A statistical model for optimizing power consumption of printers.

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Introduction

The goal of this study is to determine a policy based on the analysis of user behavior in order to reduce power consumption of printers and to adapt it to real usage patterns. To this end, we introduce a criterion defined by a compromise between power consumption and user impact. The optimal timeout is inferred by minimizing this criterion.
The printer may be in different modes with different levels of power consumption :

- printing mode: in this mode a device activates its marking engine, print path and controller and completes print requests.
- idle mode: the device is active and ready to print immediately and therefore a certain power consumption level a is required to maintain the device in a readiness status.
- sleep mode: it is the lowest level of consumption b. The device is not ready to print immediately. Indeed, a delay and a power consumption are necessary before printing.

The total energy consumption for a printer is the sum of the power consumption needed to complete print jobs, the power consumption in *idle* and *sleep* modes and the consumption due to the transition between modes (shutdown cost c and wakeup cost d).

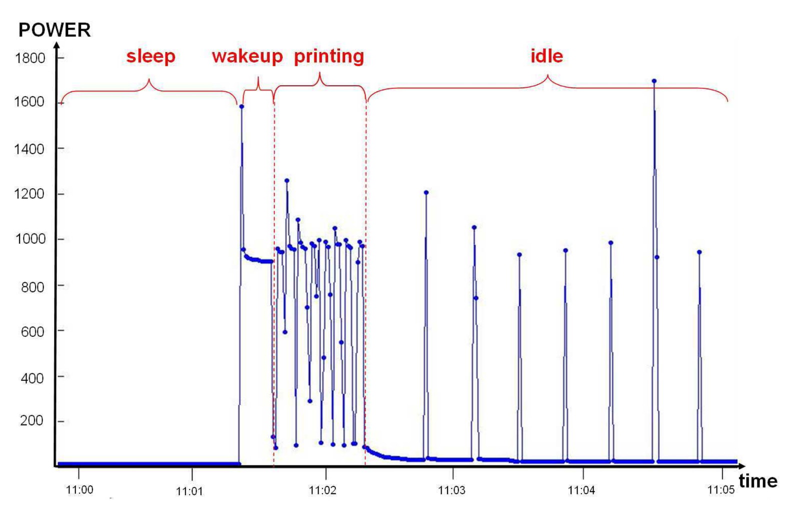

Fig 1: Real Consumption

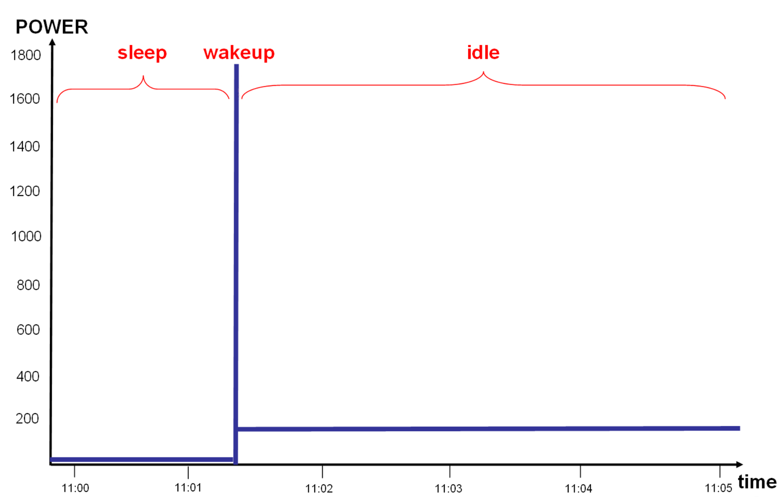

Fig 2: Consumption model

Probabilistic model

Print process model

It can be defined equivalently by :

- $\{T_i\}_{i\geq 1}$, a sequence of print events, with the convention $T_0 = 0$.
- $\{X_i\}_{i\geq 1}$, a sequence of print events where $\forall i \geq 1, X_i = T_i - T_{i-1}$ is the time between the $(i-1)^{th}$ and the i^{th} print job.

Cost between two successive print jobs

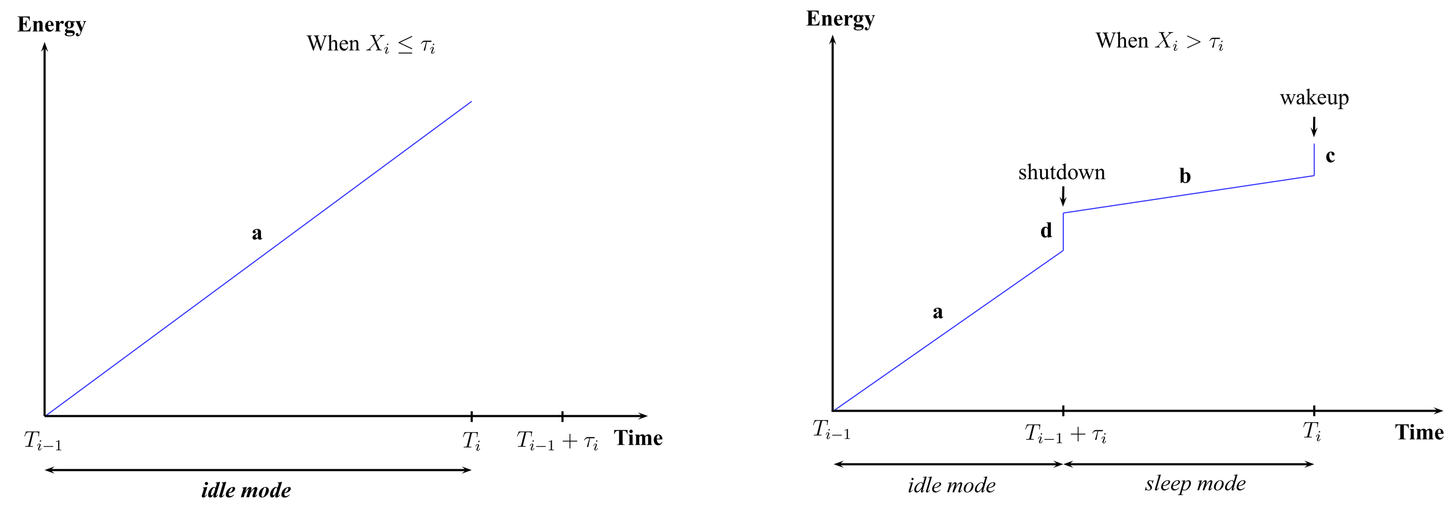

Fig 3: Consumption between T_{i-1} and T_i according to the position of T_{i-1}, T_i and $T_{i-1}+\tau_i$

By taking into account the user impact, the cost h between two successive print jobs is given by :

$$h(X_i,\tau_i) = (as + c + b(X_i - \tau_i) + d)\mathbb{1}_{\{X_i>\tau_i\}} + (aX_i)\mathbb{1}_{\{X_i\leq\tau_i\}} + \delta\mathbb{1}_{\{X_i>\tau_i\}}$$

where
- τ_i is the timeout after the i^{th} print job.
- δ is the weight applied to the user impact.

Optimal timeout period

The optimal timeout period is defined by :

$$\hat{\tau}_i = \arg\min_{\tau_i} \mathbb{E}(h(X_i,\tau_i)|X_1,\dots,X_{i-1})$$

if $z_{X_i|X_1,\dots,X_{i-1}}$ is strictly decreasing: - $\hat{\tau}_i$ is given by $z_{X_i|X_1,\dots,X_{i-1}}(\hat{\tau}_i) = \dfrac{1}{\Delta t}$

if $z_{X_i|X_1,\dots,X_{i-1}}$ is strictly increasing or constant: - $\hat{\tau}_i = 0$ if $\Delta t < \mathbb{E}(X_i)$
- $\hat{\tau}_i = +\infty$ if $\Delta t \geq \mathbb{E}(X_i)$

where
- $z_{X_i|X_1,\dots,X_{i-1}}$ is the printing rate function (the failure rate in reliability theory).
- $\Delta t = \dfrac{c+d+\delta}{a-b}$ is the duration achieving a balance between the consumption in idle mode and in sleep mode including shutdown and wake up and user impact costs.

Static timeout period

Inter-print intervals are supposed to be independent.
Two differents models have been studied :

- $X \sim Weibull(\alpha,\lambda)$
- $X \sim Gamma(\alpha,\beta)$

In both cases, the optimal *timeout* period depends on α.

if $\alpha < 1$: - $\hat{\tau}$ is given by $z(\hat{\tau}) = \dfrac{1}{\Delta t}$

if $\alpha \geq 1$: - $\hat{\tau} = 0$ if $\Delta t < \mathbb{E}(X)$
- $\hat{\tau} = +\infty$ if $\Delta t \geq \mathbb{E}(X)$

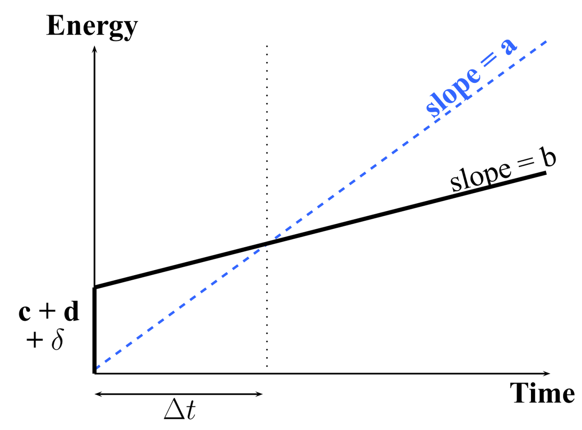

Fig 4: Illustration of Δt.

Adaptive timeout periods using Hidden Markov Models:

During the day, the printing rate is not constant. There are periods where people print more or less often. These periods can be interpreted in term of activity corresponding to various levels S_i of inter-print intervals :

- rush hours (short inter-print intervals).
- normal hours (mean inter-print intervals).
- off-peak times (long inter-print intervals).
- etc.

Thus, the inter-print interval distribution is heterogeneous but that there are some homogeneous periods where $(X_1,\dots,X_n)$ are following the same probability density function (Weibull in the sequel). Consequently, this behaviour can be modelled by Hidden Markov Models.

We propose three approaches to dynamically re-estimate τ_i.

a) Viterbi-based approach: It consists in finding the most probable state value $\hat{S}_{i+1}$ for S_{i+1}.

$$\hat{S}_{i+1} = \arg\max_k \max_{s_1,\dots,s_i} \mathbb{P}(S_1 = s_1,\dots,S_{i+1} = k|X_1,\dots,X_i)$$

b) Filtering-based approach: This is another method to find the most probable state value $\tilde{S}_{i+1}$ for S_{i+1}.

$$\tilde{S}_{i+1} = \arg\max_k \mathbb{P}(S_{i+1} = k|X_1,\dots,X_i)$$

c) Approach based on full conditional distribution: It consists in computing the printing rate function of X_{i+1} given $X_1,\dots,X_i$. Letting $\beta_i(k) = \mathbb{P}(S_{i+1} = k|X_1,\dots,X_i)$,

$$f_{X_{i+1}|X_1,\dots,X_i}(x) = \sum_{k=1}^{K} f_{\theta_k}(x)\beta_i(k) \text{ and } F_{X_{i+1}|X_1,\dots,X_i}(x) = \sum_{k=1}^{K} F_{\theta_k}(x)\beta_i(k)$$

Application to a real dataset

We tested our methodology on *Xerox WorkCentre 238* model.
The previous methods were compared with the existing policy of putting the printer into sleep mode after an inactivity, fixed to respect the Energy Star standard (30 minutes).
Dataset : 2320 jobs (half for learning parameters and the other half to test)

Power consumption :

- **Idle mode** (a): 80 J/s
- **Sleep mode** (b): 16 J/s
- **shutdown** (c): 0 J
- **wakeup** (d): 25373 J

	total Consumption (kWh)	Number of standby/low-power
Current method	96.60	356
Static method (Gamma)	78.16	1057
Static method (Weibull)	78.26	1096
Viterbi method	78.39	1160
Filtering method	78.39	1160
Conditional method	78.01	1025

Table 1: Total consumption between 1/06/06 and 31/12/06 with $\delta = 0$ (no penalty)

Without taking into account user impact, the consumption accumulated when using our methods is less important than consumption using the current strategy. The gains of energy are about 20 %. Also, we can note that the number of *shutdown/wakeup* is more important.

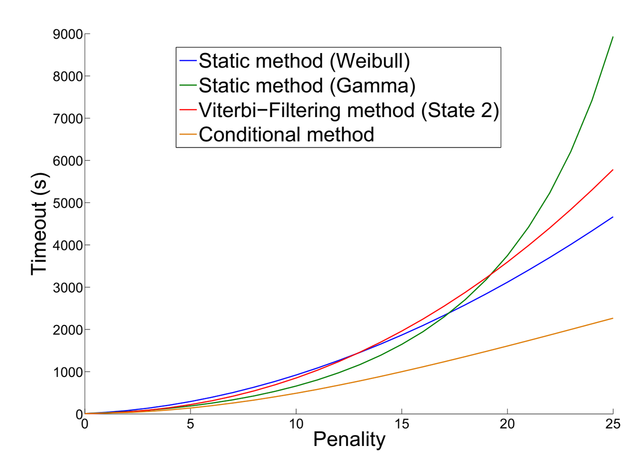

Fig 5: Evolution of Timeout as the penalty increases

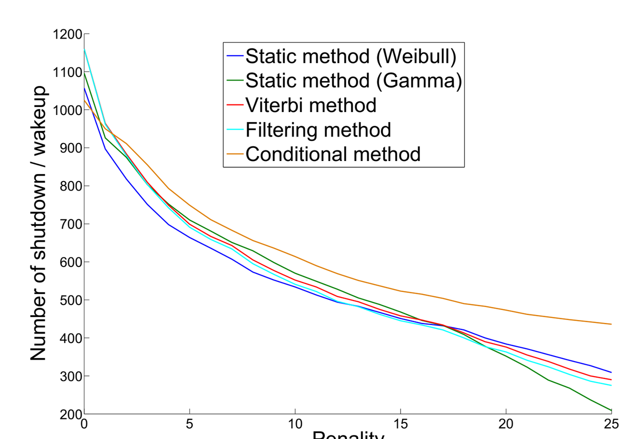

Fig 6: Evolution of the number of *shutdown/wakeup* transitions as the penalty increases

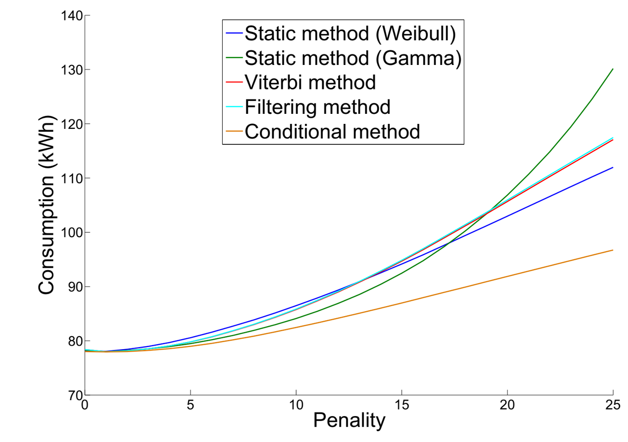

Fig 7: Evolution of consumption as the penalty increases

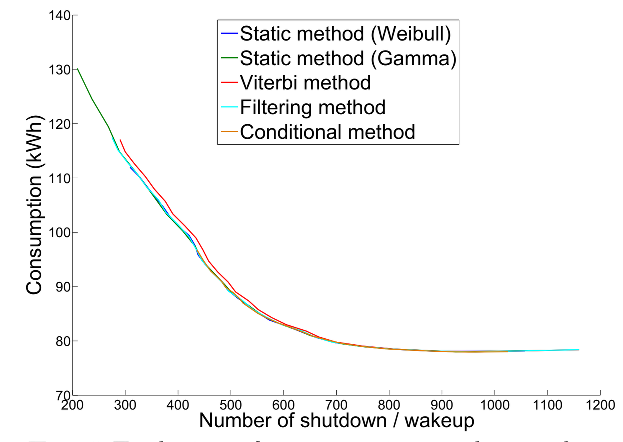

Fig 8: Evolution of consumption as the number of shutdown/wakeup increases