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ENERGY-AWARE UMTS ACCESS NETWORKS

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ABSTRACT

The sensitiveness toward energy consumption problems is driving Telecommunications operators to optimize network equipment utilization. Since cellular systems are often dimensioned for peak hour traffic, during low traffic periods, such as night, many devices are underutilized but still, by being active, consume power. In this paper, we show that dynamic planning, consisting in reducing the number of active access devices when traffic is low, can achieve significant power saving. In our study, we consider three different UMTS scenarios with a simplified traffic model describing three classes of services, quality of service guarantees, link-budget, propagation and electromagnetic exposure constraints.

I INTRODUCTION

Nowadays, energy consumption has become a key issue, from both environmental and economic side. ICT alone is responsible of a percentage which varies between 2% and 10% of the world power consumption [12] and this figure is expected to grow further in the future. Telecommunications, in particular, are greedy energy-user. For example, the energy needed by the major telephone operator in Italy is more than 2TWh a year, representing the 1% of the total national demand [11].

In the last years we have witnessed a consistent increase in the number of mobile users [5], and new services like videocall and video on demand have become very common in mobile networks. This trend has brought to the development of complex access infrastructures [10] with high energy consumption. Recently, telecommunication operators have become aware of the energy issue, and have begun to study new hardware solutions that can improve energy efficiency of the access network [9].

In this paper, we consider the possibility of a dynamic planning that, based on traffic intensity, reduces the number of active access devices when they are underutilized, such as during night periods. When some base transceiver stations are switched off, radio coverage and service provisioning are taken care of by the devices that remain active. The switching off of the access devices should be carefully decided so as to maintain quality of service guarantees and meet electromagnetic exposure constraints. In particular, we consider a UMTS radio access network and we take into account the possibility to turn off the Node B equipments. We claim that it is possible to apply these schemes to a real urban network, due to the fact that operators are providing new software features to control and even switch equipments off [4]. Considering the large number of access devices, the total energy saving for an operator can become huge.

II ARCHITECTURE AND CELLULAR MODEL DESCRIPTIONS

II.A *UMTS Radio Access Architecture*

UMTS, commonly referred to as 3G (for 3rd Generation Wireless Mobile Communication Technology), carries many types of traffic, from real-time circuit-switched to packet-switched services, and offers higher data rates and a wide range of telecommunications services, including videocall and Internet access.

The UMTS architecture is typically composed by three interactive domains: User Equipments (UE), Terrestrial Radio Access Network (UTRAN), and Core Network (CN). The UTRAN provides connectivity between the UE and the CN. Basically, the UTRAN consists of two elements: the Node B, that is the base transceiver station, and the Radio Network Controller (RNC), that controls one or more Node B's. While Node B and RNC can be co-located in the same device, typical implementations have a RNC located in a central office serving several Node B's.

As reported in [9], an individual UTRAN equipment consumes about 6 kW, including power amplifiers, digital signal processors, air-conditioning modules and feeders connecting the RNC to Node B. Considering only the Node B, its power consumption amounts to nearly 800 W [6] with power needed to transmit from the antennas usually in the range 1-40 W. The large number of equipments in the UTRAN makes the total power consumed at the access particularly significant: any reduction of power consumption at the UTRAN equipments can translate into a significant reduction of the overall consumption.

In order to model Node B behavior, we use a traditional teletraffic model based on Markovian assumptions for the involved processes; the model allows us to evaluate cell performance in terms of blocking probability for a number of different service types. Moreover, we use a link-budget evaluation and a popular attenuation model to estimate the transmission power needed at the Node B's. We focus on an urban scenario, in which cells can be assumed to have similar size and traffic is homogeneous.

II.B *Cellular Model*

We use a teletraffic model based on a multi-class M/M/N/0 queue, that was widely used in the literature for cellular systems [8]. The model focuses on a single cell in a cellular system, approximating the interaction between neighboring cells through a simplified description of the flow of handovers. There are K classes of service with different resource needs, a class i call requires an amount of bandwidth equal to C_i. The model relies on the following simple assumptions: i) users generate class i calls according to Poisson process with rate λ_i; ii) incoming handovers for class i calls occur according to a Poisson process with parameter $\lambda_{h,i}$; iii) no queuing is possible, calls are blocked if the available bandwidth is not sufficient to satisfy an incoming request; iv) class i service time is distributed according to a negative exponential pdf with mean $1/\mu_i$; v) the time spent by the user in the cell is distributed according to a negative exponential pdf with mean $1/\mu_h$. The traffic model is extremely simple, but adequate for a first estimation of the amount of energy saving that can be obtained with energy-aware planning.

The cell is described by the number of active class i calls, n_i, collected in the vector $\overline{s} = (n_1, n_2, \cdots, n_K)$. The state space, i.e., the set of all possible states, is given by,

$$\mathcal{S} = \{\overline{s} = (n_1, n_2, \cdots, n_K) | \sum_{i=1}^{K} C_i n_i \leq C_T\} \tag{1}$$

where C_T is the total UMTS maximum transfer rate. From well-known queueing theory results, the steady-state probabilities are:

$$\pi(\overline{s}) = \pi(n_1, n_2, \cdots, n_K) = \frac{\prod_{i=1}^{K} \frac{\rho_i^{n_i}}{n_i!}}{\sum_{\overline{s} \in S} \prod_{i=1}^{K} \frac{\rho_i^{n_i}}{n_i!}} \tag{2}$$

where $\rho_i = (\lambda_i + \lambda_{h,i})/(\mu_i + \mu_h)$ is the class i load. The interaction between neighboring cells, that is represented by the parameter $\lambda_{h,i}$, is derived by a fixed-point iterative procedure in such a way that, at steady-state, the incoming and outgoing handover flows are equal.

Class i blocking probability is given by the probability of the states in which an additional class i call cannot be accepted due to lack of available bandwidth:

$$P_{b,i} = \textstyle\sum_{\overline{s} \in \mathcal{S}_i} \pi(\overline{s}) \quad \text{with}$$
$$\mathcal{S}_i = \{(n_1, n_2, \cdots, n_K) | C_T - C_i < \textstyle\sum_{i=1}^{K} C_i n_i \leq C_T\} \tag{3}$$

The average number of active class i calls is:

$$E[A_i] = \sum_{\overline{s} \in S} n_i \pi(\overline{s}) \tag{4}$$

The typical applications supported by UMTS are voice, videocall/videoconference and data transmission, as reported in [3], with rates, respectively, equal to 12.2Kbit/s, 64Kbit/s and 384Kbit/s or 144Kbit/s. Thus, in our model, we consider $K = 3$ classes of service. The mean call durations, $1/\mu_i$, are set according to typical values used in the literature [2]: 3 minutes for voice, 5 minutes for videocall and 15 minutes for data connection. The UMTS maximum transfer rate is about 2Mbit/s. The value of μ_h depends on user mobility; we have considered an average speed V equal to 10m/s in the residential scenario and 5m/s in the office one, so that given the cell radius R, μ_h is computed as,

$$\mu_h = \frac{V}{4ln(2)R} \tag{5}$$

II.C Link-Budget and Propagation Model

The base station site configuration defines the maximum allowed path loss, that is the maximum power reduction of the signal between UE and Node B which still guarantees the communication. The maximum path loss computation is based on the typical link-budget parameters; the main configuration parameters are shown in Table 1 for the Uplink (UL) and in Table 2 for the Downlink (DL). For more details see [10].

The most limiting parameter in the UL is the mobile station transmitting power, P_{MS}. The DL direction limits the available capacity of the cell, since the Base Station transmission power, P_{BS}, has to be shared among all users. After computing the allowed path loss, i.e., the maximum loss among UL and DL, we use the well-known Walfish-Ikegami propagation model [1] to calculate the maximum cell radius R_{max}.

Table 1: Link-Budget main parameters for the Uplink

		Voice	Video	Data
P_{MS}	[dBm]	21	24	24
$AntennaGain_{MS}$	[dB]	0	2	2
E_B/N_0	[dB]	5	2	1.5
$ProcessingGain$	[dB]	25	18	14
$TotalNoise$	[dB]	-102	-102	-102
$AntennaGain_{BS}$	[dB]	15	15	15
$DiversityGain$	[dB]	2	2	2
LNA	[dB]	2	2	2
$SoftHODiversityGain$	[dB]	3	3	3
$SlowFadingMargin$	[dB]	13.16	13.16	13.16

Table 2: Link-Budget main parameters for the Downlink

		Voice	Video	Data
P_{BS}	[dBm]	33-37	33-37	33-37
$AntennaGain_{BS}$	[dB]	15	15	15
E_B/N_0	[dB]	4	2.5	2
$ProcessingGain$	[dB]	25	18	14
$TotalNoise$	[dB]	-99	-99	-99
$AntennaGain_{MS}$	[dB]	0	2	2
$SoftHODiversityGain$	[dB]	3	3	3
$SlowFadingMargin$	[dB]	13.16	13.16	13.16

III SWITCH-OFF SCHEMES

In this section, we describe a procedure to verify the feasibility of a cell switching-off scheme and to compute the possible power consumption reduction.

We consider a set of cells with the same radius R and the same load. Radio coverage and cell dimensioning are typically performed so as to satisfy quality of service constraints under peak traffic conditions; e.g., at peak traffic, blocking probability for each class must be smaller than a target value $P_b^{(\mathrm{T})}$. However, during off-peak periods the system is probably overprovisioned and may waste a significant amount of power. Thus, our objective is to *switch off some cells when load is low*: we have to decide the number of cells to switch off and the load conditions under which cell switching off is possible. These decisions are critical and should take into account two aspects. First, the cells that remain on must provide radio coverage over the whole area (including the portions that were covered by off cells), and, in order to increase the radius, cells could require additional transmission power. Second, the larger cell radius means also traffic load increase, under which quality of service constraints must be guaranteed. The procedure we proposed is discussed below and sketched in Fig. 1.

Let $\Lambda(t)$ be the time varying function of the new call generation rate, which we partition into service classes according to some constants α_i; in other terms, the time varying class i call arrival rate is $\Lambda_i(t) = \alpha_i \Lambda(t)$. The functions $\Lambda_i(t)$ have the typical periodic night/day pattern, such as those reported in Fig. 3[1]. Let C_{off} and C_{on} be the number of cells that, respectively, are switched off and that remain on, during low traffic periods (say, nights); x is the scaling factor $C_{\text{off}}/C_{\text{on}}$, which represents the number of off cells for each on cell. In order to cover the area left by off cells, on cells radius must increase from R to $R' = kR$, with k depending on the geometry. At instant t, in normal conditions, the traffic is given by $\lambda_i = \Lambda_i(t)$; when C_{off} cells are switched off, the traffic in on cells becomes $\lambda'_i = (x+1)\lambda_i$; correspondingly, the load is $\rho'_i = (\lambda'_i + \lambda'_{h,i})/(\mu_i + \mu'_h)$, with μ'_h given by (5) substituting R' to R, and $\lambda'_{h,i}$ derived from the handover flow balance iterative procedure.

We call *night zone*, the time period during which we can switch cells off while maintaining quality of service guarantees. Clearly, the longer the nigh zone is, the higher the power consumption reduction we can achieve. The night zone is defined by the largest value of $\Lambda(t)' = (x+1)\Lambda(t)$ that guarantees that blocking probability is smaller than $P_b^{(\text{T})}$ for each service class. The corresponding value of t, namely t^*, such that

$$P_{b,i}\left((x+1)\Lambda_i(t^*)\right) \leq P_b^{(\text{T})} \quad \forall i \tag{6}$$

plays a role similar to the peak hour used for dimensioning the system; traffic in t^* is the peak traffic of the night configuration with C_{on} on cells. Let the average number of active calls at time t^* be denoted by $E[A_i](t^*)$. Given the total base station power P_{BS}, we define the power per connection as,

$$P_{conn} = \frac{P_{BS}}{E[A_i](t^*)} \tag{7}$$

and use it in the link-budget and the Walfish-Ikegami attenuation model to find the maximum cell radius R_{max}. If $R_{max} > R'$ the switching off scheme can be implemented without increasing the power P_{BS}. Otherwise, a new value for the base station power must be computed, P'_{BS}, and electromagnetic exposure limits as described in [7] must be verified. If exposure limits are guaranteed, the scheme is feasible, and power consumption reduction can be computed from the value of P'_{BS} and the extension of the night zone. Otherwise, if either exposure limits cannot be guaranteed or no nigh zone is possible with constraint (6), a new scheme with a smaller number of C_{off} cells should be assumed.

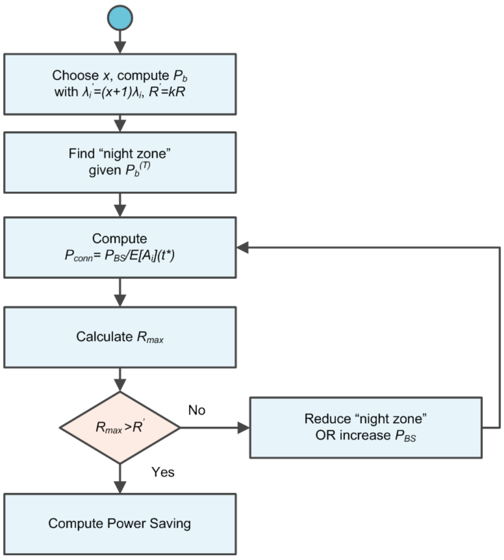

Figure 1: The procedure adopted to verify a switching off scheme

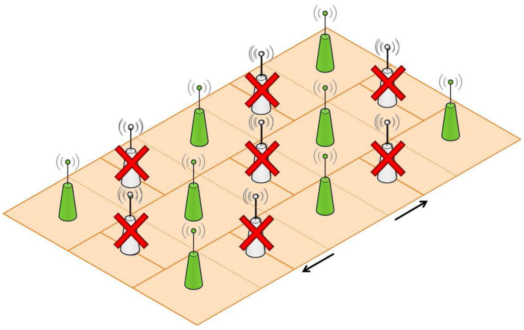

Figure 2: Switch off half of microcells

IV SIMULATION RESULTS

IV.A *Residential Scenario*

We considered a typical residential scenario, composed by μ-cells. Every μ-cell has a radius R = 100m and total power P_{BS} = 2W. The quality of service target is $P_b^{(\text{T})} = 1\%$.

A possible configuration is represented in Fig. 2: we set $x = 1$ and switch off one μ-cell every two. In this way the on cells coverage area doubles, the call generation rate doubles, and the new radius R', in the worst case, becomes R' = 200m.

Assuming that every Node B covers two μ-cells, half of Node B's can be switched off. The functions $\Lambda_i(t)$ are reported in Fig. 3 for two consecutive days, they have the simple sinusoidal shape that we assumed for night/day patterns. Fig. 4 reports the blocking probability perceived by each class of service during the two day period of analysis. The night zone extends from about 10 p.m. to 7 a.m., the extremes of this interval corresponding to the peak hour traffic for the night scenario. Blocking probability is always below the target, the

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[1] Actually, real traffic patterns have more complex period behaviors, but in order to prove that significant energy saving are achievable, a simple sinusoidal behavior is enough.

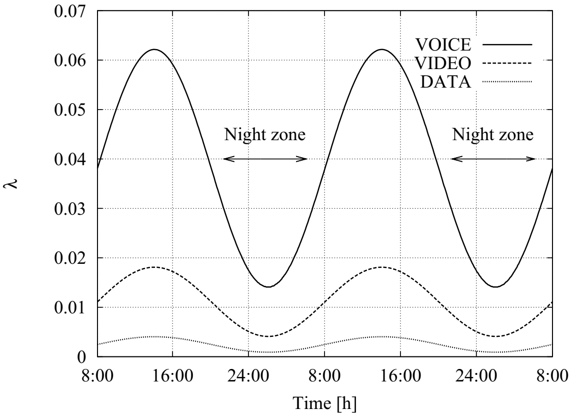

Figure 3: Call generation rate versus time in a μ-cell (Residential scenario)

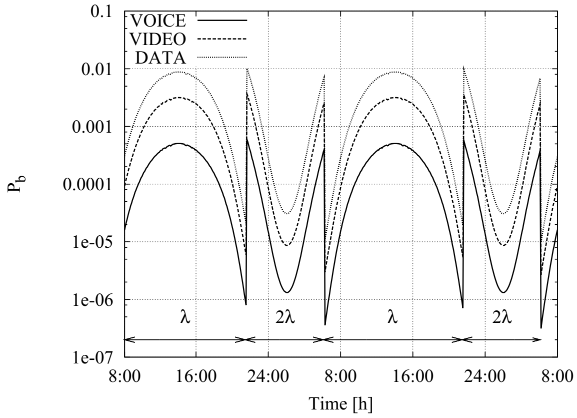

Figure 4: Blocking probability (Residential scenario)

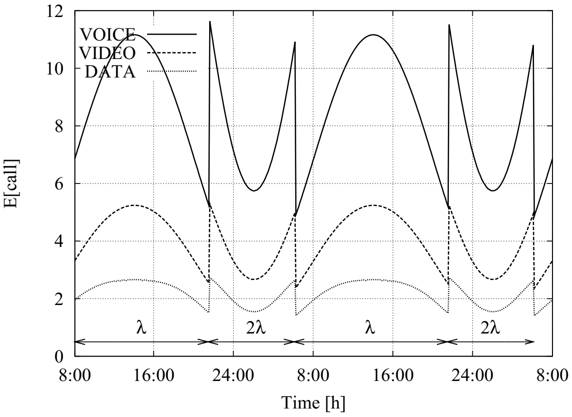

Figure 5: Average number of active calls (Residential scenario)

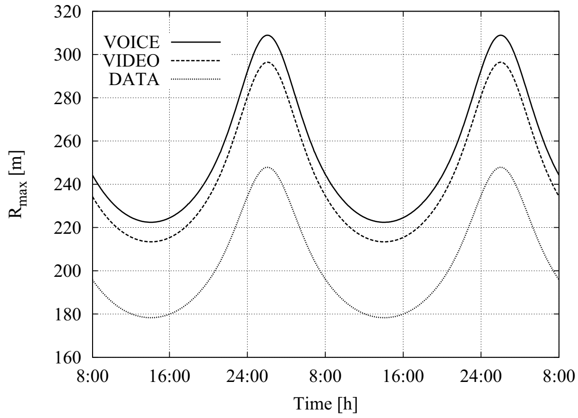

Figure 6: Maximum radius achievable when half of the cells are off (Residential scenario)

maximum is achieved at peak day and night hours. Similar behavior is shown by the average number of calls in Fig. 5. The maximum cell radius computed from the propagation and link-budget models under traffic $\Lambda_i(t)'$ is reported in Fig. 6: data traffic is the limiting case, with the smaller values of maximum radius. During the night zone, the maximum cell radius is always larger than 200 m, and, thus, no base station transmitted power increase is needed.

Every Node B can be switched off for about 9 hours, saving 37.5% of power consumption in a day. The potential saving is $800W \times 9h = 7.2KWh.$

IV.B *Office scenario*

In a typical urban area, there are many office zones. The main difference with respect to residential areas is in the load night/day pattern. In particular, the call generation rate $\Lambda(t)$ becomes negligible during night. Due to the lack of space, we report in Table 3 some results obtained in two situations that differ for the geometry of the cellular planning. The first case is similar to the previous one. In the second case, a Node B controls three cells, and three cells out of five are switched off; only two cells are in charge of covering the area of the three cells that are switched off so that, in the worst case, an on cell should cover the area of 1.5 off cells.

Table 3: Results for the Office Scenario

		Case 1	Case 2
x		1	3/2
λ'		2λ	2.5λ
R	[m]	100	100
R'	[m]	200	400
P_{BS}	[W]	2	2
P'_{BS}	[W]	2	5
T_{night}	[h]	12	6
$Saving(NodeB)$	[%]	50	25

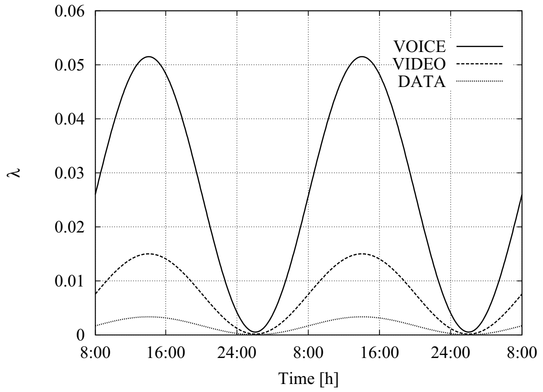

Figure 7: λ variation for a single μ-cell (Hierarchical scenario)

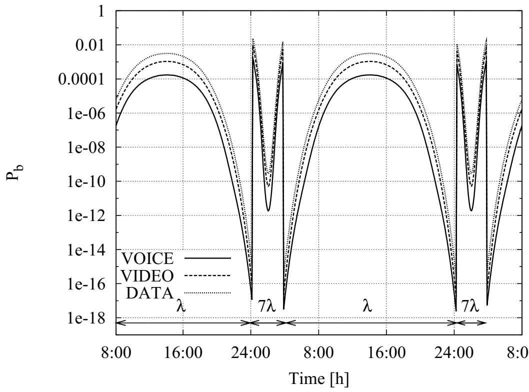

Figure 8: Blocking probability (Hierarchical scenario)

IV.C Hierarchical scenario

Some systems have a hierarchical cellular structure in which umbrella cells are used to cover shadowed regions of smaller cells and fill gaps in coverage between those cells or to manage overflow traffic. In our scenario an umbrella cell covers seven μ-cells, of 100m radius and $P_{BS} = 2$W; the call generation rate is reported in Fig. 7.

The switching off scheme consists in switching off 7 μ-cells during night, so as to turn off the Node B's that control them. The radius of the circular umbrella cell is about 265m. Blocking probability is reported in Fig. 8: during night the call generation rate at the umbrella cell is seven times the one of the single cell. Link-Budget limits give the maximum radius R_{max} versus P_{conn} shown in Fig. 9. The curves are flat when the constraint is the UL, i.e., when the limit is given by the mobile station transmission power. With radius 265 m, the umbrella cell needs a minimum $P_{conn} = 21.33dBm$, that corresponds to transmission power P_{BS} of about 3.4W.

All the 7 μ-cells covered by the umbrella cell can be switched off for about 4 hours, while in order to guarantee continuous coverage, the umbrella cell is always on. A 17% saving of power consumption in a day can be achieved if a single Node B controls the 7 μ-cells, the saving is double if two Node B's can be switched off.

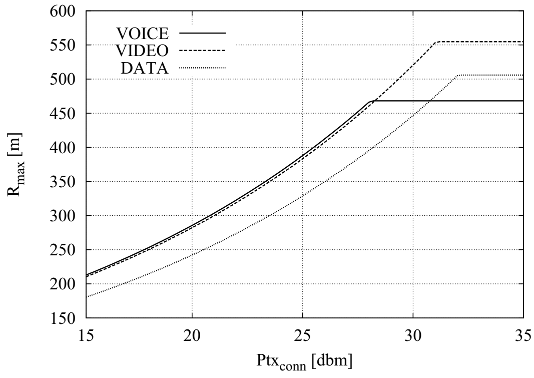

Figure 9: Maximum radius variation versus average power per connection (Hierarchical scenario)

V CONCLUSIONS AND FUTURE WORK

In this paper, we showed that a large amount of energy can be saved if a careful dynamic radio coverage planning is used instead of a static one. In particular, we showed that it is possible to switch off some cells and Node B's in urban areas during low-traffic periods, while still guaranteeing quality of service constraints in terms of blocking probability and electromagnetic exposure limits. We analyzed three kinds of scenario: residential, office and hierarchical. In all the scenarios it is possible to reduce power consumption, 50% savings can be achieved in some cases.

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