



# **"Tour de France" data for the improvement of energy consumption in devices powered by limited energy sources**

Khalil Ibrahim Hamzaoui, Soufiane Dahmani, Pierre Boulet

## **► To cite this version:**

Khalil Ibrahim Hamzaoui, Soufiane Dahmani, Pierre Boulet. "Tour de France" data for the improvement of energy consumption in devices powered by limited energy sources. *Data in Brief*, 2020, 33, pp.106334. 10.1016/j.dib.2020.106334 . hal-02558636v2

**HAL Id: hal-02558636**

**<https://hal.science/hal-02558636v2>**

Submitted on 19 Jan 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# “Tour de France” data for the improvement of energy consumption in devices powered by limited energy sources

HAMZAOUI Khalil Ibrahim,<sup>1,2,\*</sup>

DAHMANI Soufiane<sup>2</sup>, BOULET Pierre<sup>1</sup>

---

## Abstract

In this article, we propose a dataset about the energy consumption of mobile devices that was collected as part of a “Tour de France” with an electrical wheelchair. Part of these data was used to propose a mathematical model based on an experimental methodology of the energy consumed in mobile devices.

Based on these precise measurements in a real environment, we have elaborated predictive models of energy consumption. The objective of this paper is to make accessible the data related to these publications to other researchers in several fields of science (computer science, telecommunications, meteorological science, artificial intelligence, statistics ...).

To our knowledge, this is the first publication of a dataset recording real world energy consumption data in mobile devices.

*Keywords:* Energy Consumption, Collection of Data, Internet of Things, Data Processing

---

---

\*Corresponding author

*Email addresses:* [hamzaoui.khalil@gmail.com](mailto:hamzaoui.khalil@gmail.com) (HAMZAOUI Khalil Ibrahim.), [s.dahmani@ump.ac.ma](mailto:s.dahmani@ump.ac.ma) (DAHMANI Soufiane), [pierre.boulet@univ-lille.fr](mailto:pierre.boulet@univ-lille.fr) (BOULET Pierre )

*URL:* <https://pro.univ-lille.fr/pierre-boulet/> (BOULET Pierre )

<sup>1</sup>Univ. Lille, CNRS, Centrale Lille, UMR 9189 - CRISTAL - Centre de Recherche en Informatique Signal et Automatique de Lille, F-59000 Lille, France

<sup>2</sup>Univ. Mohammed Premier, FSO, Lab.LANOL, 60000 Oujda, Morocco

Specifications table	
Subject	Computer Science, Computational Theory and Mathematics
More specific subject area	Improvement of energy consumption in devices powered by limited energy sources
Type of data	Text (csv file)
How data was acquired collection	<p>These experimental data were collected during a 33 day long “Tour de France” with an electrical wheelchair:</p> <p><a href="https://www.univ-lille.fr/Tour_de_France">https://www.univ-lille.fr/Tour_de_France</a></p> <p>The data were collected on the basis of several scenarios in different places (3006 kilometers(Km)). These measures were operated out in a real environment.</p>
Parameters for data	Tablet HP Pro Slate 8 (Snap Dragon), Trepn Profiler V6.2s [1], Cpu Frequency, Cronoid 3.5.1 [2]
Data format	Raw
Description of data collection	<p>Scientific data was collected on the basis of several scenarios in different places. These measures were operated out in a real environment and confronted with the consumption measures carried out beforehand in a controlled environment.</p> <p>After each experiment, the obtained data is stored in a csv file with a large number of parameters and data retrieved.</p>
Data source location	<p>Cities : Lille, Amiens, Rouen, Le Havre, Caen, Rennes, Nantes, La Rochelles, Bordeaux, Toulouse, Montpellier, Avignon, Grenoble, Lyon, Dijon, Troyes, Paris, Valenciennes.</p> <p>Country: France.</p>

Specifications table (continued)	
Data accessibility	The raw data are available at: <a href="https://zenodo.org/record/3739472">https://zenodo.org/record/3739472</a> , with a Creative Commons Attribution 4.0 International license
Repository name	Zenodo : “Tour de France” data for the improvement of energy consumption in devices powered by limited energy sources.
Related research article	Author’s name: Khalil Ibrahim HAMZAOUI, Mohammed BERRAJAA, Mostafa AZIZI, Giuseppe LIPARI, Pierre BOULET Title: Measurement-based methodology for modelling the energy consumption of mobile devices Journal: International Journal of Reasoning based Intelligent Systems DOI: <a href="https://doi.org/10.1504/IJRIS.2020.105007">https://doi.org/10.1504/IJRIS.2020.105007</a> [3]

### Value of the data:

- The presented experimental data are useful to measure several metrics related to the energy variation in a mobile device.
- The data are beneficial for all the scientists who are exploring energy consumption in devices powered by limited energy sources as a knowledge resource.
- The data can be used to analyze the load of the Central Processing Unit (CPU) and the Graphics Processing Unit (GPU) as well as to make a more detailed follow-up of the energy variation on other type of mobile environment.
- The provided data can be used for further analysis in order to define models to improve energy handling in mobile devices, to define other types of scenarios given the large size of the data measured during the collection, or to optimize our methodology (based on part of the dataset [4, 3]).

## 1. Data description

The presented research is part of the development of mathematical models, for modeling and evaluating the energy cost in mobile environments.

Our study focused on the Android system (version 4.4.4 (KitKat)). The main objective of the data collection was to model the energy consumption of a particular application running on a mobile device.

The data collection made possible to develop a specific mathematical model of energy consumption for monitoring the energy consumption of playing a local video, remote video streaming as well as in the case of navigating with a Global Positioning System (GPS) by acting on the following parameters:

- Processor frequency,
- Initial battery level,

- Dissipated energy.

This analyse is focused on the development and measurement of energy costs. Our work focused on monitoring energy consumption based on several exper-  
 30 mental scenarios.

Scientific data was collected on the basis of several scenarios in different locations. These measures were carried out in a real environment and confronted with the consumption measures made beforehand in a controlled environment.

Collecting and analyzing massive data in a real environment and diversifying  
 35 it in a reasonable time creates a scientific challenge. The objective of the carried out research is to model the energy consumption of a particular application running on a mobile device.

In the rest of our paper, we will base ourselves on two types of case studies:

- The disconnected mode in which all the measurements were carried out in  
 40 the presence of only Global System for Mobile Communications (GSM).
- Connected mode where all connection techniques have been activated (3G, 4G, Wi-Fi, GPS, etc.) depending on the chosen scenario.

The raw data are stored in text files (in CSV format). They are divided into four main groups depending on the chosen scenarios. Table 1 presents the different  
 45 characteristics of the group of scenarios used for the evaluation.

The files are named as follows:

**scenario\_name\_freq\_GHz\_[Option]\_[departure\_city]\_[arrival\_city]**

Table 2 shows some examples of measurement files for all scenarios in disconnected mode. The list of all files relating to the disconnected mode is presented in Tables 3  
 50 and 4.

For convenience, each measurement file is divided into two sub-files: The first one contains the list of measurements made during the experiment. The second one has the same name with the suffix "\_info" which gives information about active applications during the experiment.

55 The empty files "\_info files" (Zero line), means that the option which gives information was deactivated at the time of collection for these experiments.

Table 1: Characteristics of the reference scenarios

<b>Model name</b>	<b>Meaning</b>	<b>Mode</b>	<b>Description</b>
<b>LVFF</b>	Local Video with fixed frequency	Disconnected	Monitoring the energy behavior of a local video under a fixed frequency
<b>LVVF</b>	Local Video with variable frequency	Disconnected	Monitoring of energy behavior by of a local video at a variable frequency
<b>NFF</b>	Navigation with fixed frequency	Connected	Monitoring of the energy behavior by launching navigation via GPS under a fixed frequency
<b>NVF</b>	Navigation with variable frequency	Connected	Monitoring of the energy behavior by launching navigation via GPS at a variable frequency

Table 2: Description of the disconnected scenario file names

File name Scenario	Meaning
LVVF_freq0.3GHz _Caen_Domfront.csv	Measurement with the LVVF scenario by setting the frequency at 0.3GHz between Cean (departure city) and Domfront (arrival city).
LVVF_freq0.3GHz _Caen_Domfront_info.csv	Information about present applications during the experiment, Percentage of use of CPU resources, Average of use of virtual memory per application, Average use of real memory per application, Maximum use of real memory per application, statistics of the active sensors between Caen and Domfront.
LVVF_default_freq _Lille_Amiens.csv	Mesurement with LVVF scenario with variable frequency (the default frequency) between Lille and Amiens.
LVVF_default_freq _Lille_Amiens_info.csv	Information about present applications during the experiment, Percentage of use of CPU resources, Average of use of virtual memory per application, Average use of real memory per application, Maximum use of real memory per application, statistics of the active sensors between Lille and Amiens.

Table 3: List of the LVFF files in the dataset

File name	Number of lines
LVFF_freq0.3GHz_Caen_Domfront.csv	25603
LVFF_freq0.3GHz_Caen_Domfront_info.csv	0
LVFF_freq0.3GHz_Castelsarrasin_Toulouse.csv	60723
LVFF_freq0.3GHz_Castelsarrasin_Toulouse_info.csv	124039
LVFF_freq0.3GHz_Domfront_Rennes.csv	52810
LVFF_freq0.3GHz_Domfront_Rennes_info.csv	87105
LVFF_freq0.3GHz_Rouen_Le_Havre2.csv	17675
LVFF_freq0.3GHz_Rouen_Le_Havre2_info.csv	28114
LVFF_freq1.0GHz_Le_Havre_Domfront.csv	27000
LVFF_freq1.0GHz_Le_Havre_Domfront_info.csv	0
LVFF_freq1.5GHz_Beziers_Montpellier.csv	60155
LVFF_freq1.5GHz_Beziers_Montpellier_info.csv	123842
LVFF_freq1.5GHz_Carcen_Bordeaux.csv	67142
LVFF_freq1.5GHz_Carcen_Bordeaux_info.csv	128839
LVFF_freq1.5GHz_Le_Havre_Domfront.csv	27000
LVFF_freq1.5GHz_Le_Havre_Domfront_info.csv	0
LVFF_freq1.7GHz_Carcans_Bordeaux.csv	39826
LVFF_freq1.7GHz_Carcans_Bordeaux_info.csv	76807
LVFF_freq2.2GHz_Bordeaux_Marmande1.csv	65083
LVFF_freq2.2GHz_Bordeaux_Marmande1_info.csv	150503
LVFF_freq2.2GHz_Bordeaux_Marmande2.csv	57728
LVFF_freq2.2GHz_Bordeaux_Marmande2_info.csv	146489
LVFF_freq2.2GHz_Rouen_Le_Havre1.csv	47520
LVFF_freq2.2GHz_Rouen_Le_Havre1_info.csv	114434
LVFF_freq2.2GHz_Valence_Grenoble.csv	59191
LVFF_freq2.2GHz_Valence_Grenoble_info.csv	137361

Table 4: list of the LVVF files in the dataset

<b>File name</b>	<b>Number of lines</b>
LVVF_default_freq_Chateau_Thierry_Reims.csv	53110
LVVF_default_freq_Chateau_Thierry_Reims_info.csv	113303
LVVF_default_freq_Lille_Amiens.csv	52227
LVVF_default_freq_Lille_Amiens_info.csv	103631
LVVF_default_freq_Narbonne_Beziers.csv	15874
LVVF_default_freq_Narbonne_Beziers_info.csv	28268

The connected mode can be described as follows in Table 5

Tables 6 and 7 show the storage structure of the connected mode files.

Table 5: Description of the connected scenario file names

File name Scenario	Meaning
NFF_freq1.0GHz_GPS _facebook_Provins_Paris.csv	Mesurement with NVF scenario with variable frequency (the default frequency) between Provins and Paris.
NFF_freq1.0GHz_GPS _facebook_Provins_Paris_info.csv	Information about present applications during the experiment, Percentage of use of CPU resources, Average of use of virtual memory per application, Average use of real memory per application, Maximum use of real memory per application, statistics of the active sensors between Provins and Paris.
NVF_default_freq_GPS _facebook_Provins_Paris.csv	Mesurement with NVF scenario with variable frequency (the default frequency) between Provins and Paris.
NVF_default_freq_GPS _facebook_Provins_Paris_info.csv	Information about present applications during the experiment, Percentage of use of CPU resources, Average of use of virtual memory per application, Average use of real memory per application, Maximum use of real memory per application, statistics of the active sensors between Provins and Paris.
NVF_Optimal_Freq_GPS _facebook_Lyon_Tournus.csv	Mesurement with NVF scenario with variable frequency, choosed by tool of mesurement (Optimal frequency) between Lyon and Tournus.
NVF_Optimal_Freq_GPS _facebook_Lyon_Tournus_info.csv	Information about present applications during the experiment, Percentage of use of CPU resources, Average of use of virtual memory per application, Average use of real memory per application, Maximum use of real memory per application, statistics of the active sensors between Lyon and Tournus.

Table 6: composition of NFF files in the dataset

File name	Number of lines
NFF_freq0.3GHz_GPS_facebook_Nantes_La_Rochelle.csv	166978
NFF_freq0.3GHz_GPS_facebook_Nantes_La_Rochelle_info.csv	1048576
NFF_freq0.3GHz_GPS_facebook_Paris_Chateau_Thierry.csv	50198
NFF_freq0.3GHz_GPS_facebook_Paris_Chateau_Thierry_info.csv	33904
NFF_freq0.652GHz_facebook_La_Rochelle_Royan.csv	76726
NFF_freq0.652GHz_facebook_La_Rochelle_Royan_info.csv	50716
NFF_freq0.652GHz_GPS_facebook_Avignon_Orange.csv	75297
NFF_freq0.652GHz_GPS_facebook_Avignon_Orange_info.csv	49298
NFF_freq0.960GHz_GPS_Tonneins_Castelsarrasin.csv	165784
NFF_freq0.960GHz_GPS_Tonneins_Castelsarrasin_info.csv	105922
NFF_freq1.0GHz_GPS_facebook_Dijon_Provins.csv	88883
NFF_freq1.0GHz_GPS_facebook_Dijon_Provins_info.csv	60762
NFF_freq1.0GHz_GPS_facebook_Provins_Paris.csv	92149
NFF_freq1.0GHz_GPS_facebook_Provins_Paris_info.csv	61302
NFF_freq1.0GHz_GPS_google_maps_Royan_Carcans.csv	183642
NFF_freq1.0GHz_GPS_google_maps_Royan_Carcans_info.csv	124906
NFF_freq1.5GHz_GPS_facebook_Troyes_Provins.csv	104792
NFF_freq1.5GHz_GPS_facebook_Troyes_Provins_info.csv	69203
NFF_freq1.5GHz_GPS_facebook_Viviers_Romains_sur_Isere.csv	135330
NFF_freq1.5GHz_GPS_facebook_Viviers_Romains_sur_Isere_info.csv	93228
NFF_freq1.96GHz_GPS_facebook_Tournus_Dijon.csv	140454
NFF_freq1.96GHz_GPS_facebook_Tournus_Dijon_info.csv	96312
NFF_freq2.2GHz_GPS_facebook_Rennes_Nantes.csv	36848
NFF_freq2.2GHz_GPS_facebook_Rennes_Nantes_info.csv	26773

Table 7: list of the NVF files in the dataset

File name	Number of lines
NVF_default_freq_GPS_facebook_Avignon_Viviers.csv	167713
NVF_default_freq_GPS_facebook_Avignon_Viviers_info.csv	116713
NVF_default_freq_GPS_facebook_Dijon_Montbard.csv	163712
NVF_default_freq_GPS_facebook_Dijon_Montbard_info.csv	113853
NVF_default_freq_GPS_facebook_Laon_Valenciennes.csv	106244
NVF_default_freq_GPS_facebook_Laon_Valenciennes_info.csv	74877
NVF_default_freq_GPS_facebook_Lyon_Tournus.csv	161025
NVF_default_freq_GPS_facebook_Lyon_Tournus_info.csv	113831
NVF_default_freq_GPS_facebook_Nantes_La_Rochelle.csv	166978
NVF_default_freq_GPS_facebook_Nantes_La_Rochelle_info.csv	124942
NVF_default_freq_GPS_facebook_Paris_Chateau_Thierry.csv	136027
NVF_default_freq_GPS_facebook_Paris_Chateau_Thierry_info.csv	94401
NVF_default_freq_GPS_facebook_Provins_Paris.csv	174955
NVF_default_freq_GPS_facebook_Provins_Paris_info.csv	118494
NVF_default_freq_GPS_facebook_Rennes_Nantes.csv	195970
NVF_default_freq_GPS_facebook_Rennes_Nantes_info.csv	132585
NVF_default_freq_GPS_facebook_Tournus_Dijon.csv	66718
NVF_default_freq_GPS_facebook_Tournus_Dijon_info.csv	45905
NVF_default_freq_music_with_WiFi_Carcassonne_Narbonne.csv	188758
NVF_default_freq_music_with_WiFi_Carcassonne_Narbonne_info.csv	131415
NVF_default_freq_youtube_with_WiFi_Carcassonne_Narbonne.csv	52069
NVF_default_freq_youtube_with_WiFi_Carcassonne_Narbonne_info.csv	32870
NVF_Optimal_freq_GPS_facebook_Avignon_Viviers.csv	805
NVF_Optimal_freq_GPS_facebook_Avignon_Viviers_info.csv	563
NVF_Optimal_Freq_GPS_facebook_Lyon_Tournus.csv	720
NVF_Optimal_freq_GPS_facebook_Lyon_Tournus_info.csv	486

### 1.1. Data Preparation

60 The measurement file is represented in Tables 8 and 9 for the experiment that was carried out on 6 May 2016. The obtained data are stored in "LVFF\_freq0.3GHz\_Caen\_Domfront.csv". All our raw data are available at <https://zenodo.org/record/3739472>

Table 8: Example of raw measured data (part 1)

Time	Cpu1	Cpu1	Cpu2	Cpu2	Cpu3	Cpu3	Cpu4	Cpu4
[ms]	Freq	Load	Freq	Load	Freq	Load	Freq	Load
	[kHz]	[%]	[kHz]	[%]	[kHz]	[%]	[kHz]	[%]
1208013	300000	42	0	0	0	0	2265600	57
1208113	1728000	50	0	0	0	0	2265600	41
1208218	300000	90	0	0	0	0	2265600	65
1208272	1728000	100	0	0	0	0	2265600	66
1208373	300000	66	0	0	0	0	2265600	41
1208475	1728000	20	0	0	0	0	2265600	11
...	...	...	...	...	...	...	...	...
3778779	1728000	33	0	0	0	0	2265600	18

#### Meaning of the columns of Table 8:

- 65
- Time [ms]: The interval of measurements in milliseconds (ms),
  - Cpu1 Freq [kHz]; Cpu2 Freq [kHz]; Cpu3 Freq [kHz]; Cpu4 Freq [kHz]: The respective frequencies of the 4 Central Processing Units (CPUs) in kiloHertz [kHz].
  - Cpu1 Load, Cpu2 Load, Cpu3 Load, Cpu4 Load: Percentages of respective loads of the 4 CPUs [%].

Table 9: Example of raw measured data (part 2)

Time [ms]	Memory Usage [kb]	Screen Brigh- tness	Battery Power [ $\mu$ W]	Battery Remaining [%]	GPU Load [%]	CPU Load [%]	CPU Temp [1/10 C]
1208013	1797872	15	935452	19	0	42	460
1208113	1798120	15	1120303	19	0	50	460
1208218	1798860	15	1061060	19	0	42	460
1208272	1798860	15	1955387	19	0	78	460
1208373	1797636	15	680417	19	0	80	460
1208475	1797704	15	380873	19	0	45	460
...	...	...	...	...	...	...	...
3778779	1748624	15	315252	19	0	38	530

70 ***Meaning of the columns of Table 9:***

- Time [ms]: The interval of measurements in milliseconds (ms),
- Memory Usage [Kb]: Memory used per measurement interval in Kilobyte [Kb],
- Screen Brightness: Screen brightness state,
- Battery Power\* [ $\mu$ W]: Power consumption per measurement interval in microwatt( $\mu$ W),
- 75 • Battery Remaining [%]: Remaining battery capacity,
- GPU Load [%]: Total Graphics Processing Unit load,
- CPU Load [%]: Total CPU load.
- CPU Temp [1/10 C]: Processor Temperature per measurement interval (by 1/10°C).

80 The average number of accesses per application and statistics on the sensors (Table 10), the "\_info file" contains also information about the percentage of use of CPU resources, the average use of virtual memory per application, the maximum use of virtual memory per application, average real memory usage per application and maximum real memory usage per application, all these information are detailed in the

85 Table 11.

Table 10: Statistics and Information about active applications

Identifier of the Application Sensor	Type of Application	Average Number of Accesses per Application.
200	Mobile Data State	0.00
205	Battery Remaining %	47.634
206	Battery Status	0.00
328	Memory Usage	1772465.436
331	Screen Brightness	247.383
332	Battery Power	989798.485
400	GPU Frequency	226874.220
401	GPU Load	32.800
600	CPU Load	75.213
1000	CPU1 Frequency	856941.408
1001	CPU2 Frequency	664897.739
1002	CPU3 Frequency	812255.094
1003	CPU4 Frequency	860962.047
1096	CPU1 Load	76.488
1097	CPU2 Load	68.417
1098	CPU3 Load	73.458
1099	CPU4 Load	74.583

Table 11: Example of System resource allocation

<b>Applications</b>	<b>CPU [%]</b>	<b>Average Virtual Memory Size [MB]</b>	<b>Max Virtual Memory Size [MB]</b>	<b>Average Resident Set Size [MB]</b>	<b>Max Resident Set Size [MB]</b>
Facebook	0.18	1784.41	1794.03	26.99	34.0
GsmaService	0.0018	1483.33	1485.60	5.79	6.09
Clock	0.006	257.32	1493.86	1.42	8.37
CPU Frequency	5.51E-5	606.2	1489.42	2.79	7.64
Google Play Store	0.004	15.80	1545.80	8.33	9.59
Launcher3	0.004	1589.49	1589.49	12.08	13.789
Services Google Play	0.34	4096.29	6540.66	34.89	60.18
Google Partner	5.04E-4	24.55	1486.86	0.09	5.97
Configuration					
Play-Fi	0.0017	1483.88	1483.88	5.05	5.69
Personal Dictionary	0.007	99.57	1491.23	0.52	7.94
YouTube	20.51	1966.10	1985.42	42.51	48.83
Cron Tasker Free	0.06	1330.37	1492.48	7.004	8.63
Gmail	0.050	893.47	1834.24	12.28	33.15
Google Application	0.032	3084.76	3091.49	16.81	19.653
Cronoid	0.62	1507.74	1520.84	7.97	8.94
Power Battery	0.47	1682.2	3114.73	10.07	29.05
Hangouts	0.05	19.82	1665.26	0.18	21.22
Google+	0.031	64.793	1545.664	0.487	12.356
Google keyboard	0.078	1548.13	1607.44	11.58	14.71
Mobile Network	0.28	3034.45	3035.91	14.26	16.59
Configuration					
SmartcardService	0.006	2987.34	2991.18	13.007	14.622
System Interface	0.25	1727.72	1805.57	41.59	51.07
Messenger	0.14	1871.18	1910.15	46.07	56.89
SVI Settings	3.46	9172.51	9217.14	55.79	64.84
Multimedia Storage	0.002	277.25	1495.03	1.28	7.613

The meaning of the applications not recognized are:

- **GsmaService**: The GSMA provides a range of services to assist the broader mobile industry.
- **Launcher3**: Application launcher, it is the equivalent of the desktop on Android.
- **Google Partner Configuration**: Application that helps for run and configure applications in conjunction with Google products.
- **Play-Fi**: Application for set up to streaming music.
- **Cron Tasker Free**: Application for Scheduling tasks simply by configuring the time.
- **SmartcardService**: The smart card service is a included system in the operating system in a root directory. it appears to the smart card provider [5].
- **SVI Settings**: A Switch Virtual Interfaces Represents a logical Layer 3 interface on a switch.

## 2. Experimental design, materials, and methods

### 2.1. Methodology

This dataset was used to model the energy consumption of one or more specific applications in a mobile device [6, 7]. On the one hand, it allows the monitoring of energy consumption according to the frequency and the total number of operations, on the other hand, to put into practice our proposed methodologies through several concrete case studies.

To identify the parameters of the model, our methodology must determine the type of correlation between the number of total operations and the elementary energy dissipated at a previously defined frequency. The total number of operations is calculated by summing the active clock cycles of each processor per measurement interval. This active clock cycle number is the load of the CPU multiplied by the measurement interval duration and by the CPU frequency. The dissipated energy during a measurement interval is the product between the battery power and the measurement interval duration.

The average consumption per clock cycle can be expressed as follows [3]:

$$E_{\text{clock cycle}} = \text{Regression}\left(\sum_{i=1}^4 \text{Load}_i, E_{\text{dissipated}}\right)$$

$E_{\text{clock cycle}}$  shows the total energy per clock cycle,  $\text{Load}_i$  the load of CPU  $i$  and  $E_{\text{dissipated}}$  corresponds to the dissipated energy measured experimentally.

Our methodology consists in establishing a regression of energy per measurement interval as a function of the total number of operations. The research presented proposes a methodology to evaluate and modeling the energy costs of mobile devices.

The proposed methodology is developed in three stages:

- data collection,
- data preparation,
- energy consumption modelling.

The aim is to monitor energy consumption by acting on the following parameters:

- frequency of the processors,
- initial level of the battery,
- energy dissipated by the clock cycle.

## 2.2. Tools data collection

The tools used to develop our methodology are [4]:

1. Trepn Profiler, a diagnostic tool for profiling performance and power consumption of Android applications. All tests of this experimentation were processed by version V6.2s. Trepn profiler provides information on system status, network status, graph performance, speed, processor frequency etc.
2. Cronoid, an automation tool that allows performing tasks on a regular basis (like KornShell). It also enables automatic task running when the status of the terminal changes. The version used is Cronoid-3.5.1.
3. CPU Frequency (V1.0.2), a tool that allows the user to change the CPU frequency setting to save energy or to achieve better performance.

The data collection stage of our methodology is based on the following steps:

- Preparation of the test platform (CPU frequency management based on the governor) in order to have the rights to fix the frequencies of the CPU with the CPU Frequency tool.

– The role of the Cronoid tool is to automate tasks in order to minimize  
145 interaction with the user.

In the case of variable frequencies, the same methodology can be applied by filtering  
the rows of the measurement table recorded by group of identical frequencies. To  
collect the data, a “Tour de France” was carried out using an electrical wheelchair to  
perform measurements in a diversified environment based on several scenarios. details  
150 related to the location of the measurements are detailed in Table 12

The tool used for all the experiments is a tablet (HP ProSlate 8) which was pre-  
viously rooted. This choice was linked to the capacity of the battery which allows a  
large number of tests for each charge cycle, as well as the architecture of the processor  
(Snapdragon 800) for its performance, minimal power use and temperature. The full  
155 characteristics of this tablet are :

- **Operating system:** Android 4.4.4 (KitKat)
- **Processor:** QUALCOMM Snapdragon 800
- **Max. CPU frequency:** 2.3 GHz
- **Number of cores:** 4
- 160 • **Sensors:** Accelerometer, ambient light, proximity, compass, barometer, gyroscope,  
Hall effect
- **Number of batteries:** 1
- **Technology:** Lithium polymer
- **Autonomy:** Up to 13.75 h
- 165 • **Operating temp mini:** 0°C
- **Operating temp maxi:** 40°C
- **Storage temp mini:** -20°C
- **Storage temp maxi:** 60°C

Table 12: Measurement locations in the Scientific “Tour de France”

<b>Name of the city</b>	<b>Visit date</b>
Lille	02 Mai 2016 (Departure)
Amiens	02 Mai 2016
Rouen	03 Mai 2016
Le Havre	04 Mai 2016
Caen	05 Mai 2016
Rennes	07 Mai 2016
Nantes	08 Mai 2016
La Rochelle	09 Mai 2016
Bordeaux	12 Mai 2016
Toulouse	15 & 16 Mai 2016
Montpellier	19 Mai 2016
Avignon	20 Mai 2016
Grenoble	23 Mai 2016
Lyon	24 Mai 2016
Dijon	26 Mai 2016
Troyes	28 Mai 2016
Paris	30 Mai 2016
Valenciennes	02 Juin 2016
Lille	03 Juin 2016(Arrival)

### 3. Data exploitation

170       The purpose of our study is to provide detailed monitoring of the main sources of energy consumption. In the first case, only the Global Mobile Communications system (GSM) is active. The other communication networks (third generation of mobile wireless telecommunications (3G), fourth generation of mobile wireless telecommunications (4G), Wireless Fidelity (Wi-Fi) and Global Positioning System (GPS) remain  
175       inactive throughout the different experiences.

          The second case aims at evaluating and measuring the energy consumed in connected use cases. Sources related to the data communications are activated completely (3G/4G or Wi-Fi) or partially (GPS) depending on the scenarios of the experiment. Another mobile device was present to serve as an access point for sharing the Wi-Fi  
180       connection.

          We have developed a methodology based on the processor frequency parameters, the dissipated energy and the initial level of the battery [3]. To this end, part of the collection of the produced experimental data was analyzed by statistical tools. To validate our model, we compared our results with other existing models.

185       We have presented a methodology to build a model of energy consumption of applications on mobile devices. This methodology begins with recording precise measurements of energy consumption when using the applications. The strong point of our methodology is in the technique of processing recorded data which leads to a precise model. The proposed solution can be used to define an optimal frequency for one or  
190       more applications in order to provide a better experience for users with reduced energy consumption.

          For the implementation of our methodology, we selected the following parameters, obtained by Trepro Profiler:

- Total load per CPU,
- 195   • Memory usage,
- CPU frequency,
- Battery level,
- Battery power.

### 3.1. Disconnected state

200 The measurements of the dissipated energy were carried out according to the number of total operations at a fixed frequency. Figure 1 show example of experimentation by setting the processor frequencies at 1.5 GHz.

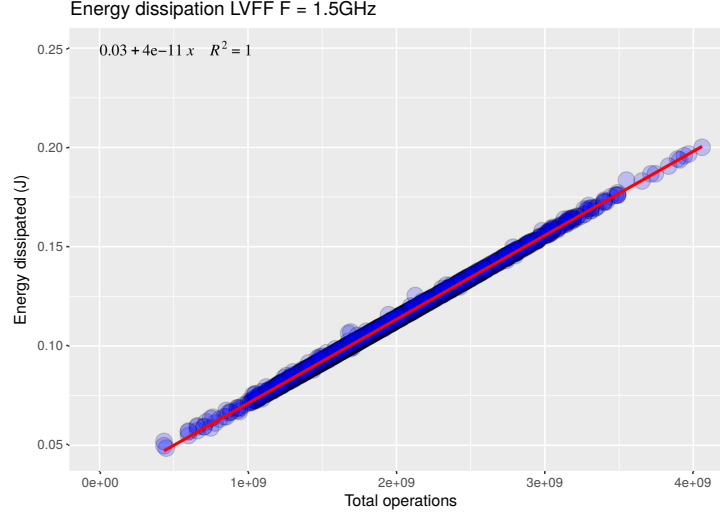


Figure 1: Energy dissipation for LVFF model, Frequency=1.5GHz [3]

### 3.2. Connected state

The aim of this section is to follow behaviour the energy consumption variation  
 205 by activating Wi-Fi. To stay in the same context, the remote video was identical to that used in disconnected mode. We determine the type of correlation between energy consumption and the number of total operations, then we compare the obtained result with those in offline mode. Figure 2 shows an example of experimentation for a remote video in navigation mode with variable frequency (NFV).

210 Raw data sources of this figure is stored in:

**NVF\_default\_freq\_youtube\_with\_WiFi\_Carcassonne\_Narbonne.csv** at Zenodo platform: <https://zenodo.org/record/3739472> In this study, we have treated the different types of dependencies between energy dissipation and the frequency of several cases in disconnected mode (LVFF, LVVF) and connected mode (NFF, NVF).

215 The difference between the types of regressions can be explained in part by the variability of the signal strength received for GPS and Wi-Fi (for connected mode).

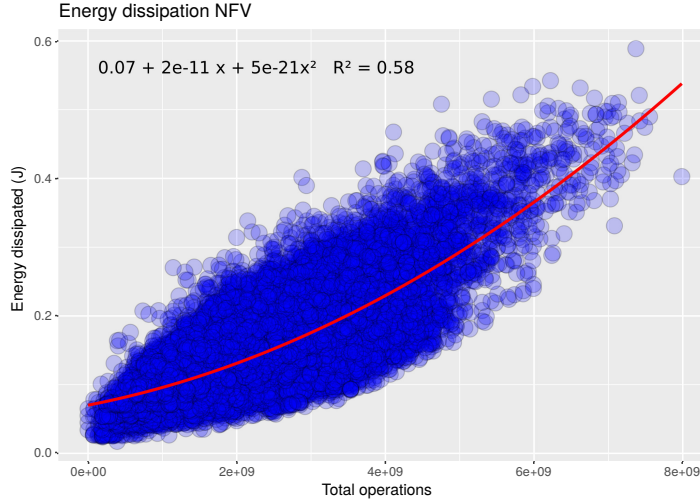


Figure 2: Energy dissipation for NFV scenario (default frequency) [3]

On the other hand, the scenarios concerned in connected mode require the activation of other parameters, which increases the rate of inputs / outputs which are partly responsible for the additional energy cost.

## 220 Acknowledgements

The authors wish to acknowledge the following institutions for their help in collecting this data and their financial support:

- University of Lille France,
- CNRS : National Center for Scientific Research (CNRS France),
- 225 • The Research Institute for Software and Hardware Components for Information and Advanced Communication (IRCICA Lille, France),
- Association of the Paralyzed in France (APF),
- City of Villeneuve d'Ascq, France.

## Conflict of Interest

230 The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Ethics statement

Our work does not involve any use of human subjects nor animal experiments.  
235 The data are purely technological.

## References

- [1] A. Bakker, Comparing energy profilers for android, in: 21st Twente Student Conference on IT, Vol. 21, 2014.
- [2] I.-L. Chen, Y.-D. Tseng, Method for changing cpu frequency under control of neural  
240 network, uS Patent 7,143,071 (Nov. 28 2006).
- [3] K. I. Hamzaoui, M. Berrajaa, M. Azizi, G. Lipari, P. Boulet, Measurement-based methodology for modelling the energy consumption of mobile devices, International Journal of Reasoning-based Intelligent Systems 12 (1) (2020) 4–16.
- [4] K. I. Hamzaoui, Contribution à la modélisation de la consommation d’énergie dans  
245 un dispositif mobile, Ph.D. thesis, Lille 1 (2018).
- [5] R. Mandelbaum, S. A. Sherman, D. R. Wetherington, Smartcard adapted for a plurality of service providers and for remote installation of same, uS Patent 5,544,246 (Aug. 6 1996).
- [6] A. Pathak, Y. C. Hu, M. Zhang, Where is the energy spent inside my app?: fine  
250 grained energy accounting on smartphones with eprof, in: Proceedings of the 7th ACM european conference on Computer Systems, ACM, 2012, pp. 29–42.
- [7] P. Mercati, V. Hanumaiah, J. Kulkarni, S. Bloch, T. Rosing, Blast: Battery lifetime-constrained adaptation with selected target in mobile devices, in: proceedings of the 12th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services on 12th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2015, pp. 80–89.
- 255