LEVERAGING ADVANCES IN MOBILE BROADBAND TECHNOLOGY TO IMPROVE ENVIRONMENTAL SUSTAINABILITY

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Advances in mobile access broadband technology have a high potential to improve environmental sustainability both directly by enabling novel network deployment concepts and indirectly by changing the way people live and work. In this paper, improvements of the network topology enabled by ubiquitous broadband access are investigated. It is shown that a joint deployment of macro- and publicly accessible residential picocells can reduce the total energy consumption by up to 70% in urban areas. In addition the high potential of indirect effects of improving telecommunication networks, such as enabling teleworking and replacing business travel through video conferencing, is demonstrated and compared with the direct effects.

1. INTRODUCTION

In recent years, the increasing cost of energy, coupled with the current international focus on climate change issues has resulted in many efforts in reducing the use of energy. Studies have shown that telecommunications can be large consumers of energy, with NTT accounting for 0.7% of Japan's total energy consumption in 2001, and Telecom Italia using 1% of Italy's total energy consumption in 2006 (Gorini 2007). In Australia, it is estimated that ICT use in business accounts for 1.4% of total national emissions, with the network operator Telstra alone accounting for 0.2% (Climate Risk 2007). Therefore, the telecommunications industry has participated in discussions of its role in reducing its impact in this field.

Apart from the social responsibility aspect, there is also a major economic motivation to reduce energy consumption in networks. For example, the price of industrial electricity has risen in the United Kingdom by 74% in the period from the beginning of 2004 to the end of 2006 (UK Department for Business and Regulatory Reform 2007). Government authorities worldwide are also considering implementing climate change policies that include proposals such as energy taxation and carbon trading that can provide further economic reasons to increase energy efficiency amongst network operators.

Therefore, while energy efficiency of networks has been important in the past, it is clear that it is becoming even more significant in coming years. One class of network systems that has been widely deployed worldwide is wireless cellular networks. Cellular networks typically require a large number, up to tens of thousands, of base stations to provide nationwide coverage. Since each base station can require – depending on the configuration, load of the cell, and age of the equipment – up to 2.7kW (Rinaldi and Veca 2007), the energy consumption for a nationwide coverage is in the order of several hundred MW. Cellular networks are therefore systems where the benefits of higher energy efficiency can be considerable.

The advancements in broadband technologies and deployments have been rapid in the past 10 years, with high data rate data connections becoming cheap and easily available in many developed countries. The indications are that the continued expansion of broadband connections will continue at a rapid pace in the future. There is a substantial opportunity to leverage the wide availability of high speed data connections to reduce both the telecommunications industry's direct impact on the environment, as well as changing the way the public behaves to offer benefits to the environment indirectly.

In this paper direct and indirect ways of how advances in broadband technology can help to improve environmental sustainability are explored. Previous work (Claussen et al 2008) which investigated a joint macrocell and residential picocells deployments to improve the energy efficiency of cellular networks is extended with an investigation of benefits coming from indirect effects such as teleworking and reduced travel through video conferencing.

This paper is organised as follows. In Section 2, the direct benefits of improving cellular networks by using broadband technology are investigated. The efficiency of current macrocellular networks in delivering high data rate services, and how moving towards small cells can help to improve efficiency, is explored. Then the concept of joint macro- and picocell coverage is presented, and results showing the potential benefits based on current technologies are discussed. Possible improvements of future technologies on the energy efficiency of base stations are presented, and results of the joint coverage scenario with these improvements are shown. In Section 3 the potential indirect benefits of advances in broadband technology are discussed. Two examples, the impact of enabling teleworking, and replacing business travel by video conferencing are examined and their potential benefit is quantified. In Section 4 the potential for direct benefits is compared with the indirect benefits. Finally, Section 5 gives the conclusions of the analysis.

2. IMPROVING ENERGY EFFICIENCY OF CELLULAR NETWORKS USING BROADBAND TECHNOLOGY

Advances in broadband technology enable new approaches to deploying cellular networks which can potentially bring significant improvements in terms of capacity and energy efficiency compared to traditional macrocellular deployments. In this section the potential benefits of a joint macro- and residential picocell deployment are explored based on today's technology. In addition the impact of future technology improvements is discussed.

2.1. EFFICIENCY OF TODAY'S MACROCELLULAR TECHNOLOGY AND CHALLENGES

Macrocellular network deployments have in the past been effective in providing coverage for voice and low-speed data traffic. However, one of the most obvious trends in wireless communications is the move towards higher data rates. Macrocells are characteristically good at providing area coverage, but are not as effective in providing high data rates per area due to their typically large coverage. While there have been many different approaches made to improve the spectral efficiency of macrocells and provide the required capacity in the future, macrocells are still generally limited due to the shared bandwidth for a large coverage area.

It has been widely argued that the shift towards the use of small cells is a route to scaling the data rates by several orders of magnitude as will be required in the future (Webb 2007). Small cells, with a coverage radius of hundreds or tens of meters, can use higher frequency bands that are more suited to providing high data rates. They also offer the localisation of radio transmissions, such that shared bandwidth can be replaced with a more “personal” use of bandwidth. Therefore, as the provision of high data rate services to mobile users starts to increase, the energy efficiency of macrocells will decrease considerably. Small cells can provide the means to control the resulting increase in energy consumption in the future.

One of the recent developments towards the direction of smaller cells is the introduction of femtocells. Femtocells are low-power, low-cost, user-deployed base stations, designed for use in residential or enterprise environments (Ho and Claussen 2007), (Claussen 2007). They are intended to provide coverage only in the deployed home or office, and hence have a very limited coverage range. They also typically employ the user's DSL or cable broadband connection as backhaul connection to the mobile operator's core network. Femtocells are expected to initially be deployed with access restricted to private users only. However, when public access to femtocells is implemented, there is a huge potential of exploiting widespread femtocell deployments to significantly reduce the energy consumption of cellular networks by using the deployed femtocells to supplement the capacity of the macrocellular network. This concept requires femtocells to have a larger range of several tens of meters, such that its coverage can extend to the outside of the home or office it is deployed in. In the rest of this paper, publicly accessible femtocells with such enlarged ranges are referred to as residential picocells.

2.2. EFFICIENCY OF JOINT MACRO- AND RESIDENTIAL PICOCELL DEPLOYMENTS WITH CURRENT TECHNOLOGY

Residential picocells are deployed in conjunction with a wide area cellular network for area coverage in an urban environment as illustrated in Figure 1. It is assumed that the residential

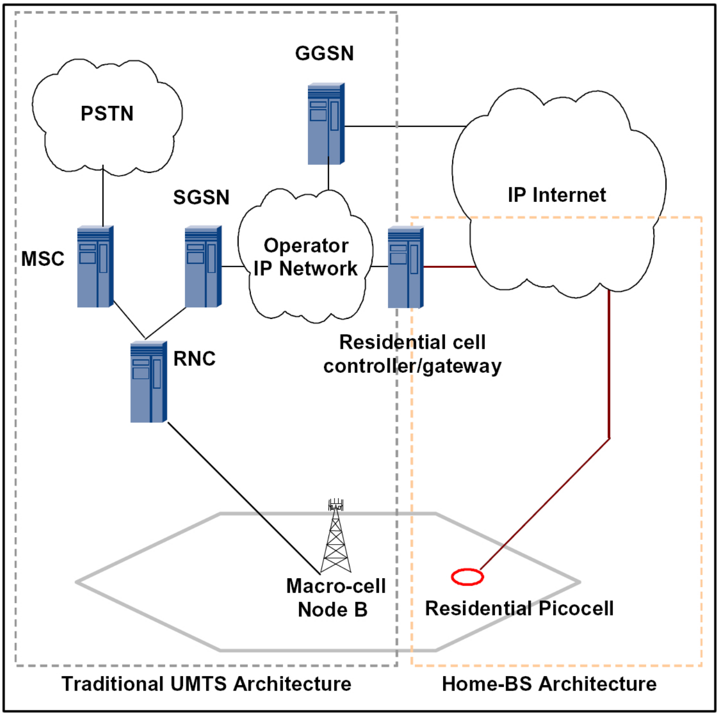

Figure 1 Overview of macrocellular underlay network with residential picocell overlay deployment

picocells have substantial auto-configuration capabilities to support simple plug and play deployment by customers.

In Claussen et al (2007) the financial impact of such a mixed macro- and picocell topology was studied and it was shown, that such a mixed deployment can significantly reduce the total network costs. This paper focuses more on the network energy consumption, the related costs, and CO_2 emissions for such networks based on current and future technologies.

2.2.1. SCENARIO AND ASSUMPTIONS

The considered scenario is a 10km x 10km urban area of Wellington, New Zealand. The following assumptions are made: A total population of 200,000 people and 65,000 homes are assumed; 95% of the population are mobile users; the usage is assumed to be 740 minutes per user per month with an average call duration of three minutes. A user demand distribution based on real measurements is used, extrapolated to the considered operator market shares. An example of the user demand map for an operator market share of 40% in terms of maximum concurrent calls within an area of 100m x 100m is shown in Figure 2.

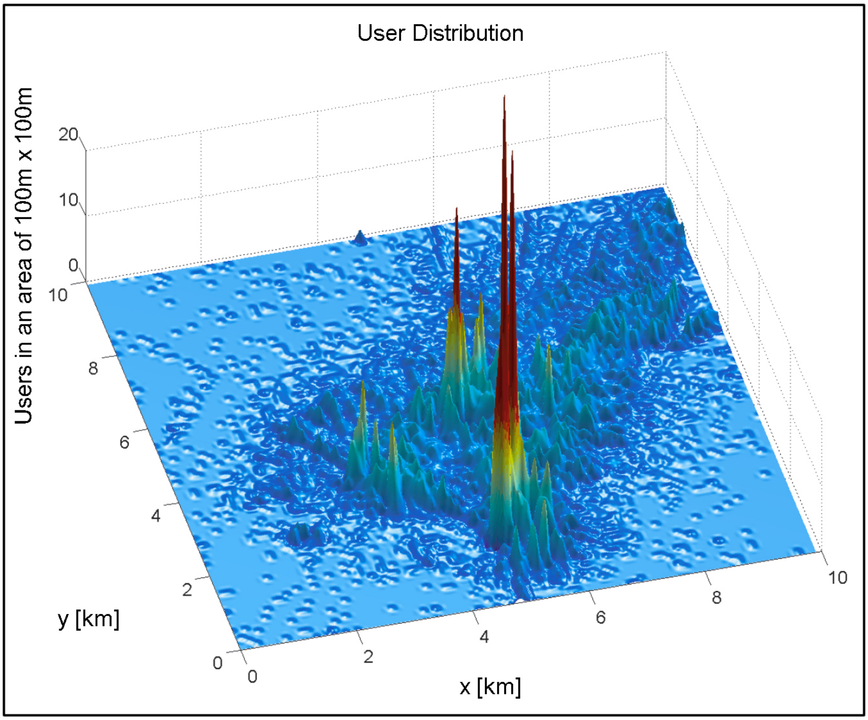

Figure 2 Maximum user demand scenario for an operator with 40% market share (resolution: 100m x 100m) in Wellington, New Zealand.

Residential picocells are deployed randomly by the end user in homes. The home distribution is assumed to be equivalent to the evening user demand distribution, since most users would be at home at this time. Each picocell is able to provide voice or high-speed data connections to up to eight users within a 100m x 100m area where it is deployed. All users that cannot be served by a picocell need to be served by the macrocellular network. The number of deployed picocells n_{pico} is calculated for different fractions of customers with picocells φ and different operator market shares ρ as

$$n_{pico} = n_{homes} \varphi \rho , \tag{1}$$

where n_{homes} is the total number of homes. It is assumed that each picocell has a power consumption of P_{pico} = 15W and since it provides public access, it operates continuously.

For the macrocellular network, it is assumed that all base stations are deployed such that each is able to serve on average a pre-defined number of u_{macro} active users. For small numbers of users, this assumption results in a best-case scenario for the macrocellular deployment, since this method does not take transmit power limitations into account. Since the macrocellular network needs to serve the remaining m users, which are not covered by the picocell network, the required number of base stations can be estimated as

$$n_{macro} = m / u_{macro}. \tag{2}$$

In order to account for different base station performance levels and voice/data traffic mixes, cases with different number of supported active users per base station are investigated. It is assumed that each macrocell has a power consumption of P_{macro} = 2.7kW (Rinaldi and Veca 2007).

The total energy consumption of the network per annum (=8760 hours) can be written as

$$E_{network} = (n_{macro}\ P_{macro} + n_{pico}\ P_{pico})\ 8760\text{h}, \tag{3}$$

under the assumption that core network components can be neglected for both macro- and picocells since their contribution to the total network energy consumption is very low.

2.2.2. RESULTS

Figure 3 shows the fractional user coverage by the residential picocells for different operator market shares dependent on the fraction of the customers with installed picocells. It becomes evident that even though the picocells are placed randomly with the home distribution, a relatively small fraction of installed units already achieve significant total user coverage. For example, if an operator has 40% market share and only 20% of its customers have picocells deployed, those picocells alone can satisfy approximately 80% of the total demand from all its customers. With less market share, the fractional user coverage becomes smaller for the same fraction of installed picocells, which is expected since the number of installed picocells is also smaller proportional to the market share. This can be a further incentive for sharing the radio access to improve efficiency, particularly for operators with low market share. Moves towards network sharing can already be seen for macrocellular networks today (Brown 2007).

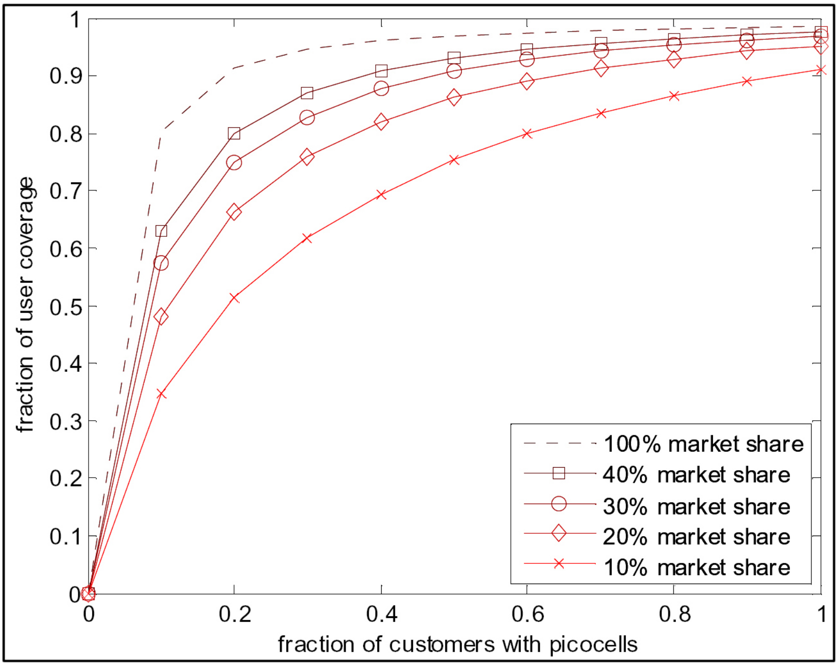

Figure 3 User coverage for different operator market shares and fractions of customers with installed picocells.

Figure 4 shows the dependency of the annual network energy consumption including both macro- and picocells dependent on the number of active users supported per macrocell for an operator market share of 40%. It is shown that the contribution of picocells to the total energy consumption increases linearly with the fraction of customers with picocells.

The energy consumption of the macrocells increases significantly with a reduced number of supported users per macrocell as a result of higher user data rates, since this has direct impact on the required number of macrocells. As a result, macrocellular coverage becomes less energy efficient with an increasing demand of high data rate services that are expected in the near future. For example for requested data rates of 384 kbit/s, a UMTS system using HSDPA with a downlink throughput of approximately 5 Mbit/s per sector is only able to sustain up to 39 active concurrent links for a three-sector cell. Furthermore, a backhaul of four E1 lines (2 Mbit/s each) per cell would limit the number of active high-data rate links to 20. For the operator, the energy consumption can be reduced significantly to less than 6% in the case where all of the customers have picocells deployed, since the energy for picocells is paid for by the customers. The energy consumption of the macrocell network never reaches zero since there are always a few macrocells that are required to provide full area coverage, even if all customers have picocells deployed.

The total energy consumption shows a mixed result for the current assumptions that all picocells are always active. When the user demand is mainly voice and therefore a large number of users can be supported by macrocells, macrocell coverage is more energy efficient than picocell coverage based on the current assumptions. For high user data rates a mixed deployment of macrocells for area coverage and residential picocells for the main demand can reduce the annual energy consumption of the network by up to 60% compared to a network with macrocells only, if around 20% of all customers have picocells deployed. This corresponds to a maximum reduction of approximately 4500 MWh per year for 30 supported users per macrocell and full population coverage in the investigated area. Assuming a price of $NZ 140 per MWh for a commercial customer the total savings for Wellington would amount to $NZ 630,000. The resulting reductions in CO_2 emissions can be calculated based on an emission factor for the consumed electricity. For New Zealand the emission factor is in the vicinity 0.6 to 0.65 tonnes of CO_2 per MWh (Concept Group Consulting, 2004), which results in a potential total reduction of 2700 tonnes of CO_2 emission per year. Once picocells become more widely deployed the energy efficiency of the network reduces. For operators this might only be of secondary concern, since the energy consumed by picocells is paid for by the end user. However, the overall efficiency is an important issue for society given that this would result in increased CO_2 emissions, which is widely accepted to negatively contribute to climate change. Therefore this problem needs to be addressed before residential picocells become more widely spread.

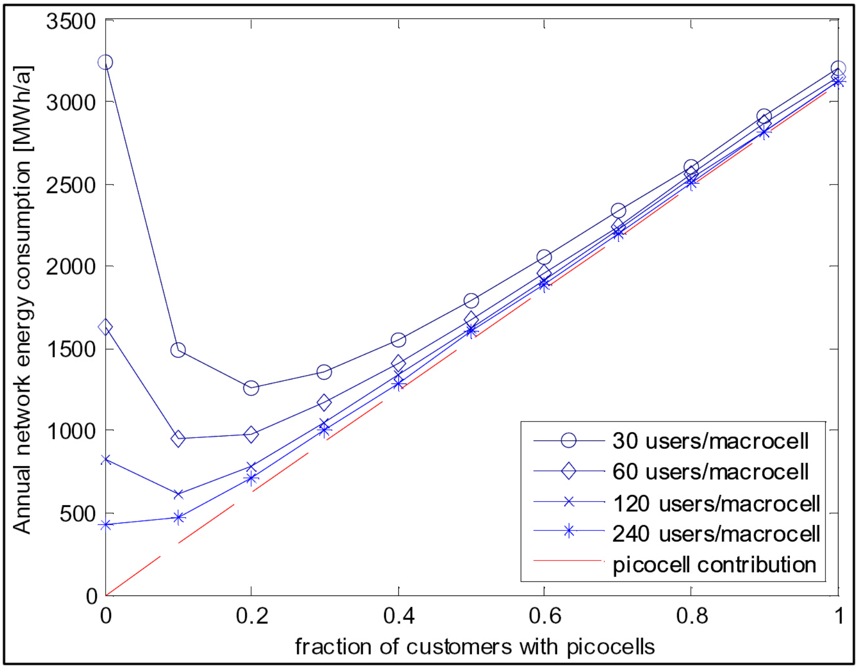

Figure 4 Annual energy consumption of the network (macro- and picocells) for an operator with 40% market share with different numbers of supported users per macrocell.

Figure 5 shows results for a different operator market share of 10%. The differences compared to the case shown in Figure 4 are a reduced total energy consumption that reflects the lower number of customers. In addition, benefits from picocell deployment are lower, which results from the lower fraction of user coverage achieved, as shown in Figure 3 for the corresponding market share. While the energy costs for the operator can still be reduced to less than 12% in a case where all customers have femtocells deployed, an overall reduction in energy consumption can only be achieved for high user data rates when only few users can be supported per macrocell.

Therefore, operators with low market share would benefit most from sharing radio access for picocells to achieve a higher fraction of user coverage.

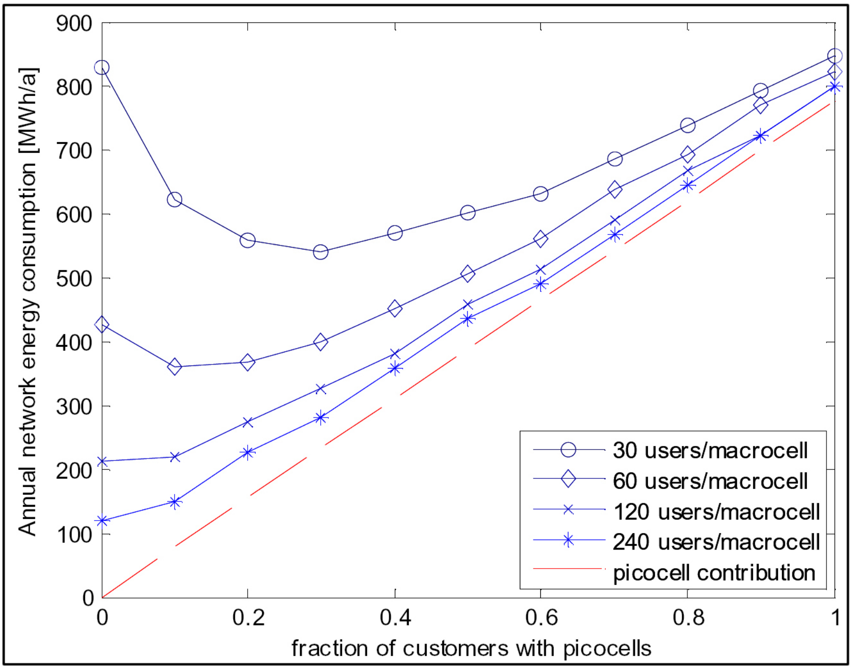

Figure 5 Annual energy consumption of the network (macro- and picocells) for an operator with 10% market share with different numbers of supported users per macrocell.

2.3. IMPACT OF FUTURE TECHNOLOGIES ON EFFICIENCY

While the results indicate that a mixed macro- and picocell topology can improve the energy efficiency in urban areas based on today's technology, future improvements of these systems will have a high impact on the results. In this section, different possible improvements for both macro- and picocells are discussed, which can further improve the efficiency, and their impact on the total energy consumption is estimated.

2.3.1. MACROCELL IMPROVEMENTS

Macrocellular base stations are one of the biggest contributors to the overall energy consumption of a wireless network. Approximately 60% to 70% of the energy required by a base station is consumed by the power amplifier (PA) units. Therefore, any enhancement of the power amplifiers will have a direct and significant impact on the power consumption of the entire network and its associated CO_2 emission. Further improvements can be achieved by introducing enhanced architectures, which won't require today's expensive, long and therefore lossy cable assemblies. So significant efficiency improvements can be achieved in terms of two aspects: the power amplifier technology itself and the overall base station architecture.

Depending on the state of the technology, the age of the equipment, and the standard (GSM, UMTS, CDMA etc.), the total efficiency of the currently deployed amplifiers range anywhere from 5% to 20% (total efficiency here in the sense of the total efficiency from AC power input to generated RF output power). The efficiency on the component level (in the sense of the amplifier transistors of the final amplifier stage) of today's amplifiers for CDMA and UMTS systems is in the order of approximately 30% to 40%, depending on technology and implementation.

These technologies (Class-AB with digital predistortion) have reached their limits. The latest technology step is the use of digital predistorted Doherty-architectures and of GaN-amplifiers, which have reached efficiency levels of over 50% (Kimball et al 2006). Further improvements can be achieved by a change from analogue RF-amplifiers to switch-mode-power amplifiers, which in theory could achieve 100% efficiency (Raab et al 2002), but the performance of the required semiconductor components and of the amplifier architecture itself is still a matter of research. It can be assumed that the achievable component-efficiency of such devices will be in the order of 70%.

If such amplifiers would replace the current power amplifier installations, this would reduce the power consumption of the currently installed power amplifier infrastructure by roughly 50% while maintaining the same RF-output power capability. Another major drawback of the currently deployed technology is the fact that the amplifiers are designed to perform best at maximum output power conditions. This is necessary to maintain the required signal quality at maximum output power, but this condition is met only at a fraction of the time (<10%) during operation. For the rest of the time, especially at night time when traffic is minimal or zero, this results in a tremendous waste of energy, since the bias of the power amplifier is still maintained for maximum power conditions. To improve this, it would require either a flexible biasing of the PA or the parallelisation of several smaller power amplifiers, which can be individually turned on and off. The design of such flexible power amplifier architectures, which would allow a better adaptation of the amplifier to the required output power, is also matter of current research effort.

Not only the design of the power amplifier itself, but also of the overall base station architecture has a large impact on the efficiency. The current macrocell design is shown in Figure 6. The digital data processor, the RF-transmitter and receiver (Radio), the power amplifier and the diplexer filter are placed within one common cabinet. This cabinet is usually located indoors to grant easy access and to keep it in a safe and climate controllable environment. The RF-connection between the top of the cabinet (TOC) and the antenna is done by long coaxial cables, usually in the order of tens of meters, depending on antenna height and cabinet location. The combined losses including these cables (~2.5dB), the loss in the antenna feeder network (~1dB) and the losses in the RF-cables in the cabinet itself, are in the order of 3dB.

This means that approximately 50% of the signal power, which is available at the power amplifier output, is lost in cables, feed-networks, filters and connectors until it reaches the antenna element itself. Therefore current developments aim to move the RF-power amplifier closer to the antenna. The connection between the cabinet and such a tower top amplifier is usually done by an optical cable or a low-power RF-cable. It would be even more beneficial to place a smaller, more flexible power amplifier directly behind each antenna element, to avoid any cables or feed networks between the amplifier and the antenna. It is obvious that these concepts, so called active antenna arrays, would not only significantly increase efficiency, but also bring other system benefits like increased receiver sensitivity and increased link budget (Fischer et al 2002) as well as enhanced reliability.

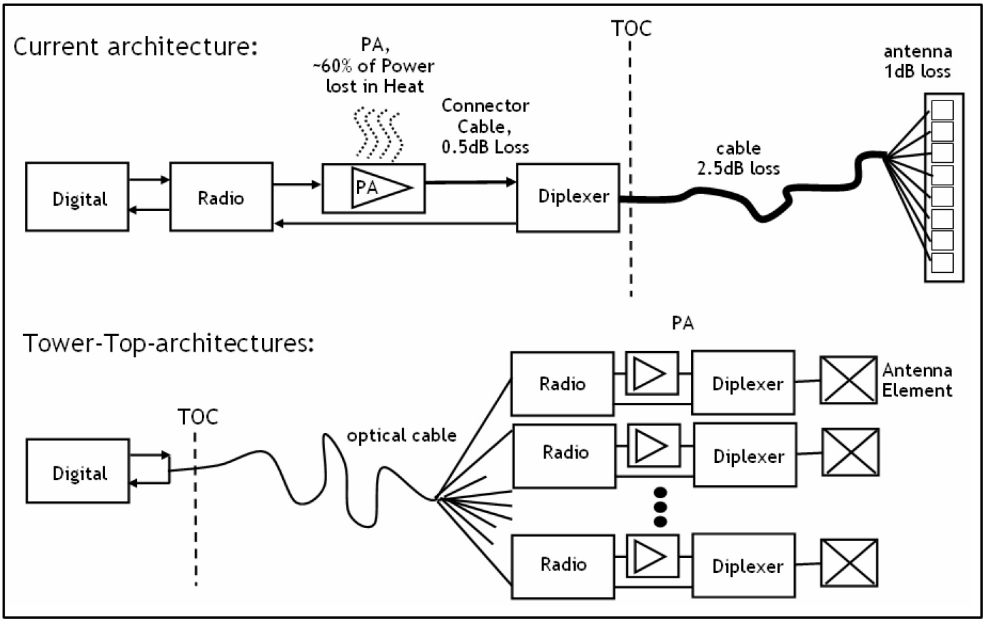

Figure 6 Macrocell base station architectures

Based upon the assumption that it will be feasible for future power amplifiers to push the component efficiency to 70% and by cutting the losses in the current systems in half, it can be estimated that the power consumption of the power amplifiers of base stations can be reduced by between 50% and 75%. This would result in an overall improvement of 33% to 50% of the entire base station power consumption. For the analysis in this paper a conservative estimation of an improvement of 33% is assumed.

2.3.2. PICOCELL IMPROVEMENTS

As discussed in Section 2.2.2, a large fraction of the total user demand can be served when only a small fraction of users have picocells deployed, as shown in Figure 3. The additional gain in terms of user coverage for higher fractions of installed picocells is only small due to the resulting high over-provisioning, but the total power consumption increases linearly with the number of deployed picocells. This results in a relatively high total network power consumption in cases where a large portion of the customers have picocells deployed.

This problem can be addressed by adding a sleep mode to picocells, so that they can switch off temporarily when in the area in which they are deployed, other picocells already provide sufficient coverage and capacity. As a result the total energy consumption of the picocells does not increase linearly with their number anymore in densely deployed areas with high over-provisioning. In most cases, such functionality could be added per software upgrade.

In addition further improvements will be achieved as the technology matures, but they are not considered here. Examples are higher efficiencies resulting from more advanced chip manufacturing processes, and refinements in power saving states for cases where the picocell is not fully loaded.

2.3.3. IMPACT ON RESULTS

Figure 7 shows the projection of the future annual energy consumption of the joint network for an operator with 40% market share. The differences compared to the results in Figure 4 result from the expected efficiency increase of the macrocells of 33%, and the reduction in picocell energy consumption due to the sleep mode to prevent over-provisioning as described in the previous section.

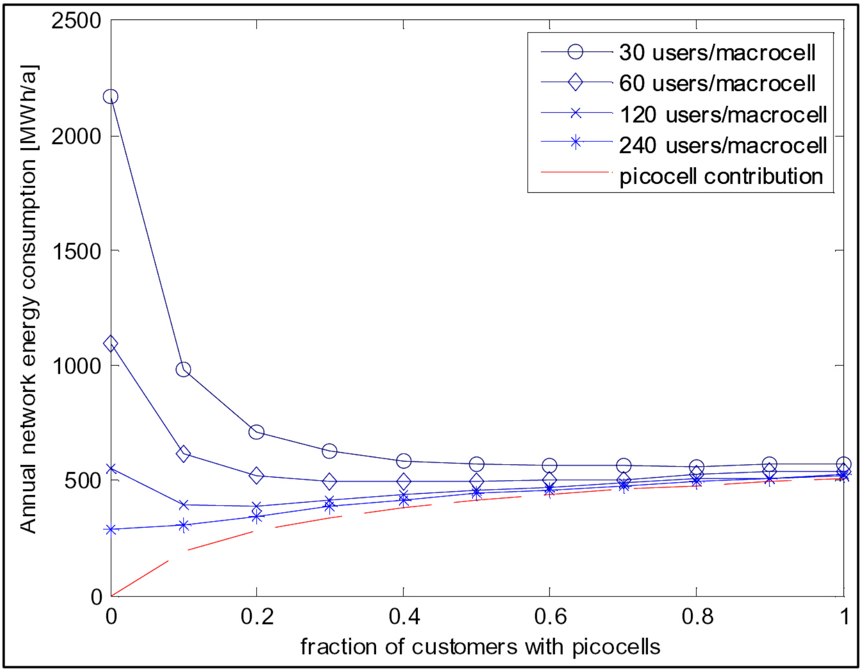

Figure 7 Future annual energy consumption of the network for an operator with 40% market share with different numbers of supported users per macrocell.

It is shown that the picocell energy consumption does not increase linearly anymore compared to the results in Figure 4, since picocells are only active when they are in an area which is not already covered sufficiently by other picocells. As a result the total energy consumption of the picocells is reduced significantly, and the beneficial fractions of customers with picocells are extended.

The energy consumption of the macrocells is also reduced due to their assumed efficiency increase. Note that, since a static demand distribution is assumed, power saving (sleep) functionality in the macrocells would not make any difference in the considered scenario since the macrocells have not been over-provisioned. This is different compared to the user-deployed picocells, as higher fractions of users with picocells result in high over-provisioning of capacity and coverage.

Compared to the previous results for this scenario shown in Figure 4, the benefits of a mixed macro- and picocell deployment will increase as both technologies mature, and will result in a significant reduction of the network energy consumption as the user demand for high data rates increases. It is shown that for high user data rates that are expected in the future, an increase in the number of deployed femtocells in the assumed urban area always results in a reduction in the total network energy consumption of up to 70%. This corresponds to a maximum reduction of approximately 4000 MWh per year for 30 supported users per macrocell and full population coverage in the investigated area, and would amount to potential savings of $NZ 560,000 and a total reduction of 2400 tonnes of CO_2 emission per year.

Figure 8 shows the projection of the future annual energy consumption of the joint network for an operator with 10% market share. Due to the lower operator market share, the benefits of the joint deployment is reduced so that improvements in the total energy consumption of the network can only be observed for high user data rates where the macrocell can support only few users. Note that even for an operator with a low market share it could be beneficial to have a high fraction of users with picocells, since this reduces the number of required macrocells and the associated energy consumption.

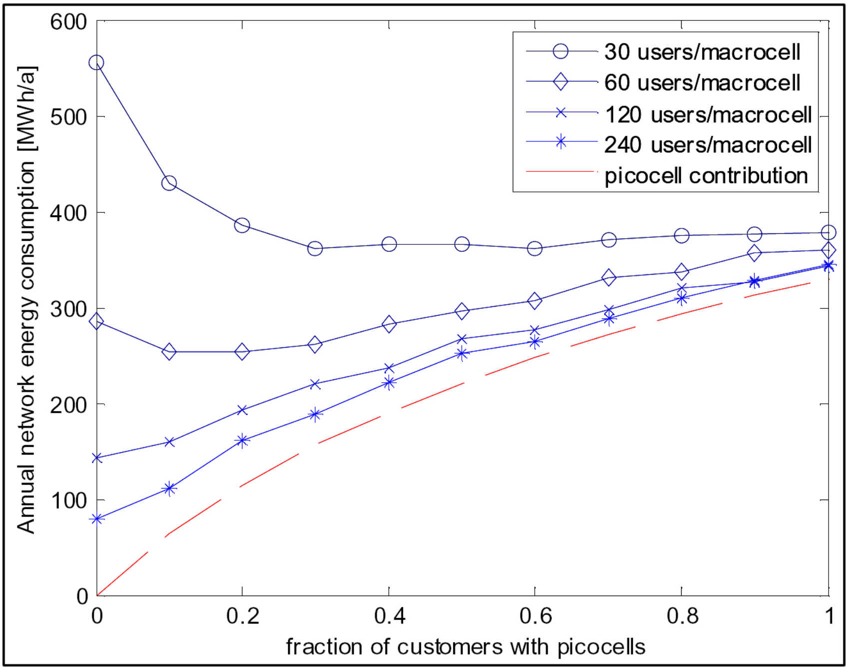

Figure 8 Future annual energy consumption of the network for an operator with 10% market share with different numbers of supported users per macrocell.

3. INDIRECT EFFECTS OF IMPROVING BROADBAND NETWORKS

In addition to the direct improvements in efficiency of networks that can be achieved as described above, advances in broadband technology also have a high potential to improve the environmental sustainability indirectly by changing the way people live and work. In this paper, two ways where broadband technology can make a significant improvement are discussed, namely by enabling more people to work from home instead of in an office, and by replacing the need for business travel by high quality video conferencing.

3.1. TELEWORKING

One of the main potential benefits of telecommunications is that it enables the concept of teleworking. Teleworking can be defined as an arrangement where the employees are given the flexibility in their working location, such that the employee's daily commute to a traditional place of work is replaced for a significant portion of days by telecommunication links. A precise definition of teleworking is difficult to give, because there are jobs that by their nature require the employee to spend significant amounts of time outside of a fixed place of work, such as field technicians and salespeople. But generally, the assumption used here is that teleworking creates a new way of working remotely for the employee.

The widespread deployment of high-speed broadband is an enabler of many services that make the use of teleworking more practical, and reduce the impact of many of the drawbacks that teleworking was associated with in the past. Along with well known and established tools such as telephone, email, and instant messaging, other new approaches are being developed, or made possible due to the increasing availability and affordability of high speed residential broadband connections. Applications such as high resolution, on demand video conferencing, and improved web conferencing software can be used to replace physical meetings very effectively.

The economic benefits of teleworking are numerous (Gray et al 1994). For example, there are obvious benefits in lower costs for employers in real estate and facilities, and in lower commuting costs for the employees. Teleworkers also tend to be healthier, and take less sick leave since employees are exposed less to factors such as pollution and stress during the daily commute, and airborne germs that can spread amongst colleagues in the office. If planned properly, teleworkers can also work more efficiently (up to 45% improvement in efficiency (Gray et al 1994)) due to spending less time in commute, and being fresher when performing the work, and at the same time, also have more leisure time.

There are also, however, disadvantages to teleworking, such as the initial costs of providing the infrastructure and training for migrating employees to a teleworking arrangement. It may also result in difficulty for managers to perform close supervision of employees. Close teamwork and communication would also not be as good as face-to-face interaction, although the advances of technologies such as high quality video conferencing and collaborative software can reduce the impact of this.

In this section, focus is given on the benefits of teleworking to the environment, particularly in the potential reduction in energy consumption. Figure 9 shows a comparison of the annual energy profiles of workers with different working arrangements based on a study made in the UK (Gray et al 1994). They show that approximately 6 MWh of energy can be saved per worker per year by switching from a full-time office work to teleworking, or a saving of 8 million tonnes of CO_2 per year in the UK when 5 million people are working from home. The savings come in part from slightly reduced heat and lighting energy, but the main contribution comes from the 33% reduction in energy taken up on transport.

Taking Wellington as an example, with a population of approximately 450,000, which is about 11% of the population of New Zealand (New Zealand Statistics Agency 2006). For comparison, the same part of Wellington considered in Section 2 with a population of approximately 200,000 is assumed. A large proportion of the working population in Wellington are involved in what can be called office-based occupations, with approximately 25% classified as

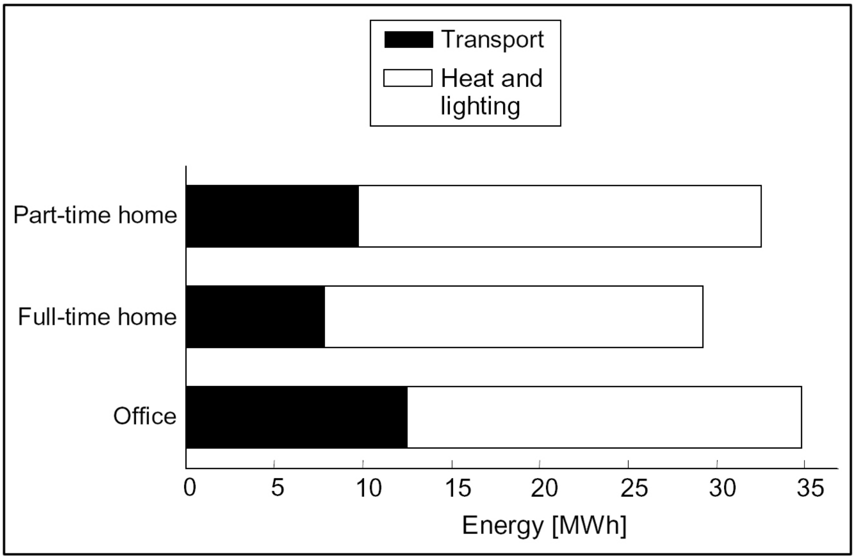

Figure 9 Annual energy profile for three different work arrangements (Gray et al 1994).

professionals, 17% as managers, and 15% clerical and administrative workers (New Zealand Statistics Agency 2006). This adds up to a total of approximately 57% of the working population. Assuming that 60% of Wellington's population is in employment, the total population that can benefit from teleworking is approximately 34%, or 68,000 people. Using the data from Figure 9, this means a potential reduction of a total of 408,000 MWh a year, or 108,800 tonnes of CO_2 per year. This amount of energy is equivalent to 1.1% of the total electric power consumed by the whole of New Zealand (U.S. Central Intelligence Agency 2008). For a typical travel distance to work and back of 20 km, and a cost for a medium car of 62 cents per km, the reduction in travel costs per person per year would roughly amount to $NZ 2700. The total cost savings in the considered area of Wellington would amount to $NZ 185,504,000 assuming that all people are travelling to work by car or other means with comparable costs.

Aided with the continuous improvements in telecommunications infrastructure along with new applications for collaboration, it is clear that the widespread adoption of teleworking can bring not only economic and social benefits, but also significant benefits to the environment in terms of reduced energy consumption and traffic pollution.

3.2. REPLACING AIR TRAVEL BY VIDEO CONFERENCING

A further example where advances in broadband technology can be used to significantly improve the environmental sustainability is the possibility to reduce air travel for business meetings. This can be achieved by using high-quality video conferencing as a replacement for a business trip, which results not only in a significant reduction of CO_2 emissions due to the reduction in the number of required flights, but also reduces the travel costs and work time required (i.e. salary costs) for such trips.

The concept of replacing travel with teleconferencing is not new. Its potential to reduce greenhouse gas emissions is widely recognised and is part of the recommendations of studies in this area, such as (Climate Risk 2007). One example of a success story in this area is Cisco in Australia, who has reduced its air travel by 16% in less than one year as a result of introducing high definition video conferencing (Ross 2007). While Cisco's solution requires significant investment in high definition video conference suites, advances in broadband technology will enable a similar experience at every personal computer at work or at home in the future.

Here, one example at Wellington Airport is considered where the impact of replacing 10% of all business trips with video conferencing is evaluated. In 2007, Wellington Airport supported a total number 93,950 domestic and 5,678 international aircraft movements, corresponding to a total number of 4,060,000 domestic and 575,000 international passengers (Wellington Airport 2007). A passenger survey undertaken by WIAL showed that 55% of the passengers were on business trips, where 25% of those business travellers were Wellington based (Wellington Airport 2007). Replacing 10% of all business related travel with video conferencing results in a reduction of 5,167 domestic and 312 international flights with a total of 223,300 and 31,625 passenger respectively.

If the average domestic flight distance is 800 km with a CO_2 emission of 11.61 kg CO_2/km, and the average international flight distance is 8,000 km with a CO_2 emission of 23.39 kg CO_2/km, a domestic flight results in a total of 9.288 tons of CO_2 emission, and an international flight in 187.120 tons of CO_2 emission. Therefore, if the number of business flights can be reduced by only 10%, the reductions in greenhouse gas emissions of both domestic and international flights amount to 106,372 tonnes of CO_2 per year (26,593 tonnes for Wellington based travellers). In addition to this significant environmental benefit, there is an additional advantage in terms of reduced travel costs. Assuming an average price of $NZ 150 for a domestic and $NZ 700 for an international flight (single direction), the total savings amount to over $NZ 55,000,000 ($NZ 13,900,000 for Wellington-based travellers) per year, which does not include the savings in work time and associated salary costs.

This example makes it clear that videoconferencing as a replacement for travel has a high potential to reduce the impact of air travel on the environment, and can result in significant cost reductions for corporations.

4. COMPARISON OF DIRECT AND INDIRECT BENEFITS

In the previous sections, direct and indirect benefits achievable through advances in broadband technology have been discussed. Table 1 shows a comparison of the different improvements in environmental sustainability discussed in the previous sections for the urban area of Wellington, New Zealand.

It is shown that direct benefits resulting from improvements of the telecommunication networks can result in substantial reductions in energy consumption, CO_2 emission, and cost. However, it is also shown that the potential indirect benefits resulting from changes in the way people live and work, have a far greater potential and exceed the direct improvements by orders of magnitude.

Teleworking from home and replacing business travel with video conferencing have an enormous potential for reducing the use of natural resources and the emission of greenhouse gases if the user experience can be improved. This can for example be achieved by future advances in broadband technology to provide the required high data rates, by improvements in video compression, and by new user friendly, intuitively operable, and reliable applications.

In the future a two-sided approach will be required: Leveraging advances in broadband technology to directly improve the efficiency of telecommunication networks, and on the other side to promote changes in the way how these networks are used. This way, advances in broadband technology can play a major role in reducing the emission of greenhouse gases and can significantly contribute to improving environmental sustainability.

An encouraging fact is that these environmental benefits do not come at high costs, but can in addition result in a significant cost reduction for network operators, corporations and individuals. These financial incentives will be the main driver to change towards a more sustainable behaviour.

	Direct benefits		**Indirect benefits**	
	Macro-pico architecture (today)	**Macro-pico architecture (future)**	**34% of population Teleworking**	**10% business flight reduction**
Energy reduction per year	Up to 4500 MWh (60% reduction)	Up to 4000 MWh (70% reduction)	408,000 MWh	n.a.
CO_2 reduction per year	2700 t	2400 t	108,000 t	26,953 t
Cost reduction per year	$NZ 630,000 (full population)	$NZ 560,000 (full population)	$NZ 185,500,000	$NZ 13,900,000 + saved time

Table 1 Comparison of direct and indirect benefits resulting from advances in broadband technology for Wellington, New Zealand. For comparison, $NZ 1 = $US 0.66 = € 0.48 = $A 0.85 (05 October 2008).

5. CONCLUSIONS

In this paper, direct and indirect ways of how advances in broadband technology can help to improve environmental sustainability have been explored. The effects of a joint macro- and picocell deployment on the network energy efficiency, enabled by widely available broadband access, have been investigated. It was shown that a joint deployment of macrocells for area coverage and publicly accessible user-deployed residential picocells can reduce the total network energy consumption by up to 60% in urban areas for high data rate user demand based on today's technology. In addition, the impact of future technologies on the energy consumption was investigated, and it was shown that benefits of a joint macro- and picocell deployment will increase further to a maximum of up to 70% of the energy consumption as both technologies mature and the demand for high data rates increases. In addition the high potential of indirect benefits of improving telecommunication networks, such as enabling teleworking and replacing business travel through video conferencing, was demonstrated and compared with the direct benefits. It was shown that the indirect benefits to the environment resulting from changes in the way people live and work are orders of magnitude higher that what can be achieved directly by improving telecommunications networks alone. The direct and indirect approaches discussed also result in a significant cost reduction for network operators, corporations and individuals, which will be the main driver to change towards a more sustainable behaviour in the future.

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Cite this article as: Claussen, Holger; Ho, Lester T. W.; Pivit, Florian. 2009. 'Leveraging advances in mobile broadband technology to improve environmental sustainability'. *Telecommunications Journal of Australia*. 59 (1): pp. 4.1 to 4.18. DOI: 10.2104/tja09004.