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Stochastic modeling of energy constrained wireless systems, recent contributions

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L. Donatiello, G. Marfia, Modelling the Energy Consumption of Upload Patterns on Smartphones and IoT Devices, August 2018, IEEE Communications Letters

Outline

- Motivation
- Model
- Solution
- Evaluation
- Final Remarks

MOTIVATION

Motivation

- We model one of the most utilized categories of apps, those that are used to collect and upload data to the cloud (e.g., Dropbox)

- We are interested to analyze the energy consumption which is driven by their use of network interfaces (i.e., the amount of data they transmit), driven by the data transfer patterns that they implement

MODEL

Assumptions

- We conform to the finding that a linear proportionality exists between the amount of data that is transferred to the cloud and the amount of energy consumed during such operation
- Data production/upload patterns are accounted for considering: (a) the average amount of data produced/stored, per unit time, by each app within an arbitrary number of apps, and, (b) the stochastic nature of when, during a given time interval, uploads occur

Assumptions

- Consider a mobile device equipped with N different apps, where each may draw, process and upload information to the cloud during a given time interval [0, t]
- We address the problem of modeling the amount of energy consumed by the N apps, resorting to a stochastic analysis approach based on the following assumptions:
  - The given N apps are all active at time 0
  - Each of the given apps collects/produces data at a constant rate in time (based on the fact that many apps collect data from sensors, which typically produce data at a constant rate, as many physical quantities are sampled periodically)
  - Each, independently, at random times, uploads its data to the cloud (e.g., simply because data may suddenly become relevant and meaningful to upload)

Modeling one app

- Consider a generic app A_v, belonging to a set of N apps, where A_v uploads data at random time instants in [0, t]. The amount of energy spent by A_v for the transmission of its data is given by $y_v = \sum_{k=0}^{K_v} y_{v,k}$, where $y_{v,k}$ amounts to the energy consumed during the upload event occurring at time $\tau_{v,k}$ with $K_v = \sup\{k \mid \tau_{v,k} \leq t\}$ (i.e., the number of upload events at app A_v) ($\tau_{v,0} = 0$ by Definition)
- Let us now compute the value of $y_{v,1}$: such quantity may be obtained as $y_{v,1} = q\tau_{v,1}$b, where q amounts to the average data collection rate and b to the average energy cost per-bit
- The values of q and b depend on multiple factors, including user behavior and hardware characteristics: we assume their average values may be obtained resorting to series of measurements or vendor reports.

Modeling N apps

- For any given $1 \le k \le K_v$, $y_{v,k}$ may be computed as $q\xi_{v,k}$b, where $\xi_{v,k}$ = $\tau_{v,k}$ − $\tau_{v,k-1}$. Hence, y_v = $\sum_{k=0}^{K_v} y_{v,k} = \sum_{k=0}^{K_v} q\xi_{v,k}$b $= qb\ \tau_{v,K_v}$ where τ_{v,K_v} = $\sum_{k=0}^{K_v} \xi_{v,k}$ amounts to the instant when the last upload event in [0, t] took place (max order statistics). Setting $\alpha = qb$, the consumption of energy of the N apps is given by $Y_N = \sum_{v=1}^{N} y_v$

- As no a priori information is given regarding the number and time of occurrence of upload events, we assume y_v all independent random variables. Y_N is hence a random variable whose probabilistic density function $f_{Y_N}(y,t)$ can be expressed as $f_{Y_N}(y,t) = (f_{y_1} * \cdots f_{y_N})(y,t)$, for $0 \le y \le \alpha t$, where $f_{Y_v}(y,t)$ amounts to the probability density functions of the energy consumed at app A_v

SOLUTION

Strategy

- We assume that:
  - Fixed the number of events in [0, t], these are uniformly distributed
  - The number of events in [0, t] may be modeled resorting to a Poisson distribution (each app, in principle, may be characterized by a different intensity of arrivals γ_v):

Solution

- Adopting such a strategy, we were able to obtain the following recursive formulation for $f_{Y_N}(y,t)$, of polynomial computational complexity:

$$f_{Y_N}(y,t) = e^{-(\sum_{i=1}^{N}\gamma_i)t}\delta(y) + \frac{1}{\alpha}\sum_{l=0}^{N-1} f_{Y_N}(y,t,l),$$

where: $f_{Y_N}(y,t,l) =$

$$= \left(\sum_{j=1}^{N} C(N,j,t,l)e^{\gamma_j y/\alpha}\right)(u(y-l\alpha t)-u(y-(l+1)\alpha t)),$$

$$C(1,1,t,0) = \gamma_1 e^{-\gamma_1 t},$$

$$C(N,j,t,l) = 0, \text{if } l < 0 \text{ and } l \geq N.$$

EVALUATION

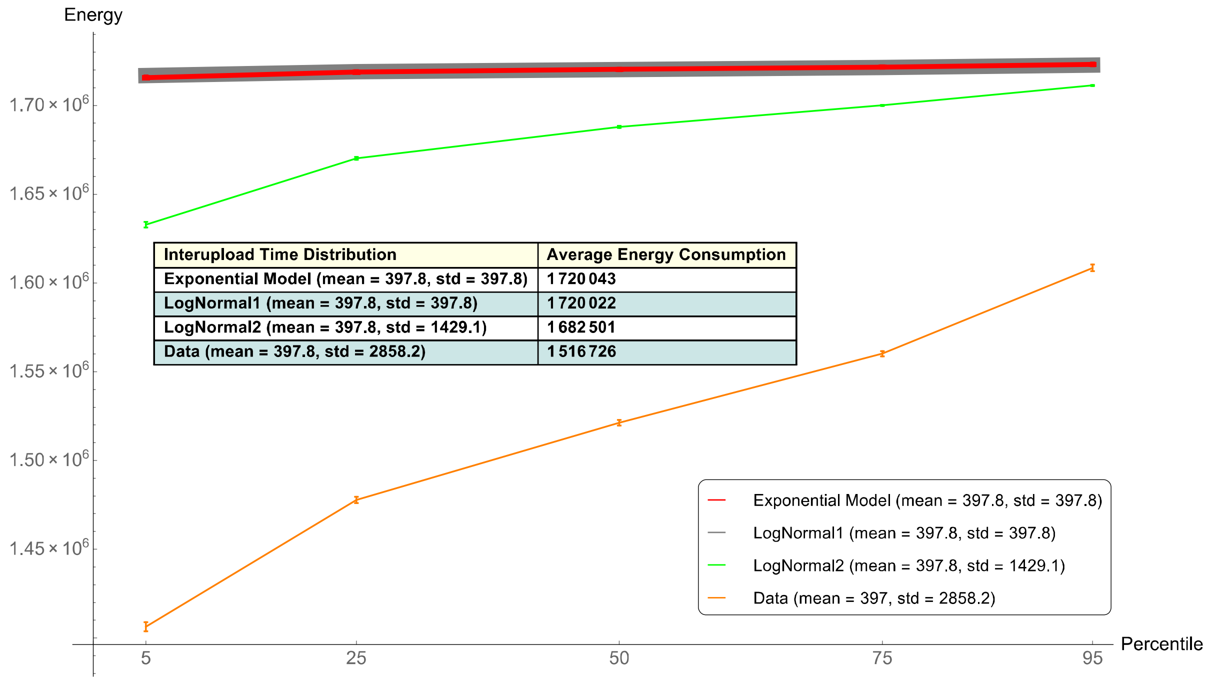
Data-driven evaluation

- To pursue an analysis based on real world data, we resorted to 350 million HTTP request logs accounting for approximately 1.4 million Android based devices uploading data to a cloud server during one week

- We processed such logs to model the random variable, denoted as ξ_{data}, representing the time interval between two subsequent uploads. From the logs of data, using standard statistical estimation techniques we obtained: $E\{\xi_{data}\} = 397.8$ s and $Var\{\xi_{data}\} = 2,858.2$ s

- We compared the total amount of energy consumed by N apps whose inter-upload times are distributed according to the empirical distribution, to N apps where the inter-upload intervals of each app are, instead, distributed according to the exponential distribution exhibiting the same average (i.e., $\gamma = 1/397.8$)

Results



Interupload Time Distribution	Average Energy Consumption
Exponential Model (mean = 397.8, std = 397.8)	1 720 043
LogNormal1 (mean = 397.8, std = 397.8)	1 720 022
LogNormal2 (mean = 397.8, std = 1429.1)	1 682 501
Data (mean = 397.8, std = 2858.2)	1 516 726

Fig. 2: Percentile and average values obtained for the 20 Apps scenario.

We observe that the group of apps which behaves according to the empirical distribution consumes, on average, approximately 15% less than the value provided by the exponential model.

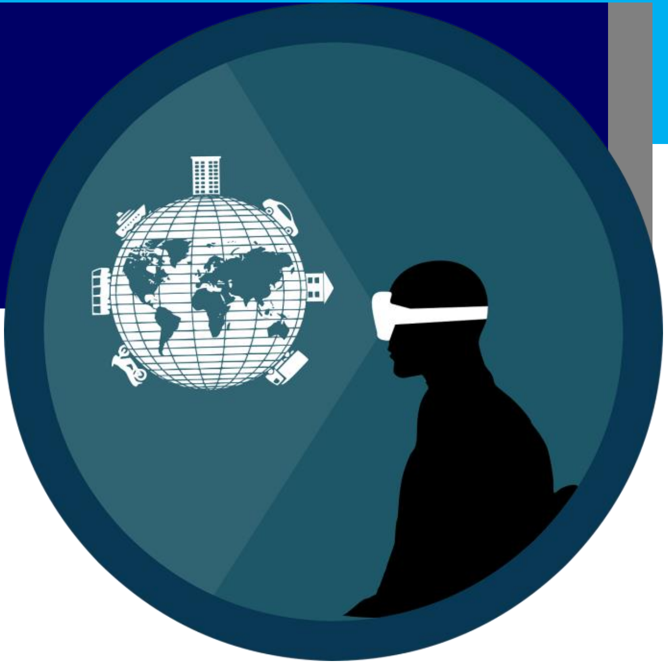
FINAL REMARKS

Possibili argomenti di collaborazione

- Da un punto di vista dell’applicazione di metodi quantitativi all’analisi di sistemi informatici, siamo sempre interessati ad opportunità di collaborazione nel settore della modellazione di sistemi basati su utilizzo di energia limitata
- Il gruppo di Bologna che aderisce ad INFQ ha recentemente intrapreso nuove attività in seguito alla fondazione del Virtual and Augmented Reality Lab (VARLAB). Settori di interesse includono:
  - Realtà Aumentata
  - Realtà Virtuale
  - Data science

VARLAB

https://site.unibo.it/varlab/en



- Il VARLAB nasce dal finanziamento AlmaAttrezzature 2017 ed è costituito da colleghi afferenti alle aree di sistemi, performance e analisi delle immagini (ad oggi, ma siamo in espansione, 4 faculty, 1 postdoc, 1 phd student)
- Il laboratorio ha una dotazione allo stato dell’arte in termini di hardware realtà aumentata (Hololens e Hololens 2), virtuale (visori e powerwall), data science (gpu tesla v100) e di acquisizione (360 cameras, scanner 3d)

THANKS!

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