

Opportunistic Load and Spectrum Management for Mobile Communications Energy Efficiency

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Abstract—Dynamic load and spectrum usage management techniques can significantly improve the energy efficiency of mobile communications systems. This paper considers: (i) the opportunistic reallocation of traffic loads between bands to allow radio network equipment in the bands that the traffic is originated from to be powered down, and (ii) the opportunistic selection of more appropriate spectrum based on propagation characteristics to minimize necessary transmission power through improving propagation and/or reducing power leaking into co-channel cells in frequency reuse cases. This paper addresses the simulation of video, FTP and HTTP (web browsing) traffic sources for configurations representing LTE and HSDPA telecommunications networks, and shows that the opportunistic reallocation of users between bands to power down radio equipment achieves a significant saving of 50% or more in from-the-socket power. Furthermore, it shows that the opportunistic reallocation of users/links to minimize transmission power through using more appropriate propagation spectrum leads to a further modest reduction in from-the-socket power consumption.

Index Terms—green communications, load balancing, spectrum management

I. INTRODUCTION

HISTORICALLY, the radio spectrum has been managed in a rather rigid fashion where the primary objective has been to minimize interference among users and systems to maintain the spectrum's viability. This regime is often extremely inefficient, because at any one time many systems are not being used thereby leaving the associated spectrum also unused. Alternative spectrum management, whereby systems not designated for a particular band may nevertheless use it if it is available, would greatly increase spectral efficiency and capacity. Fortuitously, at least from regulatory and technical perspectives, various recent developments are leading to the situation where such solutions will be realizable, albeit initially to a limited extent (see, e.g., [1], [2], [3]).

It is widely expected that communications operators will own or have access to an increasing range of spectrum bands in the future, of very different frequencies and physical characteristics. Already in many major cities around the world, there are often operators concurrently providing services in multiple bands, such as GSM 900MHz and 1800MHz, UMTS 2GHz, and 2.4GHz Wi-Fi services among others. Moreover,

the introduction of IMT-Advanced bands in the near future will further increase the range of spectrum bands available to the operator: there are already many such bands widely identified, some examples being 450-470MHz, 790-862MHz, and 2.3-2.4GHz [4]. The greater use of unlicensed spectrum, such as UNII bands (5.15-5.825GHz), will also facilitate better spectrum availability.

It is clear that significant reductions in the energy consumption of humanity must be made to sustain the planet. Moreover, the power consumption of mobile and wireless communications systems can be quite significant. Even an environmentally-aware operator, such as Vodafone, consumes approximately 40MW in running its business in the UK, the majority of which can be attributed to base stations [5]. Lowering the operational power consumptions of base stations is therefore particularly important. Enabling sleep modes for such equipment, and more generally reducing necessary transmission power, can have a very significant effect on the overall power consumption of the operator in running its network. These are the objectives of the concepts discussed in this paper, whereby given the prior observations on increased spectrum usage freedom and availability, this is done by opportunistically reallocating traffic loads between spectrum bands. This reallocation might either be between bands owned by a single operator, or ultimately could be through spectrum/load sharing between operators. In either case, the concepts and results discussed in this paper still apply.

This paper is structured as follows. In the next section, the proposed power saving concepts are explained. Section III investigates aspects of the performances of the concepts, showing significant potential for power consumption reduction. Finally, Section IV concludes this paper.

II. POWER-SAVING SPECTRUM MANAGEMENT CONCEPTS

The two concepts studied in this paper to reduce mobile communications power consumption are introduced as follows.

A. Power Saving by Dynamically Powering Down Radio Equipment

The first concept, illustrated in Figure 1, is the switching off (or entering into stand-by) of radio equipment through

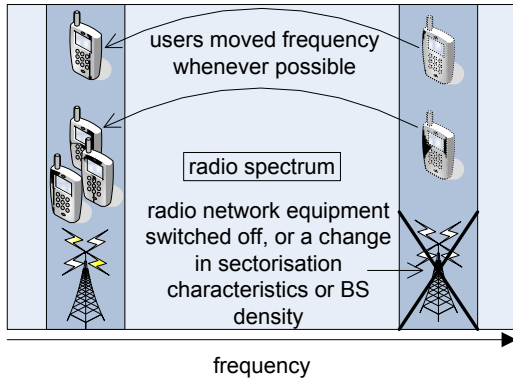


Fig. 1: Reallocating traffic load between bands to enable radio network equipment to be switched off.

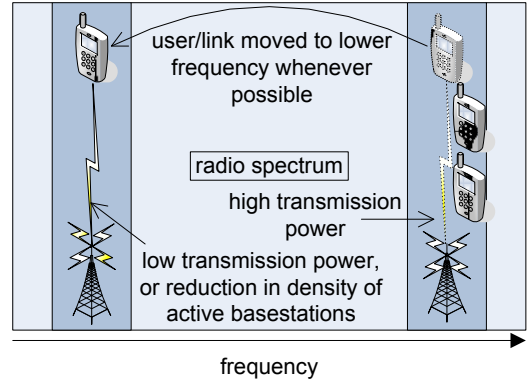


Fig. 2: Reallocating users/links to improve propagation.

reallocating load to other bands at times of low load. This is extremely promising as it implies a guaranteed power saving through radio equipment being virtually “switched off at the socket”. It is noted that for macro-cell base stations in particular, by far the biggest contribution to power consumption of the base station is merely it being switched on and in an operational state; variation of power consumption with transmission power is relatively less significant although depends greatly on the exact manufacture of the base station hence can only be very broadly generalized. The opportunistic powering down of radio network equipment based on solutions presented in this paper is therefore a readily achievable way of reducing actual from-the-socket power consumption.

There are two possibilities considered in this paper concerning the dynamic powering down of radio equipment: (i) turning off cells entirely in one network or spectrum band at that time/location, through traffic being sufficiently carried by a single network or spectrum band, and (ii) using spare capacity of one network/band to cover the required drop in load of another network/band in order to enable that other network/band operate in omnidirectional mode instead of tri-sector mode. The power saving assessments of this concept in this paper reallocate users between bands whenever possible to achieve one or both of these objectives.

B. Power Saving by Propagation Improvement

The second concept, illustrated in Figure 2, is the opportunistic reallocation of links or users to more appropriate propagation bands at times when that spectrum becomes available. This decreases necessary transmission power due to improved propagation, or alternatively in a frequency reuse scenario, reallocation based on the necessary deployed cell density/radius and the given local propagation environment can be used to reduce inter-cell interference through minimizing power “leaking” into co-channel cells.

Note that these concepts might be implicitly or explicitly employed together with the concept of reallocation to power down radio equipment, yielding further improvement in power efficiency. For instance, the opportunistic reallocation to power down radio equipment might always leave the band

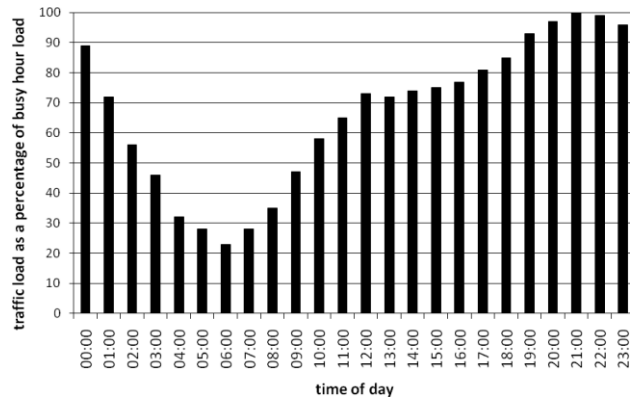


Fig. 3: Hourly variation of traffic load as a percentage of busy hour load over a typical day.

switched on that has the most appropriate propagation characteristics given the deployed necessary cell density/radius. Alternatively, links/users might always be reallocated between bands for more appropriate propagation whenever sufficient capacity is available in the target band, even if moving those users/links does not make it possible to power down any radio equipment.

III. ASSESSMENT OF POWER SAVING POTENTIAL

Power saving potential of the aforementioned concepts is assessed through simulations of cellular systems carrying either video traffic, FTP traffic, or HTTP (web browsing) traffic. Concerning the traffic models used in simulations, it is assumed that the average cell load (or in later simulations the number of users in the cell) at time of day t , $L(t)$, varies according to a set of statistics on traffic load as a percentage of busy hour load (*BusyLoad*) over a 24 hour period, pertaining to traffic in a 3G network in London, UK, obtained via interaction with Vodafone representatives within the Mobile VCE Green Radio research program. Figure 3 depicts these loads as a percentage of *BusyLoad*. All simulations assume that the traffic load is scaled according to the chosen *BusyLoad* depending on the time of day, such that if *BusyLoad* is 10 users, for example, the number of users in the network at 17:00 hours is ~80% (see Figure 3) of *BusyLoad*, i.e., 8 users.

TABLE I
SIMULATION CONFIGURATION PARAMETERS

Parameter	Value
Simulated Systems	
System configuration	Broadly reflecting LTE (Section III.A) and HSDPA Rel. 5 (Section III.B)
Bandwidth per band (LTE)	20MHz
Bandwidth per band (HSDPA)	5MHz
Channel path loss models for HSDPA (path loss is not relevant to the LTE simulations, as they concentrate only on opportunistic radio equipment powering down)	2GHz: $128.1+37.6\cdot\log(\text{distance}_{\text{km}})$ [6] 5GHz: $141.52+28\cdot\log(\text{distance}_{\text{km}})$ [6]
HSDPA pilot power	20% of cell power budget
Traffic Models	
Streaming video traffic rate per user (LTE)	384kbps
Data (FTP) traffic OFF duration	Exponentially distributed, mean 180s [7]
Data (FTP) traffic ON duration	Pareto distributed file size of mean 2MB [7], $\alpha=1.5$ (unless otherwise stated) and k calculated from the mean and α , with ON duration calculated from each sampled file size assuming a fixed data rate of 1MB per user
Data (HTTP) traffic reading time (OFF duration)	Exponentially distributed, mean 30s [7]
Data (HTTP) traffic parsing time (OFF duration)	Exponentially distributed, mean 0.13s [7]
Data (HTTP) traffic main object size (contributes to ON duration)	Truncated Lognormally distributed, $\sigma=1.37$, $\mu=8.35$, min=100B, max=2MB [7]
Data (HTTP) traffic embedded object size (contributes to ON duration)	Truncated Lognormally distributed, $\sigma=2.36$, $\mu=6.17$, min=50B, max=2MB [7]
Data (HTTP) traffic number of embedded objects per page (contributes to ON duration)	Truncated Pareto distributed, $\alpha=1.1$, $k=2$, max=55 (k subtracted from each sampled value) [7]
Per-user rate in FTP/HTTP ON durations	1Mbps (LTE), 64kbps (HSDPA)

Two simulation approaches are taken. In the first approach which simulates video traffic, it is assumed that the statistical number of active users in the cell receiving a video flow is Poisson distributed, the mean of which at any one time of day can be taken from the above-mentioned average load at that time of day, $L(t)$. Using this approach, the probability of there being k active users in the cell at time of day t is expressed as

$$P(k,t) = \frac{L(t)^k e^{-L(t)}}{k!}. \quad (1)$$

Under this first approach, our numerical assessment cycles in outer loops through a 24 hour period in steps of t of one hour, and uses the value of $L(t)$ (given *BusyLoad*) at each hourly time unit to parameterize equation (1). In inner loops, for each time unit, it then cycles through each possible value of k representing each possible number of users in the cell, for all participating frequency bands in the process, and for each set of k 's among the frequency bands ascertains the power consumption that would be required given the selected dynamic spectrum access power saving solution being applied. The actual power consumption for each such case is then given as this power consumption, multiplied by the probability of it

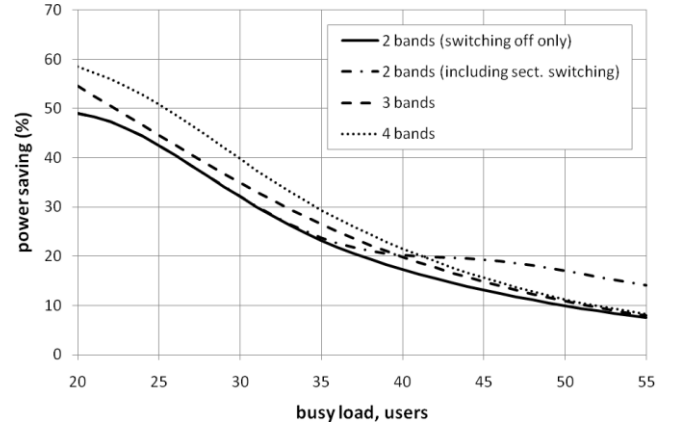


Fig. 4: Power saving against busy hour load for network powering down solutions (streaming video traffic).

happening, which is of course the product of the probabilities of the chosen values of k occurring for the participating networks/frequencies, i.e., $P(k, t)_{\text{network1}} \cdot P(k, t)_{\text{network2}}$. This result is then summed with equivalent results for all possible chosen values of k to obtain the overall power consumption at time unit t . The same operation is performed over all hourly time units in the 24 hour period, and the average power consumption is then taken among all time units. Exactly the same process is also performed to find the average power consumption of a conventional system without the dynamic spectrum access power saving operation being applied, then results are compared.

The second simulation approach assumes a separate ON/OFF traffic flow to each user, either parameterized as FTP traffic or HTTP (web browsing) traffic, whereby the number of users receiving flows varies throughout the 24 hour period according to $L(t)$ (Figure 3). The chosen FTP and HTTP ON/OFF model parameterizations are widely used in literature, taken from [7]. In this second approach, a separate simulation is performed for each hour in the 24 hour period for a given number of users being present (obtained from Figure 3 scaled by *BusyLoad*), where, at each second in the simulation duration, the simulation tallies the number of users present in each band according to the ON/OFF model being applied to each user. It then performs the power saving solution according to this number of users being present, and ascertains the power required in the before and after power saving solution cases. Results are then averaged over results achieved at each second in the simulation duration, where all such simulations are typically performed over tens of millions of seconds. Finally, results are averaged over all simulations performed at each hour in the 24 hour period.

Configuration parameters applicable to the two simulation approaches are given in Table 1.

A. Power Saving by Dynamically Powering Down Radio Equipment

Simulating the LTE system under the assumption of video traffic sources to users, Figure 4 gives the proportion of from-the-socket power that is saved through moving users between

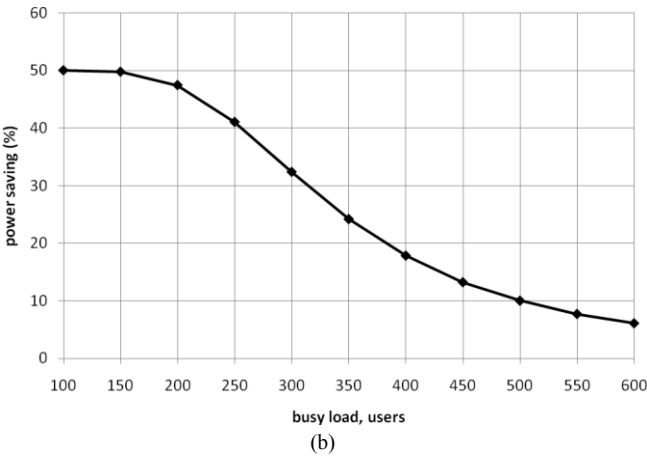
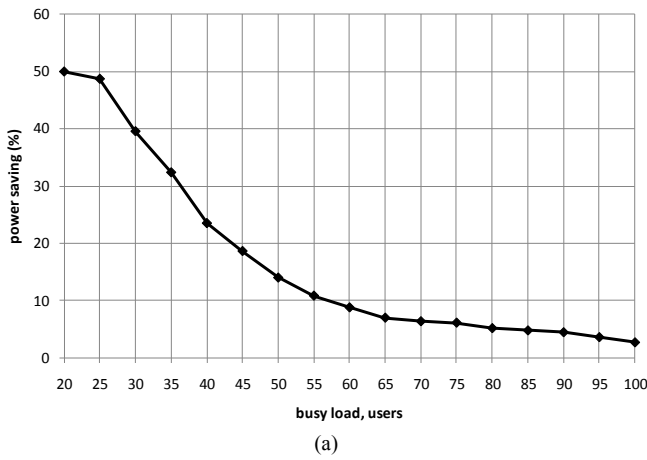


Fig. 5: Power saving against busy hour load for network powering down solution: (a) FTP ON/OFF traffic, (b) HTTP ON/OFF traffic.

bands to dynamically power down radio equipment, for 2, 3, and 4 spectrum bands participating in the process, whereby the 2-band case considers the network powering down solution with and without the sectorization switching solution operating in tandem. For ease of depicting results, all results in Figure 4 are for the case where *BusyLoad* is the same for all channels. From these results, it is clear that very significant power savings of up to 50% or more can be achieved, these savings being more typically being in the range of 20-50% if there are lesser bands participating in the process or there is a greater network loading. For the 2-band case, it is noted that if the networks are heavily loaded the sectorisation switching solution considerably improves performance compared with the network powering down solution operating alone, but offers no improvement if networks are lightly loaded. Other simulations that we have performed, not presented in this paper, show a large additional improvement in power saving attained by the sectorisation switching solution, if there is a significant difference in *BusyLoads* for the participating bands.

Figure 5 plots power saving results for the FTP and HTTP (web browsing) ON/OFF traffic models over the LTE configuration, where 2 bands are participating in the process and the assumption is that the network powering down solution only is employed. Results again show a significant power

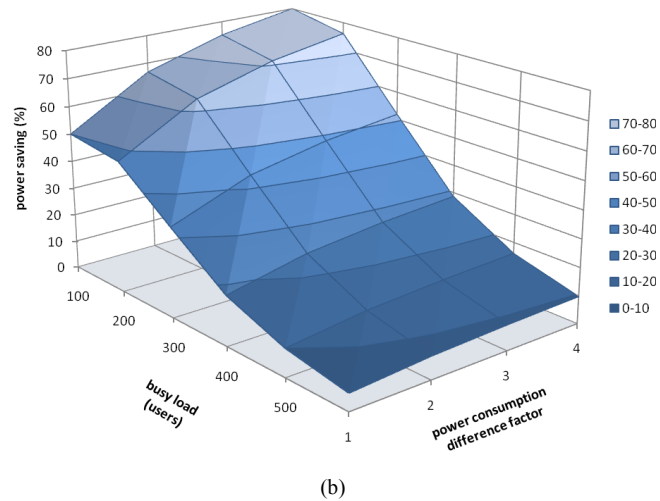
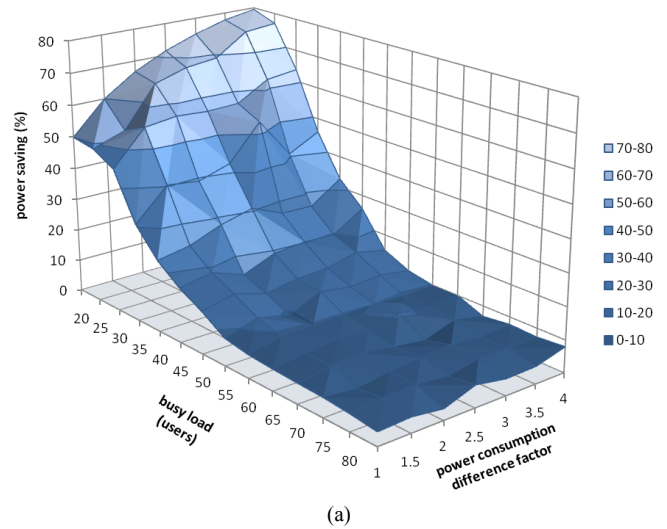


Fig. 6: Power saving against busy hour load and power consumption difference, for network powering down solutions: (a) FTP ON/OFF traffic, (b) HTTP ON/OFF traffic.

saving potential of up to 50% for low network loads. In the FTP case, power saving begins to reduce at a *BusyLoad* of ~20 users, reaching as low as 10% at a *BusyLoad* of ~50 users. In the HTTP case, power saving begins to reduce at a *BusyLoad* of ~150 users, and hits 10% at a *BusyLoad* of ~500 users. It is emphasized here that per-user traffic load for the HTTP (web browsing) case is very light compared with FTP downloads.

It might be noted that the benefits of these power saving solutions are greatly accentuated if there is a difference in the from-the-socket power consumptions of equipment operating at the two bands. This is because the solution can always choose to switch off the equipment at the more power hungry spectrum band whenever it is possible for either band to support the sum of the offered traffic loads. Figure 6 has investigated this phenomenon for FTP and HTTP traffic by varying the power consumption difference factor between the two bands. This figure shows a very significant increase in power saving if the power consumption difference factor is high, particularly if the network is lightly loaded. This increase can be as high as 30%, for the investigated range of values.

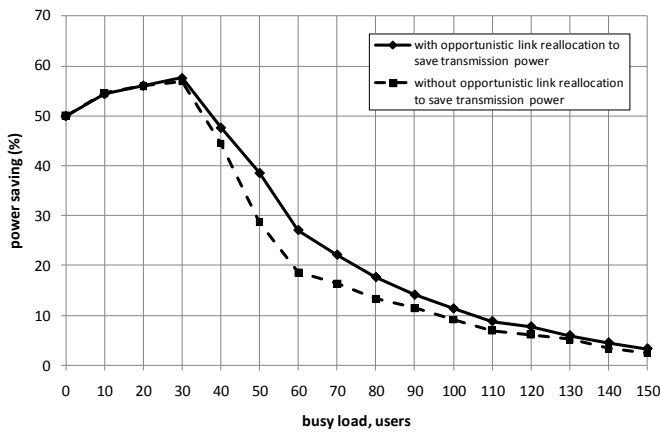


Fig. 7: Power saving against busy hour load through opportunistic link reallocation to use better propagation bands (FTP ON/OFF traffic).

B. Power Saving by Propagation Improvement

In assessing the power saving of reallocating users/links to improve propagation, we have opted to study an HSDPA system. This is because an HSDPA base station was the most modern specification base station for which detailed data was available on from-the-socket power consumption against transmission power; no such data was available for LTE base stations. For an anonymous manufacturer responding to a call for information, internal documentation within the Mobile VCE Green Radio research program indicates from-the-socket power consumption for an HSDPA basestation at 100% transmission power to be 857W, and at 20% transmission power to be 561W. It is widely observed that from-the-socket power consumption against transmission power broadly varies with an $m \cdot p + c$ relationship, comprising a fixed term c that is independent of transmission power p , and a term that varies with transmission power, $m \cdot p$. Given this, the above figures regress to give 487W as the fixed part from-the-socket power consumption c , and the gradient of variation with transmission power m as 9.25 from-the-socket Watts per transmission Watt. These values are used throughout this section.

In ascertaining necessary transmission power, we use values in Table 3 of reference [6], with 80% of the power budget being scaled by the number of users present in the system and 20% being allocated to pilot transmission. The comparison in [6] is between full HSDPA networks operating at 2GHz (as per current HSDPA deployments), and at 5GHz as argued is a good future deployment option in [6]. A 600m cell radius is chosen, where again we assume the aforementioned FTP ON/OFF traffic model as described at the start of Section III.

Results in Figure 7 show that there is significant transmission power saving potential through the opportunistic reallocation scheme. Power saving initially increases to some 58% as the busy hour load is increased to 30; this is because it is always possible to reallocate users to power down radio equipment so adding more users simply increases the number that are reallocated to better spectrum thereby saving additional transmission power. However, as the traffic load is increased further power saving decreases and a difference

begins to emerge in performance for the solutions with and without opportunistic reallocation to save transmission power. It is noted that especially if the networks are experiencing moderate load, the opportunistic reallocation of links to save transmission power saves up to an additional 10% compared with just opportunistically reallocating users/links to be able to power down radio equipment. This additional saving would be far higher if the value of m , the gradient of the from-the-socket power to transmission power relationship, were greater than the modest value of 9.25 assumed here.

IV. CONCLUSION

Energy consumption in mobile communications can be reduced significantly by the better use of spectrum.

This paper has investigated various concepts through which dynamic adaptation of spectrum allocations among the range of bands available to the operator (or, indeed, spectrum sharing among different operators' bands) can reduce operators' power consumption in providing services. Results have shown considerable power saving potential, of up to 50% or more in base station power. Among additional observations, it has been shown that if there is a significant difference in from-the-socket power consumption of the network equipment utilized at the different participating spectrum bands, the potential for power saving is further accentuated.

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