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Power Management of Base Transceiver Stations for Mobile Networks

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Abstract

A Base Transceiver Station (BTS) is a piece of equipment consisting of telecommunication devices and the air interface of the mobile network. It is referred to as the BS in 3G networks, the eNB in the LTE standard, and the GNodeB for the 5G. Any wireless service provider operates a country-wide System of BTS. The System is the part of the wireless network responsible for the reception and transmission of radio signals from user equipments (UE), like mobile phones and computers with wireless internet wireless connectivity. All BTSs need to be electrically powered and system management may investigate methods to reduce power consumption. However, saving power may turn into a waste of performance (increased *response time*), in other words, into a waste of the BTS quality of service (QoS) This paper aim is to discuss the power management of BTS stations for the best compromise between energy-saving and response to incoming calls. The BTS management strategies that optimize the BTS power consumption (minimum *absorbed Watt*), the BTS performance (minimum *response_time* to incoming calls), and the BTS performance *x* Watt (minimum *response_time* x *Watt*) are identified. To compensate for the difficulties of using analytical approaches the paper uses simulation to evaluate the strategies.

Keywords: base transceiver station (BTS); network management; power management; quality of service (QoS)

1. Introduction

A base transceiver station (BTS) is a piece of equipment consisting of telecommunication devices and the air interface of the wireless network. It is referred to as the BS in 3G networks, the eNB in the LTE standard, and the GNodeB for the 5G. Any wireless service provider operates a country-wide System of BTS. Such a system is the main source of energy consumption with a share in total network consumption greater than 50% (Deruyck et al., 2010), with each BTS absorbing order 10 kW (Lorincz, Garma, & Petrov, 2012). Therefore, system management is expected to investigate methods to reduce the BTS absorbed power. To do that, one may decide to adopt policies to periodically switch off the BTS antennas when they are in an idle state. Such policies, however, are to be sufficiently intelligent not to degrade the BTS quality of service. Indeed, returning an off-antenna to its on-state requires spending a non-negligible amount of time (called *setup-time*) that makes the BTS slower to respond to customer requests. This may turn into BTS low QoS, such as low response to incoming calls, unsatisfactory VoIP communications, and limited streaming of data (Note 5). Any research in the power management of BTS should thus look at compromises between energy saving and QoS. This paper's aim is to discuss the power management of BTS stations for the best compromise between energy-saving and response to incoming calls.

The paper related works are basically the works (Gandhia, Harchol-Balter, & Adanb, 2010; Harchol-Balter, 2010) and (Gandhia, Gupta, Harchol-Balter, & Kozuch, 2010), and the works (Iazeolla & Pieroni. 2013, 2014a, 2014b, 2016), and (Pieroni & Iazeolla 2016) that partly overview and synthesize the formers. All these works deal with the power management of server farms and/or data processing systems and give results based on analytical approaches. Since the set of the BTS sectorial antennas can also be seen as a server-farm (where the servers are the BTS antennas), this paper takes the move from all such works, to study the BTS power management. However, the BTS sectorial antennas are aesthetically but not substantially similar to server farms. Indeed, while deriving a server power consumption is quite straightforward, doing the same for an antenna is less immediate, as will be seen in Section 2.1. Moreover, since the analytical approach of the related works suffers from difficulties in mathematically studying various BTS management types in a uniform way (i.e. exact or approximate), by use of simulation this paper may investigate all BTS management types in a uniform way (see Section 3). Even though simulation does not provide exact results, these can be sustained by validations. And indeed this paper validates results by comparison with mathematical models.

The paper is organized as follows: After this Introductory Section, Section 2 introduces the BTS model and defines the BTS management strategy denoted (π, δ), consisting of power management policy π and call-queue servicing discipline δ. Section 2.1 parametrizes the BTS model. Section 3 illustrates the simulation approach. Section 4 discusses the effects of the BTS power management policy π with the δ = FIFO (i.e. serve the first arrived call first) servicing discipline. Section 5 discusses the effects of the δ = SPTF (i.e. serve the shortest-to-process call first) servicing discipline, and identifies the BTS management strategies (π, δ) that optimize: i) the BTS *power consumption P* (minimum absorbed Watts), ii) the BTS *performance T* (minimum response_time to incoming calls) and, iii) the BTS *performance x Watt PT* (minimum response_time *x* Watt).

2. BTS modeling

Let us consider the System of BTS stations illustrated in Figure1 (Iazeolla &Pieroni, 2014; Pieroni & Iazeolla, 2016), consisting of a series of so-called *cells* (only 4 System cells are drawn here). Each cell, denoted by S, is served by a central BTS. Let us assume that the confining cells are not overlapping, in other words, that the User Equipments (UE) residing in a given cell S can perform call establishment within only S.

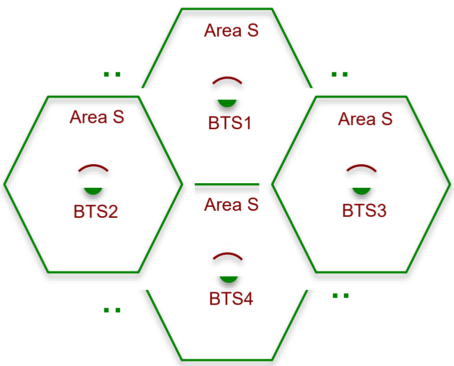

Figure 1. System of Base Transceiver Stations

Also, assume that each BTS serves the 360° degrees of its area *S* by *3* sets of antennas (each set is called a *set of sectorial-antennas*). Each set of *sectorial-antennas* serves 120° degrees of area S, called a *sector*, see Figure 2 (Iazeolla & Pieroni, 2016; Pieroni & Iazeolla, 2016). Let *c* be the number of antennas per-sector

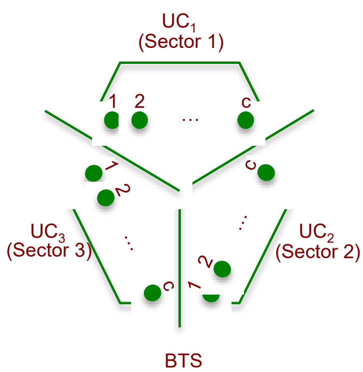

Figure 2. The three 120° degrees of area S served by the BTS

It is assumed that each set of *c* antennas per sector serves a *fixed* number of UEs, that we call User Community (UC). In other words, no mobility of UEs is assumed between sectors. Equivalently, it is assumed that there exists a balance of handovers and handoffs between contiguous sectors. A similar assumption holds between contiguous cells. Each cell of the system serves three sectors i.e. three User Communities (UC_1, UC_2, UC_3 as illustrated in Figure 2) and each UC_i is the *source* of calls for the c_i corresponding *antennas*.

For each sector *i* (i = 1, 2, 3) of a given cell, the pair [UC_i, c_i] defines queueing system, where UC_i is the source of *call packets* (that we briefly denote as calls) and c_i is the number of parallel antennas serving the incoming calls.

For the sake of simplicity, we shall denote by [*UC, c*] the considered queueing system for any sector *i*, as illustrated in Figure 3 (Iazeolla & Pieroni, 2016), where calls waiting to be served are queued in the *call queue* in front of the *c* antennas.

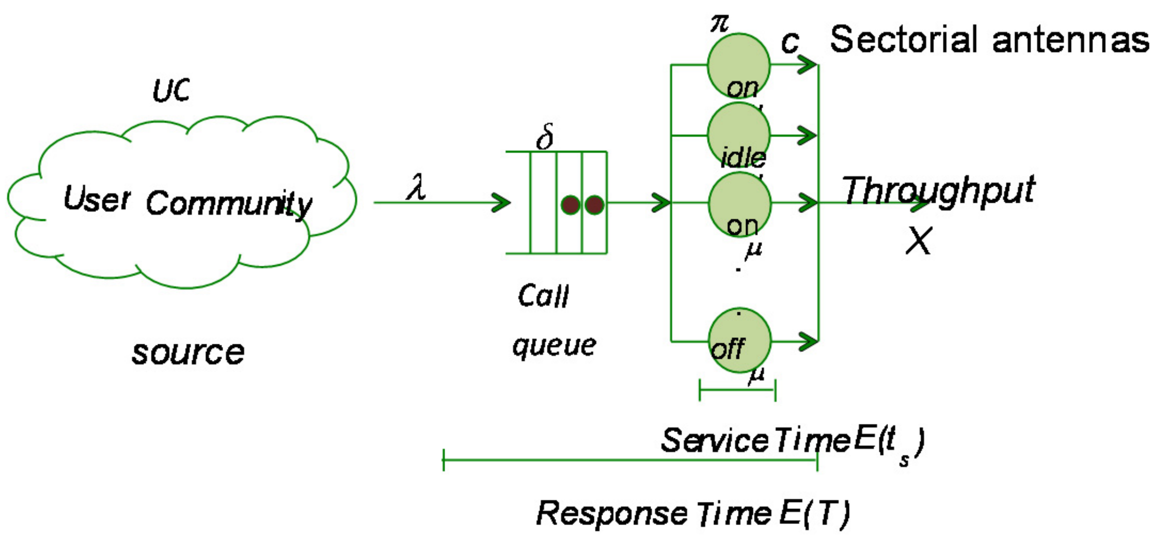

Figure 3. Queueing model of the BTS sectorial-antennas

The queueing model parameters are the arrival-rate λ of calls (number of calls per time-unit) from the source and the antenna-service rate μ. Where $\lambda = 1/E(t_a)$, with $E(t_a)$ the average call inter-arrival time and $\mu = 1/E(t_s)$ with $E(t_s)$ the antenna average call-*service time*, or the time each antenna (sometimes here also called a *server*) takes to serve one call. We shall denote by $f(t_a)$ the density function of the inter-arrival times, with average $E(t_a)$ and with $f(t_s)$ the density function of the service time, with average $E(t_s)$.

The sectorial-antennas *average response time* E(T) is defined as the total time in which the *call* remains in the BTS. In other words, the sum of the average *waiting_time* (spent in the call queue) and the average *service_time* (spent in the antenna), see Figure 3, where the *throughput* X denotes the average number of served calls per sec. The sectorial antennas *power P* is defined as the power absorption of the *c* antennas during the call service.

Based on such definitions, the following *indices* (Note 1) are considered:

1. Sectorial-antennas average *Response Time E(T)* (in sec, to be minimized),
2. Sectorial antennas average *Absorbed Power E(P)* (in Watt, to be minimized)
3. Sectorial antennas *Response time* x *Watt E(PT)* (in sec *x* Watt, to be minimized)

Good performing sectorial-antennas are the ones that ensure low response time *E(T)* to the incoming calls. In other words, low *E(T)* is an index of good QoS. On the other hand, as already said and better seen in the paper, the average response time *E(T)* can be minimized only at the cost of keeping the sectorial antennas always *on*, and thus at the cost of increasing the average power absorption *E(P).* So, saving power may turn into a waste of performance, in other words, into a waste of QoS.

Let us denote by the pair (π, δ) the sectorial antennas *management strategy,* where:

- π is the power management *policy*, or the criterion according to which the antennas are switched between the *on, off,* or *idle* state.
- δ the queue-servicing discipline, or the criterion according to which the antennas peak the waiting calls from the call queue when they become *idle*.

The *power management policy* π problem derives from the fact that antennas generally operate most of the time at between 10 and 50 percent of their maximum utilization levels (Barroso & Holzle, 2007). So, energy-saving requires avoiding powering the antennas when they are not transmitting. In other words, policies to decide in which state (*idle* or *off*) to keep the antennas when not in the *on-state* (or busy).

In order to save power, one would suggest keeping antennas in the *idle* or the *off* state when not busy. However, switching an antenna from the *off* to the *on* state implies a time-overhead (the so-called *setup-time*) with an additional power penalty. Thus, any power-saving policy may result in a time-wasting problem. As a consequence, the BTS may lose performance. This means increased response time to the incoming calls, and low *throughput* X (served calls/sec), since throughput goes in the inverse way of response time (Kleinrock, 1975; Denning & Buzen, 1978).

This paper's aim is to investigate the BTS power management strategies (π, δ) that yield the best compromise between *E(T)* and *E(P)*, namely *minimum E(P), minimum E(T),* and *minimum E(PT)*.

The *c* antennas are managed according to a given *power management policy* π. In particular, three policies are considered:

1. The *On/Idle* policy
2. The *On/Off* policy
3. The *On/Off/stag* policy

according to terminology introduced in (Gandhi, Harchol-Balter, & Adanb, 2010; Harchol-Balter, 2010).

- In the *On/Idle* policy the antennas are never turned off. All antennas are either *on* or *idle*, and remain in the idle mode when there are no calls to serve. Assuming the system consists of *c* antennas if an arrival finds an antenna in the *idle* state it starts service on it. Arrivals that find all *c* antennas in the *on* state (i.e. busy) remain in the *call queue* from which the antennas (when in the *idle* state) will pick calls.
- The *On/Off* policy, instead, consists of immediately turning off the antennas when not in use. However, there is a *setup time* for turning *on* an *off* antenna. Under this policy, an antenna is immediately shut down when not in use.
- The *On/Off/stag* policy operates to maintain to 1 the number of antennas that can be in the *setup mode*, at any point of time. This limits the setup costs, which are incurred when the antennas are turned *on*. With this policy, no other antenna can be fired-on if there is one in the *setup* status.

Two call-queue servicing disciplines δ are considered:

1. The FIFO (First In First Out) discipline, i.e. serve the first arrived call first.
2. The SPTF (Shortest Processing Time First) discipline, i.e. serve the call that requires the shortest processing time first.

We shall further illustrate the effects of such disciplines on the *E(T), E(P*), and *E(PT)* indices.

2.1 BTS Model Parametrization

The Figure 3 model resembles the queueing model known to the queueing theory as the single-source and k parallel servers model (Kleinrock, 1975). It is denoted (M/M/k) when the density function of the inter-arrival times $f(t_a)$ and the density function of the service time $f(t_s)$ are both exponential (denoted by M). In substance, $f(t_a) = \lambda \cdot e^{-\lambda \cdot t_a}$, and $f(t_s) = \mu \cdot e^{-\mu \cdot t_s}$. The model also assumes the queueing *discipline* δ to be time-independent (i.e. FIFO, LIFO, RAND). All such disciplines have the same effect on the average *E(T)* and *E(P)*.

The standard M/M/k model assumes the servers (the sectorial antennas in our case) are either in the *on* or in the *idle* state, and they remain in the *idle* state when there are no jobs (i.e. calls) to serve.

Such a behavior, thus, coincides with the above-defined *On/Idle* policy π. Indeed, under this policy, the antennas are never turned off. They all stay in the *idle* state and turn in the *on-state* when there are calls to serve.

If the $f(t_a)$, and the $f(t_s)$ are exponential and the FIFO discipline δ is assumed, the Figure 3 model can be seen as an M/M/c model and then its *E(T)* (that also gives the one of the *On/Idle* policy) is expressed by the well-known formula from queueing theory (Kleinrock, 1975):

$$E(T)_{On/Idle} = \frac{p(0)c\rho^c}{c! \cdot (1-\rho)^2 \cdot c\mu} + \frac{1}{\mu} \tag{1}$$

where

$$p(0) = [\sum_{k=0}^{c-1} \frac{(c\rho)^k}{k!} + \frac{(c\rho)^c}{c!\,(1-\rho)}]^{-1}$$

is the probability that there are no jobs (calls) in the system, and where $\mu = 1/ E(t_s)$ with $E(t_s)$ being the average service time, or the time a server (antenna) takes to serve a call and ρ is the so-called utilization coefficient, defined by ρ = λ /cμ.

To parametrize the model, one can consider that antenna service time $E(t_s)$ consists of the call processing and call transmit time, and can be defined by writing: $E(t_s)$ = Call processing + Call transmit time = Call processing + Call length / antenna bandwidth. E.g., under assumptions (Note 2) such as: Call processing time = 0.9 sec, Call length = 0.5 Mb and Bandwidth = 5Mb/sec one obtains Call transmit time = 0.5/5 = 0.1 sec. From where $E(t_s)$ = 0.9 + 0.1 = 1sec/call, and μ = 1/Et_s) = 1 call/sec.

By denoting P_{ON} as the power the antenna absorbs in the *on-state* and P_{IDLE} in the *idle-state,* the average power absorption *E(P)* is simply obtained by writing:

$$E(P)_{On/Idle} = c\rho \cdot P_{ON} + (c - c\rho) \cdot P_{IDLE} \tag{2}$$

where $c\rho$ is the expected number of antennas in the *on* state, and $(c - c\rho)$ is the expected number of antennas in the *idle* state.

To obtain P_{ON} and P_{IDLE} we are to look at the antenna operating power. According to (Tombaz S, Vastberg A, and Zander J., 2011) the average power consumption P_A of an antenna, can be modeled as a linear function of average radiated power, given by

$$P_A = a\, P_{TX} + b$$

where:

- P_A is the antenna's total average absorbed power
- P_{TX} is the power fed to the antenna to transmit
- *a* accounts for the part of the power consumption that is proportional to the transmitted power (e.g. radio-frequency amplifier power, including feeder losses), *dependent* on the traffic load.
- *b* denotes the average absorbed power that is consumed, *independent* of average transmit power (e.g. signal processing, site cooling, backhaul transceiver).

One can thus write

$$P_{ON} = P_A = a\, P_{TX} + b \quad \text{and} \qquad P_{IDLE} = b \tag{3}$$

with, according to (Tombaz S, Vastberg A, and Zander J., 2011):

$$P_{TX} = (2^{T/w} - 1)\frac{N_0 w}{\beta G} R_{cell}^{\gamma}$$

where, R_{cell} is cell radius, *w* is the system bandwidth, β and γ are the *path loss* coefficients, N_0 is the power spectral density of additive white Gaussian noise, *G* is the antenna gain and T is the required transmitter power calculated by T=w $\log_2(1+\gamma_0)$ with γ_0 the SNR of the cell edge user (Tombaz, Vastberg, & Zander, 2011). P_{TX} is thus dependent on the system bandwidth *w*. According to (Tombaz, Vastberg, & Zander, 2011), a typical value for *w* = 5MHz is P_{TX} =30 Watt and thus by assuming (Note 3) a=3 and b=150 one obtains

$$P_{ON} = P_A = 3 \times 30 + 150 = 240 \text{ Watt} \tag{4}$$

$$P_{IDLE} = b = 150 \text{ Watt.}$$

3. The simulation approach

Analytical approaches to the evaluation of the (π, δ) = (*On/Idle*, FIFO), (*On/Off*, FIFO) and (*On/Off/stag*, FIFO) strategies have been thoroughly investigated in Section 1 already referenced papers (Gandhi, Harchol-Balter, & Adanb, 2010; Harchol-Balter, 2010) and (Gandhi, Gupta, Harchol-Balter, & Kozuch, 2010), that deal with server farms. Such papers obtain exact results for the (*On/Idle*, FIFO) strategy (for the reason that, as seen above, such a strategy can be turned into a standard queuing model of simple evaluation), while only approximate results for the (*On/Off*, FIFO) and (*On/Off/stag*, FIFO) strategies (for the reason that they turn into complex Markovian processes, of high time-complexity for an increasing number *c* of servers).

For this reason and the intention to treat all cases equally with the same method (i.e. both the *On/Idle* and the *On/Off* or *On/Off/stag*, with both the FIFO and the SPTF) and obtain comparable results independently of their process complexity, this paper uses simulation in alternative to the analytical approach.

By use of simulation, this paper may also thoroughly study (see Section 5) the very positive effects of the SPTF call servicing discipline in sectorial antennas, thus overcoming the difficulty (Gupta, Harchol-Balter, Sigman, &

Witt, 2007) of analytically studying the SPTF job servicing disciplines in server farms.

The used simulation method was DES, or Discrete Event Simulation (Dannenberg, 2020), which modeled the operation of the BTS as a discrete sequence of events in time. The basic events were the *call arrivals* at the call queue, and the *end-of call-services* by the sectorial antennas.

The system random variables that needed to be characterized were the *call-interarrival-time* and the *antenna-service-time*. For this purpose, the *distribution-driven* DES was chosen (in place of the e.g. trace-driven, and program-driven), since of better flexibility. This was accomplished by introducing a set of pseudorandom number generators (Khan, 2016) to simulate the call interarrival times and the antenna service times.

With these principles, first a distribution-based DES simulation model was created. From this, a set of simulation programs was developed by use of the Java programming language. This gave place to a *deep simulation system* developed in two steps (Scorzini, 2012) and (Iazeolla, Pieroni, & Scorzini, 2013).This system, however, was conceived to study server farms.

It was then completed, again in Java, for the scopes of this paper, to introduce the BTS model parameterization of Section 2.1. This simulation system was then used to obtain the results presented in the following Sections in graphical form. The Java programs produced results in tabular form. These were then translated into the paper graphics by use of Microsoft Excel.

The simulation was carried out by observing the calls residence times T (seen in Figure 3) and the power absorption P of the *c* antennas in the course of the call services and then averaging the T and P overall observed calls, to obtain *E(T)* and *E(P)* at a 90% confidence level.

The Simulation proceeded by first removing the initial bias (which required about 1000 observed calls) and then calculating the E(T) and E(P) *confidence intervals* by the use of the *classic estimator* (Iglehart, 1976; Kleijnen, 1975).

To validate the *E(T)* and *E(P)* simulation results, these were compared to analytical results coming from formulas (1) and (2) for the $E(T)_{On/idle}$ and $E(P)_{On/idle}$, and from similar formulas in (Gandhi, Harchol-Balter, Adanb, 2010) and (Harchol-Balter, 2010) for $E(T)_{On/off}$ and $E(P)_{On/Off}$, as well as for $E(T)_{On/off/stag}$ and $E(P)_{On/Off/stag}$.

The validation was done by checking that the analytical values of *E(T)* and *E(P)* fell within the 90% confidence interval of the simulated *E(T)* and *E(P).*

Obviously, to make validation possible, the developed Java simulation code received in input the identical input values used in formulas (1), (2), and (4), and in papers (Gandhi, Harchol-Balter, & Adanb, 2010) and (Harchol-Balter M., 2010). In other words (also see Note 2 and 3), the Java code received in input: *c=30* antennas; service rate $\mu = 1/Et_s)$ = 1 *call/sec*; exponentially distributed service times and inter-arrival times; arrival rate $\lambda = 1$ through *30 call/sec*; P_{ON} = 240Watt; P_{IDLE} = 150Watt; P_{OFF} = 0 Watt; P_{setup}= 240 Watt, and *Setup time* T_{setup} = 1sec (small setup) or 10 sec (high setup).

The simulation studies of Section 4 below deal with the effects of the power management disciplines π with the δ = FIFO call servicing order. The effects of the power management disciplines π with instead the δ = SPTF are studied in Section 5, where it is proven that SPTF plays an important role in the best compromise between energy-saving and response to incoming calls.

4. Effects of the BTS power management policies π with FIFO

This Section reports the simulation results on the effects of the (*On/Off*, FIFO), (*On/Idle, FIFO),* and (*On/Off/stag, FIFO)* strategies on the BTS response time E(T) and the power consumption E(P). In particular, Sections 4.1 and 4.2 give the graphics of the effects in the case of *small setup* and *high setup* times, respectively (the curves reflect the central values of the estimated 90% confidence interval). Section 4.3 then summarizes the effects in the two cases.

4.1 Power management policies π with FIFO and small setup time

Figures 4a and 4b report the simulation results for *E(T)* and *E(P)* respectively in the *small setup* time case.

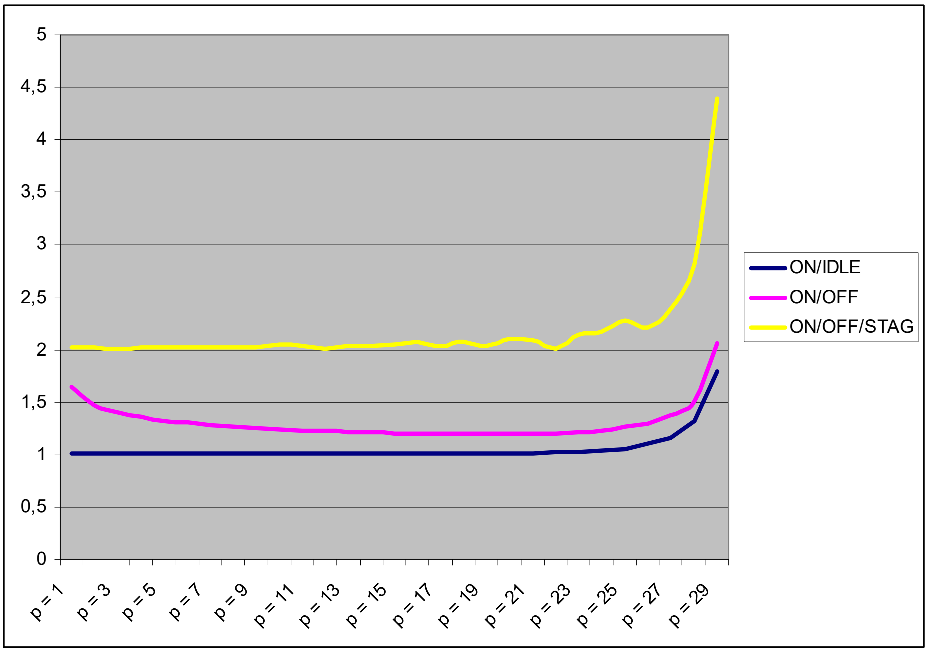

Figure 4a. E(T) (sec) simulation results versus **p** = cρ (the expected number of antennas in the on-state, or the call arrival rate λ) under the (π,δ) = (FIFO, on/idle), (FIFO, on/off) and (FIFO, on/off/stag) management strategies

Setup time = 1 sec (small setup)

Figure 4a gives the response time *E(T)* for the (π, δ) = (*On/Idle*, FIFO), (*On/Off*, FIFO) and (*On/Off/stag*, FIFO) BTS strategies in the case of *setup* time = 1 sec. The curves abscissa **p** = $c\rho$ is the expected number of antennas in the *on-state*. Note that being $\rho = \lambda/c\mu$, and μ=1 by assumption, λ = $c\rho$ also holds. So, the abscissa of the curves can also be read as λ (the call *arrival rate*).

The Figure shows that with the (*On/Idle,* FIFO) strategy, the response time *E(T)* remains substantially lower than with the other two policies since the incoming calls do not suffer from *setup time* delays. In detail, *E(T)* remains practically equal to 1 (i.e. the antenna service time $E(t_s)$) if the number **p** = $c\rho$ of antennas in the *on-state* remains less or equal to around 20 (this is indeed the case of practically no-queueing and no-waiting time for the arriving calls). For larger values of $c\rho$, instead, a rapid increase of *E(T)* takes place and tends asymptotically to infinity for $c\rho$ tending to 30, i.e. for ρ tending to 1, as analytically predicted from formula (1). In the (*On/Off*, FIFO) case, the *E(T)* shows the so-called *bathtub* behavior, i.e. higher values of *E(T)* for small ρ and high ρ. In fact, for small ρ the setup time has a greater influence, since with a lower rate of arrivals the probability that an antenna is turned off (and therefore has to be switched on) is greater, while for high ρ the asymptotic effect predominates as with *On/Idle* policy. Finally, in the (*On/Off /stag*, FIFO) case, the almost constant trend for relatively small ρ (**p** = $c\rho$ < 20) is nothing more than the sum (equal to 2) of $E(t_s)$ =1 and T_{setup}= 1, since with the *On/Off/stag* policy no other antenna can be fired-on if there is one in the *setup* status. Consequently, almost all calls experiment both an $E(t_s)$ and a T_{setup}.

Again, for the *small setup* time Figure 4b gives the absorbed power *E(P)*.

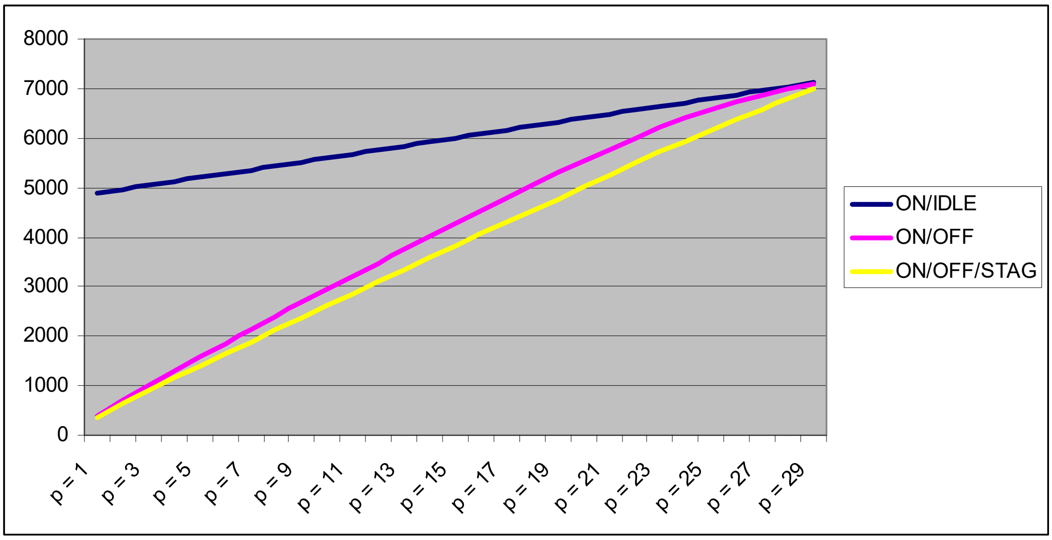

Figure 4b. E(P) (Watt) simulation results versus **p** = cρ (the expected number of antennas in the on-state, or the call arrival rate λ) under the (π,δ) = (FIFO, On/Idle),(FIFO, On/Off) and (FIFO, On/Off/stag) management strategies

Setup time = 1 sec (small setup)

The Figure shows that with the (*On/Idle,* FIFO*)* strategy the absorbed power *E(P)* remains substantially higher than with the other two (i.e. a larger amount of power is wasted) since of the power absorbed by the *idle* antennas. The Figure also shows that with such a policy there is a quite linear increase of *E(P)* with the expected number **p** = $c\rho$ of antennas in the *on-state*. The curve full-left and full-right values are quite in accordance with the formula (3) analytic prediction that, for cρ tending to 0, gives $E(P)_{on/idle} = c \times E(P_{IDLE}) = 30 \times 150 = 4500$ Watt, and for c tending to 30, gives $E(P)_{on/idle} = c \times E(P_{ON}) = 30 \times 240 = 7200$ Watt.

4.2 Power Management Policies π with FIFO and High Setup Time

Figures 5a, 5a*, and 5b give the simulation results for *E(T)* and *E(P*) respectively in the *high setup* time case.

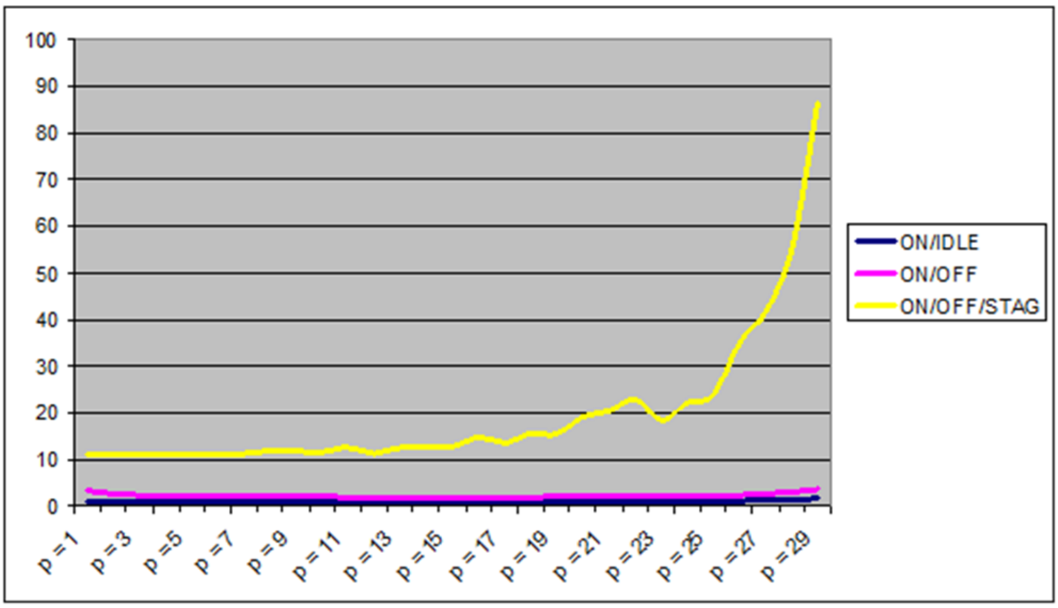

Figure 5a. E(T) (sec) simulation results versus **p** = cρ (the expected number of antennas in the on-state, or the call arrival rate λ) under the (π,δ) = (FIFO, On/Idle), (FIFO, On/Off) and (FIFO, On/Off/stag) management strategies

Setup time = 10 sec (high setup)

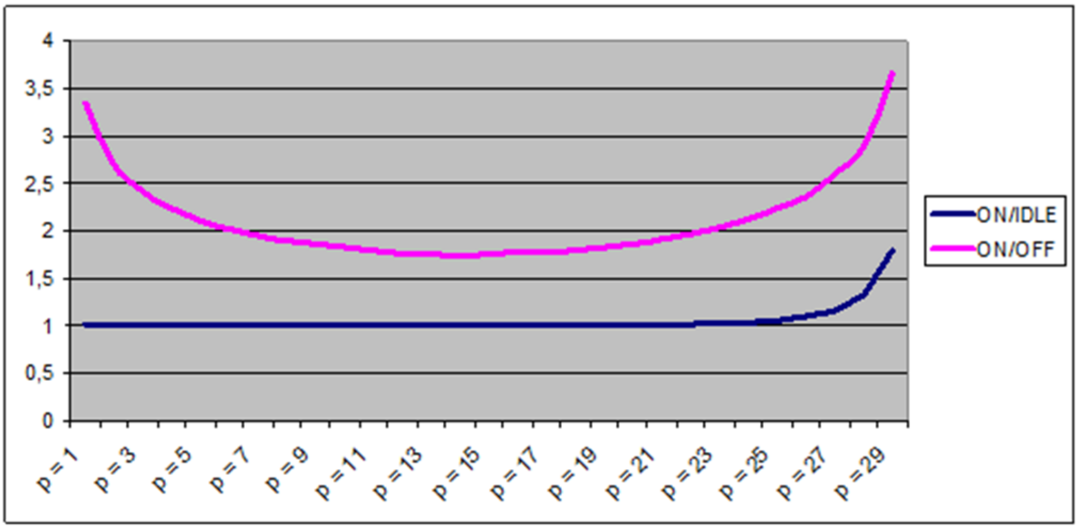

Figure 5a*. Magnification of the E(T) low curves in Figure 5a for the On/Idle and On/Off policies

Figure 5a gives the response time *E(T)* for the (π, δ) = (*On/Idle*, FIFO), (*On/Off*, FIFO) and (*On/Off/stag*, FIFO) BTS strategies in the case of *setup* time = 10 sec.

The Figure shows, for the *On/Off/stag* policy, the expected increase of *E(T)* from the base value of 1+1 of the *low setup* (Figure 4a) to the base value of around 1+10, because of the *high setup*. The presence of a base value has the same justification as in Figure 4a.

Figure 5a* shows the *bathtub* behavior of *E(T)* already seen in Figure 4a for the *On/Off* (i.e. higher values of *E(T)* for small ρ and high ρ) and shows that, due to the *high setup*, the *On/Off E(T)* turns to be considerably higher than the *E(T)* with *low setup* (Figure 4a). So the gap between the *On/Off* and the *On/Idle* (not affected by *setup*) grows in the passage from *low setup* to *high setup*. In other words, the distance of the *On/Off* from the *On/Idle* is greater in the case with a high setup and, therefore, much higher is the response time with respect to the *On/Idle*. For the purposes of the low *E(T),* therefore, in the presence of a high setup time, the *On/Idle* policy is much more convenient than the *On/Off*.

Again for the *high setup* time, Figure 5b gives the absorbed power *E(P).*

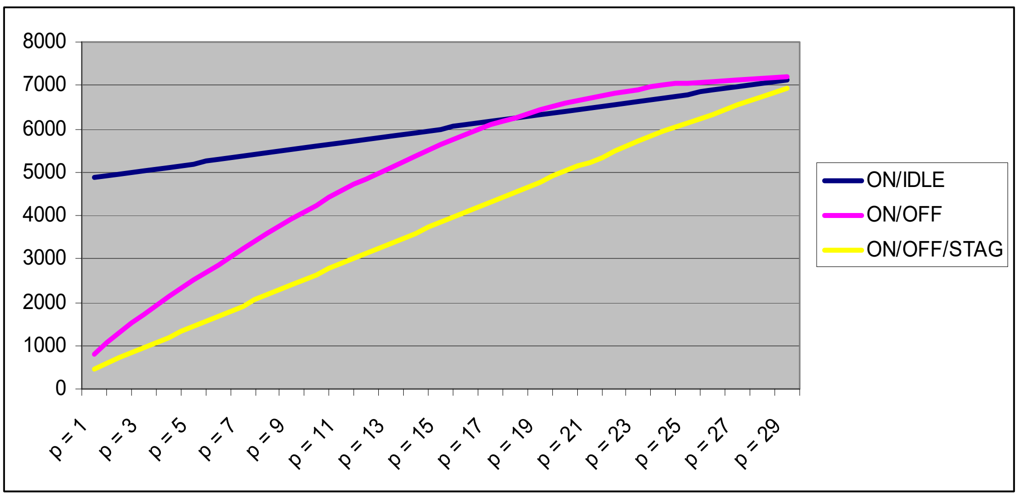

Figure 5b. **E(P)** (Watt) simulation results versus **p** = cρ (the expected number of antennas in the on-state) under the (π,δ) = (FIFO, on/idle), (FIFO, on/off) and (FIFO, on/off/stag) management strategies

Setup time = 10 sec (high setup)

In comparison with Figure 4b, the Figure shows that since of the *high setup* time, the (FIFO, *On/Off*) strategy considerably increases the consumed power *E(P)* with respect to the (FIFO, *On/Idle*). Indeed, a *high setup* involves a larger waste of energy.

4.3 Summary of the Effects of the BTS Power Management Policies π with FIFO

In conclusion, the results of the BTS power management π with FIFO can be synthesized as follows:

1) Effects on the absorbed power *E(P)*

The (*On/Idle,* FIFO) strategy is the most expensive in terms of energy consumption. Especially with a very low rate of arrivals λ (or, as said, very low *cρ*), the strategy has a very bad energy yield due to the power consumption of the antennas in the *idle state.* While as the rate λ of arrivals increases, there are fewer and fewer antennas in that state. With respect to the (*On/Idle,* FIFO) strategy, the (*On/Off*, FIFO) consumes less power since the *idle* antennas are turned off while being penalized by the presence of the *setup* consumption. The most advantageous strategy for the absorbed power *E(P)* is the *(On/Off/stag,* FIFO) having at most 1 antenna in the *setup-state*. The advantage over the (*On/Off*, FIFO) is larger in the central part of the graph (medium arrival rates λ), while for high arrival rates the three policies are almost equivalent. Increasing the setup time, the (*On/Off,* FIFO*)* strategy considerably reduces the benefits in terms of consumed power. Indeed a long setup involves a waste of energy.

2) Effects on the response time *E(T)*

Compared with the $E(T)_{On/Idle,FIFO}$, the $E(T)_{On/Off,FIFO}$ trend tends to have high values for very small and for very high values of *cρ*. Indeed, for small values, the setup time has a greater impact, since with a lower *cρ*, i.e. lower rate of arrivals *λ*, the probability that an antenna is turned off (and therefore has to be turned on) is greater. On the other hand, for high values of *cρ*, i.e. with a higher rate of arrivals *λ*, the probability increases that a call will remain in the waiting queue waiting to be processed.

All that above is synthesized in Table 1.

Table 1. Effects of the BTS Power management policies π with FIFO

	BTS Response Time	*BTS Power Consumption*
(On/Idle,FIFO)	*Small response times*	*High waste of power*
(On/Off,FIFO)	*Medium response times*	*Medium waste for low setup times, high for increasing setup*
(On/Off/stag,FIFO)	*Large response times*	*Low waste of power*

The Table (Note 6) shows the effects on the BTS response time E(T) and the power consumption E(P) of the *On/Off*, *On/Idle* and *On/Off/stag* policies, with the δ = FIFO call servicing discipline. It shows that any reduction in *power consumption* is paid for by an increase in *response times*.

The next Section evaluates the power management π effects if the δ = SPTF call servicing discipline, rather than FIFO, is used and shows the SPTF large advantages over FIFO on both the E(T) and the E(P).

5. Effects of the BTS Power Management Policies π with SPTF

Table 1 has shown that, with FIFO, any reduction in *power consumption* is paid by an increase in *response times*. So, why not adopt queueing disciplines that minimize the *response times*? The SPTF *job* servicing discipline (Shortest Processing Time First) i.e. serving the shortest-to-process *job* first, is proven in literature (Gupta, Harchol-Balter, Sigman, & Witt, 2007; Conway, Maxwell, & Miller, 1967) to give sensible advantages over FIFO in many contexts. The main advantage of SPTF with respect to FIFO is to minimize the average job waiting time and, correspondently, the job response time.

So, it is appropriate to investigate the advantages the SPTF might bring to the BTS *response time* (T in Figure 3), where the *jobs* are the arriving calls, and to the BTS associated parameters P and PT.

To this purpose, for any given (π, δ) *strategy*, i.e. policy and discipline combination, the following BTS indices will be used to extend the 3 indices introduced in Section 2:

1. **P**(π, δ), the average power *E(P)* absorbed by the *BTS* under the (π, δ) strategy. To be minimized.
2. **T**(π, δ), the *BTS* mean response time *E(T)* under the (π, δ) strategy. To be minimized.
3. **PT**(π, δ) = P(π, δ) · T(π, δ) i.e., the mean *E(PT)* power by the response-time product under the

(π, δ) strategy. To be minimized.

Minimizing the *PT* can be seen as maximizing the *performance x Watt*, with "performance" being defined as the inverse of the mean response time (Gandhi, Gupta, Harchol-Balter, & Kozuch, 2010), i.e. the call-*throughput X* (or BTS served calls/sec) in Figure 3. Indeed, as already said, it is known (Kleinrock, 1975; Denning & Buzen, 1978) that the smaller the mean response time *T*, the higher the throughput *X*.

Section 4 above has shown the effects of the δ = FIFO discipline on E(P) and E(T) for increasing values of **p** = cρ, in other words for increasing values of ρ, the BTS utilization coefficient, from 0 to 1.

Low ρ meaning low BTS load, i.e. very few calls in the waiting queue (Figure 3) and high ρ many calls in the queue. However the δ =SPTF proceeds by extracting the shortest-to-process calls first from the queue. So to be competitive with δ =FIFO it has to find more than just a few calls in the queue. Therefore in this Section, we will not study the effects of the δ = SPTF discipline on E(P) and E(T) for increasing values of ρ (so we'll not present graphics). We will only study two typical BTS loads, (*low ρ* (ρ= 0.5, i.e. c*ρ* = 15) and *high ρ* (ρ→1, specifically ρ = 0.97, i.e. c*ρ* = 29)).

However non to neglect the effects of the *policy* π, we will remain experimenting with the study of the BTS setup time T_{setup} . So, the two typical *setup times* (T_{setup}= *1sec* and T_{setup}= *10sec*) are still considered in Sections 5.1 and 5.2 below, along with the δ = SPTF queueing discipline.

Below we shall *not* consider the *On/Off/stag* policy (Note 4) studied in Section 4 and will limit the study to the *On/Off* and *On/idle* under different queueing disciplines δ. Consequently, only the following four (π, δ) strategies are investigated:

(On/Idle, FIFO) and *(On/Idle, SPTF)*

(On/Off, FIFO) and *(On/Off, SPTF).*

The same BTS parameters as in Section 4 above are used in the simulation, i.e.: *c* = 30 antennas; setup-time T_{setup}= *1sec* (or *10sec*); P_{setup}= 240W; P_{ON} = 240W, P_{IDLE} = 150W, P_{OFF} = 0 W, mean call service time $E(t_s)$ = 1sec.

Simulation results are shown in the following Sections, where they prove that the optimal *PT* (i.e. minimum response time *x* Watt, or maximum throughput *x* Watt) is obtained with the discipline δ = SPTF rather than with the FIFO, whichever is (*On/Off* or *On/Idle*) the policy π!

Results also prove that, in some circumstances, to reduce BTS *response time* E(T) (i.e. increase the BTS *throughput X*) it is better to operate on the queueing discipline *δ* than on the server policy π. And vice versa in some other circumstance!

In particular, in the *low setup* case (see the below discussion on Table 2), it is better to move from δ=FIFO to δ = SPTF*,* rather than from π = *On/Off* policy to π = *On/Idle*. But vice versa in the *high setup* case (see the below discussion on Table 3).

5.1 Power Management Policies π with SPTF and Low Setup Time

Table 2 reports simulation results (Note 6) that compare the BTS indices in the *low setup* case

(T_{setup} = 1sec)

Table 2. BTS indices results for low setup-time (T_{setup}= 1sec)

(π, δ)	*P(π, δ) (Watt)*		*T(π, δ) (sec)*		*PT(π, δ) (sec x Watt)*	
	ρ = 0.5	ρ = 0.97	ρ = 0.5	ρ = 0.97	ρ = 0.5	ρ = 0.97
On/Idle, FIFO	6000	7115	1	1.8	6000	12807
On/Idle,SPTF	6000	7100	1	1.3	6000	9230
On/Off , FIFO	4273	7106	1.2	2	5127	14212
On/Off,SPTF	4273	7106	1.2	1.35	5127	9593

- Seeing at the power consumption *P*, one notes that for *low ρ* there is no effect on *P* coming from the queueing discipline δ, while there is an effect from the policy π. In fact *P(On/Idle,FIFO) = P(On/Idle, SPTF)* = 6000 W, and *P(On/Off, FIFO) = P(On/Off, SPTF)* = 4273.

The drastic reduction (from 6000 W to 4273 W, for low ρ) from *On/Idle* to *On/Off*, takes place since, when ρ is low, the call queue is almost empty and thus a large number of antennas is in the *off* state. For *high ρ* instead, the power consumption *P* remains practically unchanged (*P* = around 7100 W) both with the policy π (i.e. no effect by the low setup time), and with the discipline (the queue is always full and thus the antennas remain always in the o*n* state).

- Seeing at the *response-time T*, one can first note what was said above, i.e. that the positive effect of the SPTF discipline (i.e. lower *T* than with FIFO, specifically 1.3 instead than 1.8 and 1.35 instead than 2) is seen when there are many calls in the queue, i.e. with a high ρ. Moreover, can note that there is an effect on *T* both by the queueing discipline and by the policy. The effects hold both for *low ρ* and for *high ρ*. In the *On/Idle* case, when ρ is low, there is no waiting in the call-queue and thus the mean response time *T* is of about the mean call service time ($E(t_s)$ = 1 sec) while it increases (*T* = 1.8sec for δ = *FIFO* and *T* = 1.3sec for δ = *SPTF*) for high ρ, but in a lower measure for SPTF due to the SPTF property of minimizing the average response time E(T).

  In the *On/Off* case, when *ρ is low*, the mean response time is higher (*T* = 1.2 sec instead than 1) since almost every arrival finds the antennas in the *off* state, and thus every call incurs in the *setup time* (however with no effects by the discipline, since the queue is empty). For *high ρ*, instead, the mean response time increases (from 1.2 to 2 sec for δ = *FIFO* and from 1.2 to 1.35 sec for δ = *SPTF*) due to the large queueing, again in a lower measure for SPTF.

  As predicted above, one can see that the reduction in *response-time* obtained moving from *FIFO* to *SPTF* is larger than when moving from *On/Off* to *On/Idle*. Indeed (see high ρ) moving from (O*n/Off, FIFO*) to (*On/Idle, FIFO*) the response time *T* changes from 2 to 1.8 (a 10% reduction). Moving, instead, from the (*On/Idle, FIFO*) to the (*On/Idle, SPTF*) the response time *T* changes from 1.8 to 1.3 (an almost 30% reduction).
- Seeing at the *PT* index, its values are a consequence of the *P* and the *T* ones. Table 2 shows that in the *low setup* case the optimal *PT* (i.e. minimum response time *x* Watt, or maximum throughput *x* Watt) is obtained, when ρ is low, only with the π = (*On/Off)* policy, whichever is the discipline δ. While, for high ρ, the optimal *PT* is obtained only with δ = SPTF, whichever is the policy π.

5.2 Power Management Policies π with SPTF and High Setup Time

Table 3 reports the simulation results (Note 6) in the *high setup* case (T_{setup} = 10sec).

Table 3. BTS indices results for high setup-time (T_{setup}= 10sec)

π δ	*Π*(π, δ*)* *(Ω)*		*T*(π, δ*)* *(σεχ)*		*ΠΤ*(π, δ*)* *(σεχ ξ Ωαττ)*	
	ρ = 0.5	ρ = 0.97	ρ = 0.5	ρ = 0.97	ρ = 0.5	ρ = 0.97
On/Idle, FIFO	6000	6956	1	1.8	6000	12520
On/Idle, SPTF	6000	6956	1	1.3	6000	9042
On/Off, FIFO	5634	7116	1.7	3.6	9577	25617
On/Off,SPTF	5634	7116	1.7	2.6	9577	18673

- Seeing at the power consumption *P*, one notes that for *low ρ* there is no effect on *P* coming from the queueing discipline δ, while there is an effect from the policy π. In fact *P(On/Idle,FIFO) = P(On/Idle, SPTF)* = 6000 W, and *P(On/Off, FIFO) = P(On/Off, SPTF)* = 5634. The reduction (from 6000W to 5634W, for low ρ) from *On/Idle* to *On/Off*, takes place since, when ρ is low, the call-queue is almost empty and thus a large number of antennas is in the *off* state.

For *high ρ* instead, the power consumption *P* shows no change from the discipline δ (since the queue is always full and thus the antennas remain always in the o*n* state) but some changes from the policy π (from 6956 *on/idle* to 7116 *on/off*) by the effect of the high setup time

- Seeing at the *response-time T*, one first notes what was said above, i.e. that the positive effect of the SPTF discipline (i.e. lower *T* than with FIFO, specifically 1.3 instead than 1.8 and 2.6 instead than 3.6) is seen when there are many calls in the queue, i.e. with a high ρ.

Moreover, one notes that there is an effect on *T* both by the queueing discipline and by the policy. The effects hold both for *low* ρ and for *high* ρ. In the *On/Idle* case, when ρ is low, there is no waiting in the call-queue and thus the mean response time T is of about the mean job service time ($E(t_s)$ = 1 sec) while it increases (*T* = 1.8sec for δ = *FIFO* and *T* = 1.3sec for δ = *SPTF*) for high ρ, again for the property of the SPTF.
In the *On/Off* case, when ρ *is low*, the mean response time is higher (*T* = 1.7 sec instead than 1sec) since almost every arrival finds antennas in the *off* state, and thus every job incurs in the *setup time* (however with no effect by the discipline, since the queue is empty). For *high* ρ, instead, the mean response time increases (from 1.7 to 3.6 sec for δ = *FIFO* and from 1.7 to 2.6 sec for δ = *SPTF*) due to the large queueing.
At the opposite of the low setup case, with the high setup now the reduction in *response-time* one may obtain moving from *FIFO* to *SPTF* is smaller than the one when moving from *On/Off* to *On/Idle*. Indeed (see high ρ) moving from (O*n/Off, FIFO*) to (*On/Idle, FIFO*) the response time *T* changes from 3.6 to 1.8 (a 50% reduction). Moving, instead, from the (*On/Idle, FIFO*) to the (*On/Idle, SPTF*) the response time *T* changes from 1.8 to 1.3 (a 30% reduction).

- Seeing at the *PT index*, its values are a consequence of the *P* and the *T* ones. Opposite to the *low setup* case (Table 2), the *high setup* case of Table 3 shows that the optimal *PT* (i.e. minimum response time *x* Watt, or maximum throughput *x* Watt) is obtained, for low ρ, only with the π = (*On/Idle)* policy, whichever is the discipline δ. While, for high ρ, only with δ = SPTF, whichever is the policy .

5.3 Summary of the effects of the BTS power management policies π *with SPTF*

In summary, the effects of the BTS discipline management δ = SPTF can be synthesized as follows:

- In the *low setup* case, the optimal (i.e. minimal) *PT* is obtained, when ρ is low, only with the π = (*On/Off)* policy, whichever is the discipline δ. While, for high ρ, only with the discipline δ = SPTF, whichever is the policy .
- In the *high setup* case the optimal (i.e. minimal) *PT* is obtained, for low ρ, only with the π = (*On/Idle)* policy, whichever is the discipline δ. While, for high ρ, only with the discipline δ = SPTF, whichever is the policy π.

In substance, both in the low and the high setup case, the SPTF discipline ensures the best *PT* (i.e. minimal response time *x* Watt). In other words the best compromise between energy-saving and QoS (all that may affect the *cost / benefit* ratio of wireless services such as response to incoming calls, VoIP communications and streaming of data (Note 5).

6. Conclusion

Any *wireless service provider* operates a country-wide System of Base Transceiver Stations (BTS). Such a System is the main source of energy consumption with a share in total network consumption greater than 50%. Therefore, system management is expected to investigate methods to reduce the BTS absorbed power. To do that, one may decide to adopt policies to periodically *switch off* the BTS antennas when they are in an *idle state*. Such policies, however, are to be sufficiently intelligent not to degrade the QoS of the BTS.

To this scope, this paper has studied the combined effect of the BTS **policy π** (or criterion according to which the BTS antennas are switched between the *On, Off,* or *Idle* state) and of the BTS queueing **discipline *δ*** (or the criterion according to which the BTS antennas serve calls: FIFO or SPTF, i.e. serve the first arrived call first. or serve the shortest-to-process call first).

Four BTS management strategies (π, δ) are considered, *(On/Idle, FIFO)*, *(On/Idle, SPTF)*, *(On/Off, FIFO)* and *(On/Off, SPTF)* to evaluate three quality indices:

1) *BTS power consumption P* (absorbed Watt),
2) *BTS performance T* (response time),
3) *BTS performance x Watt, PT* (response time *x* Watt).

The paper simulation results prove that:

1) Whichever is the policy (*On/Off*, or *On/Idle*), if the *δ* = *FIFO* discipline is used, any reduction in *power consumption* P is paid by an increase in *response times* T, i.e. is paid by a reduction of QoS (low response to incoming calls, unsatisfactory VoIP communications and limited streaming of data (highly compromised by long delays T).
2) Whichever is the policy (*On/Off*, or *On/Idle*) if the *δ* = *SPTF* discipline is used, one obtains the best compromise between *power consumption* P and QoS. In other words the best PT, or *BTS performance x*

Watt, i.e. minimum *response time* T per consumed power P. That means minimum power consumption to obtain a quick response to incoming calls, satisfactory VoIP communications and good streaming of data.

The distribution-driven DES method (Discrete Event Simulation) has been used to build a simulation model. From this, a set of simulation programs, developed in Java programming language, has given place to a deep simulation system used to obtain the paper results. All simulation results were validated by comparison to mathematical models.

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References

Barroso, L. A., & Hölzle, U. (2007). The case for energy-proportional computing. *Computer*, *40*(12), 33-37. https://doi.org/10.1109/MC.2007.443

Conway, R. W., Maxwell, W. L., & Miller, L. W. (1967). *Theory of scheduling*. Courier Corporation.

Dannenberg, R. (2020). *An Introduction to Discrete-Event Simulation*. Carnegie Mellon School of Computer Science 2020.

Denning, P. J., & Buzen, J. P. (1978). The operational analysis of queueing network models. *ACM Computing Surveys (CSUR)*, *10*(3), 225-261. https://doi.org/10.1145/356733.356735

Deruyck, M., Vereecken, W., Tanghe, E., Joseph, W., Pickavet, M., Martens, L., & Demeester, P. (2010, April). Power consumption in wireless access network. In *2010 European Wireless Conference (EW)* (pp. 924-931). IEEE. https://doi.org /10.1109/EW.2010.5483506.

Gandhi, A., Gupta, V., Harchol-Balter, M., & Kozuch, M. A. (2010). Optimality analysis of energy-performance trade-off for server farm management. *Performance Evaluation*, *67*(11), 1155-1171. https://doi.org/10.1016/j.peva.2010.08.009.

Gandhi, A., Harchol-Balter, M., & Adan, I. (2010). Server farms with setup costs. *Performance Evaluation*, *67*(11), 1123-1138. https://doi.org /10.1016/j.peva.2010.07.004.

Gupta, V., Balter, M. H., Sigman, K., & Whitt, W. (2007). Analysis of join-the-shortest-queue routing for web server farms. *Performance Evaluation*, *64*(9-12), 1062-1081.

Harchol-Balter, M. (2010). *Open Problems in Power Management of Data Centers*. IFIP WG7.3 Workshop, University of Namur, Belgium Nov. 20, 2010.

Harcol-Balter M. (2013). *Performance Modeling and Design of Computer Systems*. Cambridge University Press, 2013.

Iazeolla, G., & Pieroni, A. (2013, August). Power control and optimization in ICT. In *Proceedings of the Power Control and Optimization Conference (PCO'13)*.

Iazeolla, G., & Pieroni, A. (2014a). Power management of server farms. In *Applied Mechanics and Materials* (Vol. 492, pp. 453-459). Trans Tech Publications Ltd. https://doi.org/10.4028/www.scientific.net/AMM.492.453

Iazeolla, G., & Pieroni, A. (2014b). Energy saving in data processing and communication systems. *The Scientific World Journal*, *2014*. https://doi.org/10.1155/2014/452863

Iazeolla, G., & Pieroni, A. (2016). *Energy Efficiency in wide band Wireless Systems* (Unpublished Technical Report). Dept. of Innovation and Information Engineering, Guglielmo Marconi University, Rome, Italy, May 2016

Iazeolla, G., Pieroni, A., & Scorzini, G. (2013). *Simulation study of server farms power optimization* (Unpublished Technical Report RI.01.13). Software Engineering Lab., University of Roma TorVergata, Jan. 2013.

Iglehart, D. L. (1976). Simulating stable stochastic systems. Quantile estimation. *Journal of the ACM, 23*(2), 347-360.

Khan. (2016). *Pseudorandom number generators*. Khan Academy, Mountain View, Ca.

Kleijnen, J. P. C. (1975). *Statistical techniques in simulation*. New York, Marcel Dekker.

Kleinrock, L. (1975). *Queueing Systems* (Voll.1,2). Wiley.

Lorincz, J., Garma, T., & Petrovic, G. (2012). Measurements and modelling of base station power consumption under real traffic loads. *Sensors*, *12*(4), 4281-4310. https://doi.org/10.3390/s120404281

Pieroni, A., & Iazeolla, G. (2016). Engineering QoS and energy saving in the delivery of ICT Services. In P.Vasant and N Voropai (Eds), *Sustaining Power resources through energy optimization and engineering*, Ch.9, IGI Global 2016. https://doi.org/10.4018/978-1-4666-9755-3.ch009.

Scorzini, G. (2012). *Simulation study of server farms* (Unpublished master's thesis). Guglielmo Marconi University, Roma, Italy, 2012.

Tombaz, S., Vastberg, A., & Zander, J. (2011). Energy and cost-efficient ultra-high-capacity wireless access. *IEEE Wireless Communications*, 18(5), 18-24. https://doi.org /10.1109/MWC.2011.6056688

Vaser, M., & Forconi, S. (2015). QoS KPI and QoE KQI relationship for LTE Video streaming and VoLTE services. *the 9th International Conference on Next Generation Mobile Applications, Services and Technologies,* Cambridge, UK, Sept. 2015.

Notes

Note 1: Such indices are *sectorial antennas* indices. In the text, however we shortly write *BTS indices*, considering that the BTS consists of 3 sets of sectorial antennas, and the indices derived for one set are assumed to be maintained for the remaining two sets.

Note 2: Such assumptions are here made to allow the validation of the simulation results through comparisons with available analytical results (see Section 3). Different choices would however not compromise the derivations of this paper.

Note 3: In an analogous way, such assumptions are here made to allow the validation of the simulation results through comparisons with available analytical results (see Section3). Different choices would however not compromise the derivations of this paper.

Note 4: Indeed, authors (Gandhi, Gupta., Harchol-Balter, & Kozuch, 2010) have proved that to obtain the optimal, or nearly optimal *PT* (π, δ) there is *no need* to consider other policies than the *On/Off,* the O*n/Idle* and the *On/Off/sleep* policy (the latter being practically equivalent to the *On/Off/stag*). Moreover, they prove that the *On/Off* and *On/Off/sleep* show practically similar behaviors.

Note 5: Indeed the QoS of VoIP communications and Data streaming is highly compromised by long delays T (Vaser & Forconi, 2015).

Note 6: Tables 1, 2 and 3 refer to and report simulation results obtained for our sectorial antennas of BTS stations. Such Tables are graphically similar to ones appearing in (Iazeolla & Pieroni, 2013) and (Iazeolla & Pieroni, 2014) that, however, refer to and report values obtained for server farms.

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