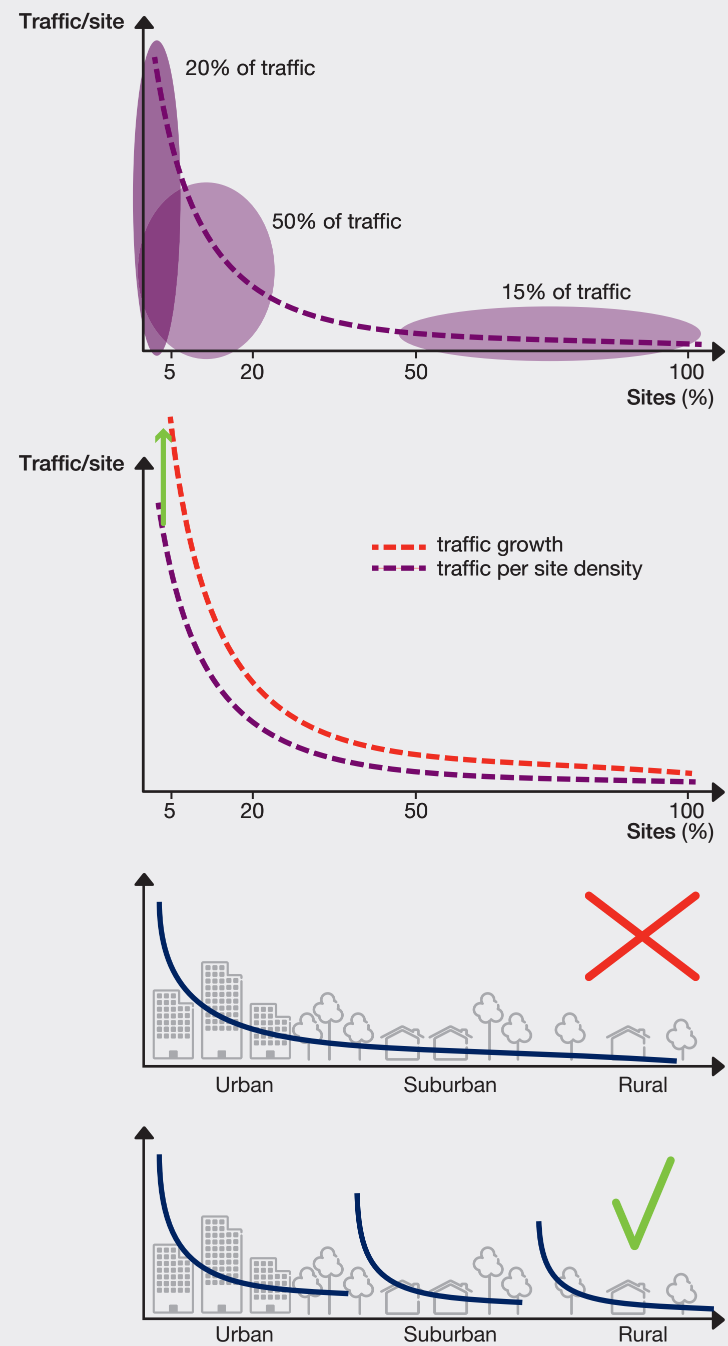
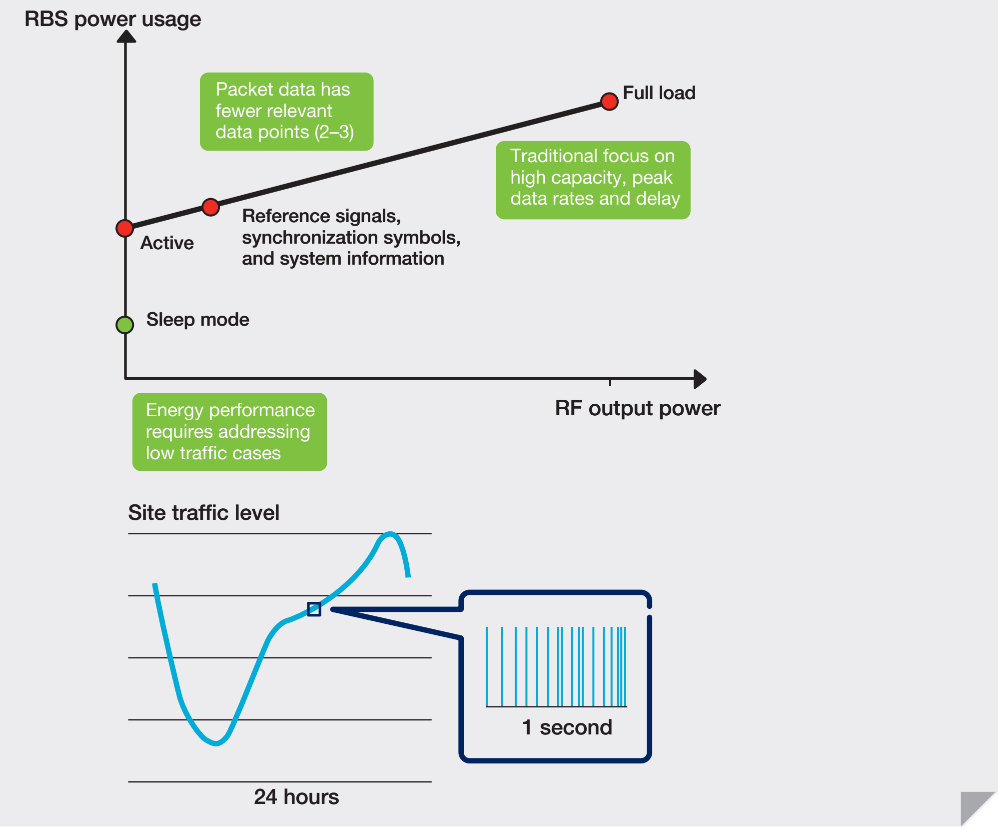


**FIGURE 2** **Top: radio base station power consumption as a function of load in terms of RF output power; bottom: typical radio base station traffic variation examined over 24 hours with details of a typical one second interval**




where loads are already low (as shown by the middle part of Figure 1). By extrapolating these trends we can conclude that even a future network, where hotspot peak-hour traffic might be 1,000 times greater than today, will still feature low traffic loads most of the time and in most locations.

It is also important to highlight that sites with both low and high loads exist in all environments – urban, suburban and rural. Some sites in dense urban areas experience little traffic, while some rural sites cover large geographical areas and carry comparably high traffic loads (as shown by the lower part of Figure 1).

Even when there is no subscriber traffic in a cell, the radio base station needs to be active and transmit mandatory signaling. The good news is that the large variation in load over a network presents great opportunities for energy saving. Capacity scaling, for example, is just one way to make use of the load variation to reduce consumption.

The top graph in **Figure 2** shows power consumption of a typical radio base station as a function of RF output power. A state-of-the-art macro base station consumes around twice as much power at full load compared with the load when no user data is being transmitted. As our industry has traditionally focused on performance at peak loads – and although high load optimization is crucial to future proof networks to cope with higher peak traffic capacities as well as for site dimensioning – energy consumption is in fact dictated by how well a radio base station performs at low load.

Our research shows that using a timescale of fractions of a second, packet-based data transmission in combination with very high data rates can often result in very low load (see bottom graph in Figure 2). This is because data is either being transmitted, resulting in loads approaching 100 percent, or no data is being transmitted, in which case the load instantly falls close to zero percent. The higher the capacity, the faster data packet transmission can be completed, increasing the amount of time without data transmission.

Research carried out using a millisecond timescale has shown that, in an average LTE cell, packet data communication occurs less than 5 percent of the time. So, on average, for more than 95 percent of the time no user data is being transmitted[2]. Using radio-network simulators, it is then possible to see how much energy a network actually consumes under different conditions. The EU-funded research project EARTH derived models to describe a nationwide LTE network for a typical European country (43 percent area coverage, 88 percent population coverage)[3]. Simulations showed that such an LTE network with traffic loads set to forecast levels for 2015 consumes only 1.4 percent more energy compared with the same network with no traffic at all[2]. From this model-based result, it can be reasonably concluded that the relative increase in energy consumption due to loading the network with traffic is in the single-digit percent range.

**BOX B**
**Three rules of traffic**

**Rule 1** – traffic is unevenly distributed
**Rule 2** – low traffic sites => slow growth
**Rule 3** – high and low traffic in all areas

### Enhancing energy performance

**Figure 3** shows some examples of how to reduce power consumption through improved adaptation to traffic variations. Dynamic site reconfiguration of the RBS from 3-sector to omni-operation has great potential to reduce energy consumption, as does antenna muting, in which multi-antenna transmissions are only activated when there is user data to transmit. In computer simulations, these types of solutions have been shown to provide impressive energy savings on an individual basis[4,5].

In the EARTH project, the combined effects of a number of promising LTE energy-saving functions were studied[6]. Results indicated that some of best techniques included hardware improvements, discontinuous transmission (DTX), antenna muting, and a dynamic 3-to-omni-sector reconfiguration. As illustrated in **Figure 4**, simulations carried out on the LTE network model (introduced above) show that a solution combining these techniques provides a total energy consumption reduction potential of 76 percent when compared with the same LTE network without these features[7].

In addition to these energy-saving techniques, multi-standard nodes – in which several radio-access technologies (RATs) are provided by the same equipment – also have great potential to reduce energy consumption. This is because these nodes share both common functionality as well as some components. Running a multi-standard node in mixed mode typically uses much less energy (around 40 percent) than running a separate radio base station for each standard[2].

Heterogeneous network architecture, when implemented correctly, also has the potential to both improve performance and to reduce energy consumption. Small-cell designs can enhance user performance while reducing total network energy consumption compared with a pure macro network. When small-cell nodes are added to a highly loaded macro network, energy consumption typically increases but so does capacity. If placed correctly, small nodes can provide users with better radio conditions than the macro node, which means that higher data rates are possible with less transmission energy.

Introducing energy-saving features, such as small-cell sleep mode and discontinuous transmission (DTX) in radio base stations, reduces total energy consumption in the network. Studies carried out on energy efficiency in heterogeneous networks[4] show that adding energy-reducing features does not cause user experience to degrade. The addition of small nodes increases capacity, allowing most packet data transmissions to be completed much faster. Consequently, energy-reducing features can be active for longer periods of time, which often results in lower energy consumption compared with the original macro-only network.

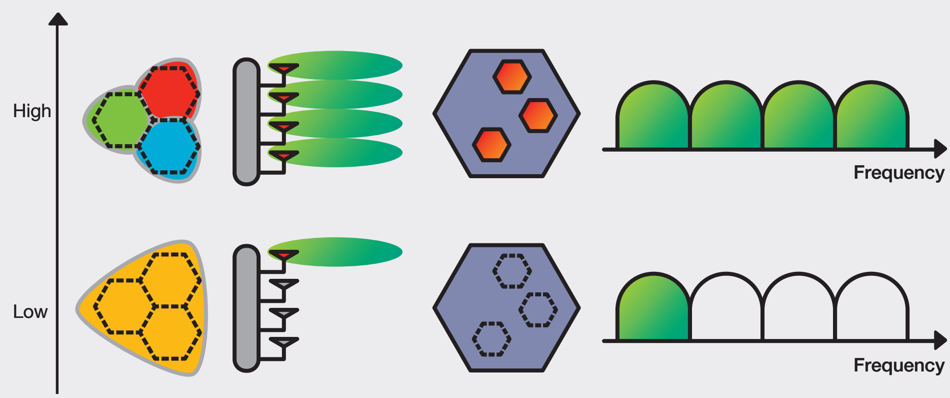
### Network evolution – an opportunity

When analyzing energy usage in mobile networks, one of the first obvious considerations is the number of installed base stations. Infrastructure equipment is typically designed for long term usage, and so the stock of installed base stations in operation today includes a wide range of nodes of varying generations dating from around the mid-1990s up to today.

In today's networks, energy usage is dominated by GSM and WCDMA equipment, some of which has been in operation for 10 to 20 years. While they were state-of-the-art when they were installed, modern GSM and WCDMA base stations have much better energy performance. But replacing old hardware with new is not the only option. The energy consumption of the vast number of installed radio sites can be improved by activating RAN-specific energy-reducing software features, giving operators the potential to reduce energy consumption in existing radio equipment by 5-25 percent.

Some concerns have been raised about putting LTE into the mix and how an additional technology might further increase total energy consumption. So far, however, there are no signs that this is actually the case. On the contrary, adding LTE to an existing network is an incentive to replace old single-standard GSM and WCDMA equipment with more modern multi-standard hardware – which results in significantly »

**FIGURE 3** **Examples of using 3-sector-to-omni reconfiguration, antenna muting, and small-cell and extension carrier sleep mode to enhance the overall energy performance of a radio network**




**BOX C**

**Legend for Figure 4**

**B** – the baseline system[3];
**H** – hardware improvements (EARTH project);
**D** – base station DTX;
**A** – antenna muting; and
**S** – dynamic sector-to-omni reconfiguration.

**FIGURE 4** **Power per area unit for a typical European nationwide LTE network for different configurations**

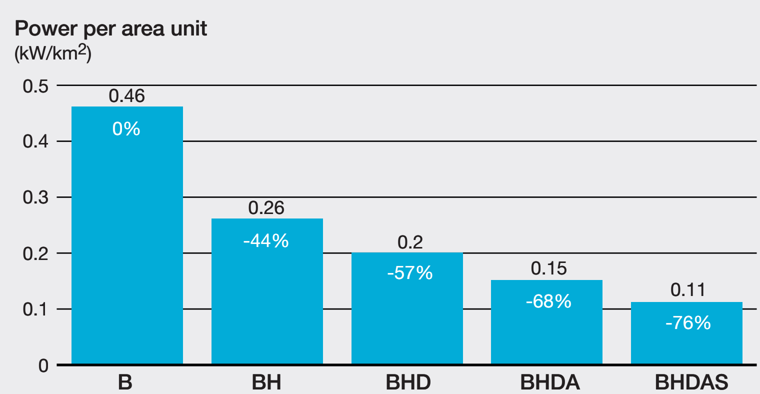
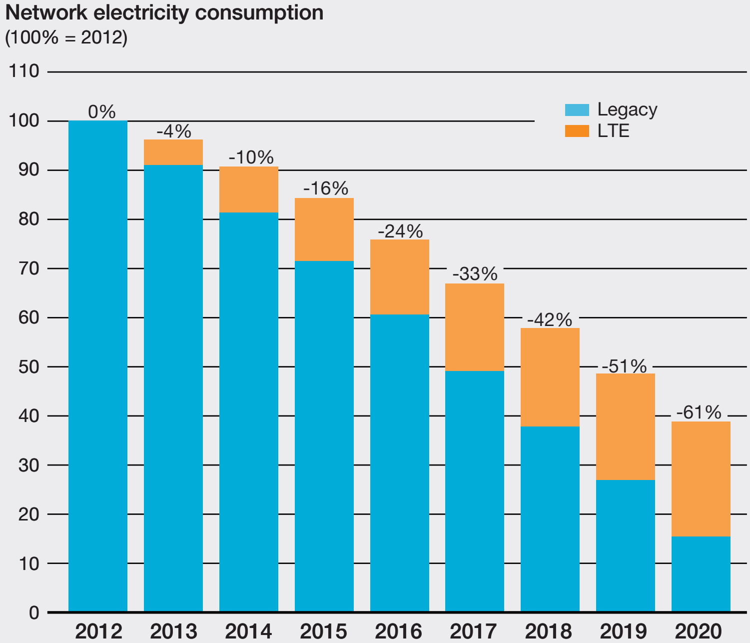


**FIGURE 5** **Distribution of energy used by both legacy GSM/WCDMA equipment and LTE equipment per year, according to a scenario in which GSM/WCDMA equipment is modernized at the same pace as LTE is introduced**




reduced energy performance overall. Multi-standard hardware has already replaced single standard equipment in many networks, and the energy saved by this modernization is typically greater than the energy used by all the new LTE equipment.

Given the evolution of network equipment and current rate of deployment, it is reasonable to assume that total energy consumption may actually decrease over time. This should hold true even with the addition of LTE and with aggressive network densification, in which a large number of new small cells are installed to handle massive growth in peak hour traffic.

The decrease in energy consumption will be, in most part, due to improved radio base station hardware, which can be expected to gradually replace existing legacy equipment until 2020. As shown in Figure 5, the results of a recent study[8] carried out in a mature market and including LTE showed that total radio-access network energy consumption in 2020 could be 60 percent less than the consumption in the reference year (2012) prior to the LTE rollout. These results were based on certain assumptions of the energy consumption of future base stations, which will be attainable if telecom vendors continue to prioritize energy performance.

## Energy-efficient products and services

Telecom vendors must fulfill a wide range of multi-standard cellular coverage and capacity requirements to meet the needs of different types of operator all over the world, and this includes meeting requirements for energy-efficient operations.

Placing radio transmitters so that they are close to antennas – remote radio units (RRUs) – is a well-established approach for improving the quality of the radio link. And so, building base stations with such a distributed architecture provides additional benefits in terms of eliminating energy losses in feeder and jumper cables as well as reducing cooling needs. However, as this approach causes the number of radio modules and antennas in the tower to increase, it makes radio sites with many frequency bands more complex.

To keep transmitters close to the antenna and remove the complexity for multi-frequency sites, the AIR solution – when compared with standard base stations and combined with passive antennas – eliminates feeder losses and has a simplified cooling system, resulting in a 40 percent reduction in energy consumption[9]. With fewer units and fewer interconnections compared with traditional site solutions, AIR solutions allow a new standard or frequency band to be introduced easily, which reduces installation and network evolution costs.

Providing solutions to meet capacity demands in highly loaded urban areas is a special challenge. When a dense macro layer is no longer enough, a second capacity layer can be added to form a heterogeneous network that is fully integrated and coordinated. This capacity layer is often implemented by connecting base stations to different versions of distributed radio heads. The low power requirements of such radio heads can, in some cases, enable them to operate using a single LAN cable that provides both power supply as well as radio signals. This concept is used in the Ericsson Radio Dot System, which is a clear example of how energy performance has directed the path of new technology and innovative solutions.

### *Good dimensioning*

With many product variants to choose from, operators can create radio base station site configurations with both sufficient capacity and minimum energy consumption. However, due to the exceptional radio efficiency and processing capacity available in modern products, the maximum available capacity tends to be far greater than needed for the majority of the radio base station sites.

Contrary to what might be expected, over-dimensioning does not always result in performance gains. Instead, it more often leads to increased opex, higher energy consumption, and inflated capex – all of which impact TCO. In one trial, energy consumption of a deployment with traditional large capacity radio base stations was compared with that of a more precisely matched mix of solutions. Results showed that it is possible to reduce energy consumption by 40 percent while maintaining network performance. As illustrated by **Figure 6**, the drop was achieved through judicious selection of the right products for each site – shifting from power to precision.

Instead of blindly choosing high-capacity solutions for all sites, only the high-traffic segment (red) should be matched with a high-capacity configuration. For sites with medium (blue) and low (green) traffic demands, more suitable but sufficiently high-performing configurations were chosen to obtain the desired overall precision and corresponding reduction in energy consumption. The different site capacity demands were matched with different variants of baseband and radio products optimized for each of the desired traffic segments.

*A unique high-performing low-energy macro*

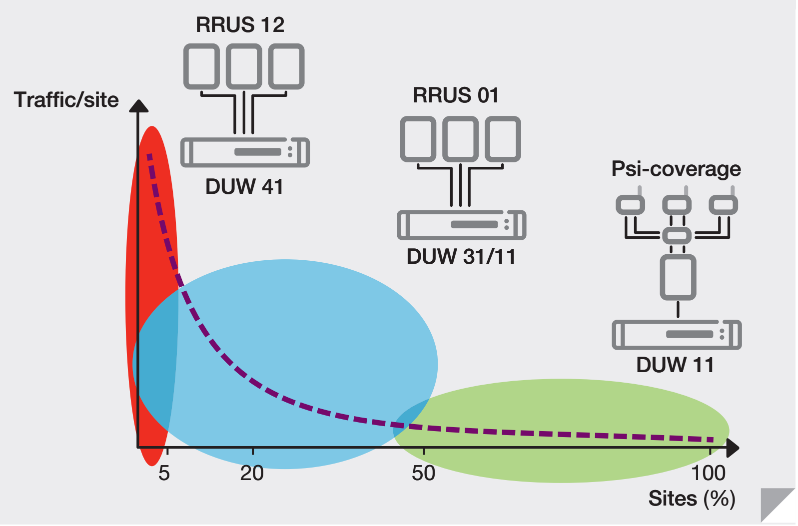
The Psi-coverage solution uses a single radio unit to provide the same coverage as an ordinary 3-sector base station equipped with three radio units. Using less hardware, the solution is more energy-efficient and it can be – at least – applied to the 50 percent of sites that experience relatively low traffic (the green segment in Figure 6). When and if more capacity is needed, additional radio units can be easily installed – securing the upgrade path.

The Psi-coverage approach overcomes coverage challenges thanks to the three tower-mounted amplifiers with frequency shifting (TMF) units in combination with advanced software functionality in the radio. The energy-saving potential of this approach is immense; field trials in operator networks have shown energy reductions of more than 40 percent on node level without sacrificing user performance, compared with regular 3-sector sites – as shown in **Figure 7**[10]. Consumption reduction on such a scale is fundamentally achieved through less hardware, both in terms of fewer modules and in terms of adapting the capacity of the remaining modules to the actual capacity demand.

*Power supplies*

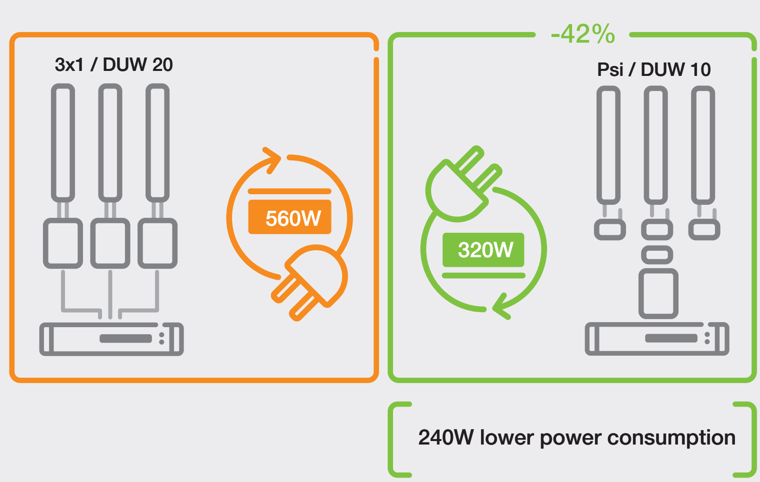
Building energy-efficient networks requires additional technology when radio base station sites are put into operation. How power is supplied is obviously a crucial issue. Solutions, for example, that increase the efficiency of AC/DC conversion for high-performing power supply units, as well as solutions with integrated power supply that optimize energy-efficiency by reducing cable losses are key. To get the most energy-efficient operation at site level, there is a need to continually manage, maintain and optimize the active and passive network infrastructure from an energy perspective.

**FIGURE 6 Reducing total cost of ownership by matching products with traffic segmentation demands**




The choice of battery and how batteries are used are critical, as maximizing lifetime and improving battery efficiency can save a lot of energy. For the many off- and poor-grid sites that are diesel-powered, one innovative way to improve battery usage is to combine advanced batteries with a site controller that can operate diesel generators more efficiently. When batteries are fully charged, the controller shuts off the diesel generators so that the site runs on battery power until recharging

**FIGURE 7 The power consumption of a Psi-coverage site is 42 percent lower than a corresponding site with a traditional 3-sector deployment**



is needed. By consuming power in this way, fuel consumption has been shown to drop by up to 50 percent, and total costs are further reduced as the number of fuel deliveries required also drops. By enabling site surveillance, the site controller can help to lower costs even further by eliminating unnecessary site visits. In addition, sites are not limited to a single source of energy, as the controller can choose from a mixture of available energy sources including wind-generated and solar-powered.

**Summary**

To build multi-standard radio networks that are capable of managing a massive increase in traffic, operators need products and solutions that not only provide excellent performance but that are also highly resource efficient. The definition of a best performing network needs to be extended beyond best coverage, capacity and traffic execution to also include best energy performance.

The way to incorporate energy performance into basic network considerations is to utilize more precise solutions and a wider variety of products that specifically fit the traffic situation of each radio base station site rather than simply optimizing the network for high capacity. Psi-coverage for low traffic nodes is a good example of such a precision solution.

The number of installed nodes in today's networks is substantial, and consequently the potential saving through application of software features that, for example, reduce the number of active transmitters in low-traffic periods, or dynamically lower transmission levels to meet quality demands, or tune transmitted power levels to handle control signaling, is considerable – even if savings-per-node are modest. However, it is clear that energy consumption improvements must also address hardware operation and that the largest potential savings – in terms of energy and the bottom line – lie in a combination of improved hardware and software solutions.

In the Networked Society, with its ubiquitous real-time connections, consumption per subscriber should remain quite low, but from an aggregated global view, new mobile requirements and opportunities will put significant pressure on energy usage.

Energy-efficiency is already gaining importance on the political agenda at a local, national and an international level, making this a critical issue not just for the ICT industry, but also for a broad spectrum of industries, governments and other organizations. And this attention enhances the attractiveness of innovative solutions that reduce energy consumption. It is crucial that the telecom industry continues its efforts to reduce total energy consumption in mobile networks, while continuously improving performance so that it can cater for increasing traffic and the next billion subscribers.

The continued close cooperation between vendors and operators can achieve great improvements in the energy performance of cellular networks – improvements that will benefit our global society.

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**Magnus Olsson**

joined Ericsson Research in 2000. He has worked on several radio access technologies, as well as areas such as advanced antenna systems, interference rejection techniques and energy efficiency of RAN. He has also held leading positions in internal – as well as various European – research projects. In 2008-2009, he managed Ericsson's research activities on multi-antenna technologies targeting LTE-Advanced, and in 2011-2012 he was the technical manager of the EARTH project on RAN energy efficiency. Currently, he is a senior researcher specialized in energy performance. He holds an M.Sc. in engineering physics and an H.Dip.Bus., both from Uppsala University, Sweden.


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