Network Sharing and its Energy Benefits: a Study of European Mobile Network Operators

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ABSTRACT

In this paper we investigate the potential energy saving inherent in the network sharing approach, whereby all (or significant parts) of the network infrastructures existing in a country can be shared by different network operators. In our study we consider European mobile network operators, and we use simple analytical models to show that in most European countries the amount of energy necessary to run mobile networks can be reduced by 35 to 60% with respect to the case in which each operator manages a separate network infrastructure.

1. INTRODUCTION

The telecommunication market in Europe was dominated by monopolistic public companies for about a century (in Italy, the first experimental telephone calls date back to 1877), until competition started with mobile digital telephone services (adopting the GSM 2G cellular technology) in the mid '90s. Since then, competition has been fierce for over a decade; in those years, any form of cooperation among mobile network operators (MNOs) was out of the question: the networks of different MNOs were completely separated, as if physical walls existed around each network. The interactions between networks, necessary to allow customers of one MNO to reach customers of another, required specific gateways.

Then, some initial, limited cracks in the walls were opened, mostly because of the difficulty in identifying good new antenna sites, and the concept of "mast sharing" [1] emerged, through which different MNOs can place their antennas on the same pole.

More recently, MNOs on the one hand are under strong pressure for cost reduction, and on the other hand they are faced with an explosive growth of smartphone users (predicted to reach half a billion in Europe by 2014), with a corresponding exponential increase of mobile data traffic, growing at annual rates close to 80% worldwide (68% in Western Europe) and forecasted to reach almost 11 exabytes per month by 2016 (see [3]). In these conditions, MNOs are starting to share base stations (BSs), through a concept often called "tower sharing" [2], and the idea of "network sharing" [4, 5], whereby all (or significant parts) of a network infrastructure can be shared by different MNOs, is not considered today as sinful as it was just few years ago. For example, a recent announcement of an agreement between Orange and T-Mobile says that their UK customers will be allowed to use either network interchangeably [6]. Of course, many difficulties still exist in the path to network sharing, that relate to both operational problems and commercial sensitivity of information; for example:

- the high initial cost incurred to allow the sharing of networks, due to the complexity of the control of several parallel networks operated as a pool
- the need for extended roaming and billing procedures to allow the seamless transfer of services from one network to another, and to share revenues between the involved MNOs
- the need for the definition of cost sharing approaches for the introduction of new technologies (e.g., LTE)
- the difference in the QoS levels adopted by MNOs, and the fact that each operator tries to use its QoS level (in terms of both performance and coverage) as a service differentiator, thus being reluctant to transfer its customers to a different network
- the possibility for competitors to profile a MNO's customers and to attract the most profitable ones

In this paper we investigate the energy saving potential of the network sharing concept in several European countries. Our early papers on energy efficiency in cooperative cellular networks [7, 8] investigated the same issue in an abstract setting, by defining simple mathematical models that allow the quantification of the energy saving that can be achieved when cellular network infrastructures in a country can be collectively managed, so as to minimize energy consumption. In that period, the time for the network sharing concept had not yet come, and our study was dismissed by industry insiders as a nice theory, but technically and commercially naive, see [9]. Today, MNOs are beginning to see the advantages behind the network sharing concept, and network sharing is becoming a reality in some European countries, although with different motivations from energy efficiency (mainly reduction of capital costs). It seems thus important to revisit the energy efficiency aspects of network sharing, with special reference to European countries, so as to provide at least a first rough indication of the potential energy savings inherent in this approach.

In this paper we first summarize the approach developed in [7, 8] and we then apply that methodology to the mix of MNOs existing in several European countries, showing that the energy saving possible with the infrastructures and the equipment available today is of the order of at least 40%. This value is comparable to the energy saving potential of BS sleep modes within an individual network, as shown for example in [11, 12, 13, 14, 15, 16, 17, 18], but the two approaches are not incompatible, so that a combination of an inter-network approach with an intra-network approach can lead to even higher amounts of energy saved. In addition, it should be considered that the characteristics of the intra-network and inter-network approaches are different, so that they might be applicable in different portions of the service area. An intra-network approach might be more suited to a dense urban area, where cells are many, and highly redundant in terms of coverage. An inter-network approach might be more suitable for a rural area, where cells of one MNO are few, and overlaps are scarce.

The rest of this paper is organized as follows. In Section 2 we introduce our definition for the network sharing scenario and we summarize the approach developed in [7, 8]. In Section 3 we present numerical results for European countries with more than 15 million mobile subscriptions, and finally in Section 4 we present our conclusions and directions for future work.

2. NETWORK SHARING

We consider an area served by n MNOs, which operate separate networks. Each one of the n networks is exactly dimensioned according to the peak traffic demand of the operator's customers, so as to provide full coverage of the service area, while meeting a fixed QoS constraint at all times. In other words, we assume that all MNOs provide equivalent coverage and QoS.

Note that, for starters, we assume that at peak traffic no excess capacity or overprovisioning exists. This is quite a conservative assumption for our study, as we shall see later on.

Due to end user behavior (i.e., the combination of user activity and mobility patterns), traffic fluctuates significantly during a day. For example, plots in Fig. 1 show the traffic measured on cells of an Italian mobile network in operation; solid lines refer to a cell in a business area; the empty markers identify the profile of a week-day, solid markers refer to a week-end day. Traffic values are obtained by averaging the measurements (at 15 minute intervals) collected during a week, and are then normalized to the peak average value in the cell. The steep growth of traffic in the morning of week days corresponds to people arriving at work; traffic decreases from mid afternoon to evening, when people go home. At night, and during weekends, traffic is extremely low, as is usual and expected in business neighborhoods.

Quite a different behavior can be observed in the same figure for the traffic profile of a cell in a consumer area, shown with dashed lines. Peaks occur now in the evening, differences between weekdays and weekends are less significant, and transitions from peak to off-peak periods are slower.

Obtaining such real traffic data from MNOs is extremely problematic, since they are considered sensitive information. We could not obtain equivalent data for all the European countries we will consider later on, but we can confidently assume that the general behaviours shown by the traffic profiles in Fig. 1 are representative of any business and consumer area, irrespective of the European

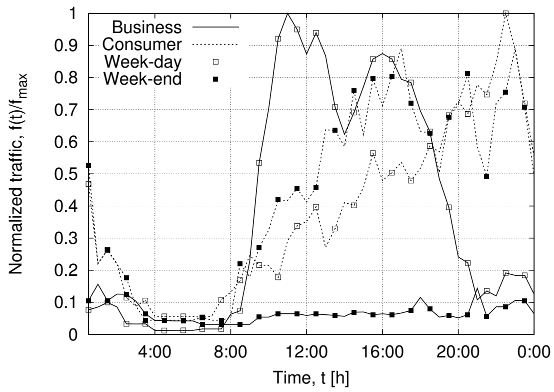

Figure 1: Daily traffic profiles for a cell in a business area and a cell in a consumer area, week-day and week-end profiles measured in a network in operation.

country.

The traffic profiles clearly indicate that a network which is exactly dimensioned to meet a given QoS constraint at the peak traffic load, offers a capacity which is underutilized for long periods of time, during which traffic is lower (possibly much lower) than the peak. In terms of consumed energy, most networking devices, including BSs of mobile networks, tend to consume about the same quantity of energy, regardless the amount of carried traffic; i.e., the consumption of a device that carries no traffic is almost as large as the consumption at full load. Due to this characteristic of networking devices, we can say that networks consume power more for the *deployed* capacity, than for the *used* capacity. The network sharing concept can therefore be used to reduce energy consumption.

When n MNOs coexist in the same service area, the underutilization of the access networks capacity occurs for all access networks roughly at the same time, due to similar average customer behaviors. The network sharing approach allows MNOs to take advantage of this situation and save energy, by modulating the active capacity so as to follow the traffic demand. The key idea underlying the energy efficiency of network sharing is that network capacity supply can be modulated by switching off some networks for the time periods in which traffic is low over the service area, so that a subset of the access networks is sufficient to provide the capacity necessary to achieve the desired QoS. Of course, while the network of an MNO is off, its customers must be allowed to roam to the networks of the MNOs that are active. Note that the delay required to allow users to roam out of a cell that is about to be switched off has been analysed, and shown to be of the order of one minute [19], considering that switch-offs occur in periods of low utilization, so that the users that must handover out of the cell are few.

Let $\mathcal{N} = \{1, 2, \cdots, n\}$ be the set of access networks of the n MNOs. Denote by S_i the number of subscribers of operator i, and by $f_i(t)$, with $t \in [0, T]$ spanning over $T = 24$ hours, the daily traffic profile of network i. We assume that the average per-user traffic in all access networks is the same, so that the overall traffic of each network is proportional to the respective number of users:

$$f_i(t) = \alpha_i f(t) \tag{1}$$

with $\alpha_i/\alpha_j = S_i/S_j$. Assume the function $f(t)$ to be continuous and differentiable, and let f_{max} identify its maximum; $\alpha_i f_{max}$ is, thus, the maximum traffic that network i can carry without violating the QoS constraint, under our assumption of no overprovisioning. If some spare capacity were available, say that there is an overprovisioning factor $(1 + x)$, then the maximum traffic that network i could carry without violating the QoS constraint would become $(1 + x)\alpha_i f_{max}$.

With no loss in generality, we consider $\alpha_1 > \alpha_2 > \alpha_3 > ... > \alpha_n$ and we take $\alpha_1 = 1$ so that α_i is the relative number of subscribers that operator i has with respect to the largest operator, i.e., operator 1. We assume also that the function $f(t)$ has a minimum, f_{min} and it is monotonically decreasing from f_{max} to f_{min} and monotonically increasing from f_{min} to f_{max}. This corresponds to an abstraction of what happens in reality, but is supported by the shape of the measured traffic profiles shown in Fig. 1.

We assume that a subset of the access networks can be switched off when the total traffic reduces to a level such that the networks that remain on can carry the entire traffic of all networks without violating the QoS constraint. Users can roam through any network, and when some networks are switched off, their customers roam to the networks that remain on, with a probability proportional to the network size. In [7], we called *Roaming-to-All* this roaming scheme.

Consider a *network switch-off configuration* in which the networks in the subset $\mathcal{N}_a \subset \mathcal{N}$ are powered on, while the remaining networks are off. This configuration is possible at time t, if:

$$f(t) \sum_{i \in \mathcal{N}} \alpha_i \leq f_{max} \sum_{i \in \mathcal{N}_a} \alpha_i \qquad (2)$$

where the left side of the expression represents the total traffic to be carried at time t, and the right side is the maximum traffic that the networks in $\mathcal{N}_a$ can carry in total, without violating the QoS constraint. Expression (2) defines the times during a 24 hour period in which the configuration is feasible. In particular, as indicated in Fig. 2, the extremes of the period in which the switch-off configuration is feasible are T_a^{off} and T_a^{on}, given by:

$$f(T_a^{\text{off}}) \sum_{i \in \mathcal{N}} \alpha_i = f(T_a^{\text{on}}) \sum_{i \in \mathcal{N}} \alpha_i = f_{max} \sum_{i \in \mathcal{N}_a} \alpha_i \qquad (3)$$

$$T_a^{\text{off}}, T_a^{\text{on}} = f^{-1}\left(\frac{f_{max} \sum_{i \in \mathcal{N}_a} \alpha_i}{\sum_{i \in \mathcal{N}} \alpha_i}\right) \qquad (4)$$

with $T_a^{\text{off}} > T_a^{\text{on}}$. Obviously, T_a^{off} cooresponds to a negative value of the derivative of $f(t)$, and T_a^{on} to a positive derivative value. Notice that if the term in brackets, i.e., the argument of $f^{-1}(\cdot)$ that is represented by the straight horizontal line in the figure, is smaller than f_{min}, the minimum value of $f(t)$, the network switch-off configuration is not feasible without violating the QoS constraint.

Also note that, in the case of a factor $(1 + x)$ of overprovisioning in all networks, the interval in which the switch-off configuration is feasible would have extremes

$$T_a^{\text{off}}, T_a^{\text{on}} = f^{-1}\left(\frac{(1 + x) f_{max} \sum_{i \in \mathcal{N}_a} \alpha_i}{\sum_{i \in \mathcal{N}} \alpha_i}\right) \qquad (5)$$

and would thus become longer.

2.1 Energy cost

Denote by W_i the energy cost to operate network i, expressed as either the needed power, or a corresponding monetary cost. In general, W_i is given by the sum of two terms: one which is constant

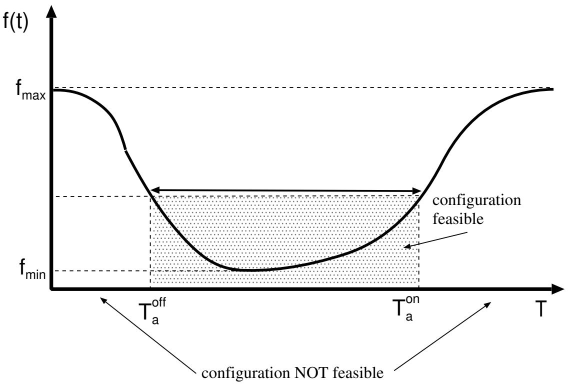

Figure 2: Sketch of a traffic profile with indication on how to derive the switching times.

with respect to S_i (the number of subscribers of MNO i), and one which depends on S_i. Indeed, the energy cost of the backbone infrastructure and of the access network devices that provide complete radio coverage are roughly independent of the number of subscribers; on the contrary, the number of additional devices needed to provide the necessary capacity in the access network heavily depends on the number of users. For simplicity, we will always consider the two extreme cases in which W_i is either constant (this case will be termed *constant cost*), or directly proportional to S_i (this case will be termed *variable cost*). Thus, in the *constant cost* case we set $W_i = C$ irrespective of the number of subscribers of network i, and in the *variable cost* case we set $W_i = cS_i$. The values of the constants C and c are arbitrary, since they are only used when comparing network energy savings in the next section, and in this case they cancel away.

For a given switch-off configuration, such as the one previously considered, in which the networks in $\mathcal{N}_a \subset \mathcal{N}$ are powered on, while the remaining networks are off, the daily energy cost can be computed as:

$$E = \left(T - T_a^{\text{on}} + T_a^{\text{off}}\right) \sum_{i \in \mathcal{N} \setminus \mathcal{N}_a} W_i + T \sum_{i \in \mathcal{N}_a} W_i \qquad (6)$$

since the networks in $\mathcal{N}_a$ are on all the time, while the others are on for the time indicated in brackets.

So far, we have assumed that the energy cost W_i is independent of the amount of traffic actually carried by network i, as long as network i is switched on. The energy cost drops to a very low value when network i is switched off. This assumption comes quite close to the characteristics of the presently installed networking 2G and 3G equipment [10]. New generations of equipment (LTE, for example) exhibit better proportionality of energy consumption to traffic, with about 60% of the peak power consumption being a fixed energy cost to have the equipment on, and the other half being proportional to traffic [20]. To extend our analysis to the case of devices with some degree of load proportionality, in some cases we will assume that a fraction L_P of the consumption is load proportional, meaning that under a load ρ_i, with $0 \leq \rho_i \leq 1$, the MNO i consumes

$$W_i(\rho_i) = (1 - L_P)C + L_P C \rho_i \qquad (7)$$

The assumption of a very low power consumption during the periods in which a network is switched off is justified by the fact that fast network reactivations are not necessary, since the network switch-on time can be scheduled in advance, based on historical traffic traces.

2.2 Roaming traffic

When network i switches off, its traffic must roam to the networks that are still powered on. The switch-off of network i at time T_a^{off} and its switch-on at time T_a^{on} generates a daily roaming traffic R_i equal to:

$$R_i = \int_{T_a^{\text{off}}}^{T_a^{\text{on}}} \alpha_i f(t) dt \quad (8)$$

This roaming traffic is directed to the active networks in $\mathcal{N}_a$. Assuming that users roam to the networks in $\mathcal{N}_a$ proportionally to the destination network size, the daily traffic roaming from network i to network $j \in \mathcal{N}_a$ is,

$$R_{i,j} = \frac{\alpha_j}{\sum_{k \in \mathcal{N}_a} \alpha_k} R_i \quad (9)$$

2.3 Switch-off Patterns

We focus now on different *switch-off patterns*, indicating with this term the sequence according to which the networks are switched off, together with the switch-off and switch-on instants. We assume that all but one networks switch off, in each 24h period.

A switch-off pattern P is thus defined by,

- $\{x_i, i = 1, \cdots, n-1\}$ with $x_i \in \{1, 2, \cdots, n\}$ – the sequence that specifies the order in which networks switch off; e.g., $x_i = k$ means that the $i-$th network to switch off is network k. Denote by x_n the network that does not appear in the sequence and that never switches off in pattern P.
- $\{T_i^{\text{off}}, i = 1, \cdots, n-1\}$ with $T_i^{\text{off}} \in [0, T]$ – the sequence of switch-off instants, i.e., network x_i switches off at time T_i^{off}.
- $\{T_i^{\text{on}}, i = 1, \cdots, n-1\}$ with $T_i^{\text{on}} \in [0, T]$ and $T_i^{\text{on}} > T_i^{\text{off}}$ – the sequence of switch-on instants, i.e., network x_i switches on at time T_i^{on}.

The energy cost of switch-off pattern P, E_P, can be computed as:

$$E_P = \sum_{i=1}^{n-1} \left(T - T_i^{\text{on}} + T_i^{\text{off}} \right) W_{x_i} + T W_{x_n} \quad (10)$$

from which saving is derived by normalizing C_P over the energy cost of the always-on scenario and taking the complement:

$$G_P = 1 - \frac{E_P}{T \sum_{i=1}^{n} W_i} \quad (11)$$

Note that switch-off and switch-on instants can be rather accurately determined by the analysis of historical traffic traces, which exhibit a remarkable periodicity, adding margins to account for both unpredictable local traffic variations, and transient delays. The fact that network switch-on events can be scheduled in advance, based on traffic predictions, justifies the assumption of very low power consumption during the periods in which a network is off.

The level of precision with which the available capacity is adapted to traffic fluctuations depends on the number of switch-on and switch-off instants during one day. In this paper we will assume that each network is at most switched off and then on again once a day. In [18] we proved that, in the intra-network case, one switch-off per day is sufficient to obtain most of the possible energy saving.

Country	MNOs	Market share [%]				Subscr. [M]
France	3	46	36	19	-	58.2
Germany	4	32	31	21	16	113.6
Greece	3	51	28	21	-	15.4
Italy	3	38	36	26	-	84.0
Netherlands	3	46	26	28	-	19.0
Poland	4	29	29	28	14	47.5
Portugal	3	45	40	15	-	16.4
Spain	3	44	34	22	-	51.4
Romania	3	41	32	26	-	24.2
Russia	3	37	33	30	-	189.7
Ukraine	3	48	37	15	-	52.3
U.K.	3	39	33	28	-	68.5

Table 1: Characteristics of the considered countries: Number of MNOs offering both 2G and 3G services, market share for each of the MNOs, total number of subscribers.

3. ENERGY BENEFITS IN EUROPE

In this section, we assess the effectiveness of network sharing in terms of achievable energy saving by considering a number of European countries. In particular, we focus on the 12 countries indicated in Table 1, which are the countries whose total number of subscribers is larger than 15 Millions, according to publicly available data.

For each country we collect approximate data about the number of subscribers for each of the active MNOs and the kind of provided services. We then assume that network sharing is applicable only among the MNOs that offer both 2G and 3G services. Indeed, a MNO offering access to 2G terminals only cannot switch off its network and make the users roam to a purely 3G network. In this case the operator would probably switch off the 3G network leaving the 2G access network on; however, since we only have access to data about the total number of subscribers and not the breakdown with respect to technology, we make the simplistic assumption that network sharing is implemented only among MNOs offering services to both 2G and 3G users.

Interestingly, the considered European countries present quite similar scenarios. As summarized in Table 1, except for two cases, namely Germany and Poland, all considered countries have 3 MNOs offering both 2G and 3G services with relatively fair share of market. The smallest of the 3 MNOs has a share that is usually between 20 and 30%, only in the case of Ukraine and Portugal the smallest of the three operators accounts for as low as 15% of the subscribers. Conversely, the largest of the 3 MNOs exceeds 50% of the market share only in Greece, where it is about 51%; otherwise, it is between 37% and 48%. The case of Germany, with 4 MNOs, is interesting because it presents two dominant operators with about the same number of subscribers, 36 millions, corresponding to 31% of the market, and other two smaller MNOs that share the remaining market. In Poland, three operators are about the same size, with almost 30% of the share each, while the fourth operator accounts for 14% of the market only. This substantial similarity of the situations is probably due to historical reasons: in most of the European countries similar network evolutions occurred roughly at the same

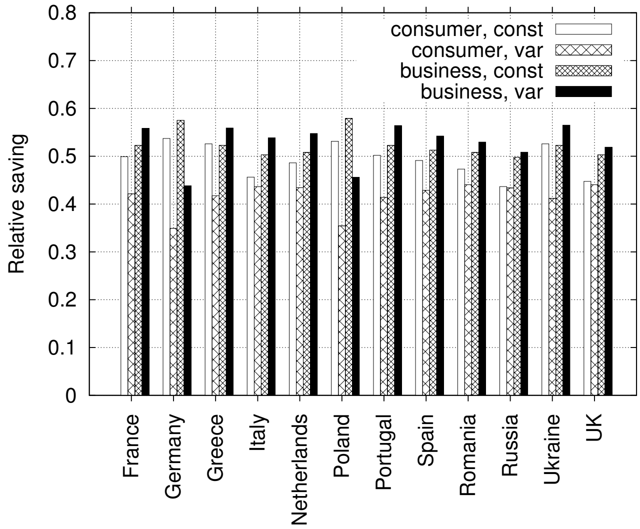

Figure 3: Saving achievable with network sharing in the European countries with more than 15M subscribers; business and consumer profiles, constant and variable cost models.

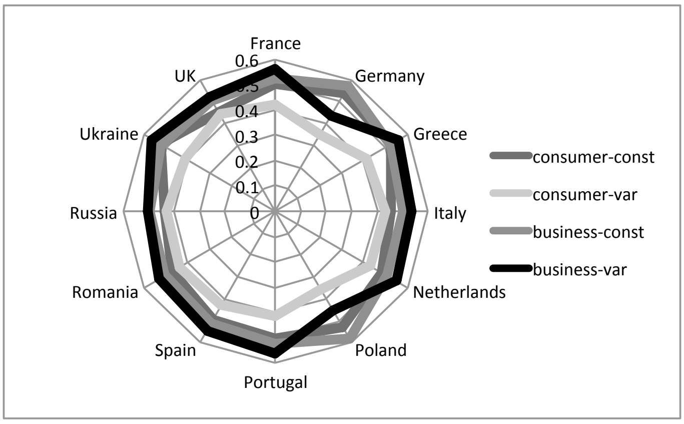

Figure 4: Kiviat diagram of the saving achievable with network sharing in the European countries with more than 15M subscribers; business and consumer profiles, constant and variable cost models.

time.

We compute the energy saving achievable through network sharing for each of the selected countries, and for both the consumer and the business traffic profiles shown in Fig. 1 (implicitly assuming that the traffic profiles in Fig. 1 can be representative of traffic in all considered countries). Given a traffic profile and a country, we consider all the possible switch-off patterns, i.e., all the possible orderings in which the MNOs of that country might switch off. Savings are obtained as described in the previous section, by deriving switch-off and switch-on instants from (4), and by computing saving from (11). Both the cases of variable and constant cost models are evaluated. The saving achievable during week-days and week-ends are properly weighted to get the average weekly saving.

Figs. 3 and 4 report the maximum achievable energy saving, among those obtained from different switch-off patterns in a given scenario. Fig. 3 uses a bar representation, while Fig. 4 reports the same data with a Kiviat diagram. The savings are really significant, typically larger than 40%: this confirms that network sharing, besides being a viable approach, already feasible with today technology, is very promising in terms of energy consumption reduction.

Observe also from the figure that the business traffic profile leads to the largest saving. This is due to the profile having particularly steep transitions between peak and off-peak, and long periods of very low traffic. Clearly, in reality, large service areas are characterized by a mixture of neighborhoods, some mainly with business-like behavior of the users and others with consumer-like traffic profiles. A switch-off scheme should then be applied by adapting, neighborhood by neighborhood, switching times to the specific profiles. For example, a MNO that is going to switch-off its access network, might probably start from portions of the network in business areas, as soon as traffic drops below some threshold; some time later, when traffic drops also in the consumer areas, other portions of the access network would be powered off. In terms of saving, this means that the achievable saving will be in between what can be obtained from a business area and a consumer area, with actual values depending on the traffic profiles and on the proportions of areas with business-like or consumer-like behavior. In case of some spare capacity, deployed to absorb medium term traffic growth, some additional saving can be expected. With an overprovisioning factor $1 + x = 1.2$, for example, it is possible to reach savings between 50 and 59% for the consumer profile and between 53 and 63% for the business profile under the constant cost model. These values are even closer to the maximum theoretical saving that would be achieved when one network only has enough capacity to carry all the traffic; the maximum theoretical saving is equal to 66% for 3 MNOs, corresponsing to 1 network over three that is carrying traffic, and it is equal to 75% for 4 MNOs.

A positive side-effect of network sharing is that active resources are more effectively used than in traditional scenarios without sharing. Indeed, network sharing aims at reducing energy wastage that derives from daily periods of over-provisioning by making the available capacity more closely follow the traffic profile. To evaluate this effect, we compute the daily average utilization of the access network resources, by dividing the amount of generated traffic by the amount of available capacity. The results are reported in Fig. 5, for both business and consumer profiles and distinguishing week-days from week-ends. When no network sharing is used (first group of bars in the figure), the utilization is about 0.38 for week-days under both traffic profiles and it is 0.07 and 0.43 for week-ends, respectively, in business and consumer areas. When network sharing is implemented, the average utilization increases to about 0.6: it almost doubles. Network sharing turns out to be really effective. Notice that week-ends in business areas still present relatively low resource utilization; this is due to the fact that traffic is so little that even one network alone serving all the traffic of the 3 or 4 coexisting MNOs is sort of under-utilized. It is worth noting that increases in network utilization are specially welcome in periods of reduced operational margins, like the one we are living.

MNOs perceive as one of the most critical aspects of network sharing the fact that, by having the opportunity to serve roaming users, a competitor MNO might profile subscribers. We, thus, compute the amount of outgoing roaming traffic that a MNO generates once it powers off its access network. Focusing on the Italian case, Fig. 6

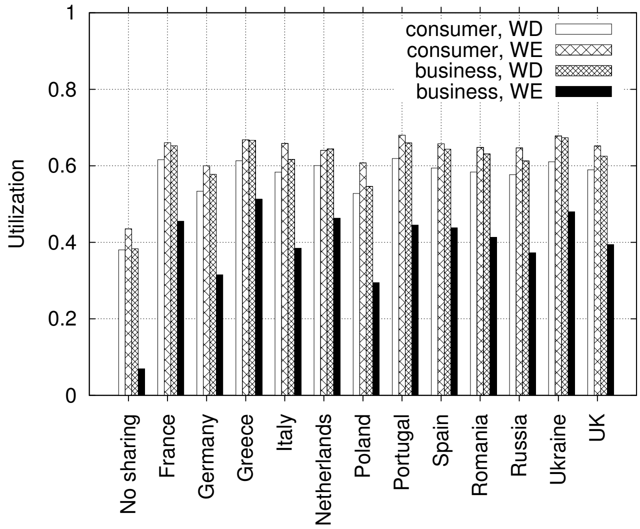

Figure 5: Utilization achievable with network sharing in the European countries with more than 15M subscribers; business and consumer profiles, week-days and week-ends.

reports the amount of roaming traffic in various possible switch-off patterns. Patterns are denoted by a pair of values (i, j) that indicates that the access network of MNO i is the first one to be powered off and it is followed by the network of MNO j. The label 'B' or 'C' associated to patterns indicates the traffic profile (business or consumer). Roaming traffic is normalized with respect to the total traffic of the MNO. For completeness, the figure reports also the saving achieved by each switch-off pattern under the constant cost model (see the dashed curve). The amount of roaming traffic can be pretty large, up to 40-50% of the traffic of a MNO. However, due to the relatively similar size of the MNOs, different patterns correspond to similar percentage of roaming traffic and achieve more or less the same saving. This means that, to reciprocate the inconvenience of roaming traffic to a competitor, MNOs might establish schemes in which switch-off patterns alternate periodically.

So far, we assumed that the energy consumption of the network is independent of the carried traffic. This assumption is justified by the fact that today most of the installed network devices, both the BSs at the access network, and the switches and routers in metro and core networks, consume at full load about the same amount of power that is consumed when they are active, but carry no traffic. Newer equipment (for example, LTE BSs) shows a better proportionality between power consumption and load. Clearly, the energy saving achieved with network sharing reduces, when network devices exhibit an increasing load proportionality (and would completely vanish in the case of perfect load proportionality). In order to assess this energy saving reduction, we look now at the case in which the network power consumption is load proportional for a fraction of power consumption expressed by the parameter L_P, as in (7). The energy savings achievable with network sharing for different values of L_P are reported in Figs. 7 and 8 for the European countries considered in this paper. Also in this case, Fig. 7 uses a bar representation, while Fig. 8 reports the same data with a Kiviat diagram.

While the energy savings decrease with increasing values of L_P,

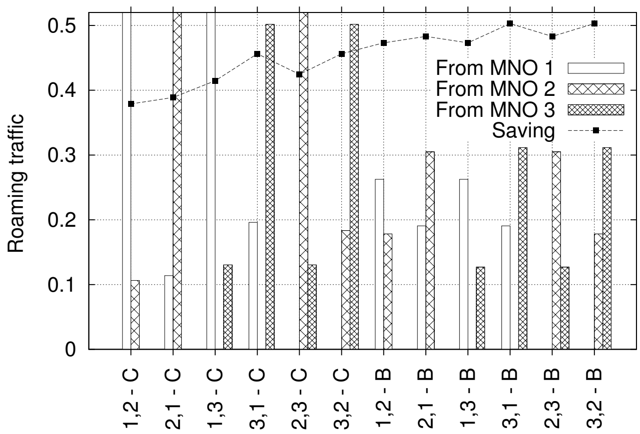

Figure 6: Roaming traffic out of a MNO with various switching patterns and for both business and consumer traffic; Italian scenario.

we can observe that the absolute values of the savings remain large, even for $L_P = 0.4$. Notice that, as we already said, in real networks the actual value of L_P is very low today, since most of the network devices are not load proportional, and only very recent equipoment (like LTE BSs) can achieve, individually, a value of L_P around 0.4.

4. CONCLUSIONS

In this paper we have quantified the energy savings which could be achieved by mobile network operators offering service in the largest European countries, as a result of a widespread adoption of the network sharing approach.

Our results indicate that about half of the energy cost presently incurred by operators could be avoided by cleverly exploiting the fact that most European countries are today covered by several (3-4) overlapping cellular network infrastructures.

These savings are actually achievable thanks to the presence of parallel cellular networks, which thus constitute a significant asset for the identification of energy-efficient solutions. If only one network were available, with a capacity corresponding to the sum of the capacities of all networks of today, and competition would rely on virtual operators exploiting the same infrastructure, the approach discussed in this paper would not be feasible; it should, more effectively, be replaced by energy-efficient management approaches within the only available infrastructure. In other words, the fact that the total available access network capacity is fractioned in several parallel infrastructures, allows simple approaches for the improvement of the proportionality between energy consumption and overall traffic load.

Acknowledgement

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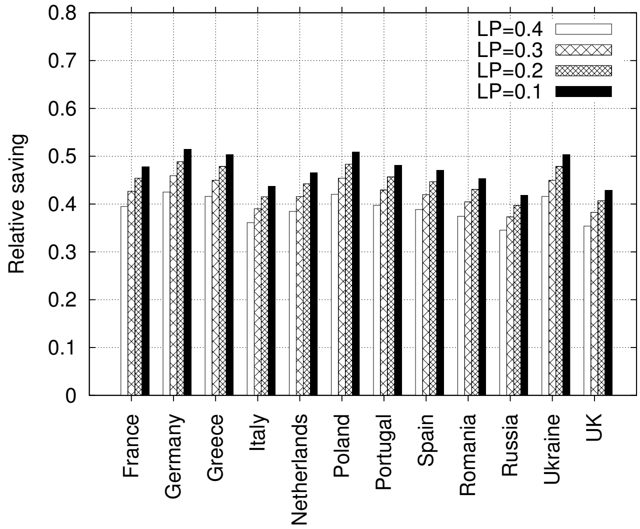

Figure 7: Saving achievable with network sharing in the European countries with more than 15M subscribers when a fraction L_P of energy consumption is load proportional; consumer traffic profile.

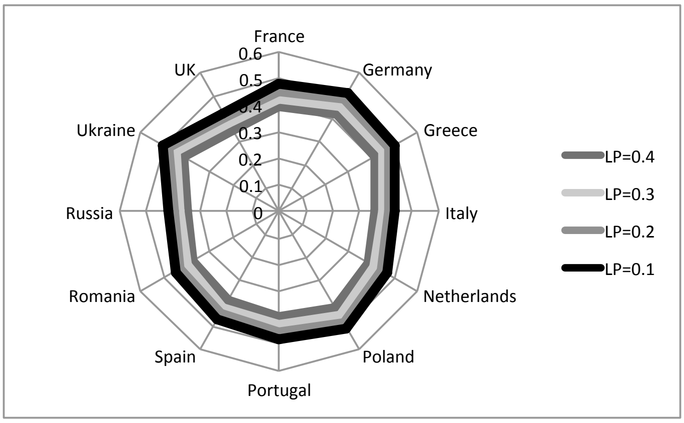

Figure 8: Kiviat diagram of the saving achievable with network sharing in the European countries with more than 15M subscribers when a fraction L_P of energy consumption is load proportional; consumer traffic profile.

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