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: the device is always online and ready to print.
- idle mode: the device is active and ready to print immediately and therefore a certain power consumption level is required to maintain the device in a readiness status.
- sleep mode: it is the lowest level of consumption. 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 $d$).

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 $i \geq 1$, $X_i = T_i - T_{i-1}$, is the time between the $(i-1)^{st}$ and the $i^{th}$ print job.

Cost between two successive print jobs

Cost $J$ is given by:

$$J(X_i) = \max(z + c + b(X_i - \tau)) + (X_i)\mathbb{1}_{(X_i < \tau)} + \hat{J}(X_{i+1})$$

where $\tau$ is the timeout after the $i^{th}$ print job.

$\sigma$ is the weight applied to the user impact.

OPTIMAL TIMEOUT PERIOD

The optimal timeout period is defined by:

$$\tau = \arg \min_{\tau} \mathbb{E}(X_i,H_{X_i}^\tau|X_1, \ldots, X_{i-1})$$

if $X_i|X_{i-1} \leq \tau$ is strictly decreasing:

$$\tau_i = \frac{1}{\mathbb{E}(X_i)}$$

if $X_i|X_{i-1} \leq \tau$ is strictly increasing or constant:

$$\tau_i = \infty$$

where $X_i|X_{i-1}$ is the printing rate function (the failure rate in reliability theory).

$\tau_i = \frac{1}{\mathbb{E}(X_i)}$ is the duration achieving a balance between the consumption in idle mode and in sleep mode including shutdowns and wake-ups and user impact costs.

Static timeout period

In off-peak intervals are supposed to be independent:

- $X_i \sim \text{Weibull}(\rho, \lambda)$
- $\lambda = \text{Gaussian}(0, 1)$

In both cases, the optimal timeout period depends on $\rho$, $\sigma$.

- if $\sigma < 1$: $\tau = \frac{1}{\mathbb{E}(X_i)}$
- if $\sigma \geq 1$: $\tau = \infty$ if $\mathbb{E}(X_i) < \sigma$

- if $\sigma \approx \mathbb{E}(X_i)$:

$\tau = \frac{1}{\mathbb{E}(X_i)}$ if $\mathbb{E}(X_i) < \sigma$

$\tau = \infty$ if $\mathbb{E}(X_i) \geq \sigma$

ADAPTIVE TIMING PERIODS USING HIDDEN MARKOV MODELS

During the day, the printing rate is not constant. There are periods where print volumes are low or high. These periods can be interpreted in terms of activity corresponding to various levels of inter-print intervals:

- peak hours (short inter-print intervals),
- off-peak times (long inter-print intervals),
- normal hours (mean inter-print intervals),
- idle times.

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

We propose three approaches to dynamically estimate $\tau$:

a) Viterbi-based approach: It consists in finding the most probable state $S_{t+1}$ for $S_t$.

$$\tilde{S}_{t+1} = \arg \max_{s_{t+1}} \mathbb{P}(S_t = s_t, S_{t+1} = s_{t+1} \mid X_{t+1})$$

b) Filtering-based approach: It consists in computing the most probable state $\tilde{S}_{t+1}$ for $S_{t+1}$.

$$\tilde{S}_{t+1} = \arg \max_{s_{t+1}} \mathbb{P}(S_t = s_t, S_{t+1} = s_{t+1} \mid X_{t+1})$$

c) Approach based on full conditional distribution: It consists in computing the printing rate function of $X_{t+1}$ given $X_1, \ldots, X_t$. Letting $X_{t+1} = X_{t+1,k}$, then

$$f_{X_{t+1} \mid X_{t+1,k}}(x_{t+1}) = \sum_{i=1}^{k} f_{X_{t+1} \mid X_{t+1,k}}(x_{t+1} \mid X_{t+1,k})$$

APPLICATION TO A REAL DATASET

We tested our methodology on Xerox WorkCentre 2328 model.

The previous methods were compared with the existing policy of putting the printer in sleep mode after an inactivity, fixed to respect the Energy Star standard (30 minutes).

Dataset: 2328 jobs (half for learning parameters and the other half to test).

Power consumption:

- Idle mode ($\sigma$): 30 J/s
- Sleep mode ($\sigma$): 15 W
- Shutdown ($\sigma$): 0 J
- Wakeup ($\sigma$): 25373 J

<table>
<thead>
<tr>
<th>Power consumption (kJ)</th>
<th>Number of shutdowns/wakeup periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current method</td>
<td>5.30</td>
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<tr>
<td>Static method (Gamma)</td>
<td>78.16</td>
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<tr>
<td>Static method (weibull)</td>
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<td>Viterbi method</td>
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<tr>
<td>Filtering method</td>
<td>78.29</td>
</tr>
</tbody>
</table>

Table 1: Total consumption between 13/03/06 and 13/12/06 with 0 ≤ $\sigma$ (penalty).

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