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Methods for Reducing the Energy Consumption of Mobile Broadband Networks

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Up until recently, very little consideration has been given to reducing the energy consumption of the networks supporting mobile communication. This has now become an important issue since with the predicted boost in traffic, network operators are required to upgrade and extend their networks, increasing also their overall energy consumption. However, traffic analysis shows that during a 24-hour period, the volume of carried traffic varies continuously, with the network operating anywhere close to its full capacity for very short periods of time. The problem is that during hours of low network traffic the energy consumption remains high. This article proposes two major solutions for mitigating this problem. In the first case, an energy saving between 14% and 36% is observed by allowing the network to dynamically optimize its available capacity based on the traffic being carried. In the second case, energy saving is obtained by reducing the amount of required network upgrades. This is done by accommodating increasing traffic during less busy hours to provide an adequate incentive for subscribers to spread some of their daily traffic. Over a period of five years, besides saving on the investments, an indirect energy saving of 30% is possible. In all investigations, the network performance is given priority and always maintained.

1 Introduction

The recent (Dec '09) United Nations Climate Change Conference, held in Copenhagen, has attempted to get world leaders to extend and intensify their commitment for safeguarding the environment from global warming. An uncontrolled increase in global temperature is feared capable of causing worldwide devastation, with greatest concerns being directed towards small island states [1] and developing countries. Away from the politics that surround such delicate negotiations, various industries, companies, and individuals have long been actively looking at methods for limiting their contribution towards climate change. This can generally be done in either of two ways: *directly* – by reducing the emissions of greenhouse gases, mainly carbon dioxide (CO₂), or *indirectly* – by reducing the consumption of energy that originates from non-renewable sources of energy, giving off CO₂ in the process. Besides the direct benefits towards the environment, a reduction in the energy consumption also results in a number of additional advantages.

The reward for consuming less energy comes directly in the form of cheaper energy bills. For large operators, whose operational expenditure (OPEX) is heavily based around energy, a reduction in its consumption can result in substantial yearly savings. Besides, an effort in reducing the energy consumption can also improve the way that people look at that specific industry or company. In a society where consumers and the general public are well aware of the phenomena of climate change, any industry or company that shows a serious commitment to reducing its carbon footprint might gain a competitive edge over its 'pas-

sive' competitor. This has for many companies led to fierce competition to become the 'greenest' within their respective industry. Most players in the various industries have already publically set their targets for reducing their overall CO₂ contribution.

Although not specifically for environmental purposes, within mobile devices, energy efficiency has always been a necessity. Advances in various fields have allowed for mobile devices to become smaller and more powerful while consuming less energy. Unfortunately, this has not been the case for the underlying networks that support the communication between these devices. In 2008, the operation of mobile networks consumed nearly 80 TWh of electricity. It is believed that around 80% of this energy is consumed by the access network. [3] This is that section of the network that provides a wireless communication link between mobile devices and the central, or core, section of the network. Within a mobile network, the main structure providing such a link is commonly referred to as a base station site. Power consumption of the RF (radio frequency) power amplifier and the large quantities of such sites are a few of the reasons why the energy consumption in such sites is so high (Figure 1).

2 Energy, a Pressing Issue for Network Operators

2.1 Traffic Boom

Following the massive deployment of high speed packet access (HSPA), most of which took place in 2007-2008, mobile network operators could offer

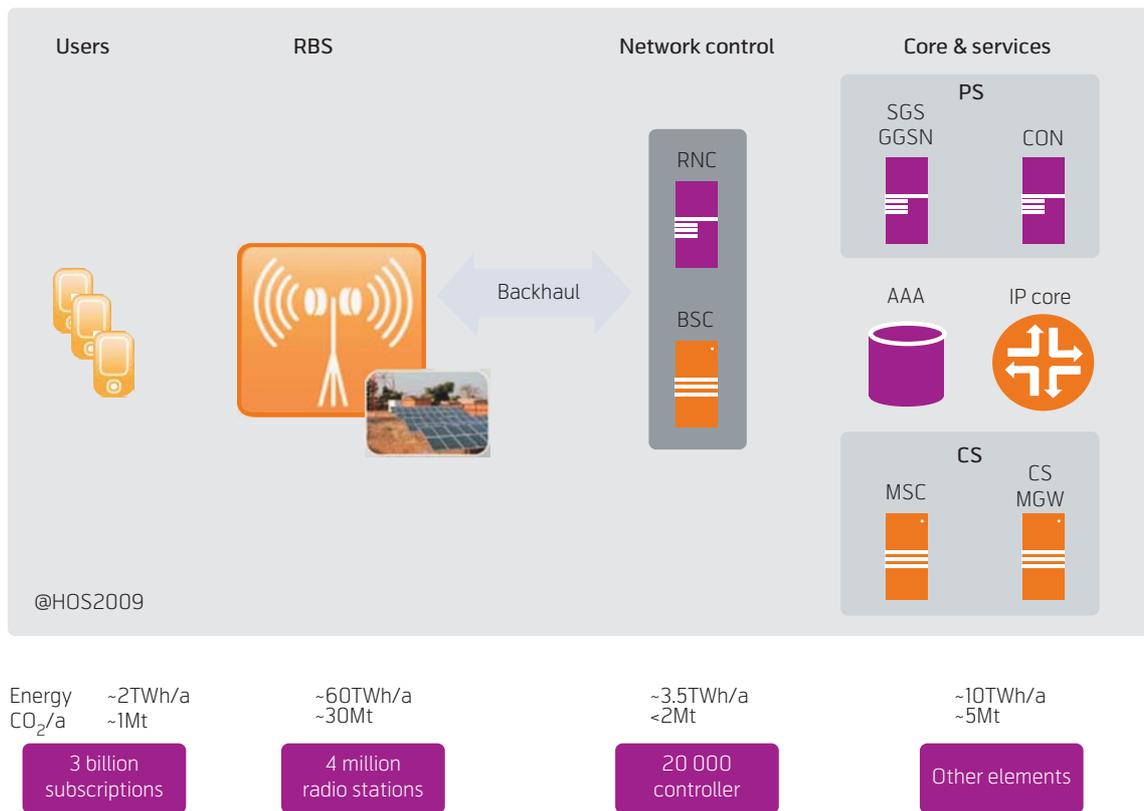


Figure 1 This figure shows how the global energy consumption varies in various areas of a typical mobile network. While the overall consumption is based on the individual elements, the number of such elements also plays a crucial role. This figure also highlights why an improvement in the energy efficiency within base station sites (BTS) is essential for reducing the overall energy consumption of mobile networks [Source: Telecom Power Consumption and CO₂ Footprint Analysis] [2]

faster, more reliable data services, now widely referred to as mobile broadband. These services started to pick up soon after with the introduction of various smart phones, USB dongles / data cards, and

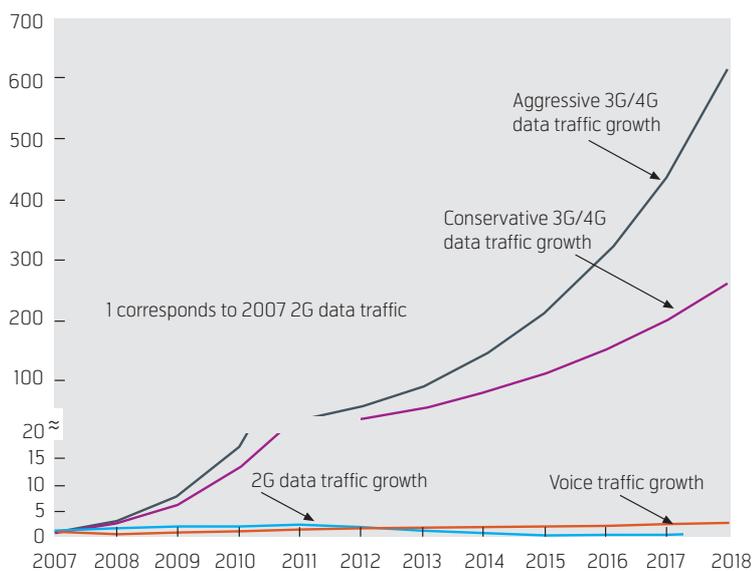


Figure 2 Conservative and aggressive prediction curves for the expected growth in mobile-broadband over a period of years. The y-axis represents the factor of growth as compared to the 2G data traffic in 2007 [Source: 3G Americas] [6]

flat-rate tariffs. These provided mobile users continuous and most importantly location independent access to the internet, allowing them to browse, stream, share, and communicate in the same way as if they were sitting at their computer. As Rob Conoway, Chief Executive Officer of the GSM Association puts it, the “uptake of mobile broadband services is surging in many countries as consumers and business users see the benefit of having a high-speed connection available to them at all times”. [4] Over a few years this has led to a massive boost in data traffic, with mobile operators reporting annual increases ranging from 300% to 700%. [5] Since the number of subscribers making use of such data services is expected to keep increasing, together with the volume of data used by each subscriber, predictions (Figure 2) show that similar trends are to be expected for years to come. [6] While for network operators traffic represents revenue, they also have to ensure that their network can handle the demand, safeguarding the reliability of their services.

The primary requirements for mobile networks have for long been coverage and capacity. Coverage is the ability of a network to provide some basic service over a wide enough area, ensuring that subscribers

can make use of their services irrespective of their location. On the other hand, capacity defines the volume of traffic that can be carried. The number of sites to be deployed in a specific area of the network is based on the required capacity, which is in itself based on the maximum expected traffic. In communication terminology, the hour of the day when this maximum traffic occurs is referred to as the busy hour. The greater the traffic, the more base station sites are required.

2.2 Evolution of the Network

Following the great success of GSM, network operators generally already have good nationwide coverage. In order to reduce costs, most of the sites housing GSM equipment are also used for the 3G equipment. In particular areas where large volumes of data traffic are expected, additional 3G-only sites are added. The upgrade of 3G sites to HSPA provides a substantial boost in network capacity, allowing the network to provide higher peak data rates and/or to support a larger number of users.

With the peak traffic rapidly increasing, network operators have to regularly upgrade the capacity of their networks. This can come in either a single or a combination of upgrades. A boost in capacity can come in the form of a feature upgrade, such as MIMO, which involves parallel transmission over multiple antennas. Alternatively, if the available spectrum license permits it, additional carriers can be added to off-load the existing carrier/s. Depending on the traffic, certain areas might also require the installation of an entirely new base station site, increasing capacity by having each site serve a smaller area of the network.

The energy efficiency of the necessary equipment to upgrade the network is continuously improving. Nonetheless, the installation of additional equipment, especially when an entire new site is required, will always result in an increase in energy consumption for the network. With the rate at which traffic is increasing it becomes clear that unless something is done to limit this increase, the operational costs and carbon footprint of the mobile communication industry are set to keep rising. A particular research project conducted at Aalborg University, in collaboration with Nokia Siemens Networks and Telenor Denmark, is looking at possible methods to limit this increase in energy consumption for current and future mobile networks.

3 Network Traffic and its Relation to Energy Consumption

Within a specific location, networks are scaled such that they can cope with more than the maximum predicted traffic. However, the actual volume of traffic that is carried by any communications network varies continuously, creating daily, weekly, and seasonal patterns. These patterns are formed by habits of the subscribers that generate traffic. For instance, on a daily basis, during the early hours of the morning, most people are generally asleep, thus generating very little or no traffic. On the other hand, seasonal variations can be attributed to the mobility of subscribers, moving for a period of time to a different location. For instance parts of the network that cover an area by the coast are likely to have very low volumes of traffic during the winter, but increasing during the warmer seasons. Nonetheless, there are always some unpredicted extraordinary occasions or events that generate a sudden surge in network traffic, disrupting the otherwise relatively regular patterns.

Traffic measurements taken from the Copenhagen area of Telenor Denmark's 3G network over a period of three weeks show some of these patterns. These measurements are taken from every individual cell (a single base station site generally has three cells), and show the accumulated volume of HSDPA traffic, in kilobytes, that is carried by that cell over a period of one hour. Considering the fact that around three hundred cells are considered, a measurement for every hour for every cell ultimately results in a large quantity of data. However when appropriately sorted this data starts to show a number of interesting trends. For example, it becomes clear that during weekends, the average volume of traffic is about 25% less than that during weekdays. Besides, it is noted that in this particular area the busy hour generally occurs at around 9pm. By looking at the daily averaged traffic profile (Figure 3) in more detail, it can be observed that during an eight hour period, the network carries about half of the daily traffic, and that when compared to the busy hour traffic, the minimum volume of traffic carried is around 75% less.

The energy consumption of any individual base station is only partially based on the load, or carried traffic, that the site experiences. This is because communications equipment within any base station site can be grouped either as being load dependent or independent. Due to the latter, temporal variations in network traffic ultimately also effect the overall energy consumption of the network. However, available models, which focus on the main communications equipment, suggest that for a large reduction in network traffic, the energy consumption is only marginally reduced. More specifically, if we consider the

Averaged network traffic - normalized over 24 hours (%)

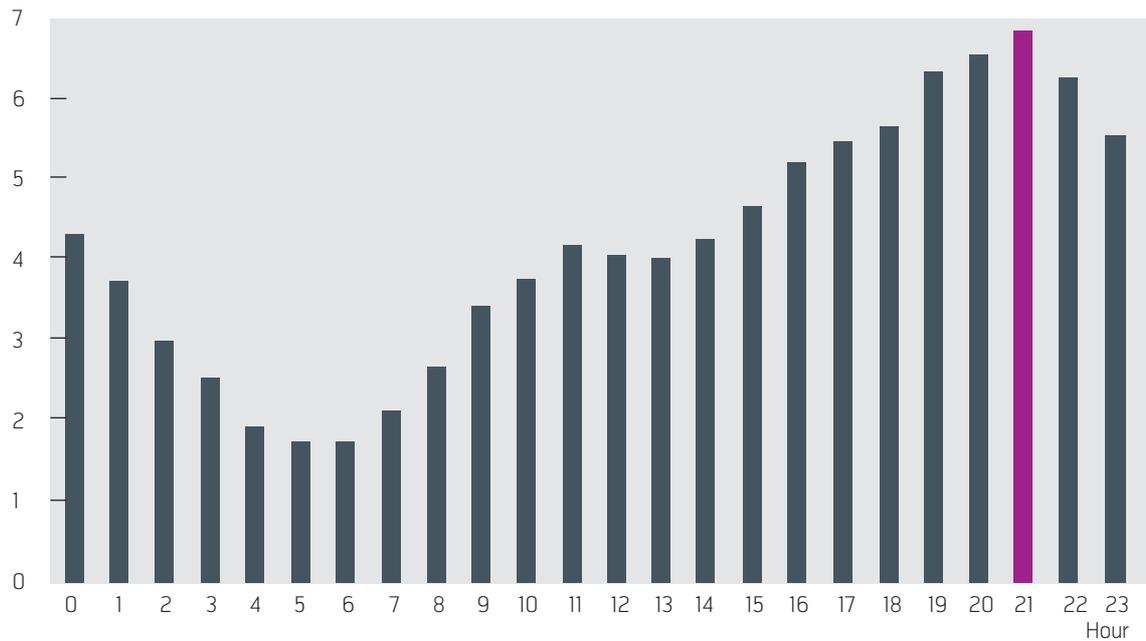


Figure 3 Typical variation in the average daily carried traffic of a real mobile network. This figure is based on real data traffic values, extracted over a period of three weeks, from Telenor Denmark's Copenhagen area. The purple bar highlights the busy hour which in this case occurs at around 9pm. The figure also shows that almost 7% of the daily traffic is carried during the busy hour [Source: Telenor Denmark]

traffic data from Telenor Denmark, which shows a maximum reduction in traffic, or load, of 75%, this reduces the energy consumption by a bit more than 20% (Figure 4).

This variation between network traffic and energy consumption highlights a major problem, namely that the network energy consumption is mostly based around the overall peak capacity and not the traffic being carried. Hence, as the traffic keeps increasing,

network upgrades will increase both capacity and the energy consumption of the network, irrespective of the fact that the traffic generated during most of the day could have been comfortably carried prior to any upgrades. The ultimate objective for network vendors and operators alike is to carry more traffic for the same or possibly less amount of energy.

4 Solutions for Improved Energy Efficiency

By taking the above into consideration, the main options for limiting the rate by which the energy consumption increases are two. On the one hand, this can be done by having the capacity of the network to dynamically adjust around the requested traffic. On the other hand, rather than varying the capacity of the network, the available capacity can be more efficiently used. Both cases aim at bridging the gap between variations in energy consumption and carried traffic. In the first case, this is done by further reducing the energy consumption when traffic is low, whereas in the second case, the inevitable increase in traffic is accommodated within other less busy hours. For both cases, the ongoing research project at Aalborg University is attempting to quantify the potential energy savings, and the effect that they could have on the performance of the network.

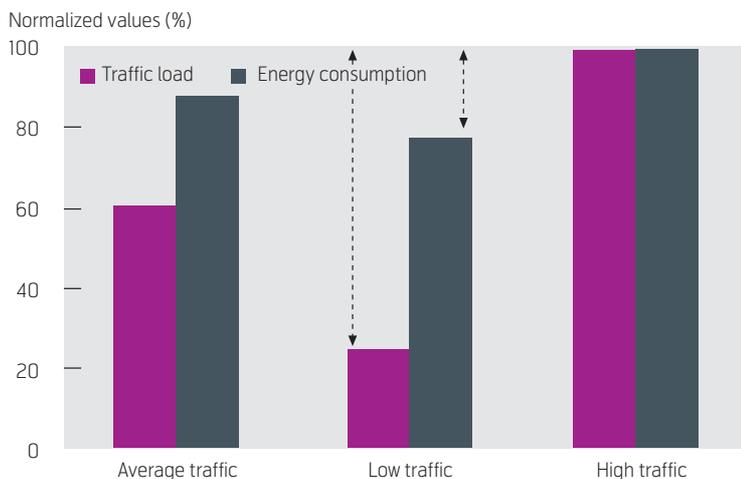


Figure 4 This figure shows the variation in energy consumption as a function of the load, or carried traffic. It becomes clear that the energy consumption is very lightly related to the volume of traffic being carried

4.1 Reduction in Network Capacity

A reduction in network capacity can be achieved, either by putting a site into sleep mode, or by disabling/switching off specific capacity enhancing features. Such methods can result in substantial energy savings since they also eliminate the effect of load independent components.

4.1.1 Switch Off Sites

In current HSPA networks, the area being covered by any cell varies continuously, and is proportional to the amount of users within that site. More users generate more interference, requiring that worst effected devices, generally the ones that are furthest away, to either transmit at a higher power, or move closer towards their serving cell. This effectively leads to the serving area of a cell shrinking with an increasing number of users. Within wireless communication this is more commonly referred to as 'cell-breathing'. If neighboring cells are not close enough, this can result in a number of coverage holes, or areas within the network where no basic services can be guaranteed. For any network operator this is highly undesirable, highlighting why planning of any mobile network is focused around the busy hour. Similarly, when the number of users within a cell drops, the cell expands towards its neighbors. Since the number of sites, and the distance between each neighboring site is based on the busy hour, extensive coverage overlaps are inevitable. These overlaps can in some points be so drastic that sites effectively become redundant. This means that the network coverage and performance would not be affected if such sites were not there in the first place. If the energy consumption of the network has to be reduced by switching off, or putting into sleep mode, a number of base station sites during hours of low traffic, such redundant sites would make the ideal candidates.

A case study is carried out to quantify the potential energy that can be saved by putting base station sites into sleep mode during hours of low network traffic. A snap-shot based simulator, loaded with the appropriate network and traffic information is used. The previously referred energy model is used to measure the overall daily energy consumption of the network. On the other hand, network performance is primarily measured through the percentage of user satisfaction. Each user requests a minimum data rate of 256 kbps, and if the network can deliver anything equal or above this data rate, then the user is assumed satisfied. For the performance of the network to be deemed acceptable, a 95% user satisfaction rate is required. Another network performance measure noted throughout is the average achievable user data rate.

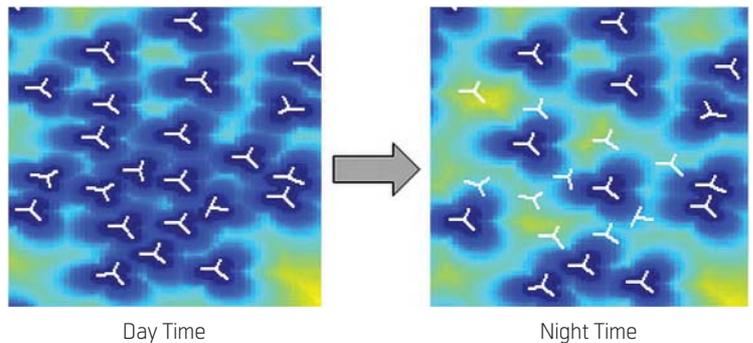


Figure 5 A graphical representation of putting sites into sleep mode. In this section of the network almost half of the available sites are deemed unnecessary and are put into sleep mode. The colours represent received signal strength. Since there are fewer users, weaker signal strengths do not necessarily limit user satisfaction

An algorithm that checks and decides which sites to put into sleep mode is implemented. For any traffic scenario, the algorithm checks whether the load of a specific site is below a specific threshold. This threshold controls the sensitivity of the algorithm, with the selected threshold prioritizing network performance. If the load is below this threshold, that site becomes a candidate for being put into sleep mode. Once all sites are checked, the algorithm selects one of these sites and puts it into sleep mode. Since neighboring sites are required to take over any traffic previously carried by the site now in sleep mode, their load is recalculated and is again compared to the threshold, making a new candidate list. This is repeated until there are no candidate sites. Since each base station site is generally composed of three individual cells, this investigation is carried out twice. In the first case, the entire site (all three cells) is put into sleep mode, whereas in the second case, individual cells are put into sleep mode.

Results (Figure 6) show that over a 24 hour period some substantial energy saving is possible. In the first case, which allows for entire sites to be put into sleep mode, an energy saving of 24% is noted. In the second case, given a greater flexibility in choosing which cell to put into sleep mode, the energy savings observed were higher, 32%. This energy saving is achieved without any negative effect on the rate of satisfied users. However, since the average distance between some users and their serving base station site increases, this has an effect on the achievable data rate. By considering the original network layout during hours of low traffic, the average achievable data rate is 536 kbps. When putting individual cells into sleep mode (worst of the two cases), this value is noted to fall by a bit more than 20%. This is however still within the minimum required data rate of 256 kbps. The presented energy saving figures can be consid-

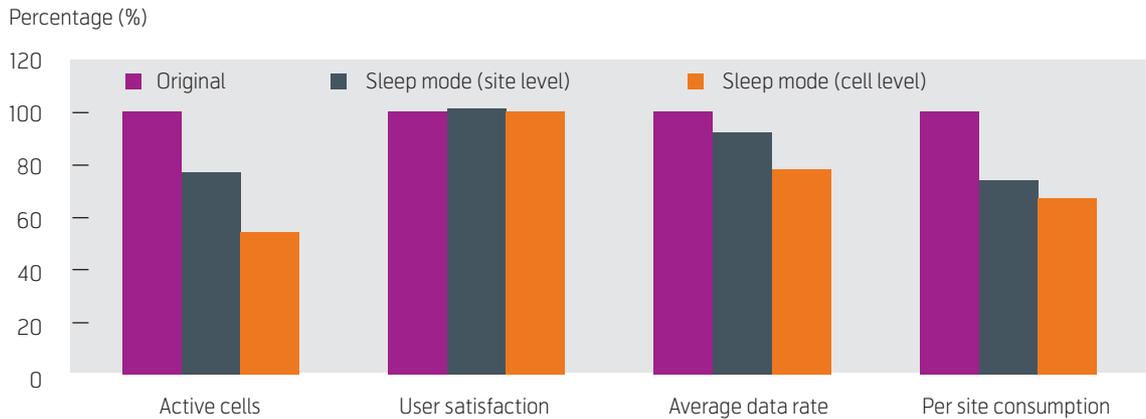


Figure 6 The bar chart shows a summary of the results obtained for putting cells or sites into sleep mode during hours of low network traffic. It is noted that user satisfaction is not affected. However, the energy savings observed come at the cost of a reduction in the average data rate. It is also clear to note that putting individual cells into sleep mode gives an extra flexibility, thus increasing the potential for energy saving

ered to be more on the conservative side, since in both cases sleep mode is only allowed during hours with low network traffic, which in this particular case amounted to about 12 hours. [7]

4.1.2 Switching Off Features

Another similar analysis is carried out on an upcoming technology called Dual-Cell or Dual-Carrier HSDPA (DC-HSDPA). DC-HSDPA allows for a single user to access available resources on two adjacent carriers. In a single user scenario, DC-HSDPA allows that user to theoretically achieve twice the data rate that is possible over a single HSDPA carrier. Based on the existing equipment within base station sites,

the addition of a secondary carrier will generally require additional radio equipment, also increasing the energy consumption. However, this also offers an opportunity for reducing network capacity during hours of low traffic, without any compromise for the overall coverage area of the network. This is safeguarded by one of the two carriers that are always left active. If we assume that within a specific area all sites have DC-HSDPA implemented, this means that the maximum achievable energy saving is limited to 50%. By considering a number of different traffic scenarios, representing different areas of the network, an energy saving ranging from 14% to 36% is observed. Once again, the design of the algorithm enabling this

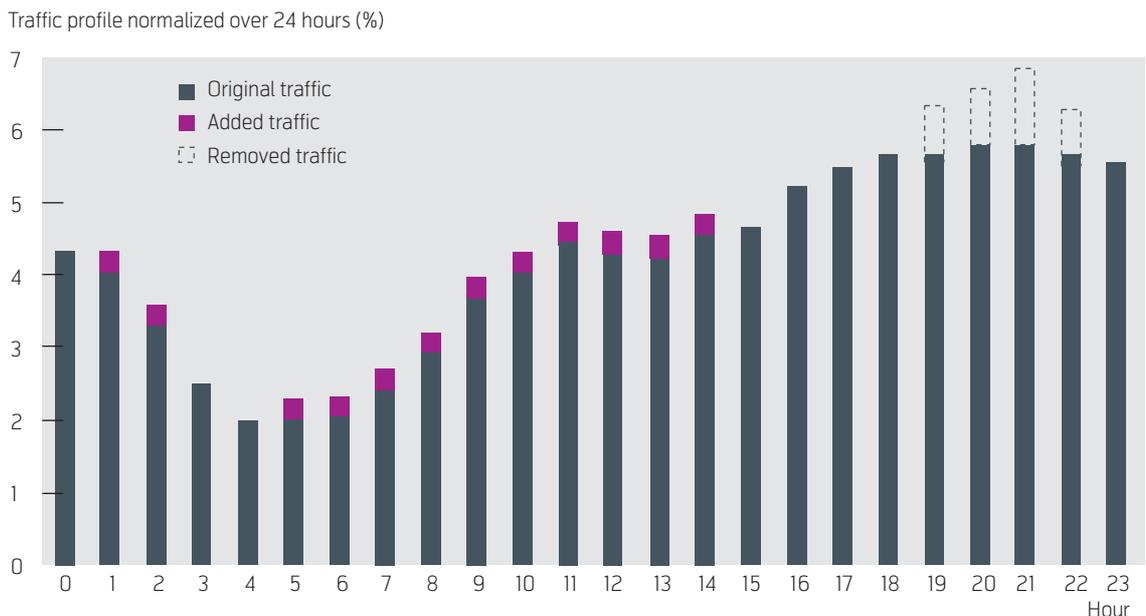


Figure 7 This figure shows the concept behind traffic filtering, whereby network traffic is shifted away from the busy hour. This traffic is distributed over some of the remaining hours (in purple). This improves the capacity utilization of the network while also reducing the need for additional network upgrades to handle the same volume of traffic

feature prioritizes the performance of the network. This ensured that switching off the secondary carrier did not have any major negative effect. [8]

4.2 Traffic Filtering

While the two previous methods involve limiting the capacity of the network during hours of low traffic, the second option being looked at involves making a more efficient use of the already available capacity. With traffic continuously increasing, the idea of traffic filtering is to exploit hours of low network traffic to off-load some of the additional traffic from the busy hour. The most effective way to do this is to have an appropriate pricing strategy. The concept is almost identical to what energy companies are already doing with electricity. Network operators can offer better rates for loading the network during hours with lower traffic. While this can boost the overall volume of traffic, it also provides an incentive for subscribers to schedule the download of non-essential content during more affordable hours. Traffic filtering would to some extent limit the rate by which the busy hour increases, while still carrying all of the additional traffic. The idea is that by doing this, fewer network upgrades are required. This is very advantageous for network operators. On the one hand, since fewer upgrades are necessary, this reduces the yearly capital expenditure (CAPEX). By having fewer upgrades, there are also inherently less OPEX, of which energy consumption plays a major role. Besides these financial benefits, a delay in having to increase the capacity of the network can give network operators enough time to consider other alternatives, or wait for a more radical upgrade.

The concept of traffic filtering is again tested out through a case-study. The Copenhagen area of Telenor Denmark's network, together with the predicted increase in traffic over a period of five years are used to assess the number of macro network upgrades required. The upgrade path of each site is pre-defined and ranges all the way from having regular single carrier three sector sites to having larger six sector sites with three carriers and MIMO configuration. By shifting less than 4% of the daily traffic away from hours around the busy hour it is noted that 60% less sites required the final upgrade towards six sectors. As a result, in the fifth year, the energy consumption is noted to 'indirectly' fall by more than 30%.

5 In Conclusion

With the threat of global warming and climate change, and the effects of increasing energy consumption, mobile network operators are putting energy efficiency within their requirements. The current trend clearly shows that a massive increase in data traffic is at this point unavoidable. While this

increases revenue, network operators have to ensure that their networks can sustain this increase in traffic, ensuring that their subscribers are in no way limited from using their regular services. This will come in the form of a number of network upgrades, which besides boosting network capacity will also increase the overall energy consumption of the network. Improvements in the energy efficiency of the used radio equipment help in limiting the overall increase in energy consumption. Nonetheless, the gap between energy consumption and actual carried traffic is still large, highlighting the need for additional features to further reduce the energy consumption during hours of low network traffic.

This article has looked at two main solutions for bridging this gap. In the first case this is done by reducing the overall energy consumption of the network by either putting some selected sites into sleep mode or by disabling/switching off some specific capacity enhancing feature. For putting sites into sleep mode, a maximum energy saving of 32% is observed. Switching off DC-HSDPA is tested on different traffic scenarios, with results showing a daily energy saving varying from 14% to 36%.

In the second part of the article, the concept of traffic filtering is introduced. The idea of traffic filtering is to shift some traffic away from the busy hours through an appropriate pricing strategy that motivates subscribers to do so. Over a period of time, this allows for the network to carry more traffic but with fewer network upgrades. This allows network operators to save on CAPEX, and OPEX, while also giving them enough time to consider alternative solutions or technologies. Through a case study it is observed that by shifting less than 14% of daily traffic away from hours around the busy hour, over a period of five years, far less network upgrades are required. Besides the obvious CAPEX savings of not requiring such upgrades, the network can carry the same volume of traffic with 30% less energy.

These first investigations have demonstrated the potential energy saving that is possible by optimizing the use of the available network capacity. This can be looked at in further detail, highlighting also the network requirements and modifications needed to actually implement such features. This work mainly focuses on the operation of the radio access part of the network. Ultimately, in order to considerably reduce the overall energy consumption in the mobile communication industry, an end-to-end approach is required. Such an approach would consider all of the involved components, and where possible introduce energy saving features that maximize network performance from an energy point of view.

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