Data Driven Smartphone Energy Level Prediction

- Five centuries in the life of BlackBerry users

Earl Oliver, Ph.D. Candidate

University of Waterloo

Take-aways

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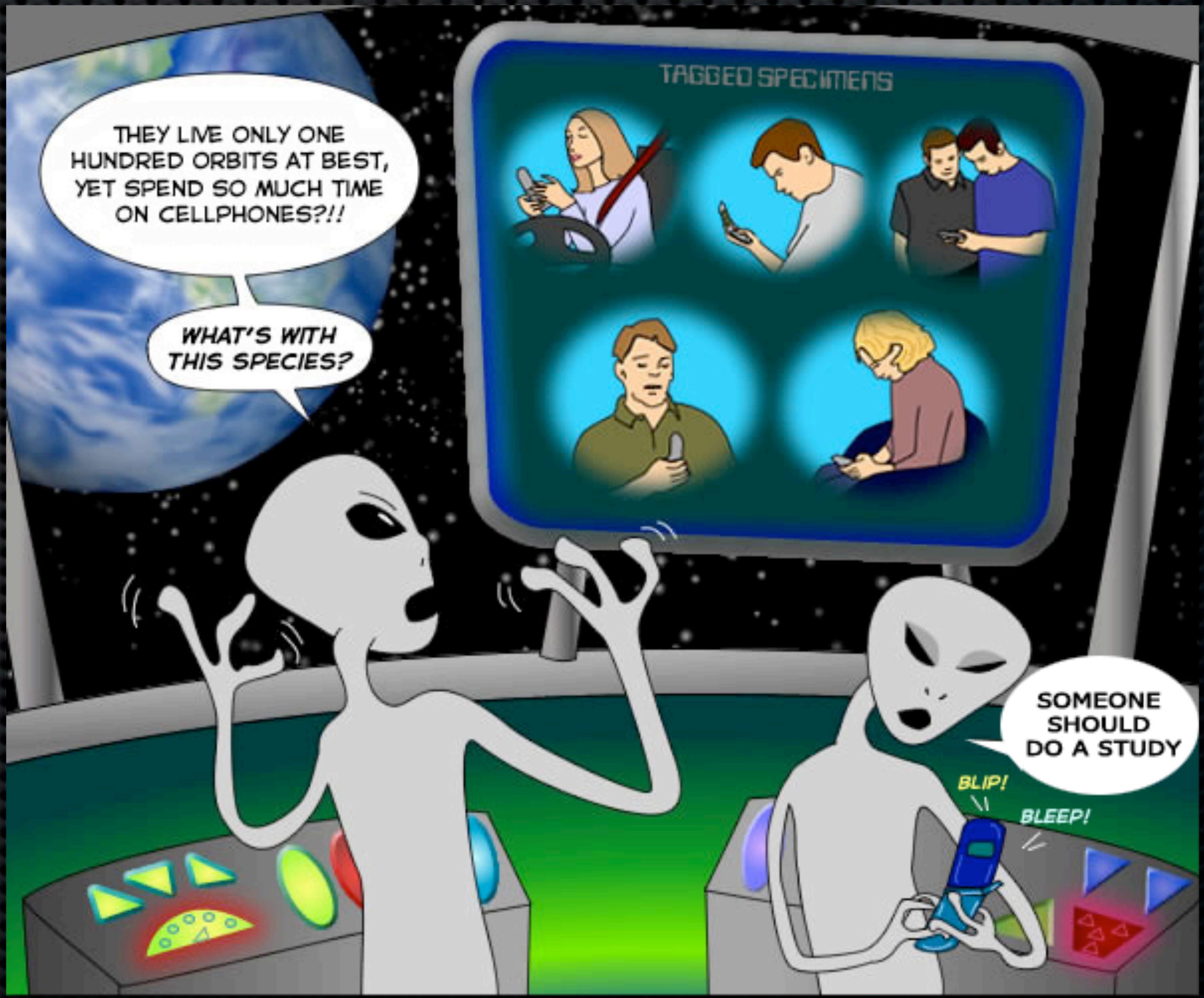
- Demonstrate that clustering users by energy consumption characteristics can improve battery level prediction by ~***54%*** over long durations.
- Constructed the ***App-Predict*** tool to simulate the successful execution rate of energy intensive mobile applications.

Outline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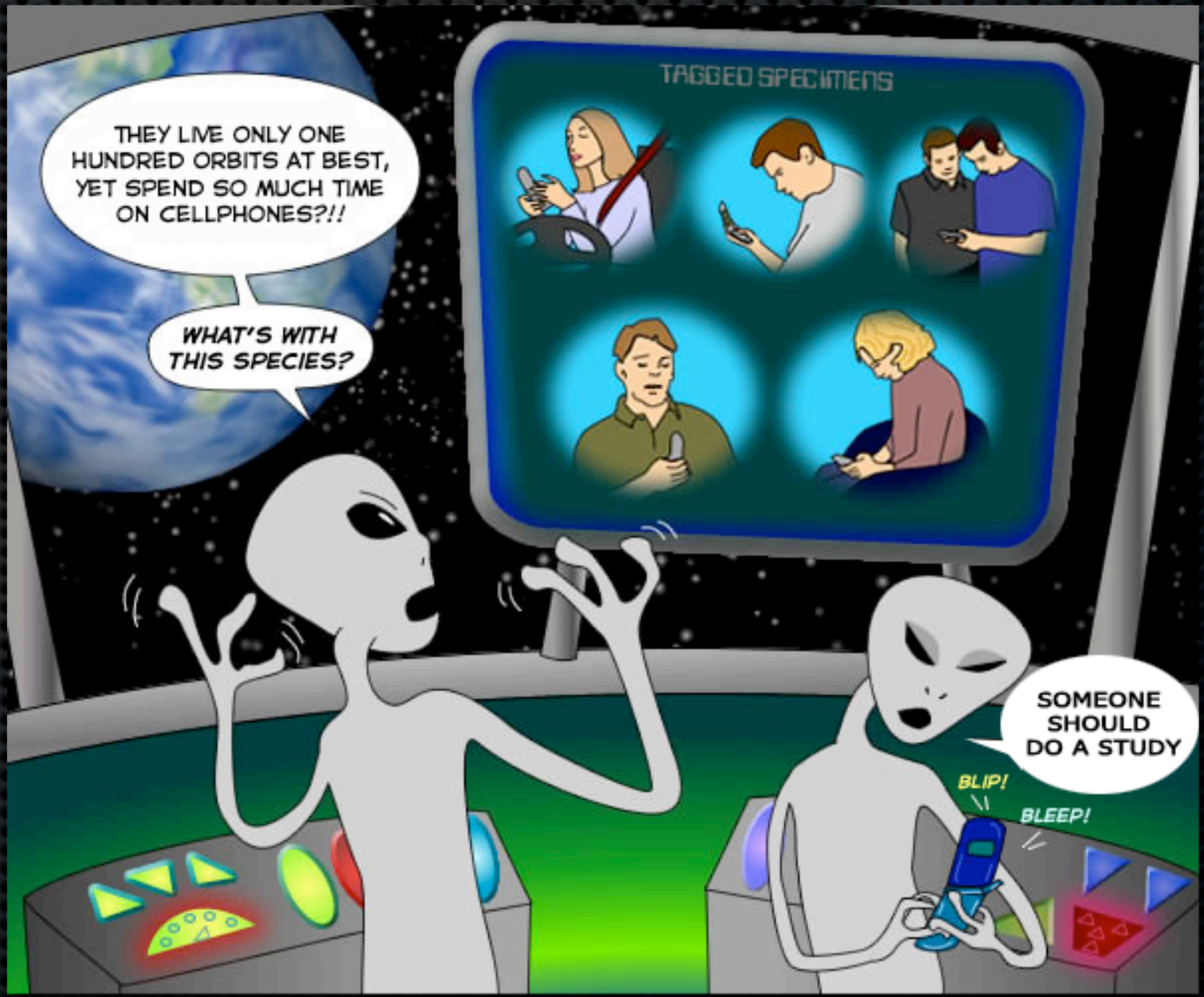

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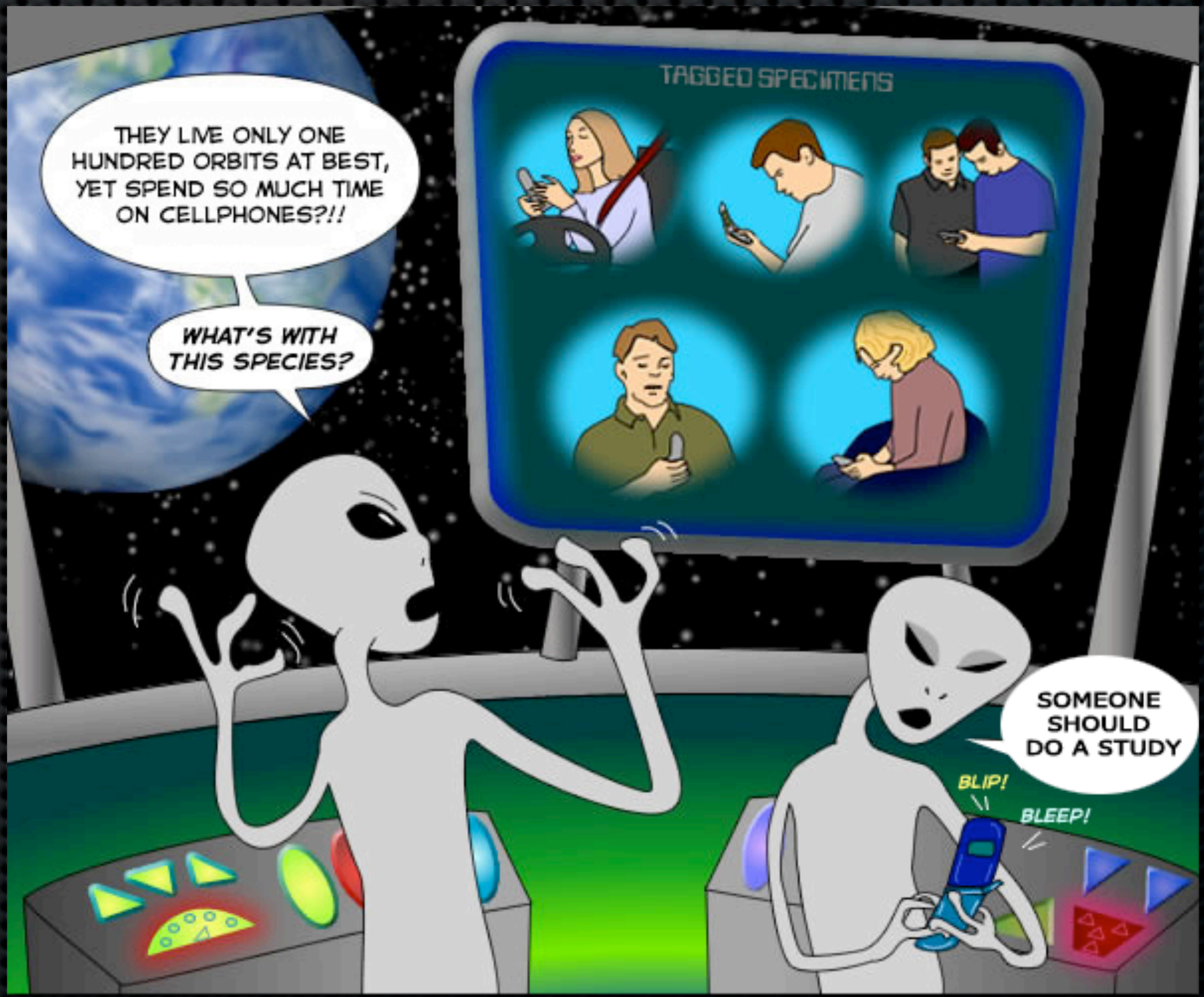
  - Challenges



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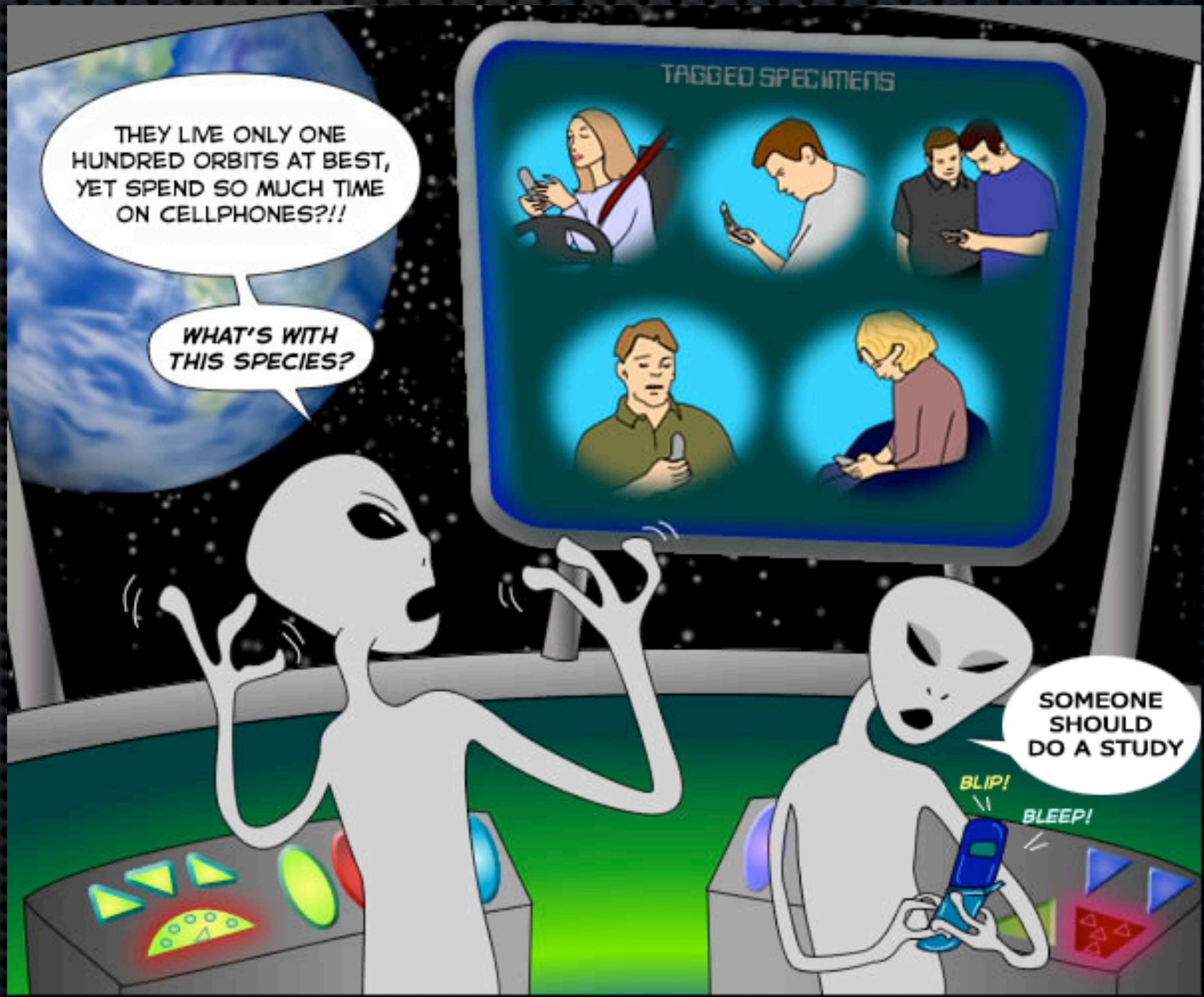

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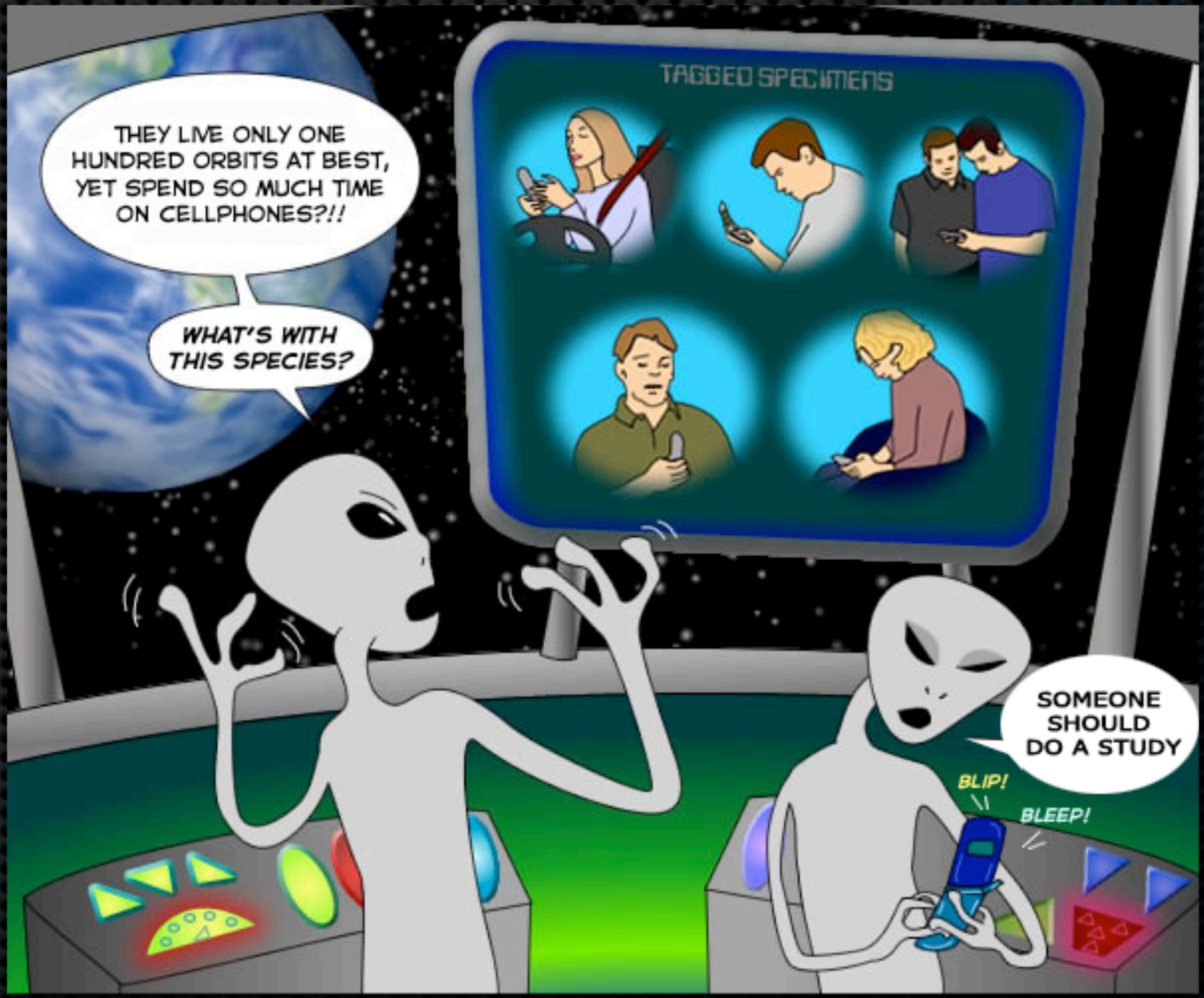

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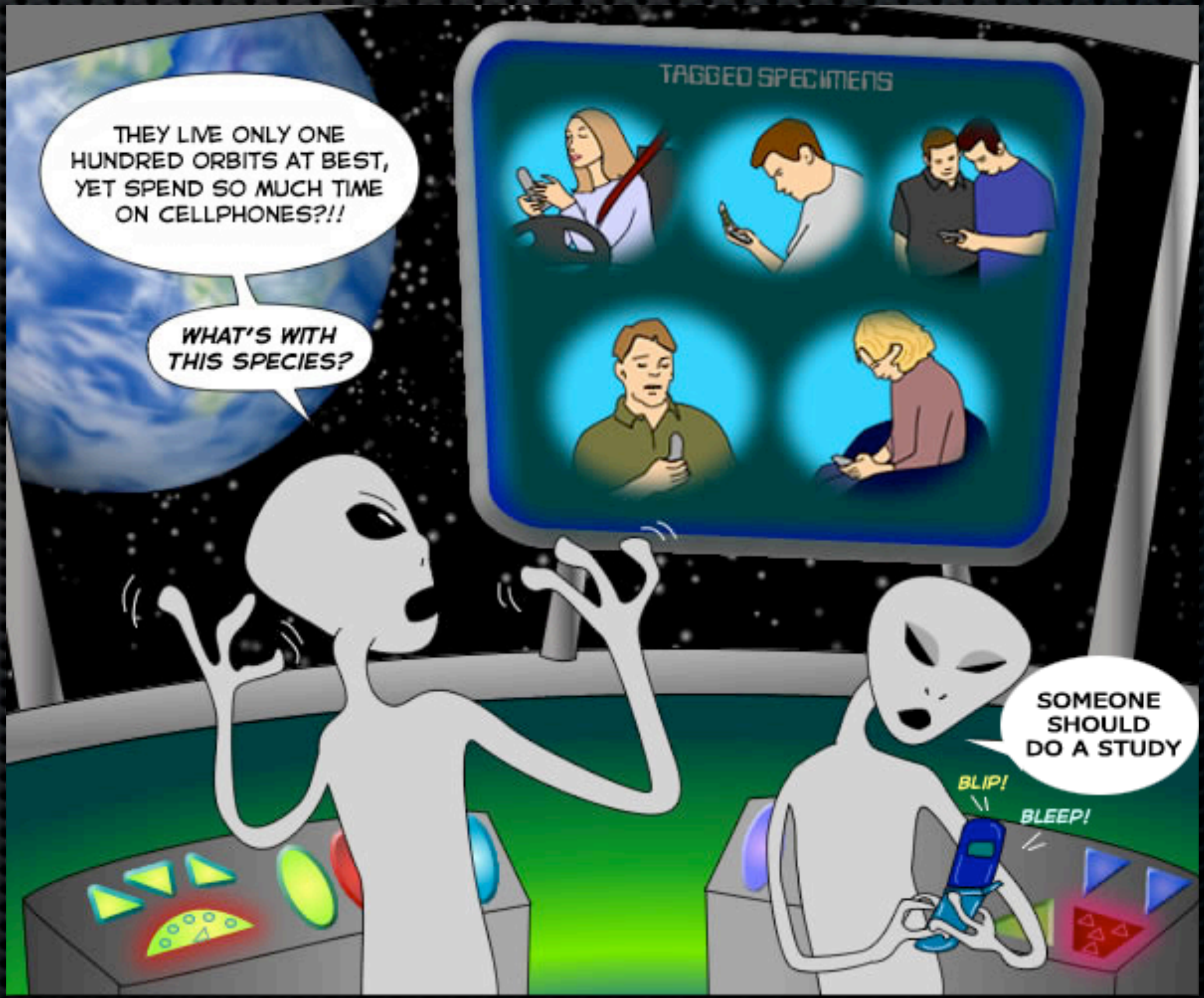

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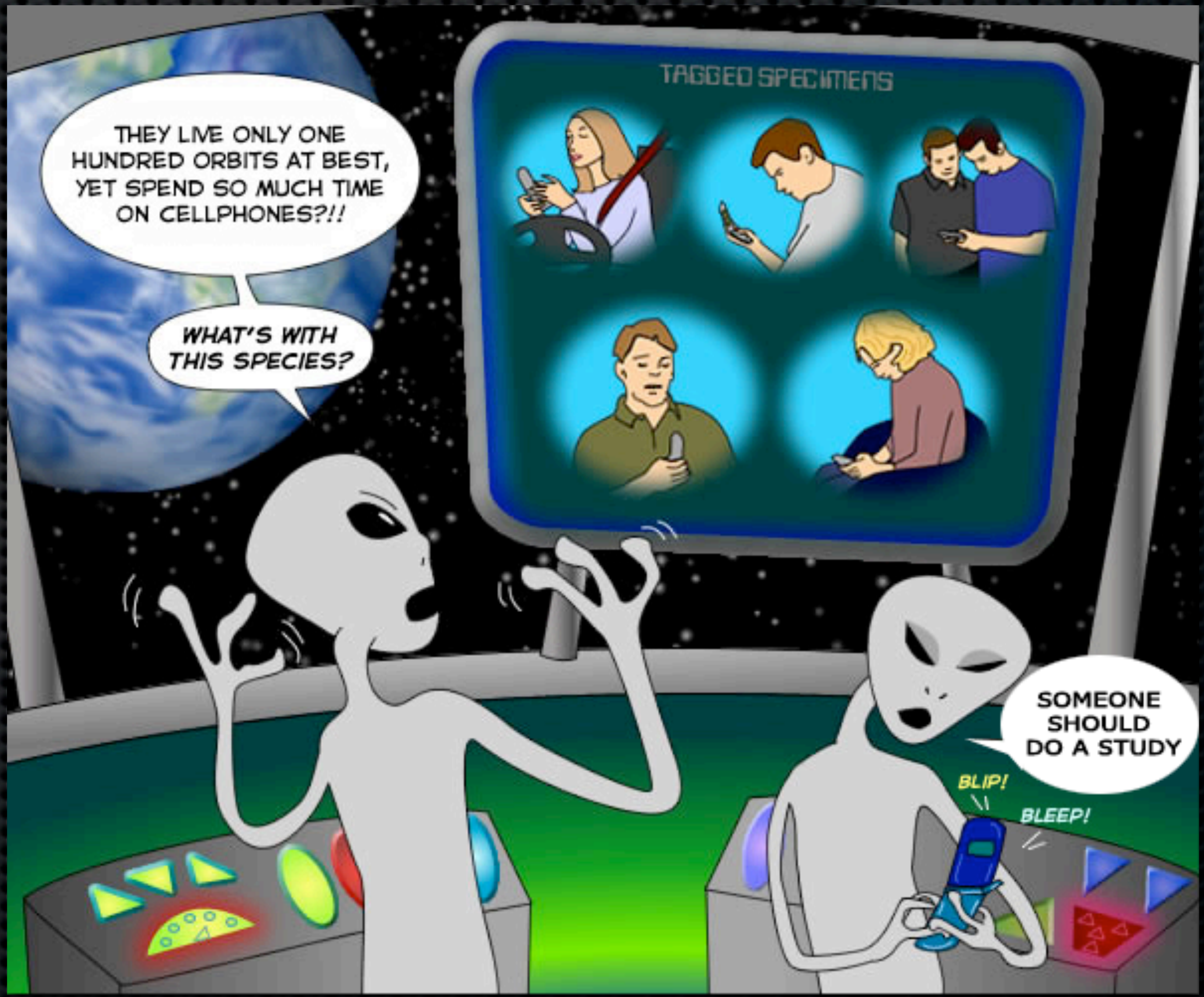

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Mobile applications

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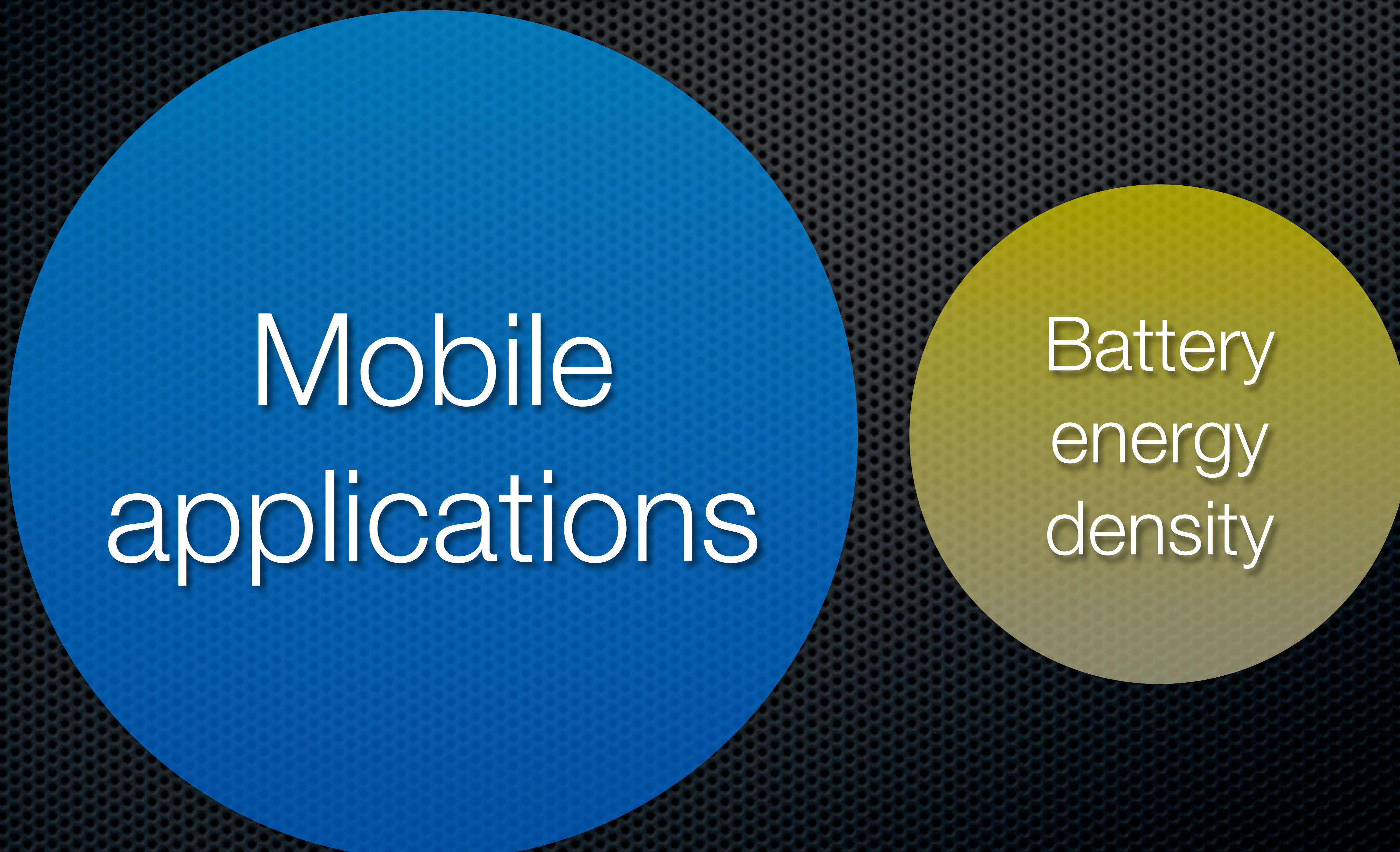
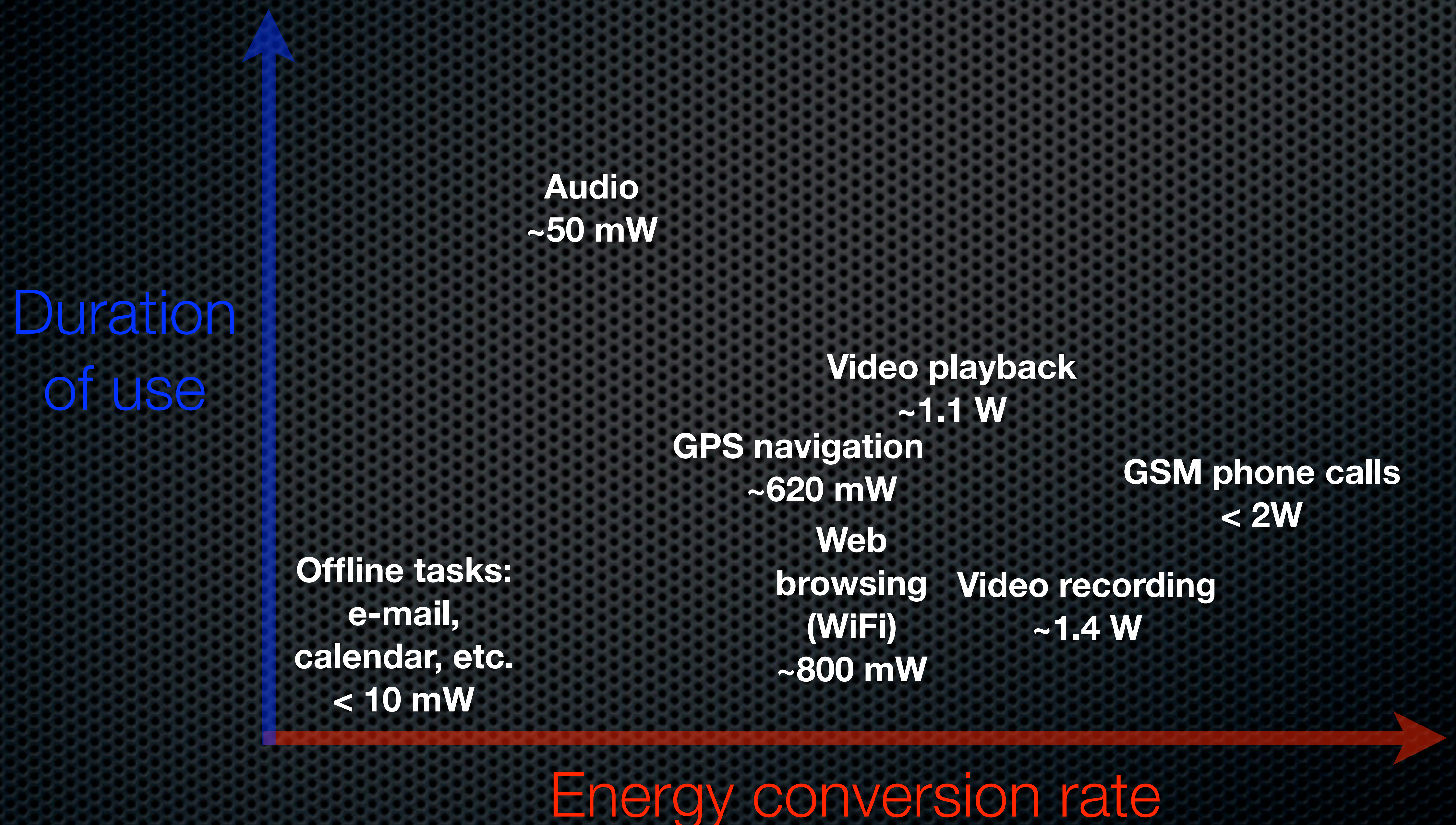


Execution continuum



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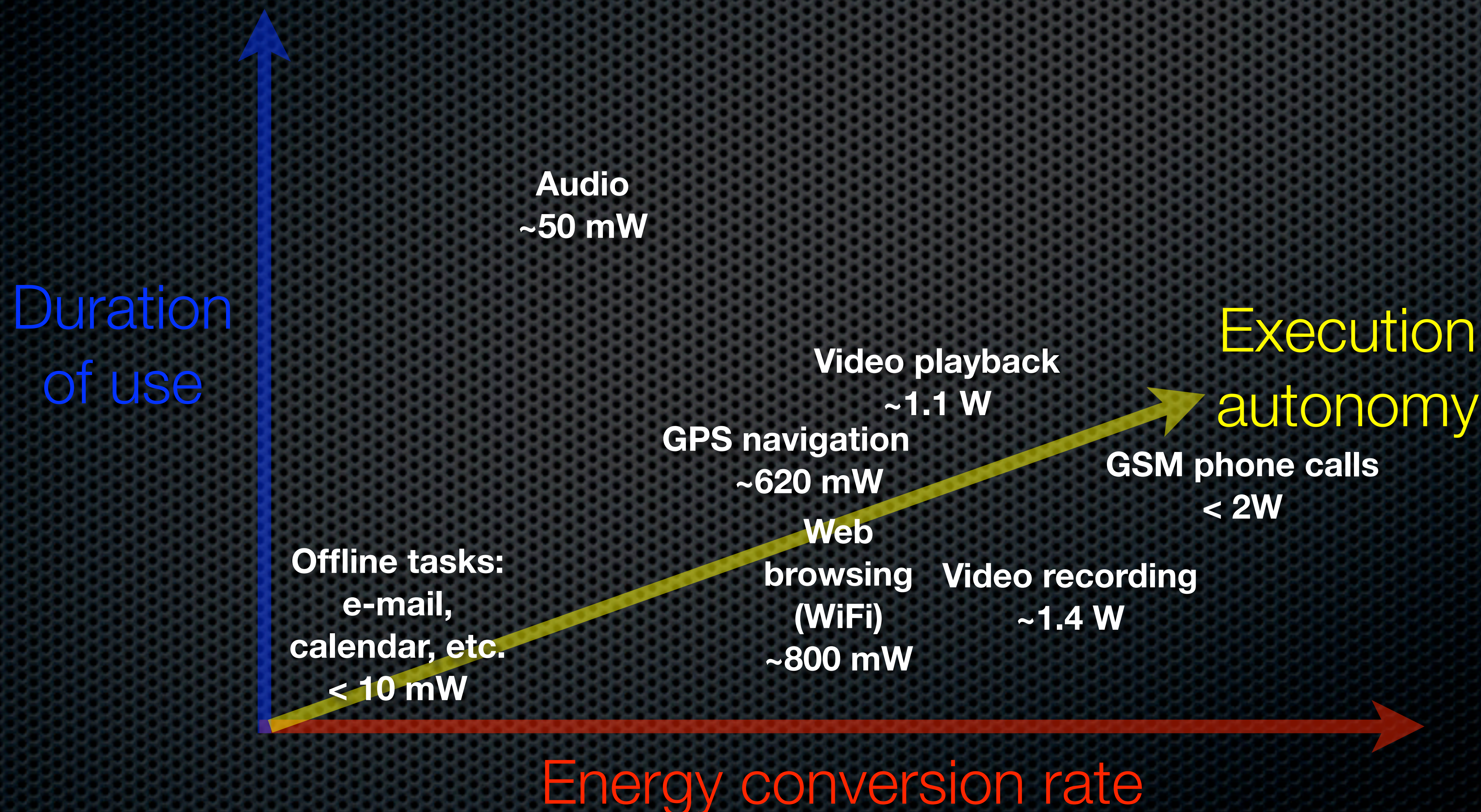

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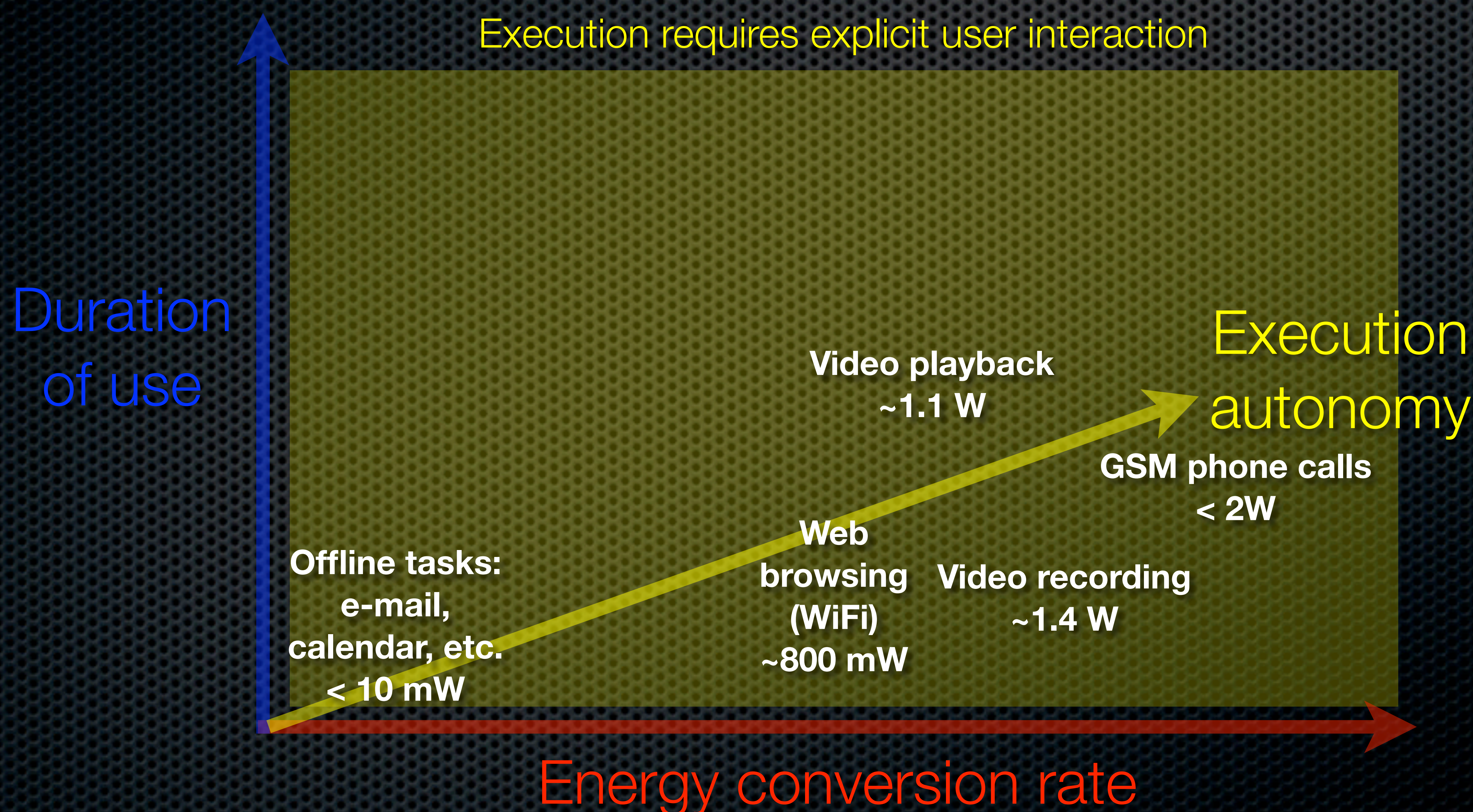

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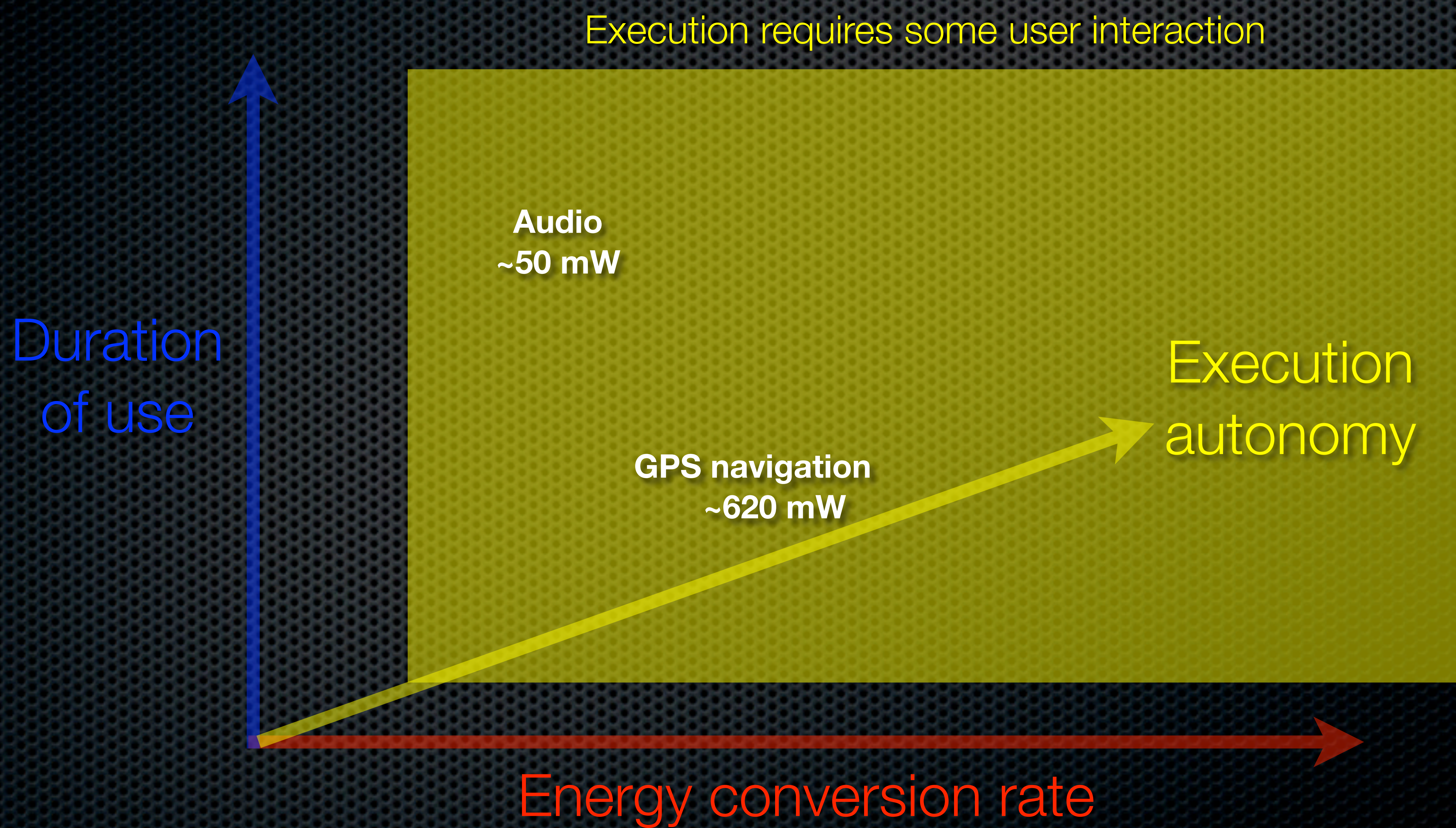

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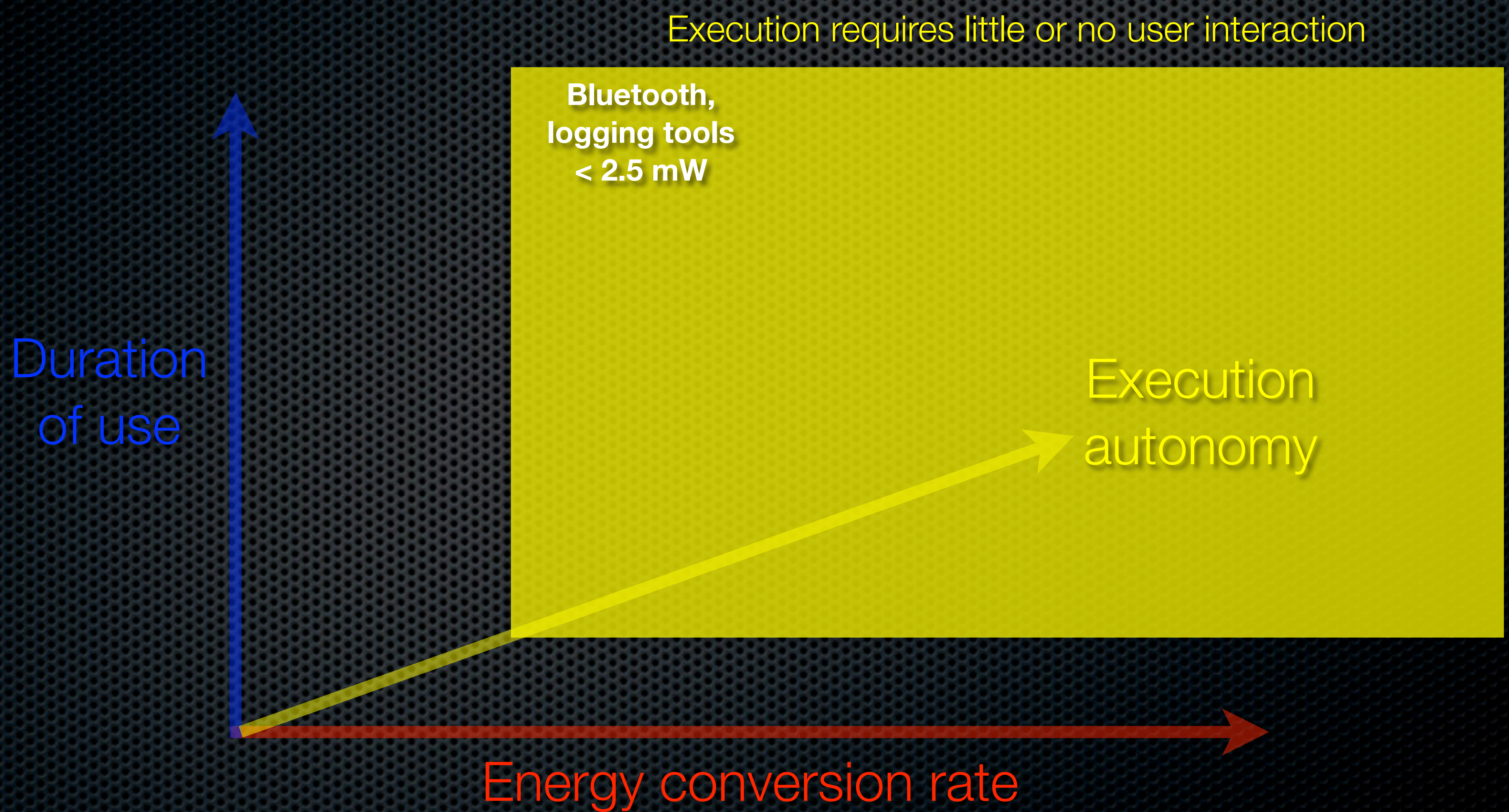

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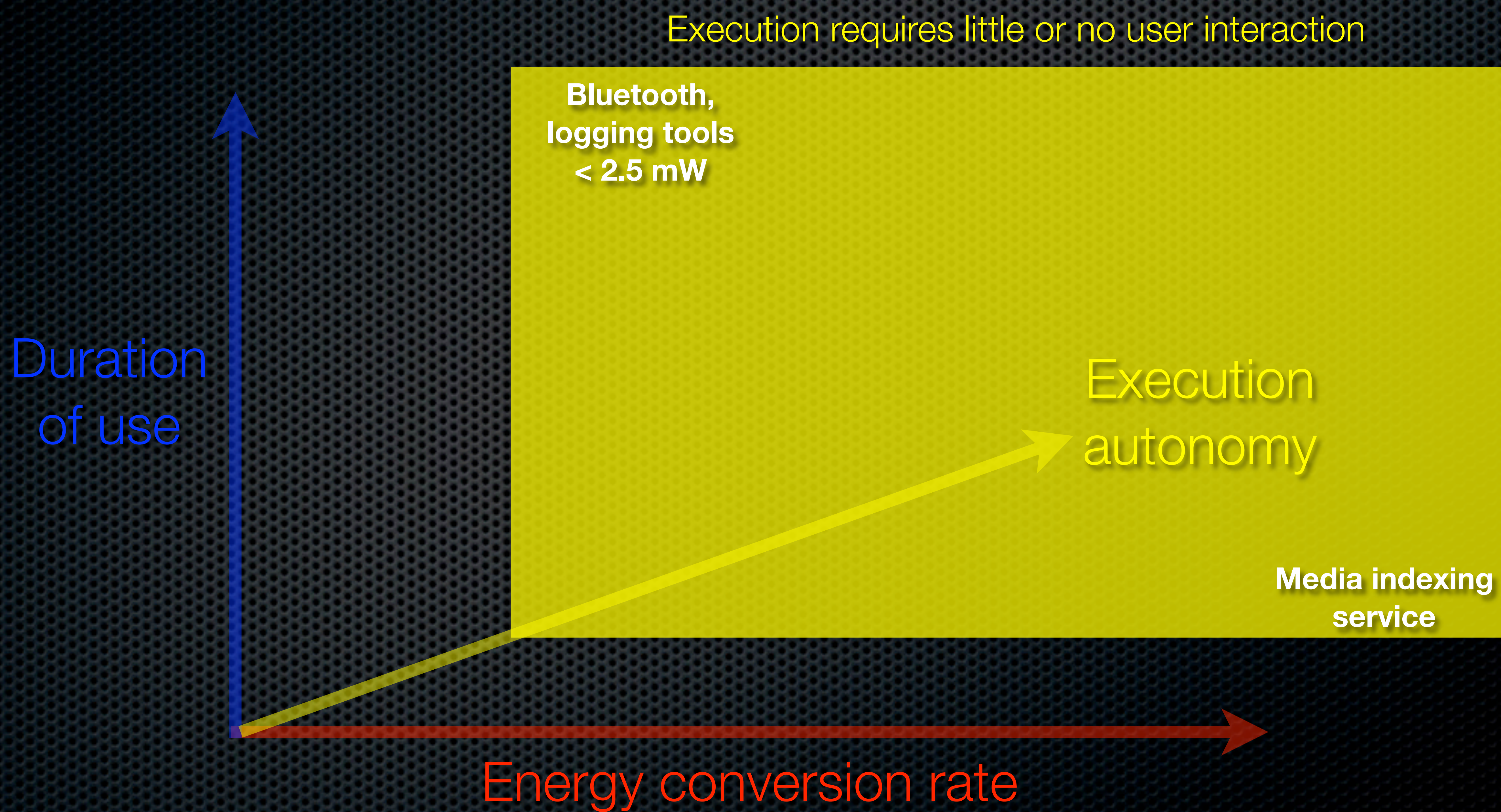

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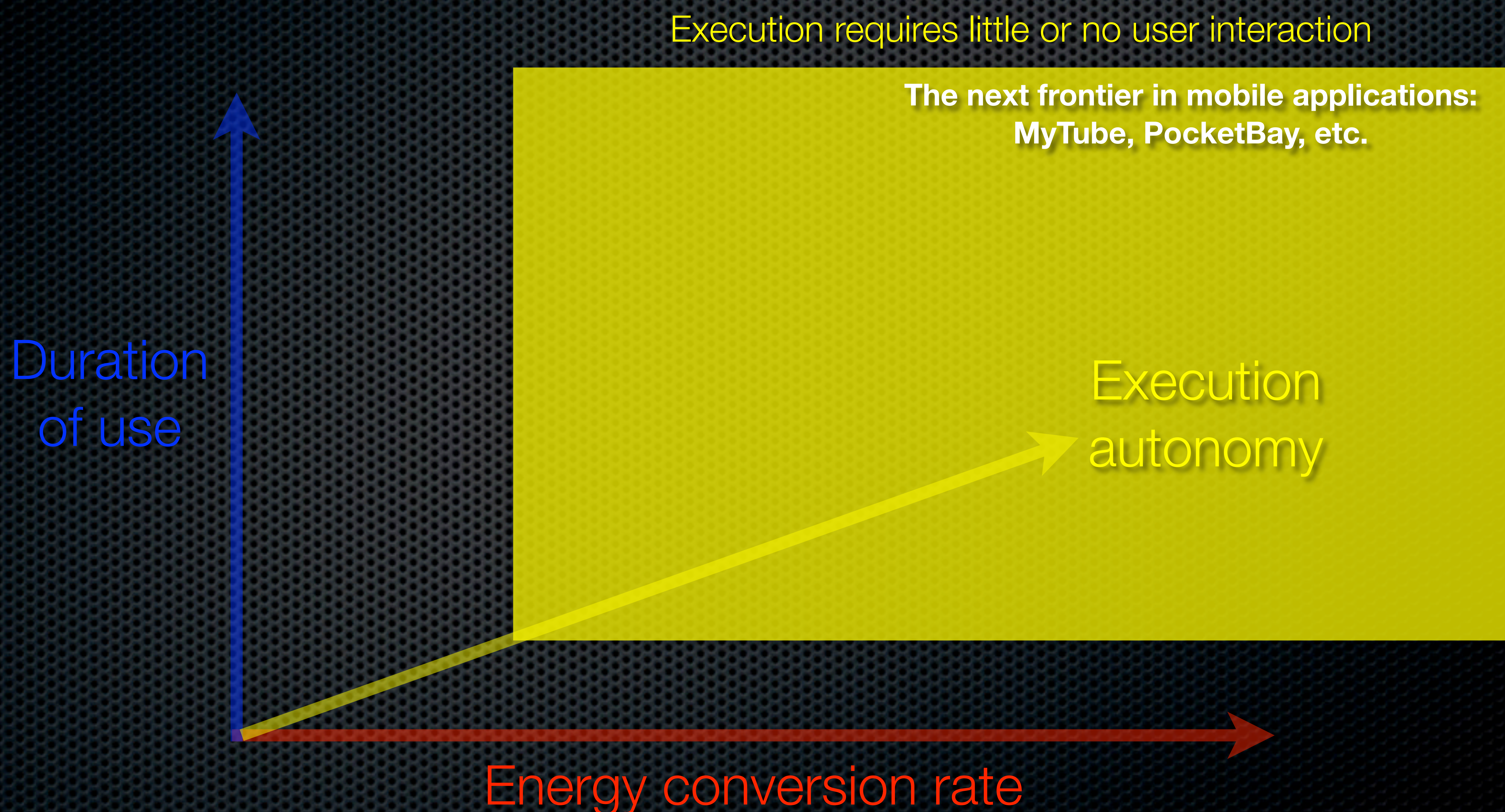

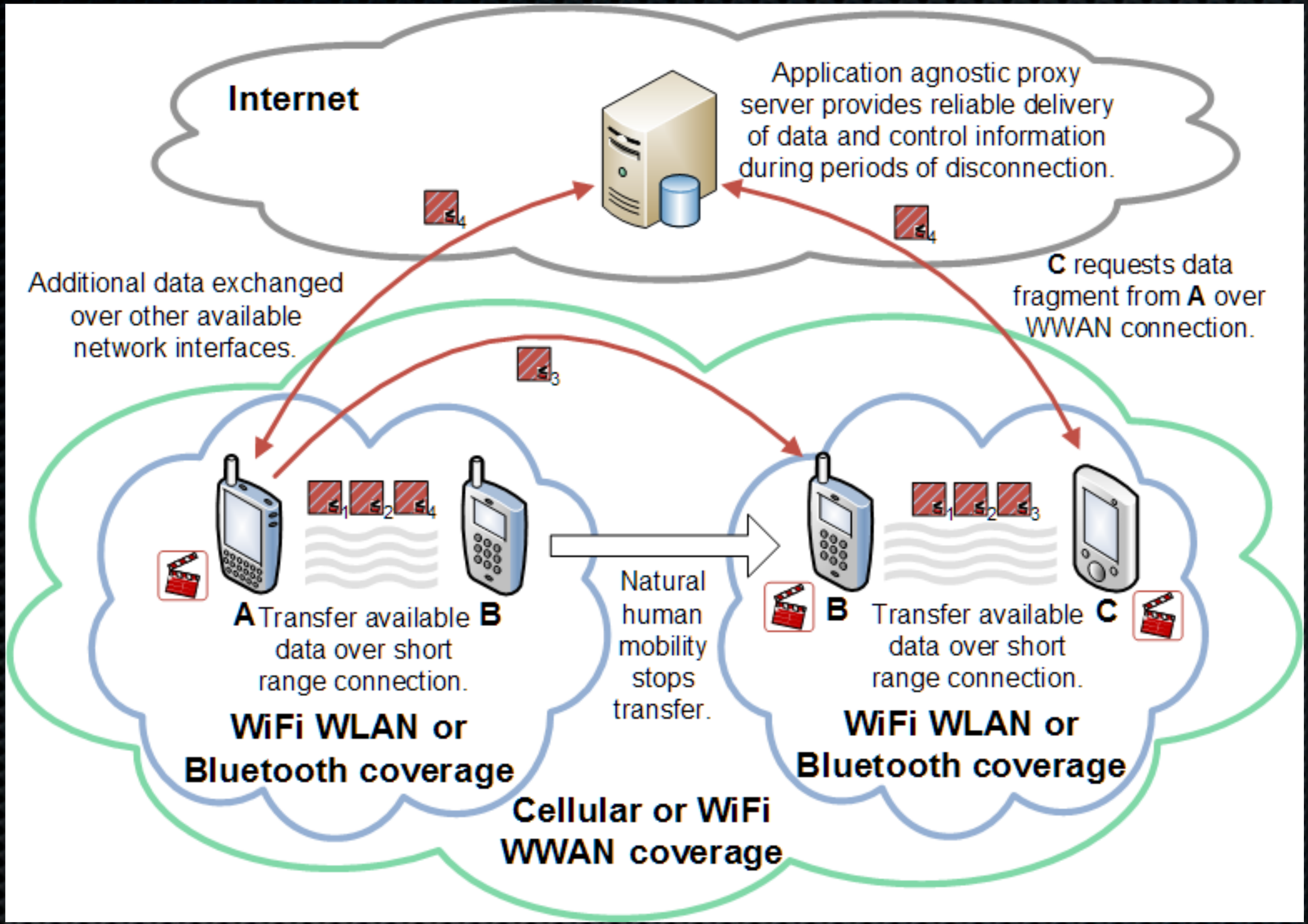

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  - **Unacceptable**

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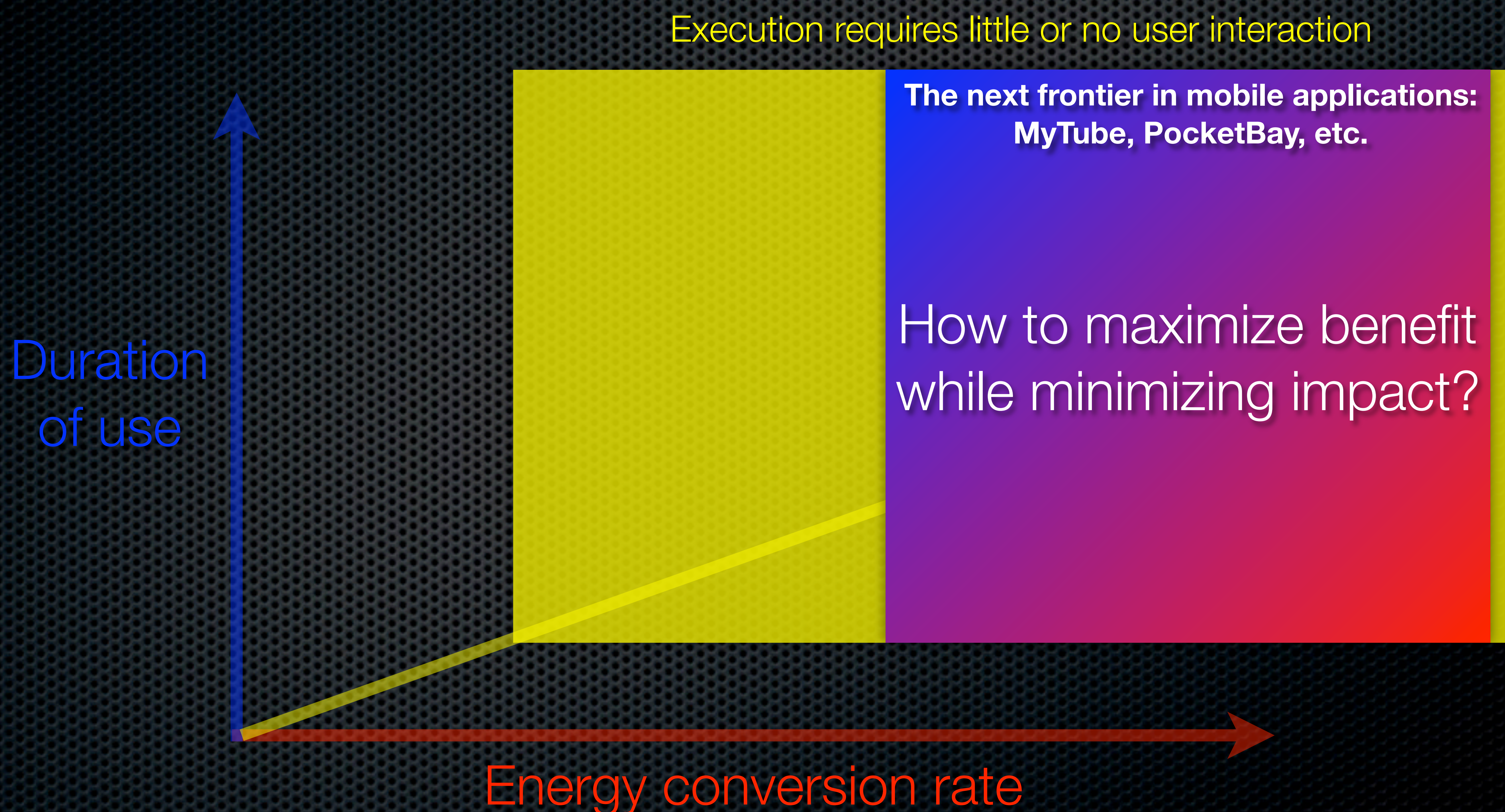

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- Two goals:
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  - **Predict the successful execution rate** of energy intensive applications given known consumption

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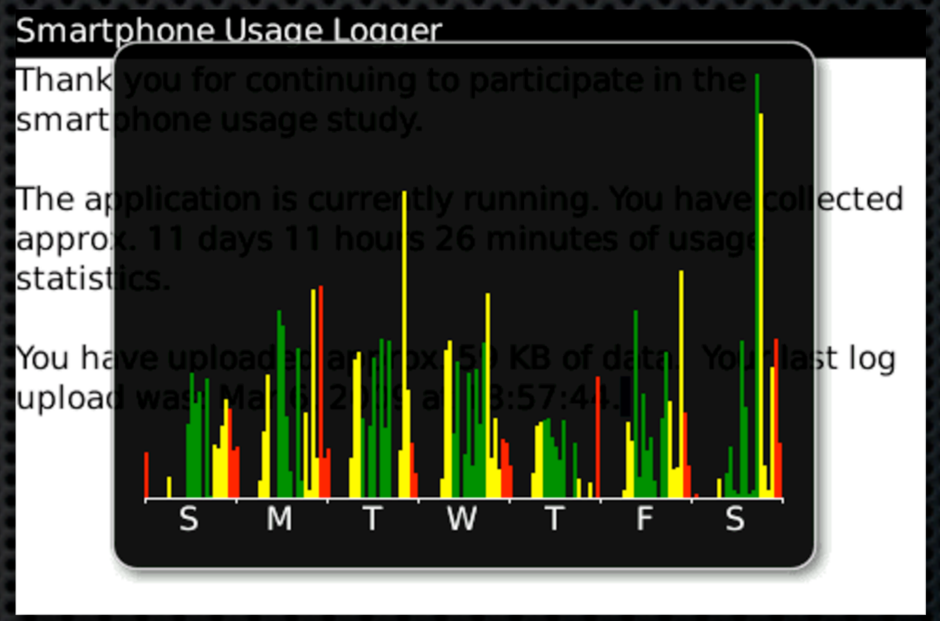
        - Impact -> uninstallation

Design of the usage logger

- Information collected:




```
# Device name = 9000
TZ: -5
1260792769426 off
1260792769426 66 false
1260793007161 65
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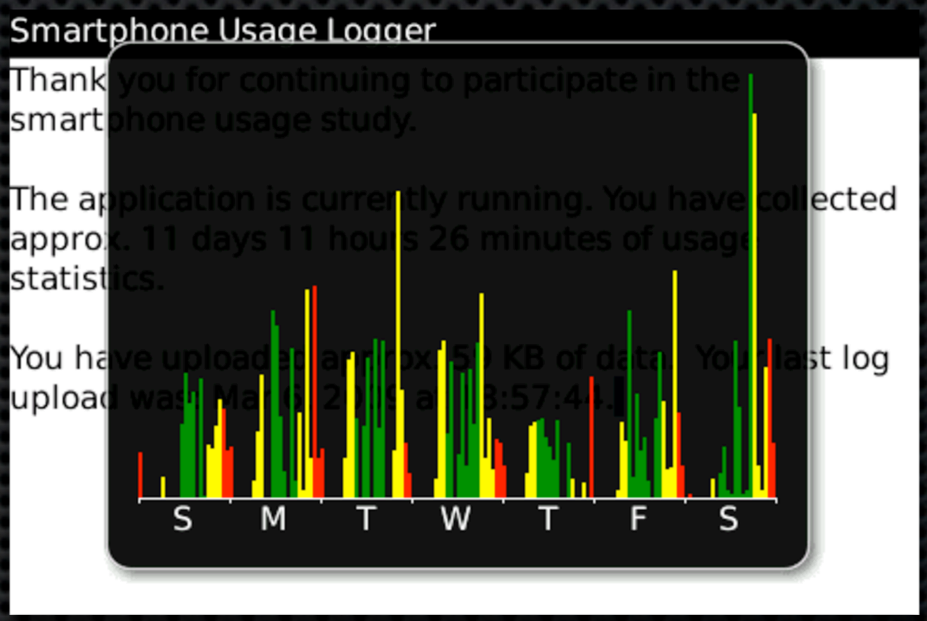

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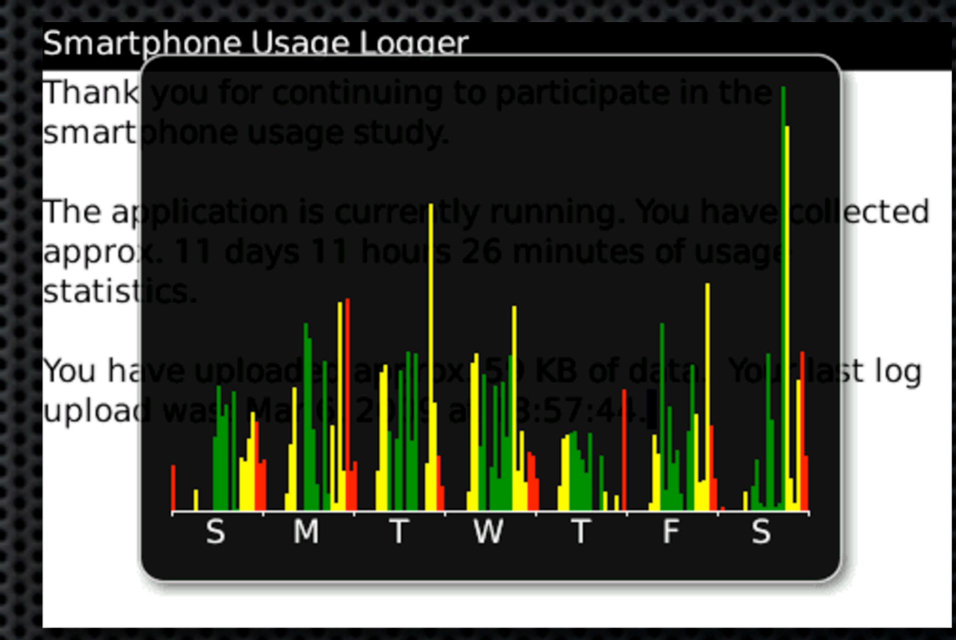

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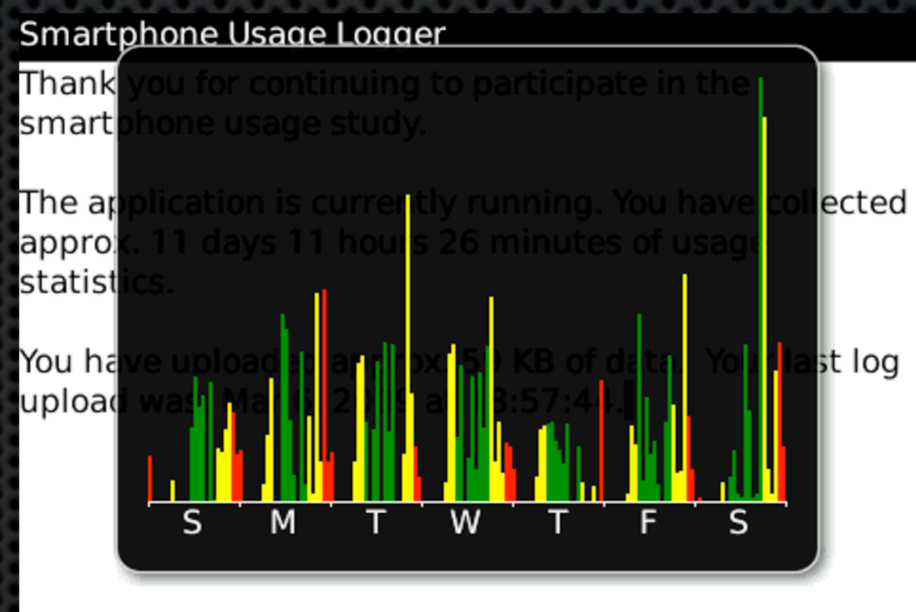

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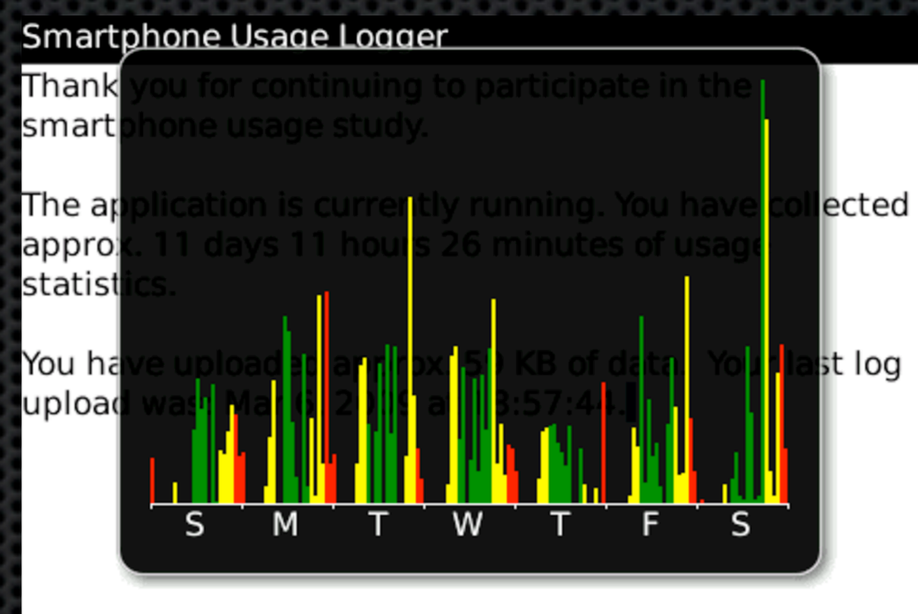

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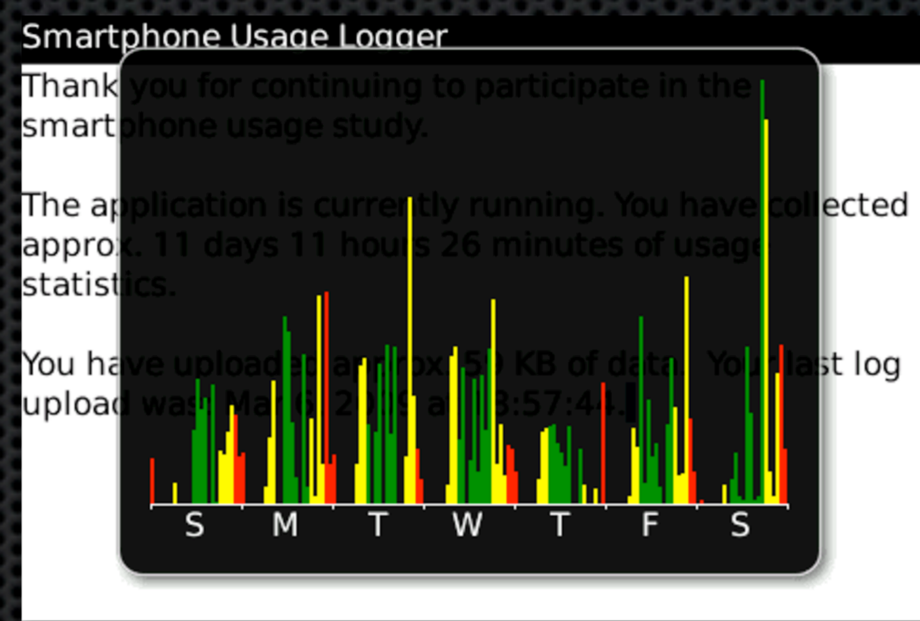

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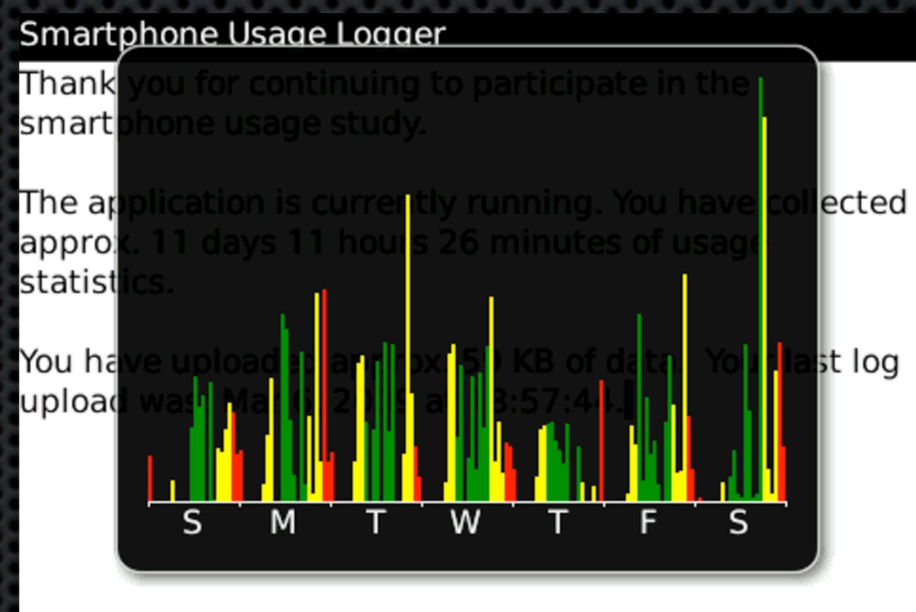

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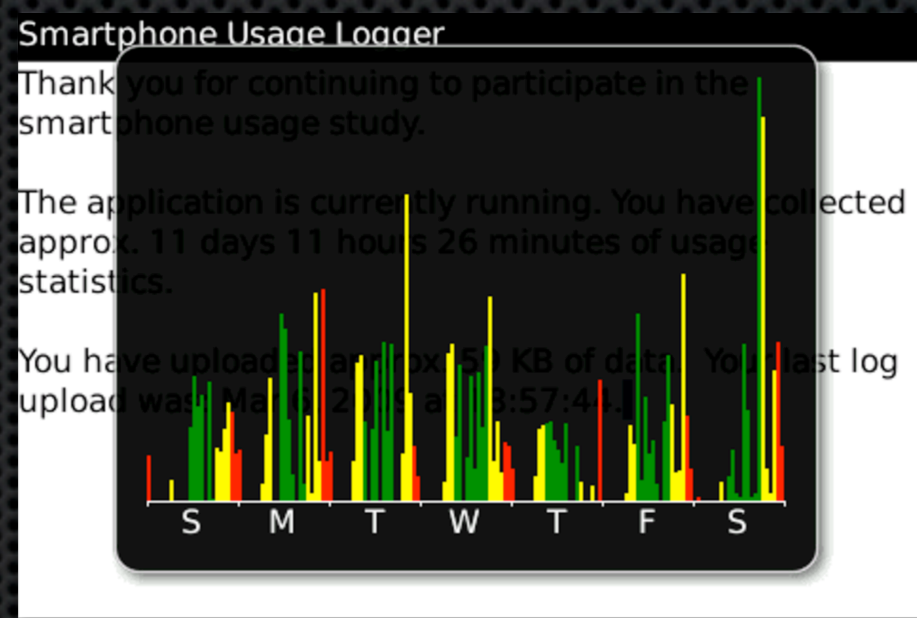

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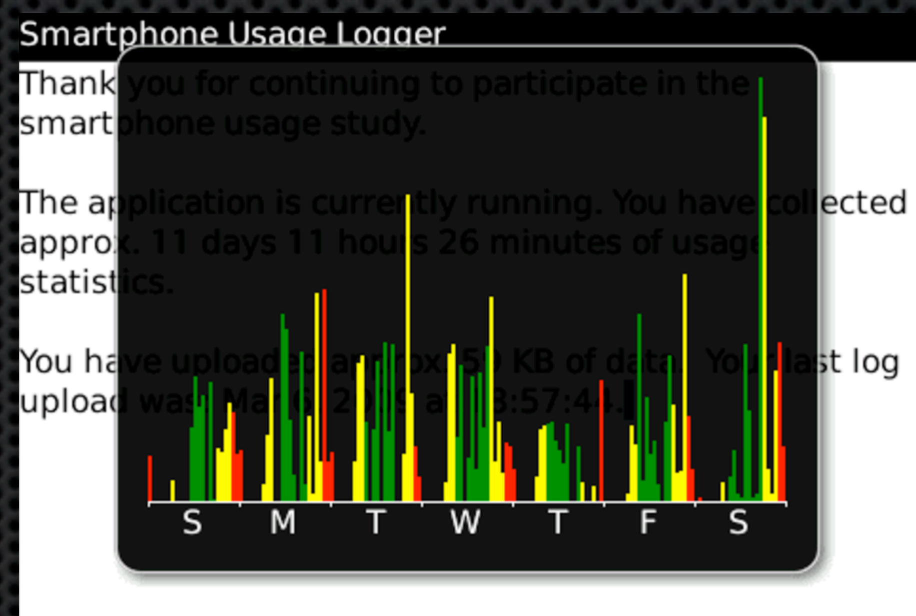

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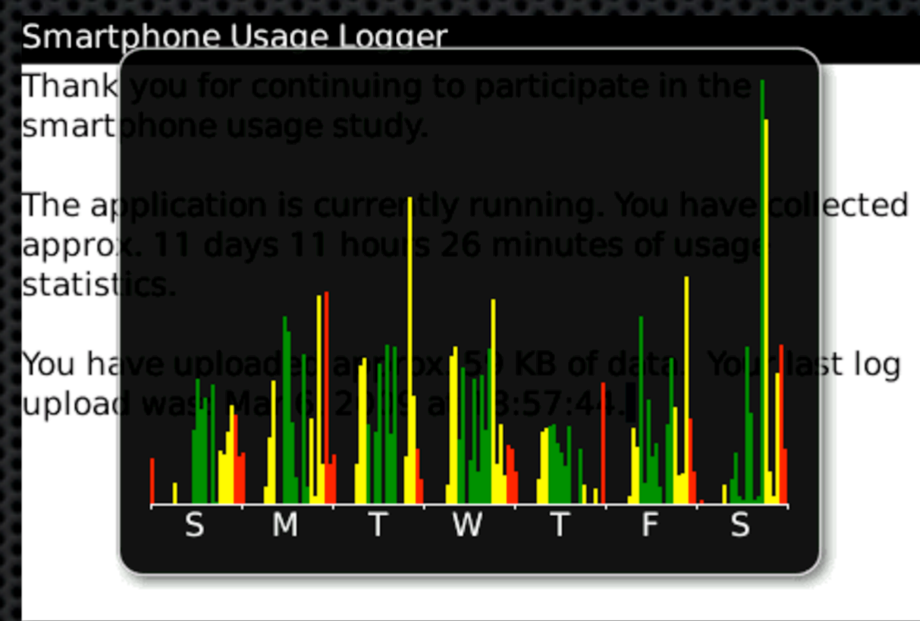

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    - Clusters of download in Apache logs
  - ~65% of data collected by standard logger was questionable and discarded

Hardware characteristics

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- Radios
  - GSM
  - CDMA
  - iDEN
- Wi-Fi
- Camera
- GPS
- Screen sizes from: 240x260px to 360x480px

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- Radios
  - GSM
  - CDMA
  - iDEN
- Wi-Fi
- Camera
- GPS
- Screen sizes from: 240x260px to 360x480px
- Isomorphic to other devices from other manufactures.

Dataset

* As of 16:00h February 2, 2010

Dataset

- 3.5 years of cumulative smartphone usage as of September 2009

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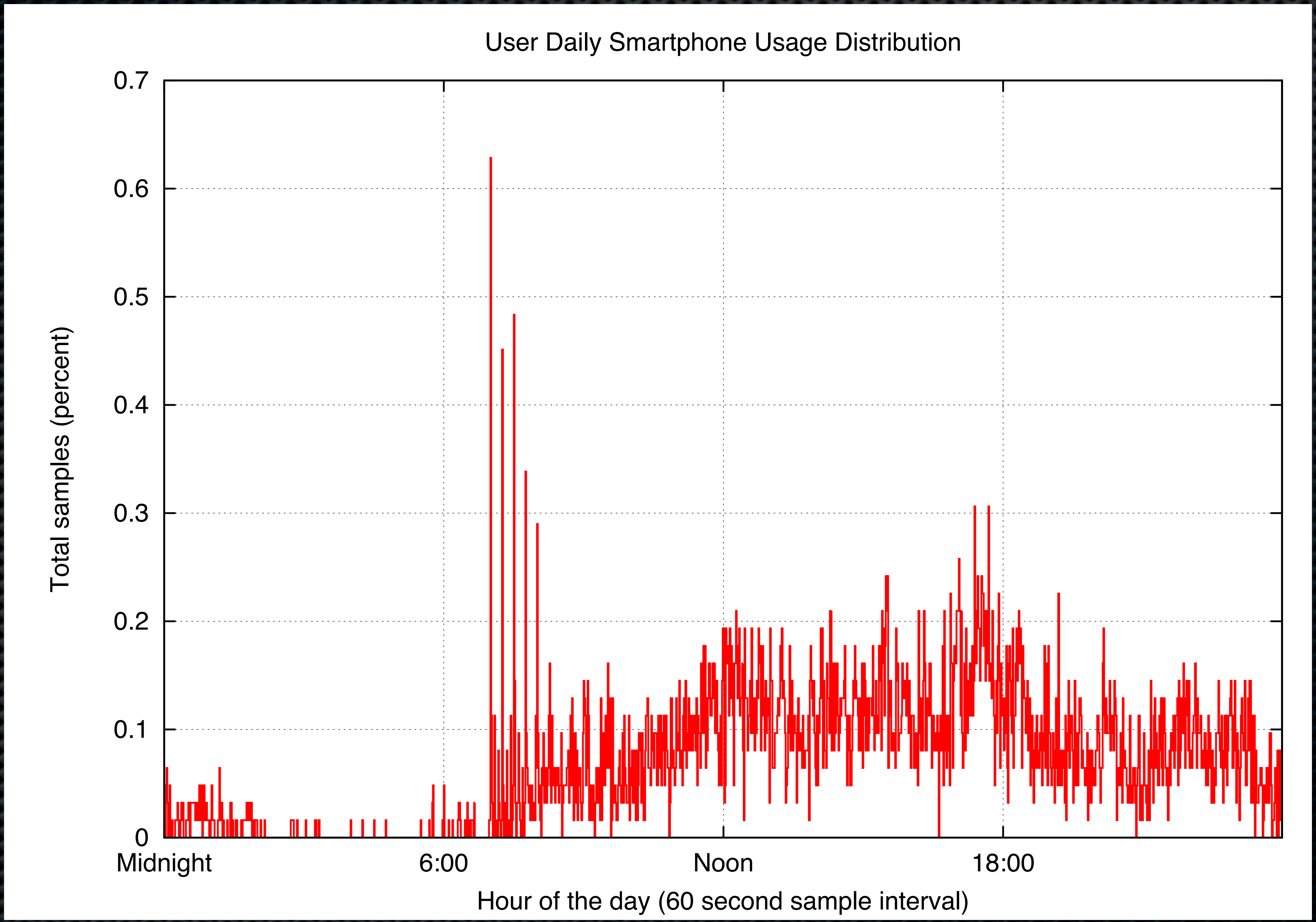
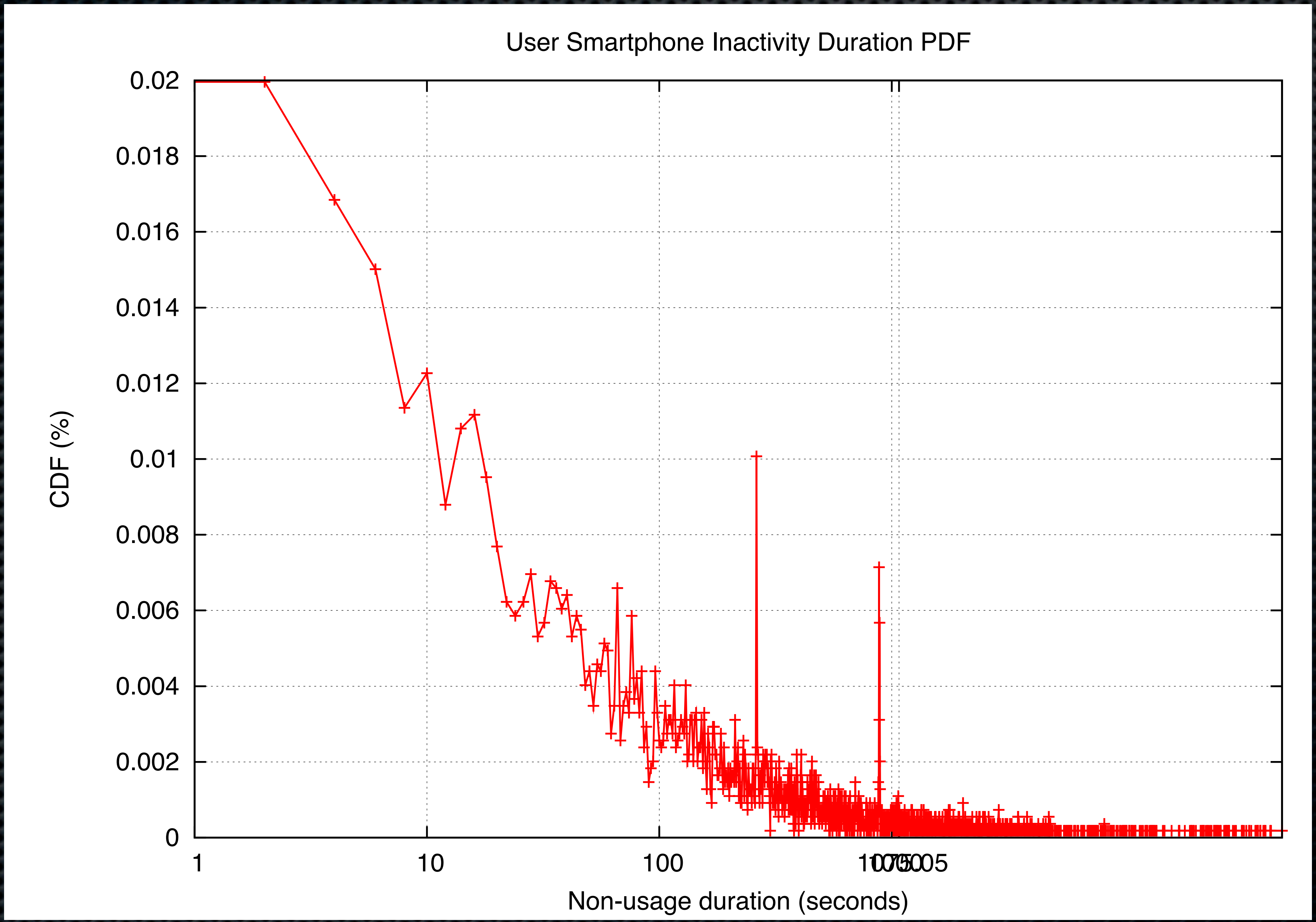
Dataset

- 3.5 years of cumulative smartphone usage as of September 2009
- 0.512 millennium of usage as of February 2010
  - 13523 BlackBerry users
  - Spanning 11 types of devices, 23 timezones
- Mean/median user contribution: 13.8/15.3 days

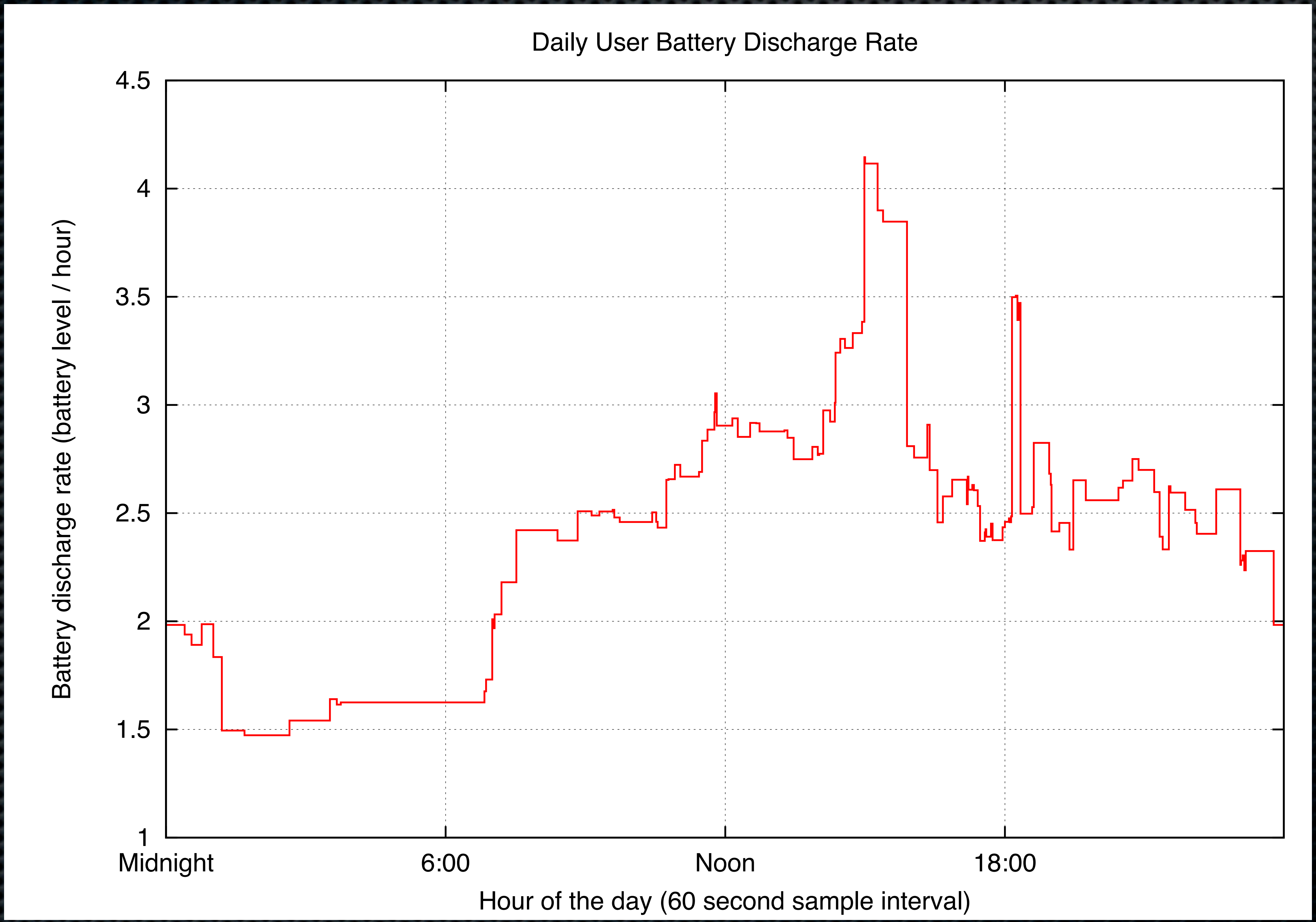
* As of 16:00h February 2, 2010

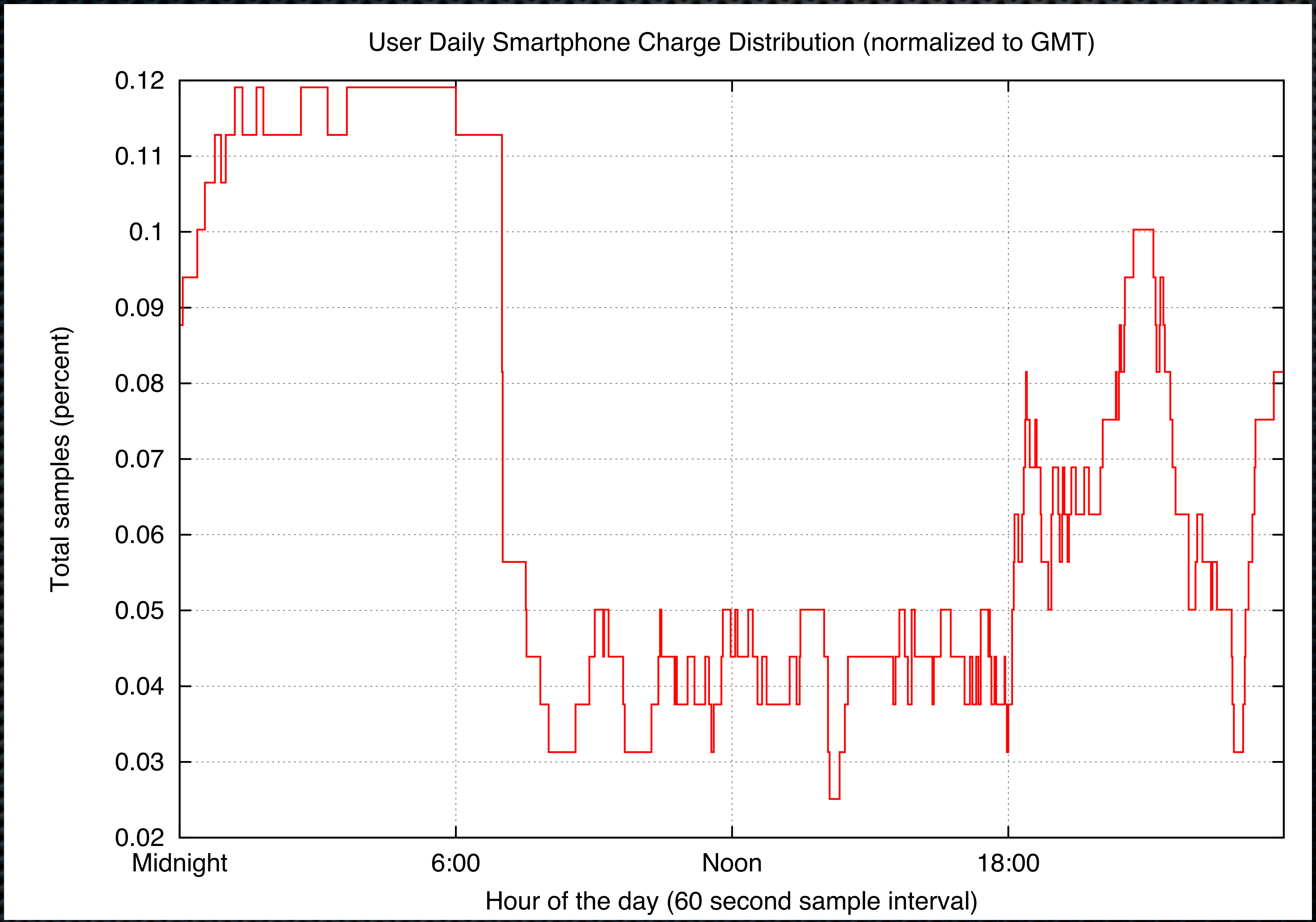
Sample usage traces

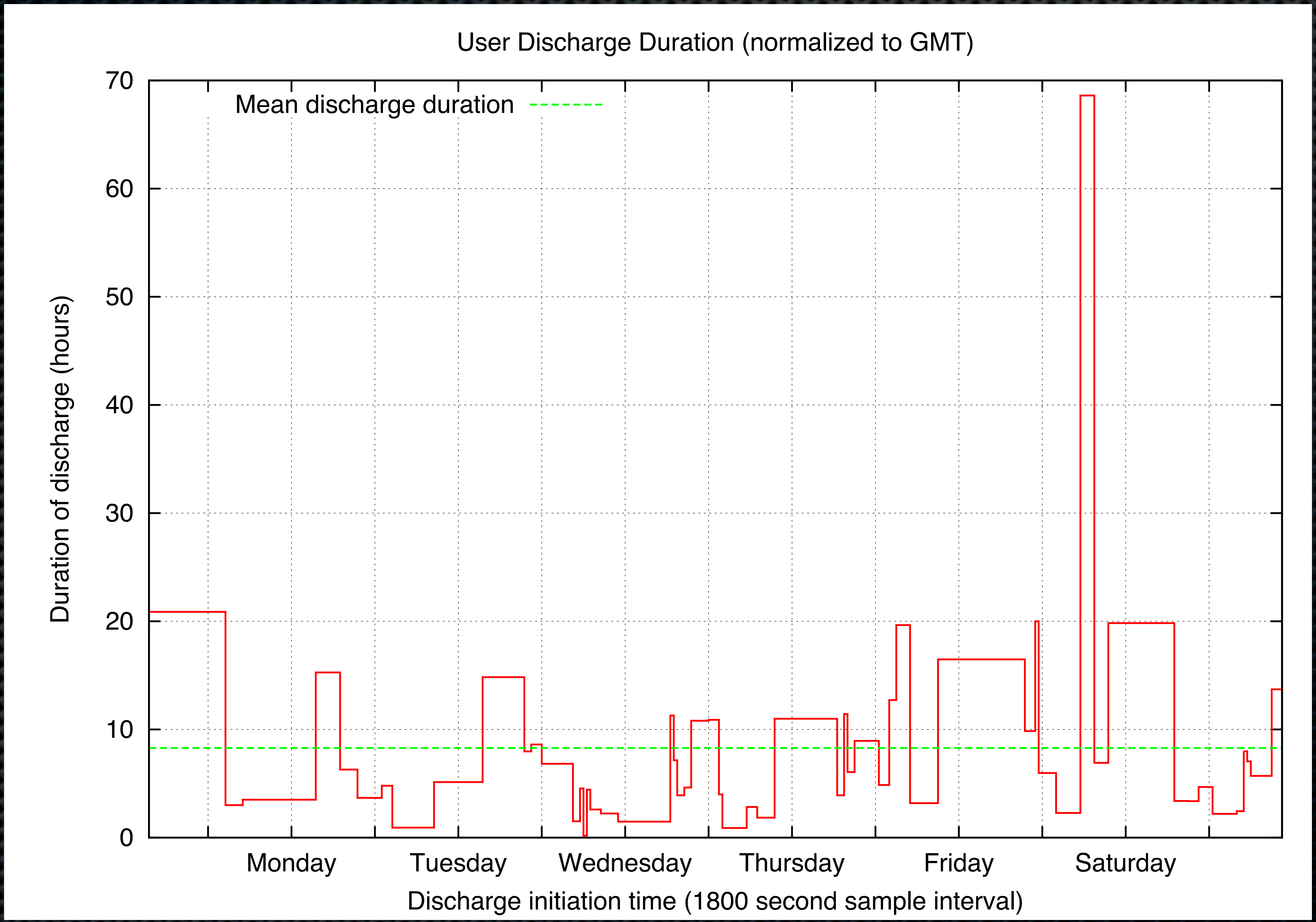



User Smartphone Inactivity Duration PDF
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
CDF (%)
1
10
100
1075005
Non-usage duration (seconds)

Sample energy traces




User Daily Smartphone Charge Distribution (normalized to GMT)
Total samples (percent)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
Midnight
6:00
Noon
18:00
Hour of the day (60 second sample interval)


User Discharge Duration (normalized to GMT)
Mean discharge duration
Duration of discharge (hours)
0
10
20
30
40
50
60
70
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Discharge initiation time (1800 second sample interval)

Energy level prediction

Half way!

You're doing great!

Energy level prediction

- Variables of interest:

Half way!

You're doing great!

Energy level prediction

- Variables of interest:
  - charge duration

Half way!

You're doing great!

Energy level prediction

- Variables of interest:
  - charge duration
  - discharge duration

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Energy level prediction

- Variables of interest:
  - charge duration
  - discharge duration
  - battery level when a charge is initiated

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- Variables of interest:
  - charge duration
  - discharge duration
  - battery level when a charge is initiated
  - charge rate

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- Variables of interest:
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  - discharge duration
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  - charge rate
  - discharge rate

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Energy level prediction

- Variables of interest:
  - charge duration
  - discharge duration
  - battery level when a charge is initiated
  - charge rate
  - discharge rate
  - device type

Half way!

You're doing great!

Energy level prediction

- Variables of interest:
  - charge duration
  - discharge duration
  - battery level when a charge is initiated
  - charge rate
  - discharge rate
  - device type

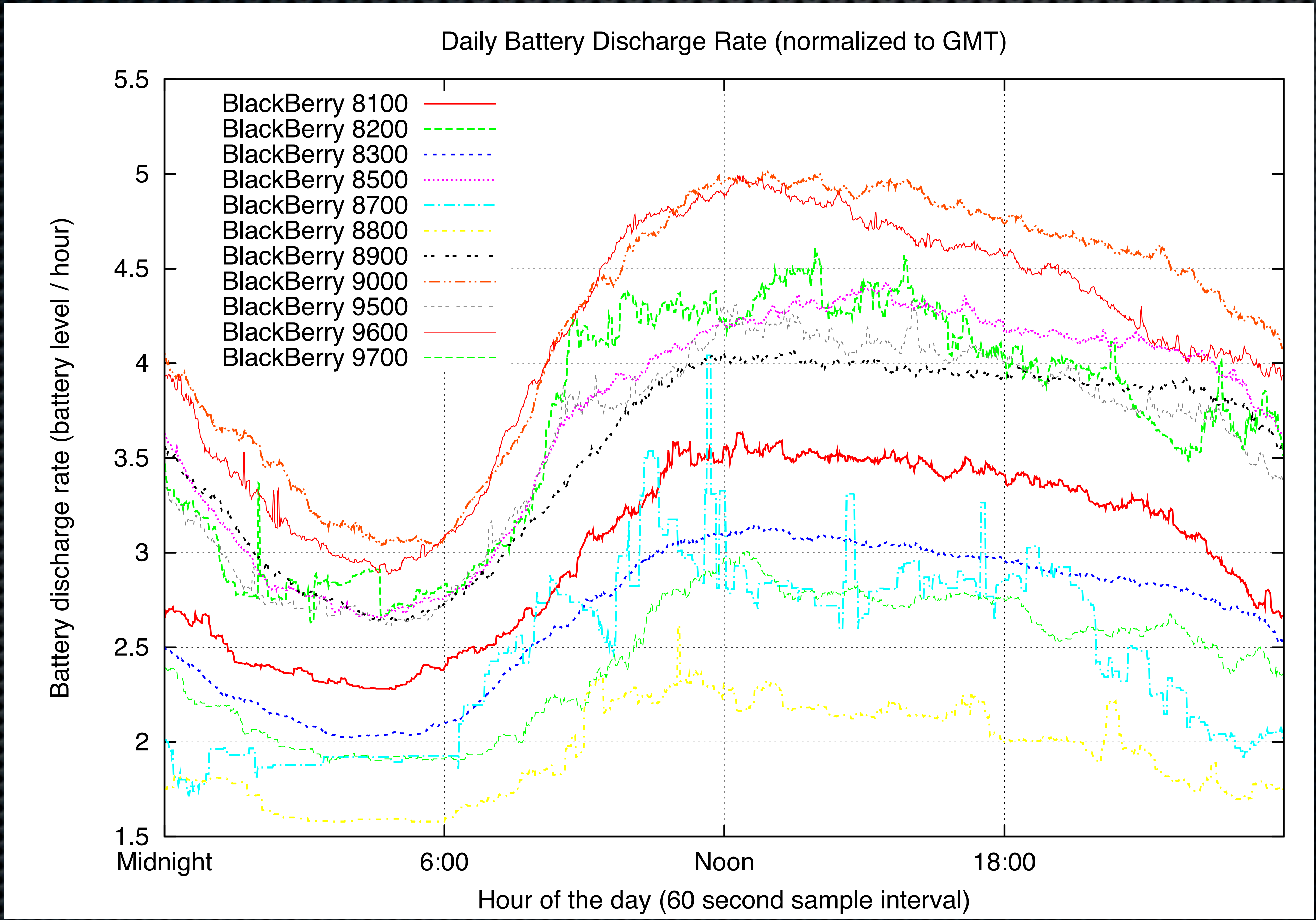
Time of the day/week

Half way!

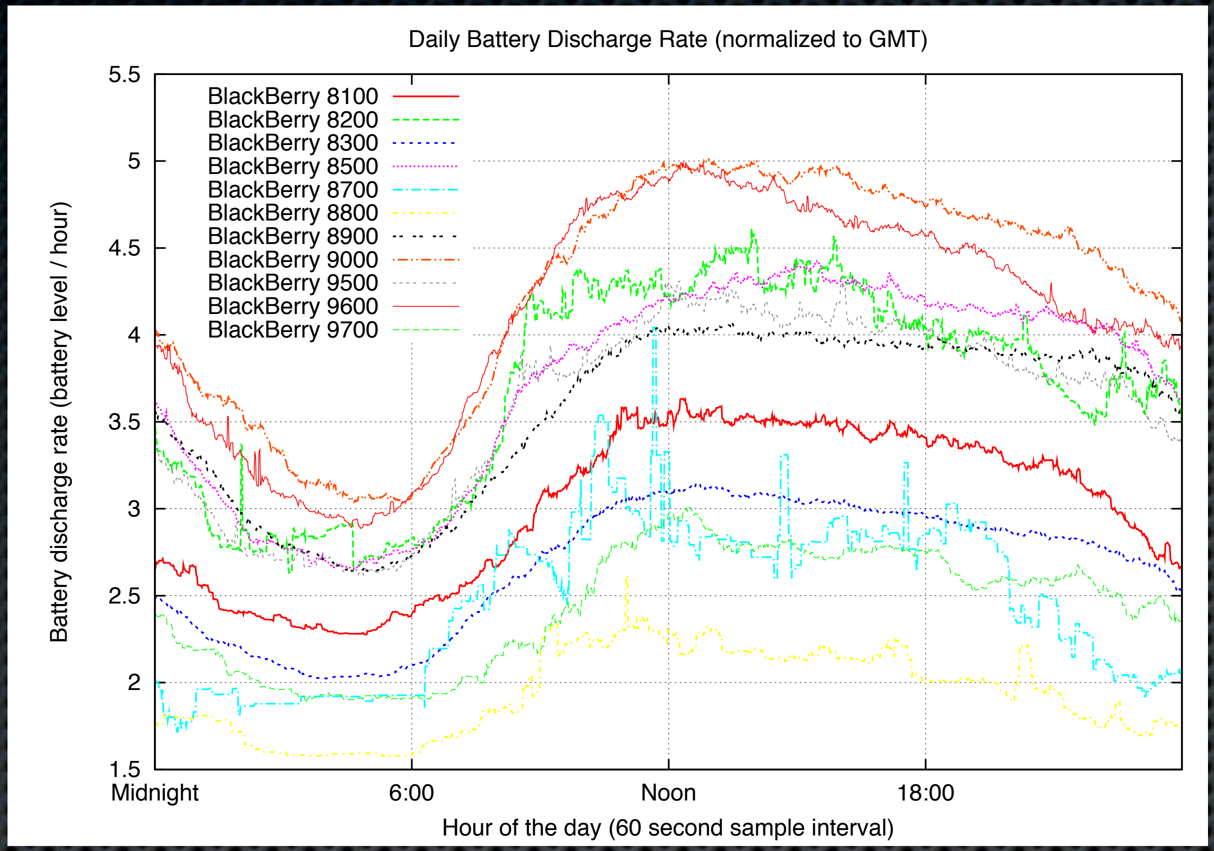
You're doing great!

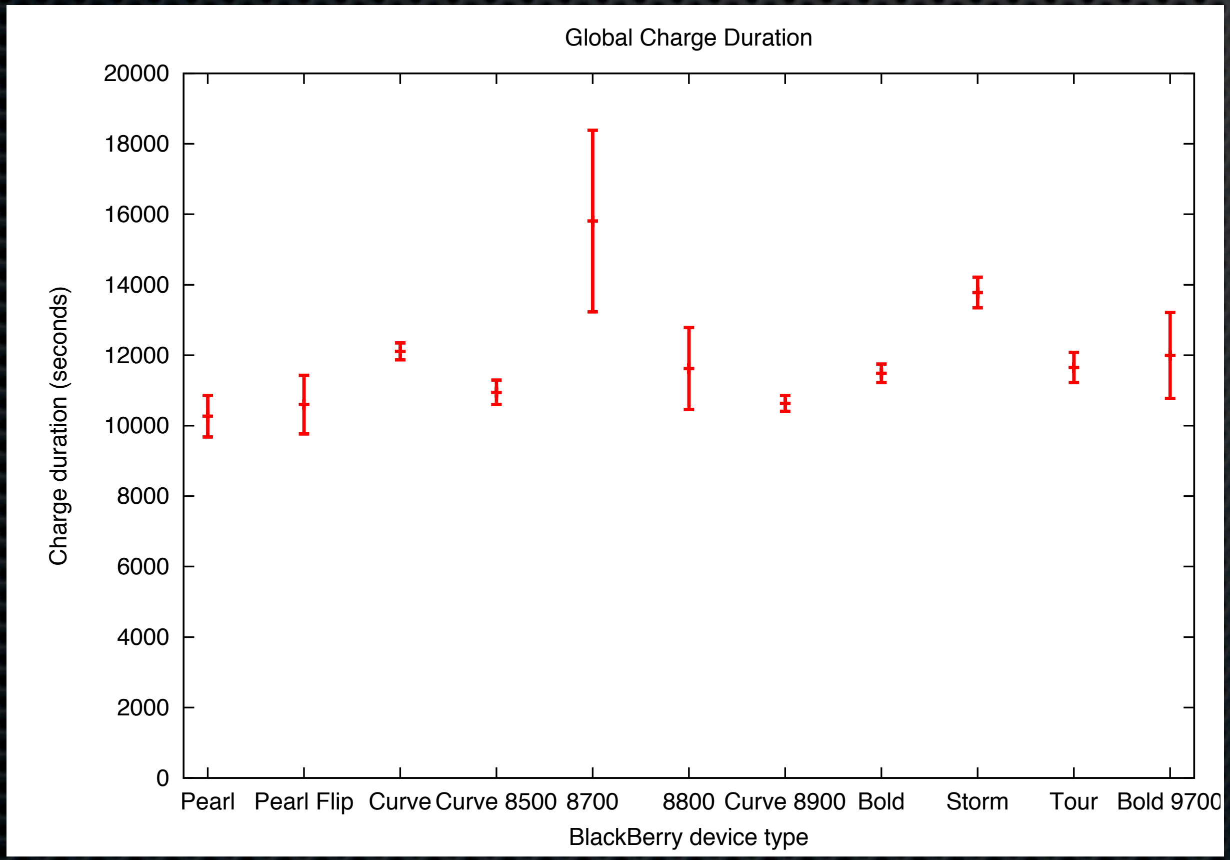
User classification

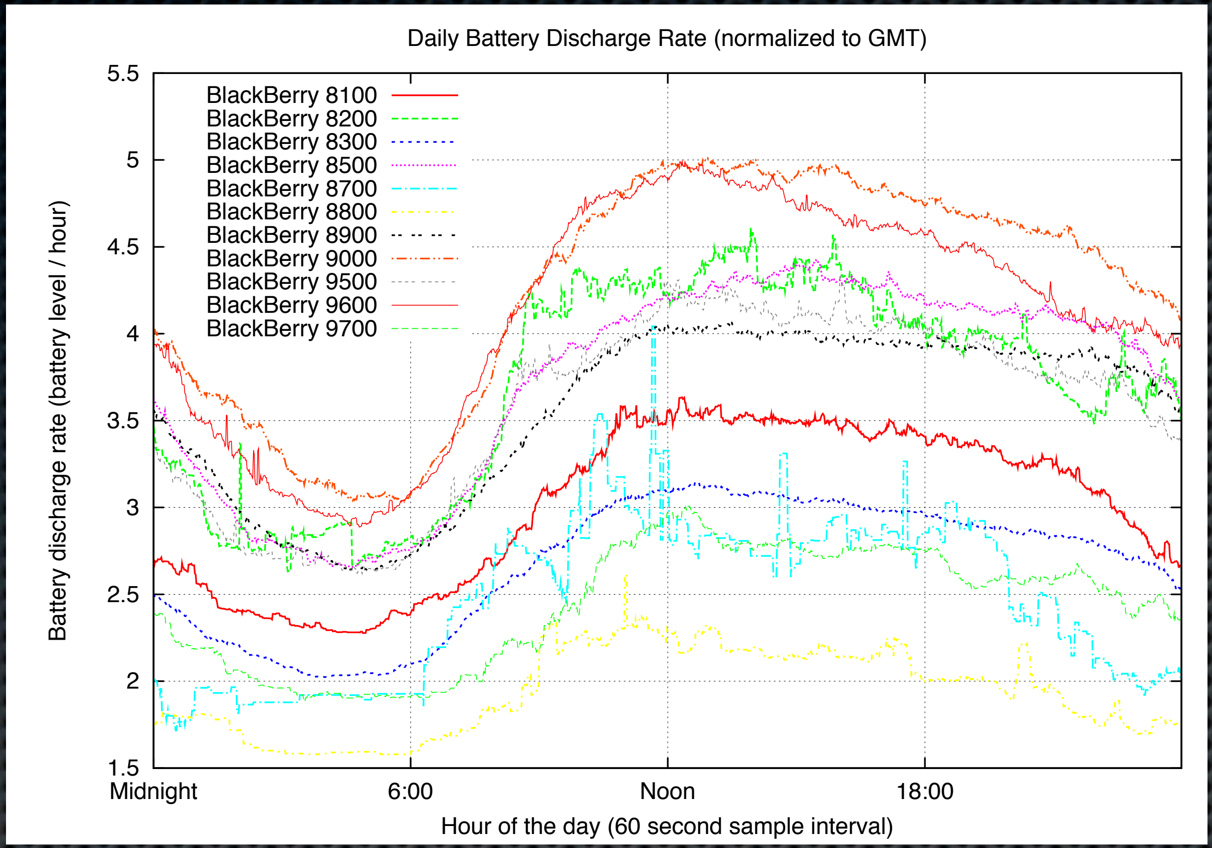
- Cluster by device



Daily Battery Discharge Rate (normalized to GMT)
Battery discharge rate (battery level / hour)
5.5
5
4.5
4
3.5
3
2.5
2
1.5
Midnight
6:00
Noon
18:00
Hour of the day (60 second sample interval)
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700


Daily Battery Discharge Rate (normalized to GMT)
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Battery discharge rate (battery level / hour)
Midnight
6:00
Noon
18:00
Hour of the day (60 second sample interval)


Global Charge Duration
Charge duration (seconds)
Pearl
Pearl Flip
Curve
Curve 8500
8700
8800
Curve 8900
Bold
Storm
Tour
Bold 9700
BlackBerry device type


Daily Battery Discharge Rate (normalized to GMT)
BlackBerry 8100
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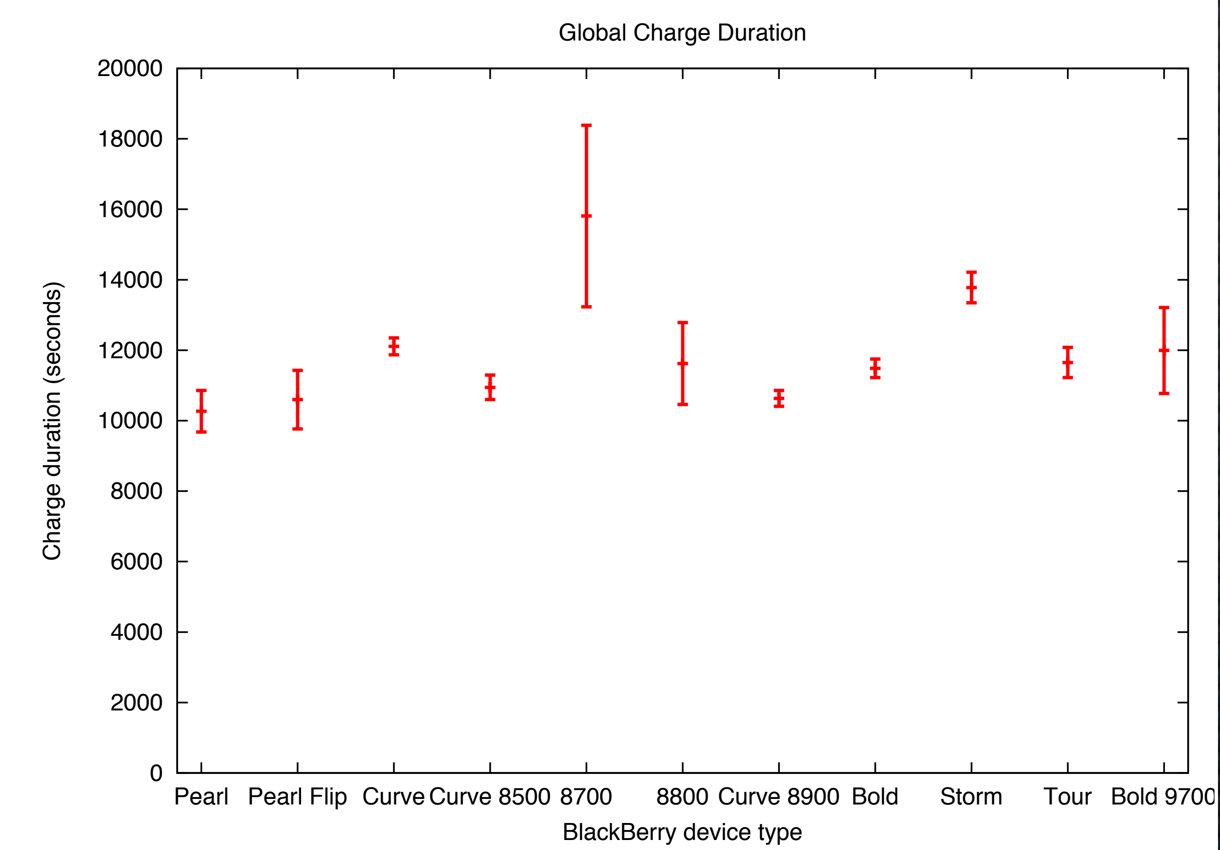
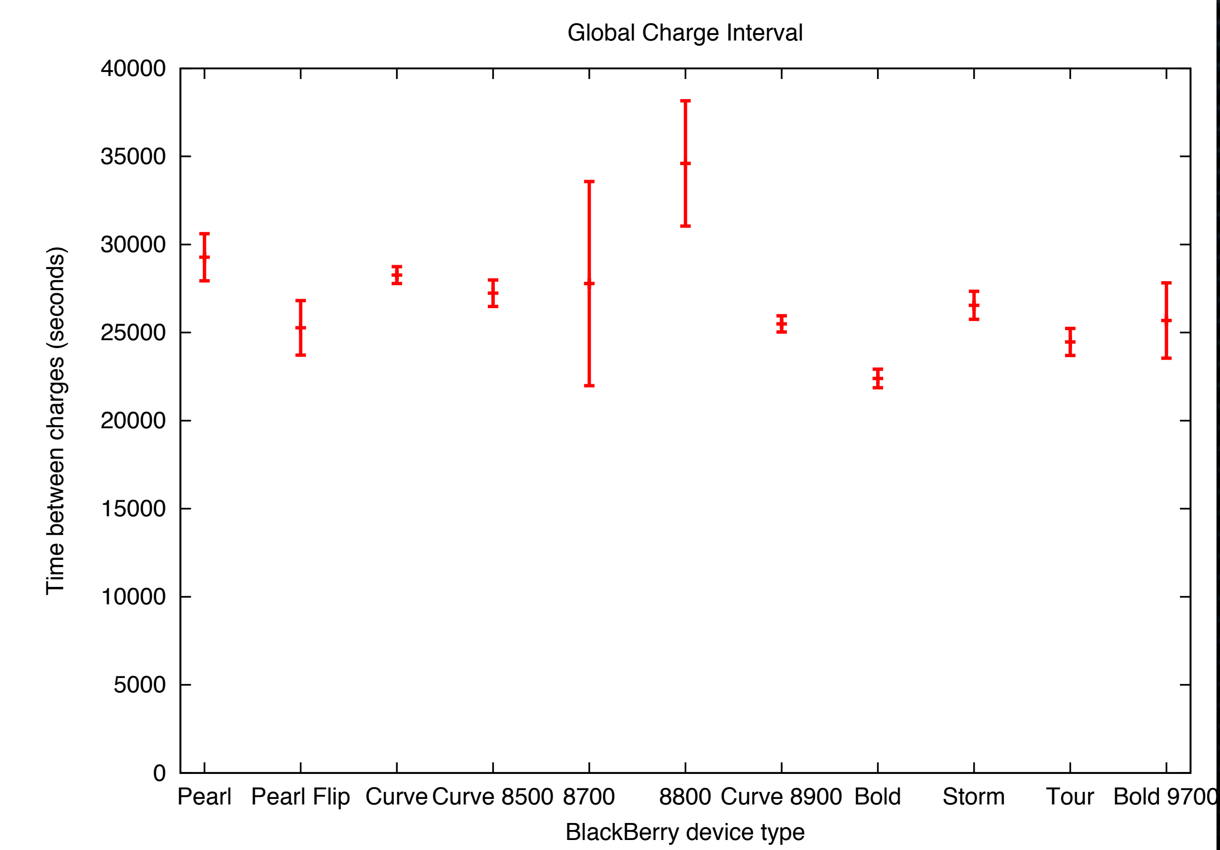
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Battery discharge rate (battery level / hour)
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Midnight
6:00
Noon
18:00
Hour of the day (60 second sample interval)


Global Charge Duration
Charge duration (seconds)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Pearl
Pearl Flip
Curve
Curve 8500
8700
8800
Curve 8900
Bold
Storm
Tour
Bold 9700
BlackBerry device type


Global Charge Interval
Time between charges (seconds)
0
5000
10000
15000
20000
25000
30000
35000
40000
Pearl
Pearl Flip
Curve
Curve 8500
8700
8800
Curve 8900
Bold
Storm
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User classification

- Cluster by device
- Cluster by energy consumption/replenishment characteristics
  - Which set of characteristics are best?
    - The set that yield the best prediction results.

Prediction algorithm

Algorithm 1 Calculate future battery level

Require: $\delta_{charge|discharge}$, $\rho_{charge|discharge}$, b_{curr}, β, γ, t_{last}, $t_{predict}$

$i \leftarrow 0$

for $i < t_{predict}$ **do**

  if $\gamma \wedge t_{curr} < t_{last} + \delta_{charge}(t_{last})$ **then**

    $\gamma \leftarrow$ **false**{The charge period has ended.}

    $t_{last} \leftarrow t_{last} + \delta_{charge}(t_{last})$

  else if $\neg\gamma \wedge t_{curr} < t_{last} + \delta_{discharge}(t_{last})$ **then**

    $\gamma \leftarrow$ **true**{The discharge period has ended.}

    $t_{last} \leftarrow t_{last} + \delta_{discharge}(t_{last})$

  end if

  if γ **then**

    $b_{future} \leftarrow b_{future} + \rho_{charge}(\beta, t_{curr})$

  else

    $b_{future} \leftarrow b_{future} - \rho_{discharge}(\beta, t_{curr})$

  end if

  $i \leftarrow i + BUCKET\_SIZE$

  $t_{curr} \leftarrow t_{curr} + BUCKET\_SIZE$

end for

return b_{future}

Prediction algorithm

t_{last} = last time that the device began charging or discharging

δ_{charge_t} = mean charge duration of a charge initiated during *bucket(t)*

$\delta_{discharge_t}$ = mean discharge duration of a discharge initiated during *bucket(t)*

ρ_{charge_t} = mean charge rate during bucket(t)

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bucket size = 30 minutes

Prediction algorithm

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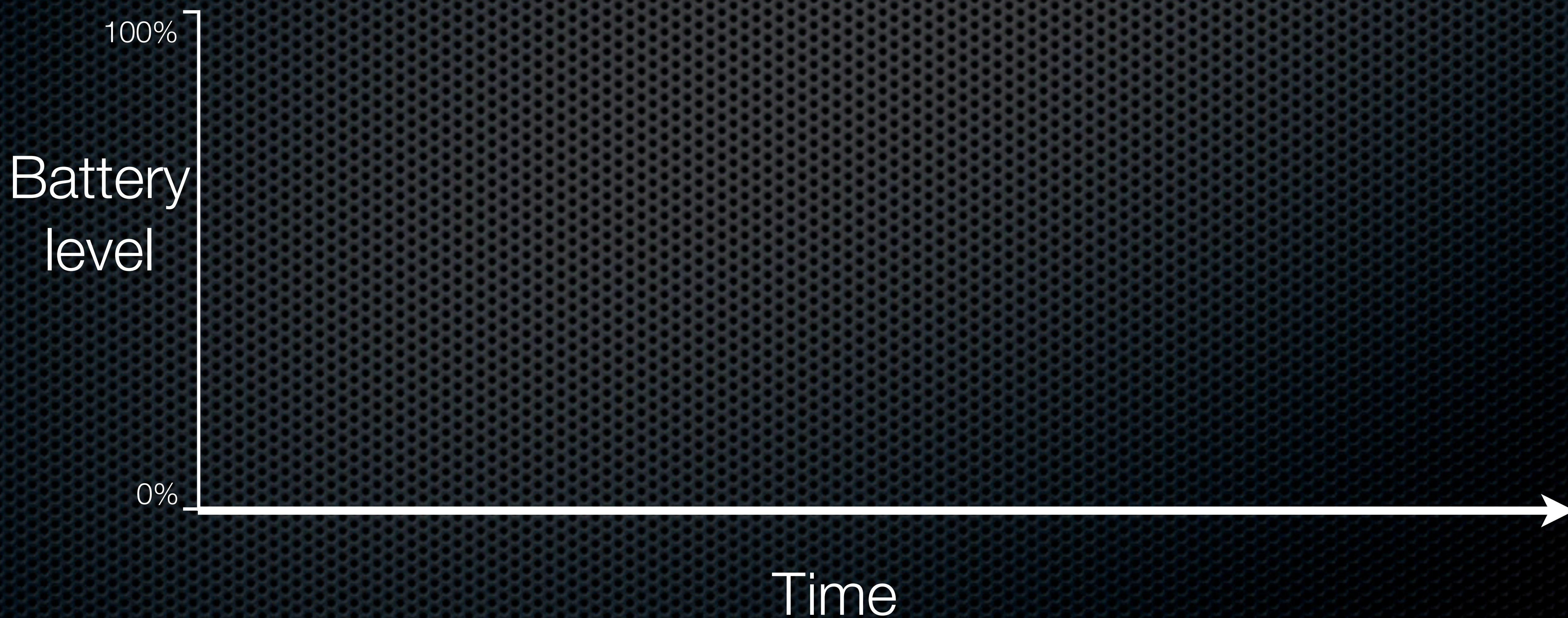

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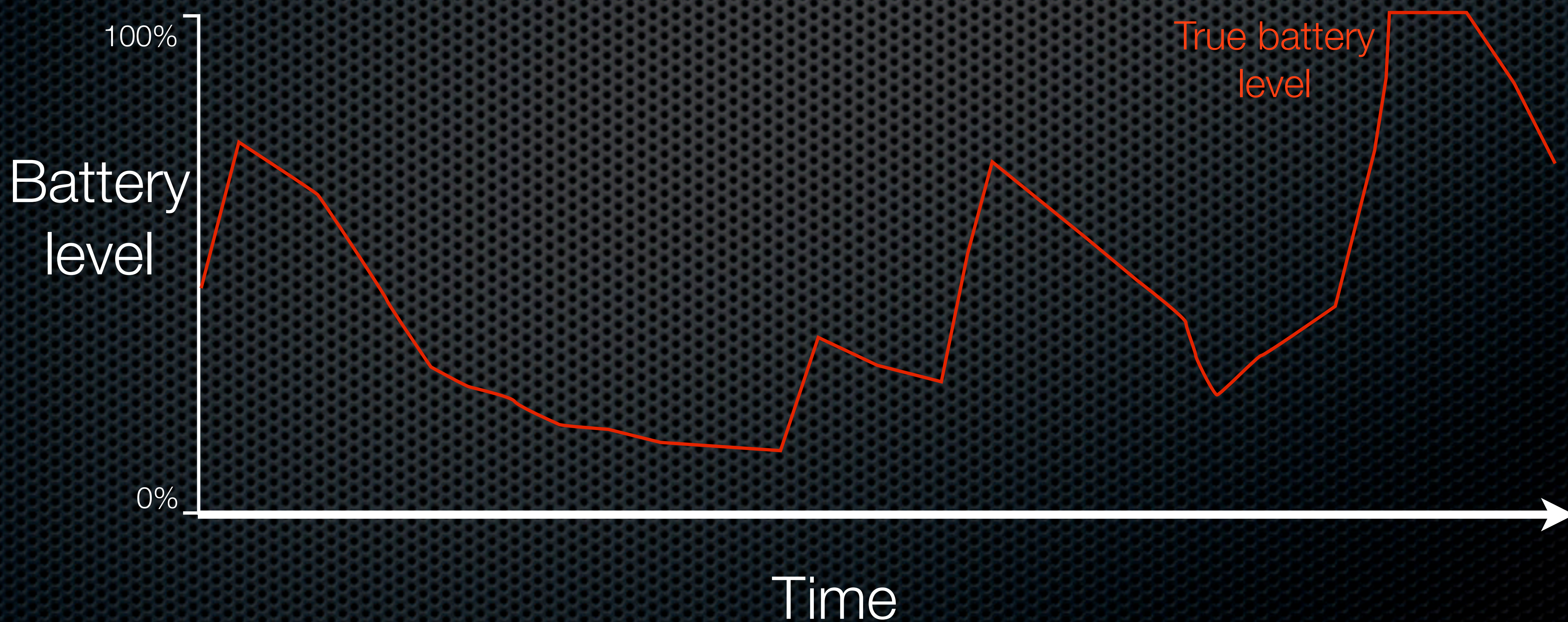

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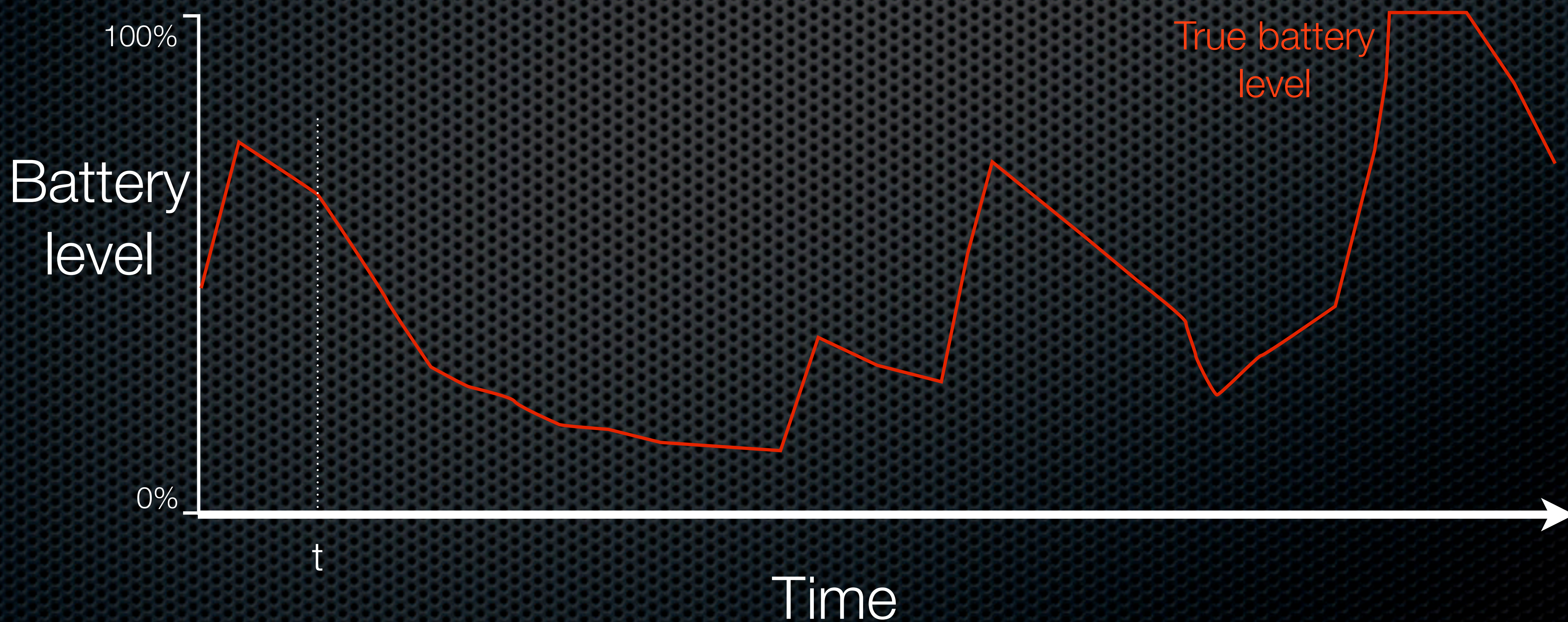

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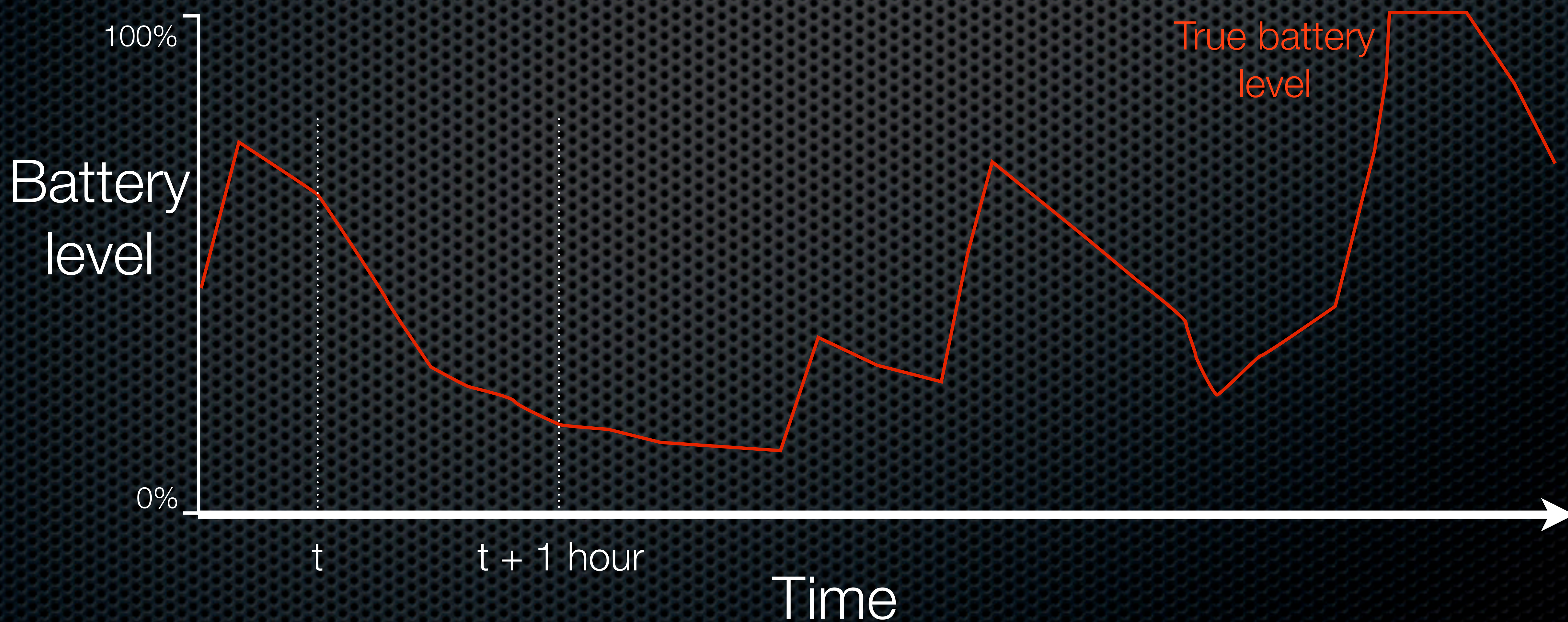

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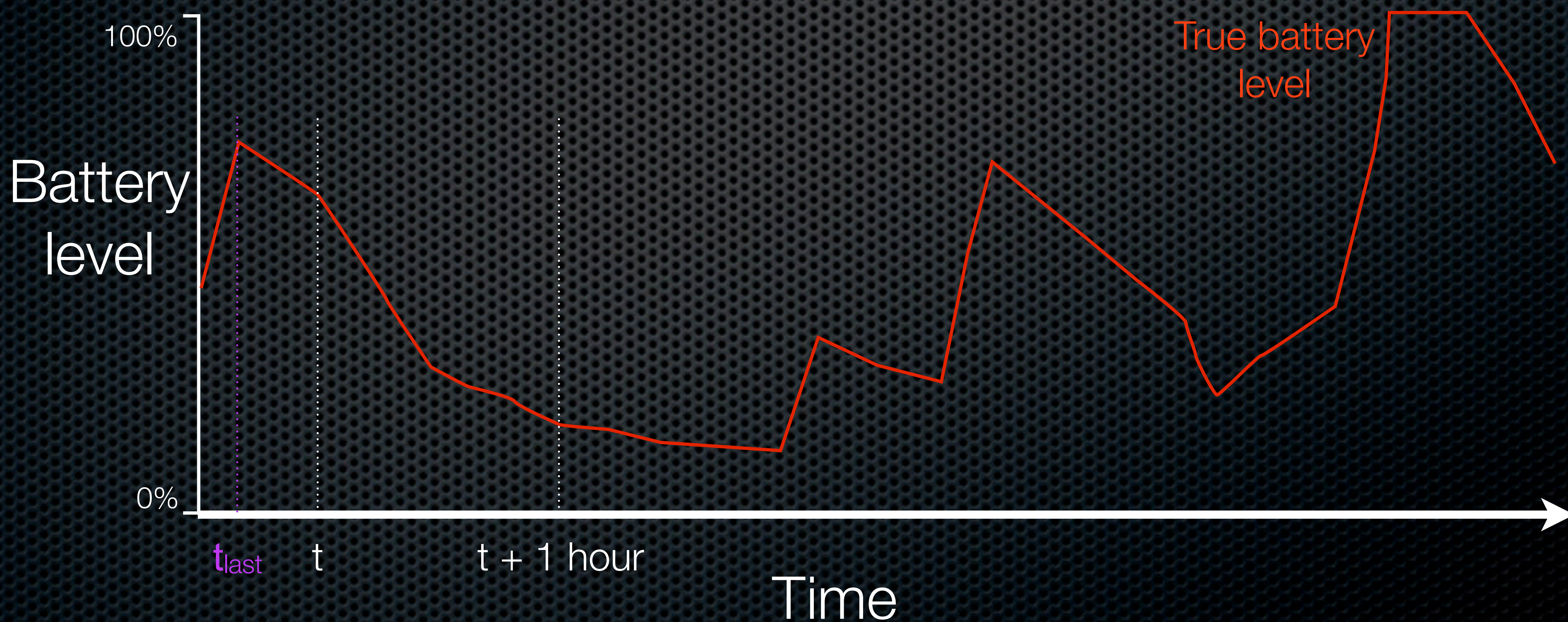

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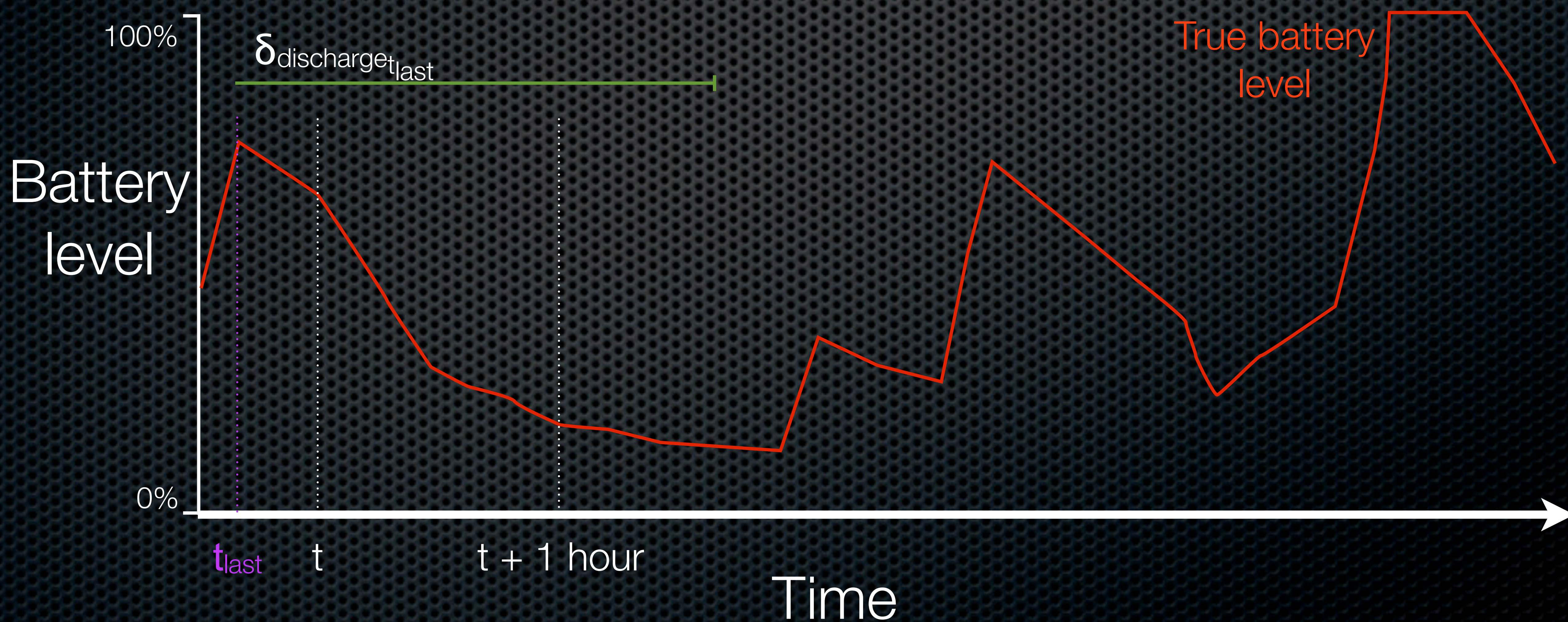

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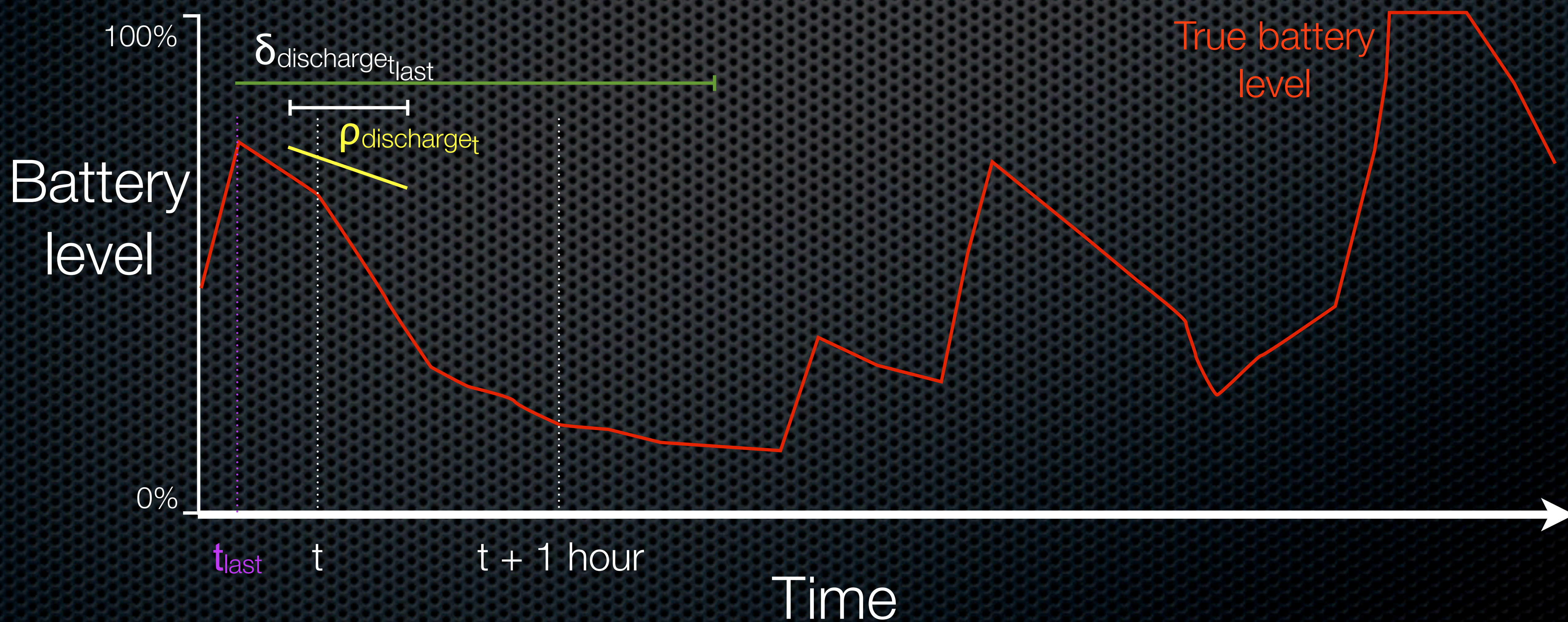

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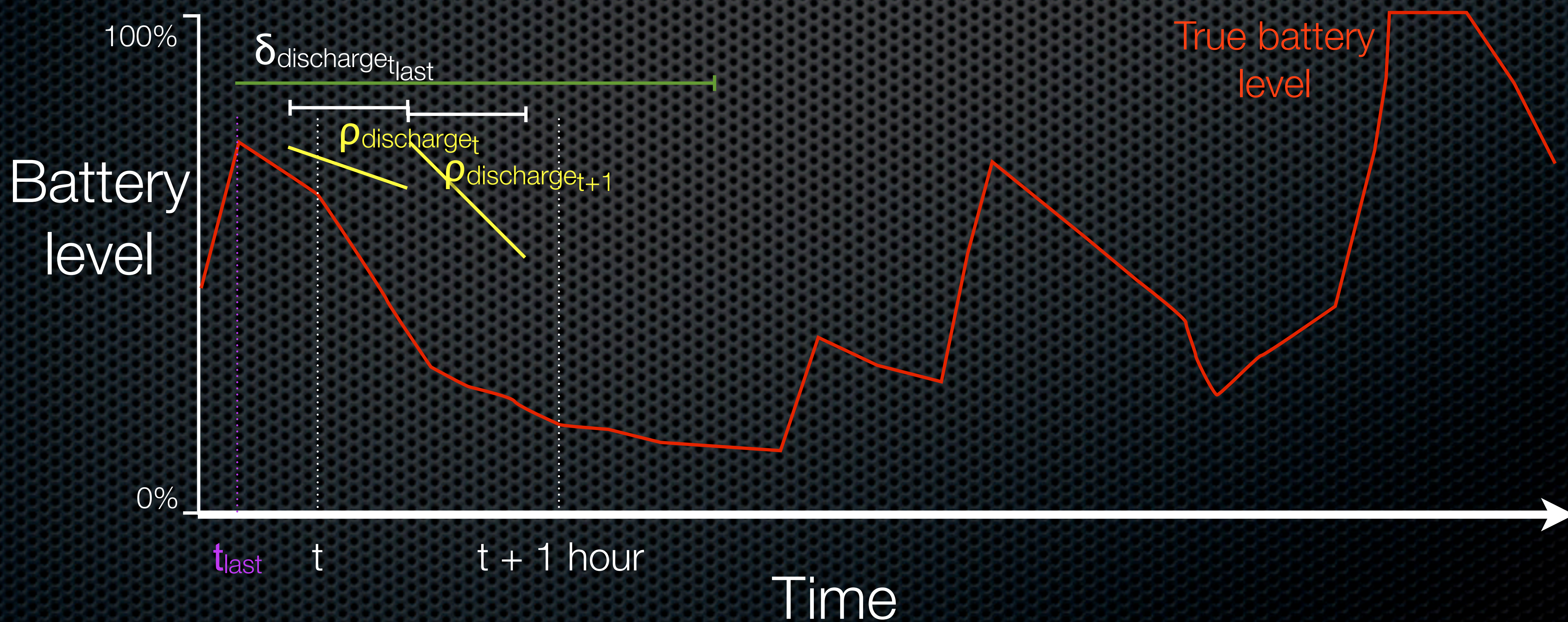

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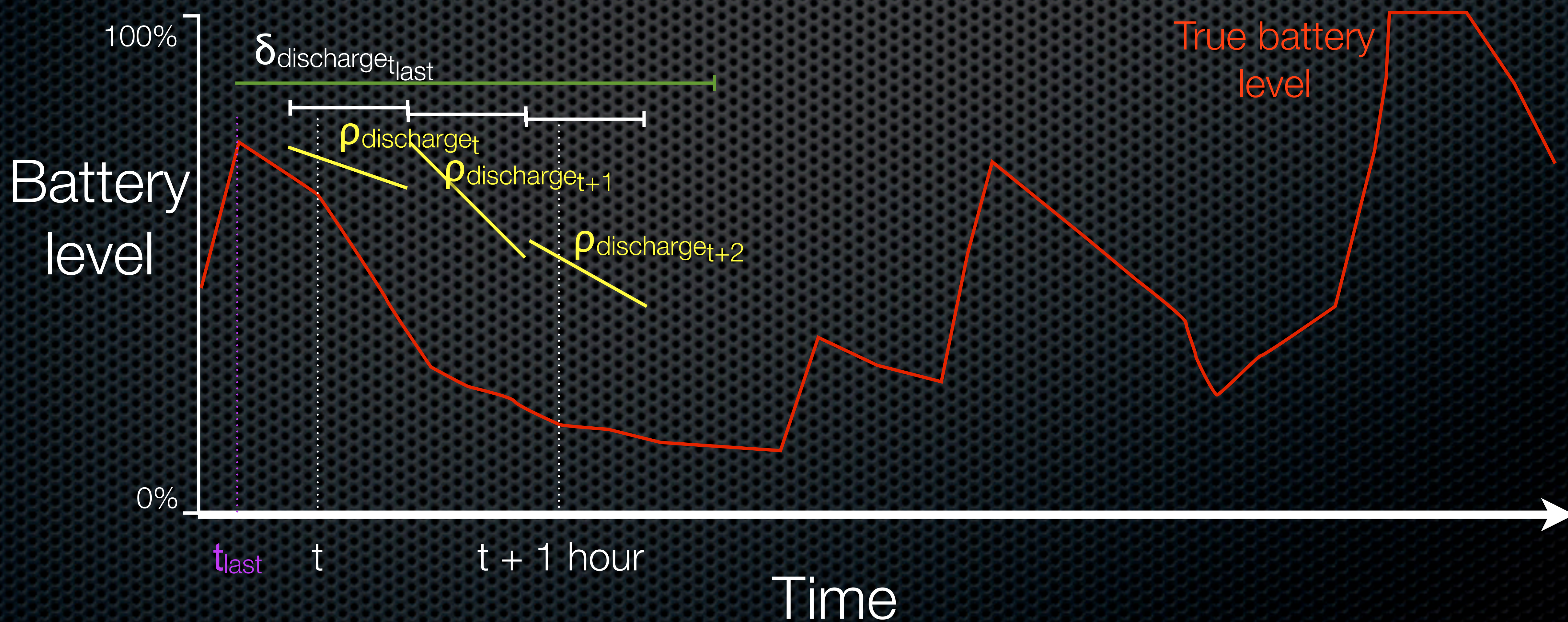

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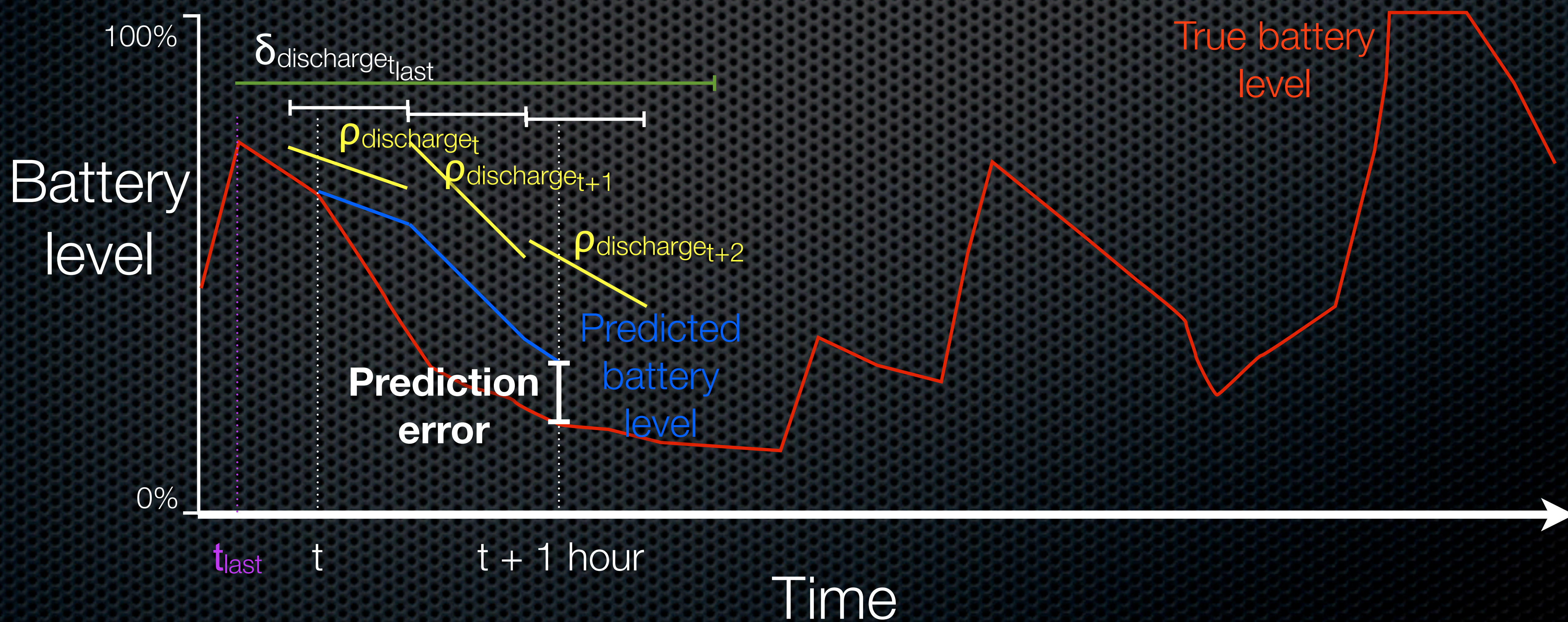

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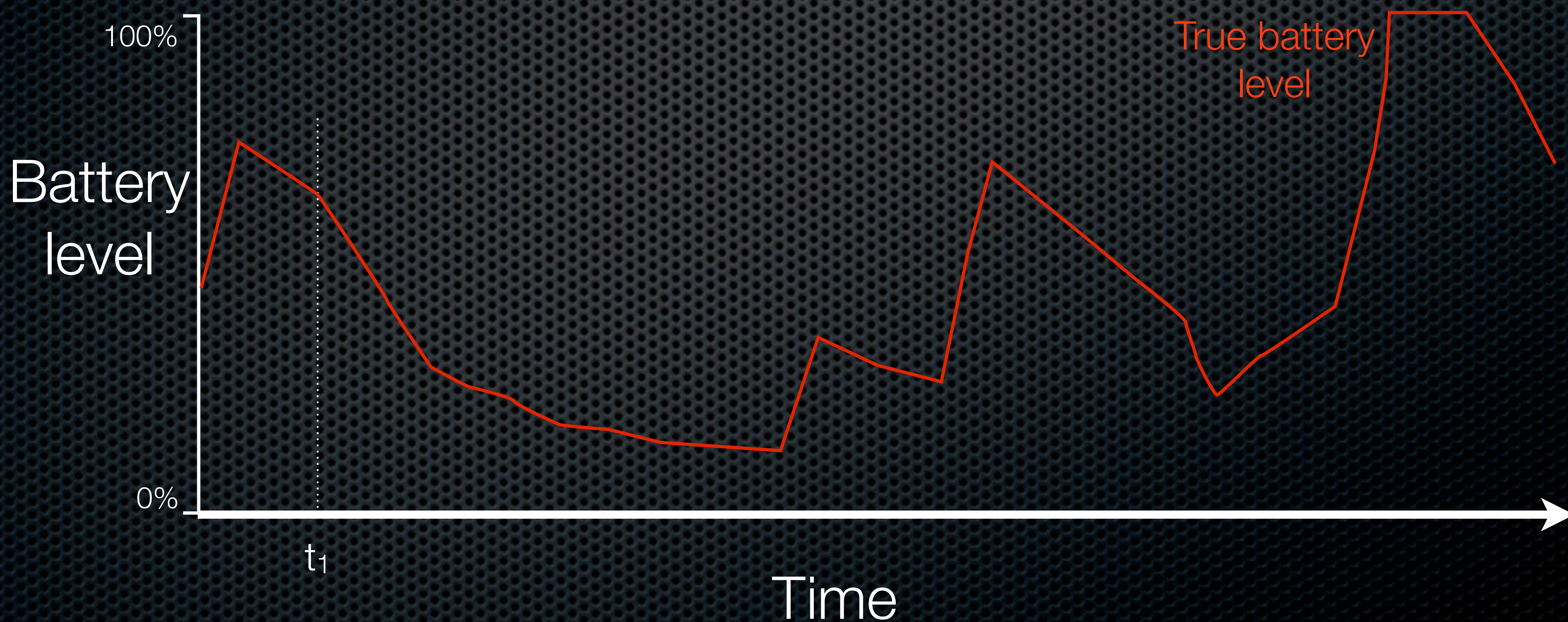

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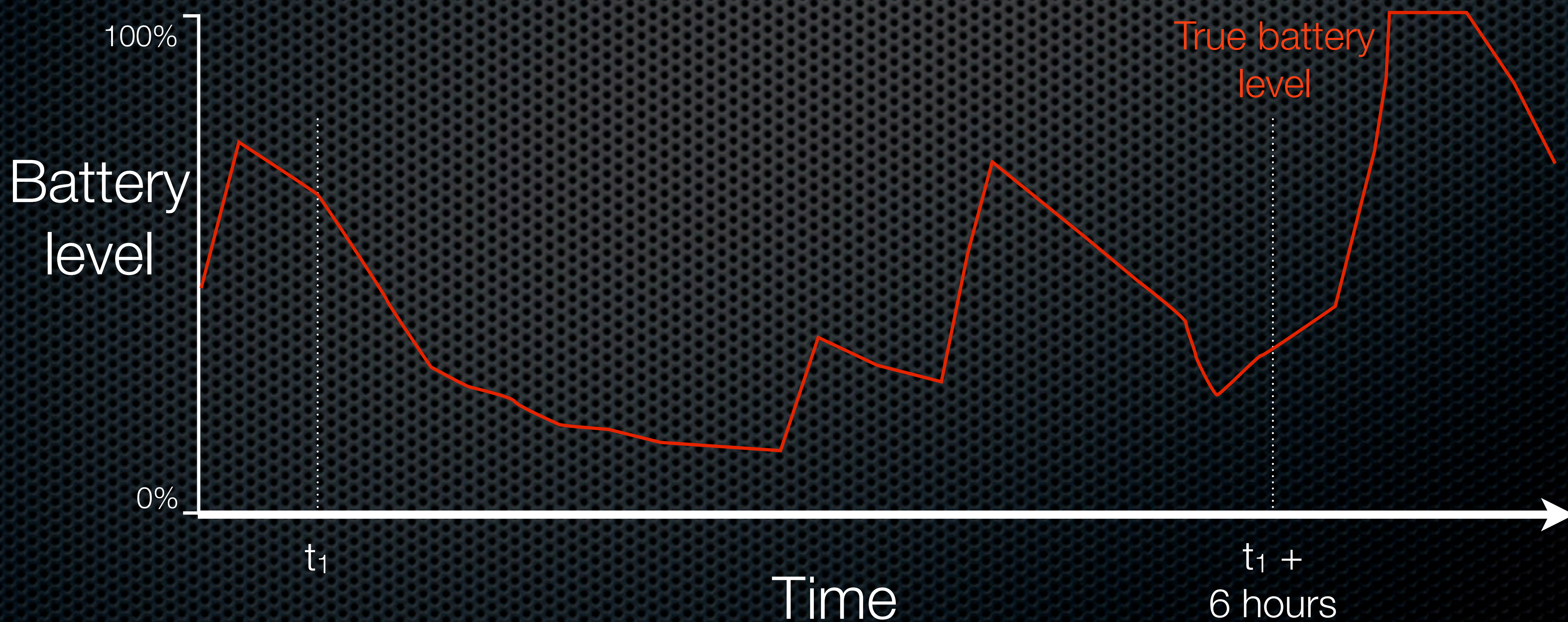

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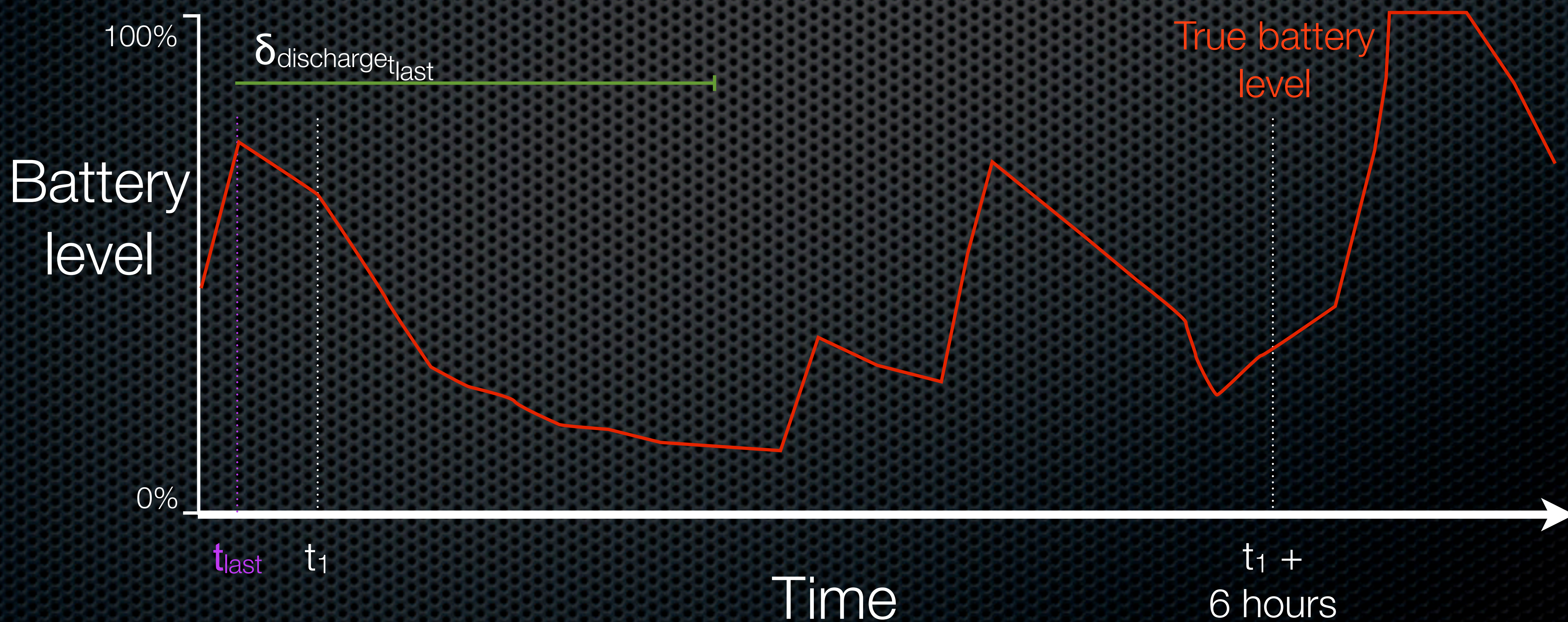

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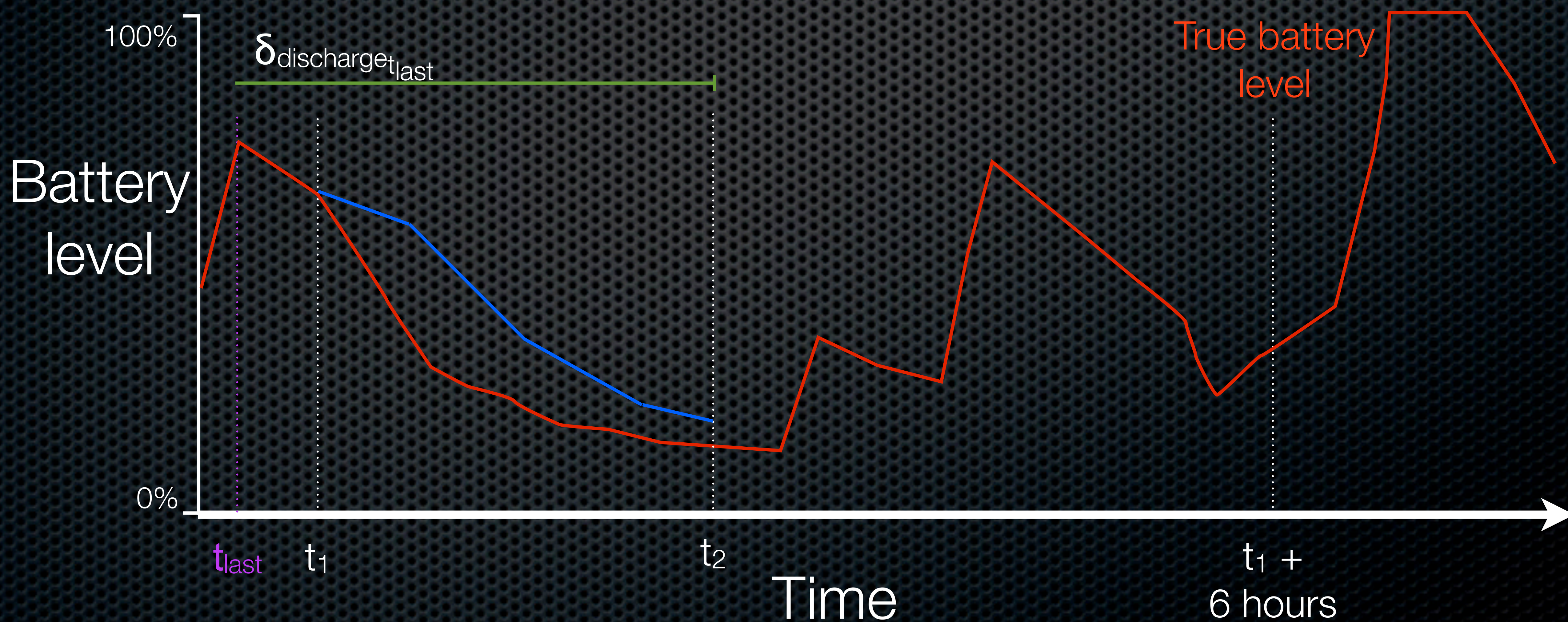

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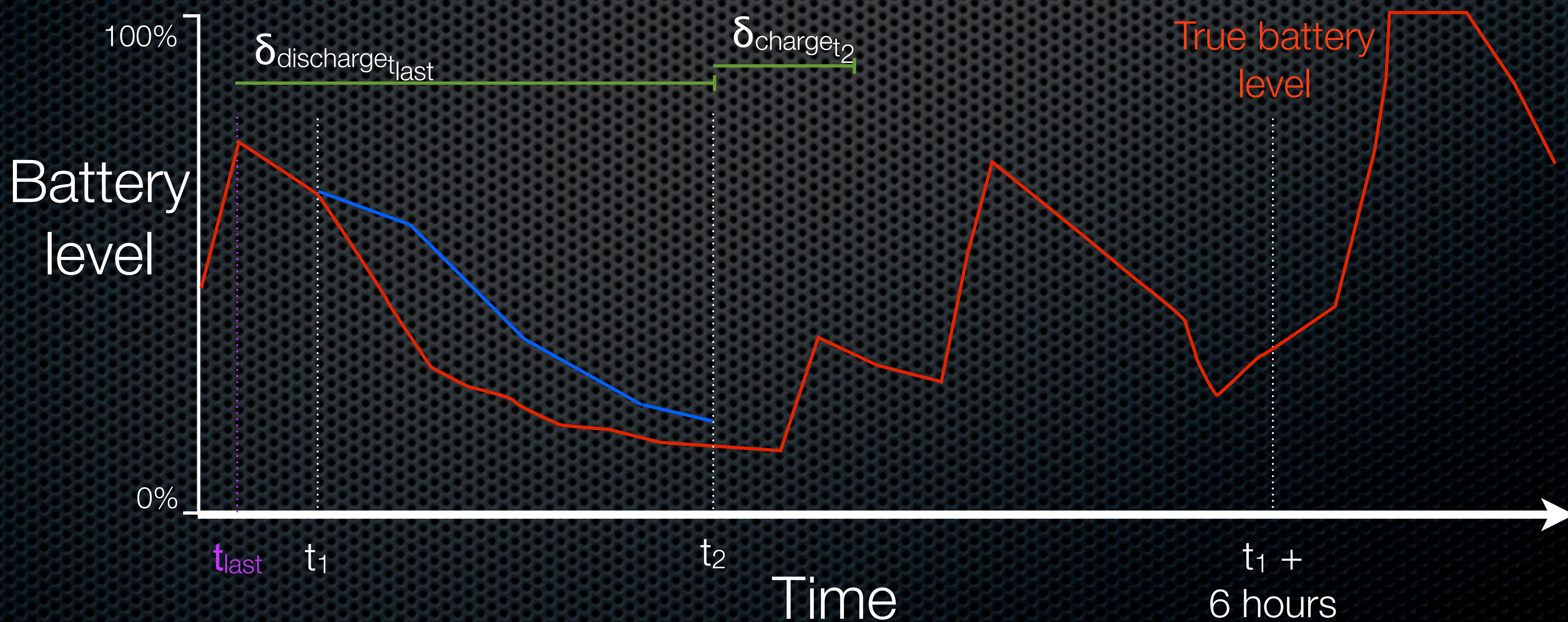

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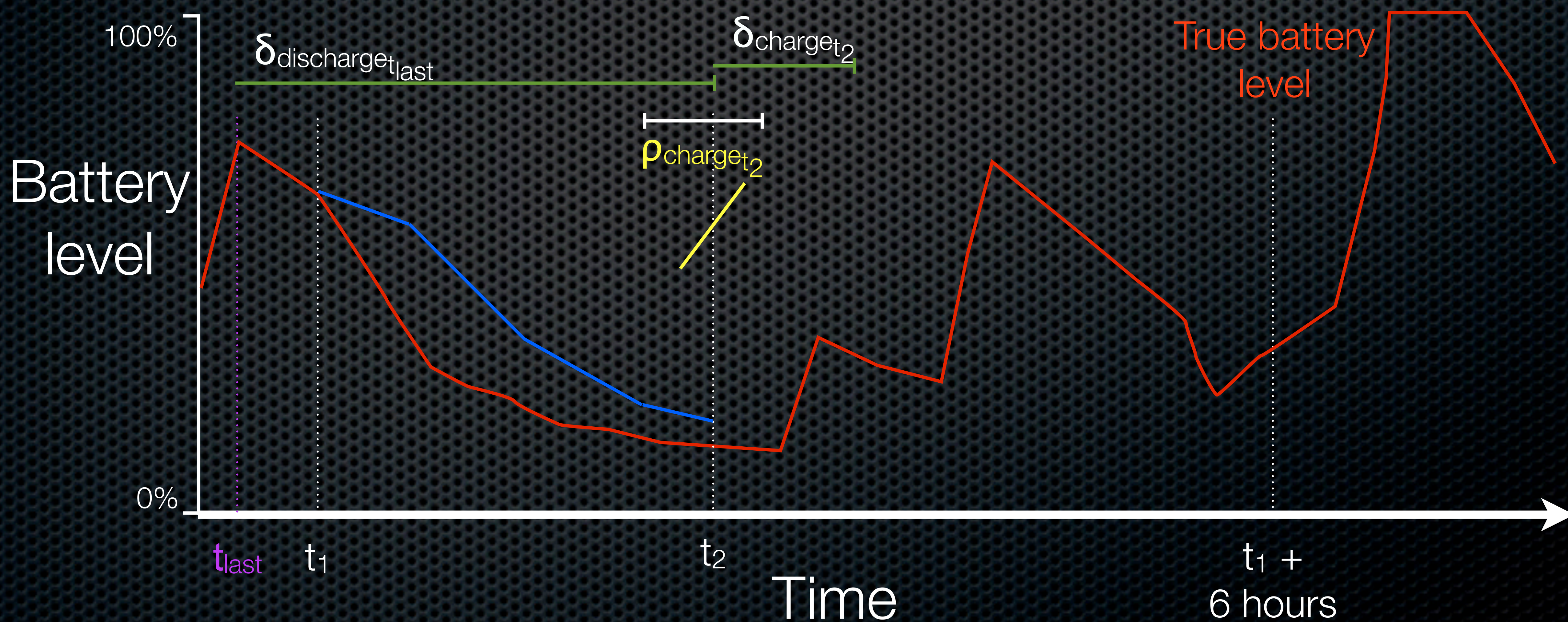

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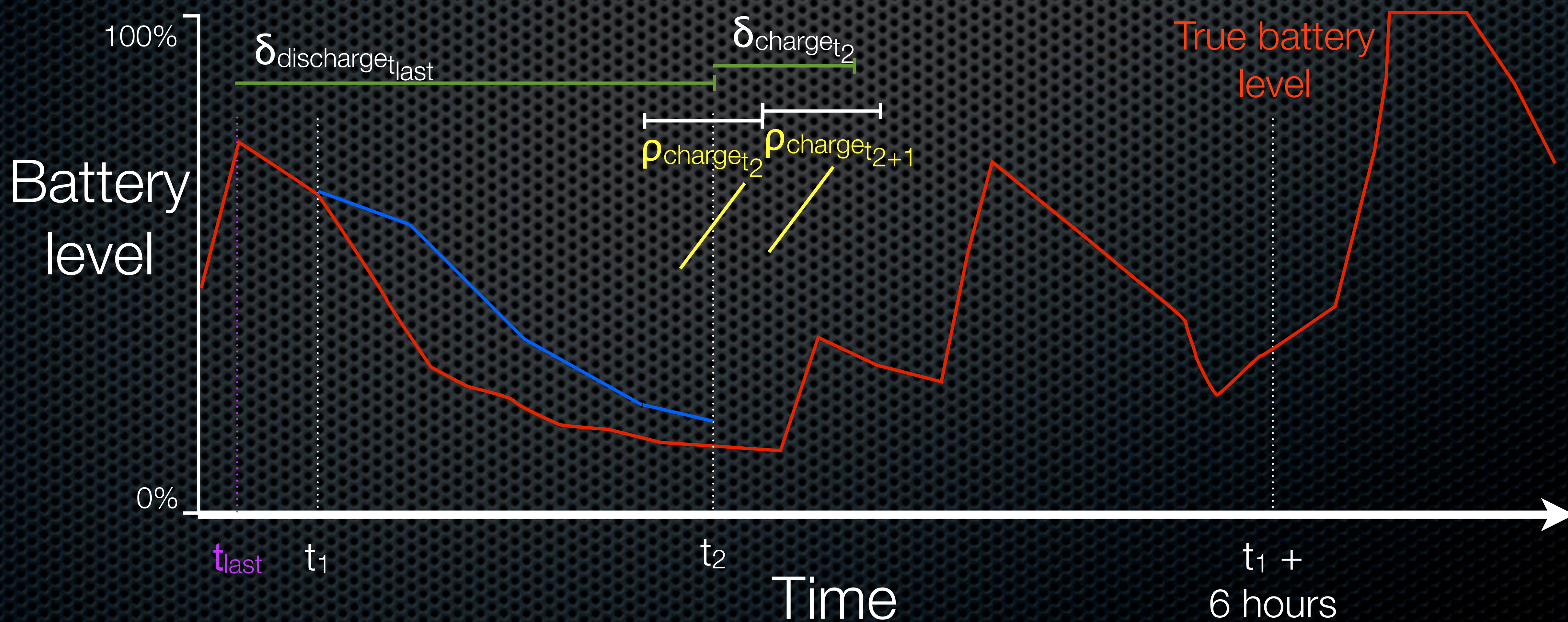

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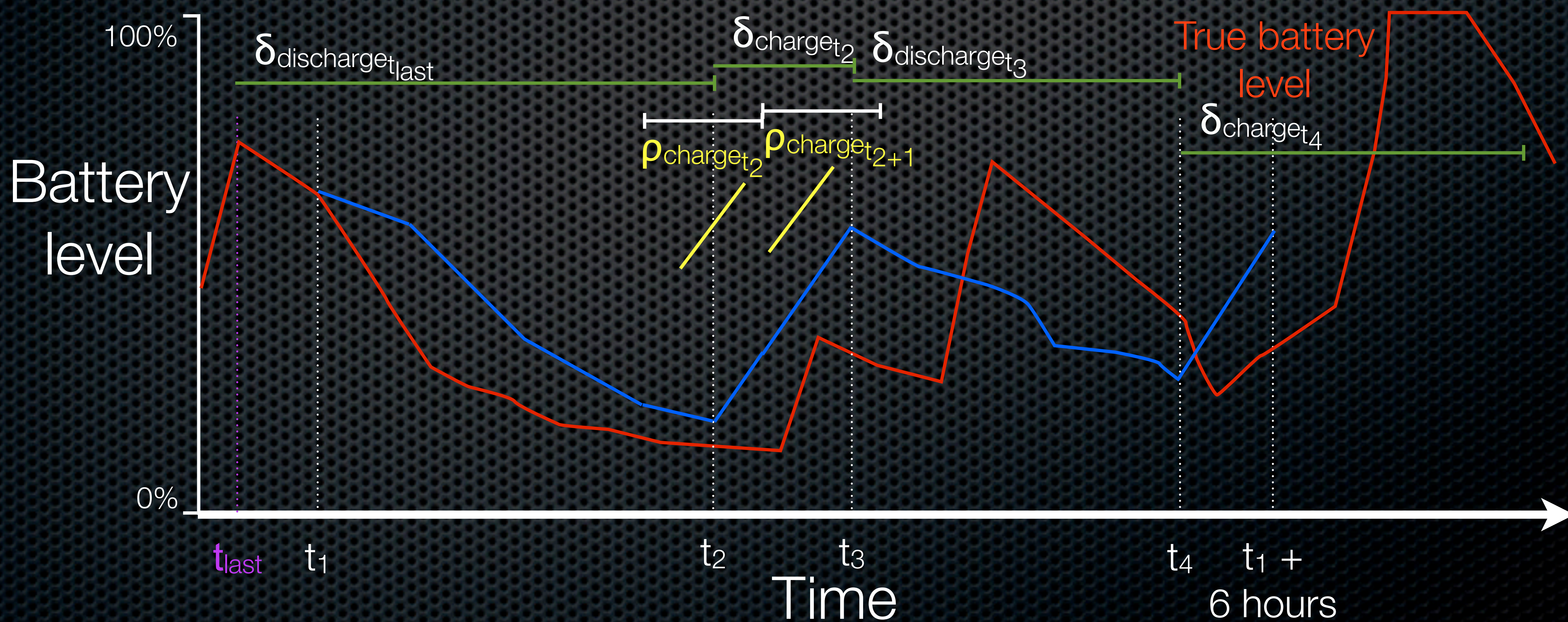

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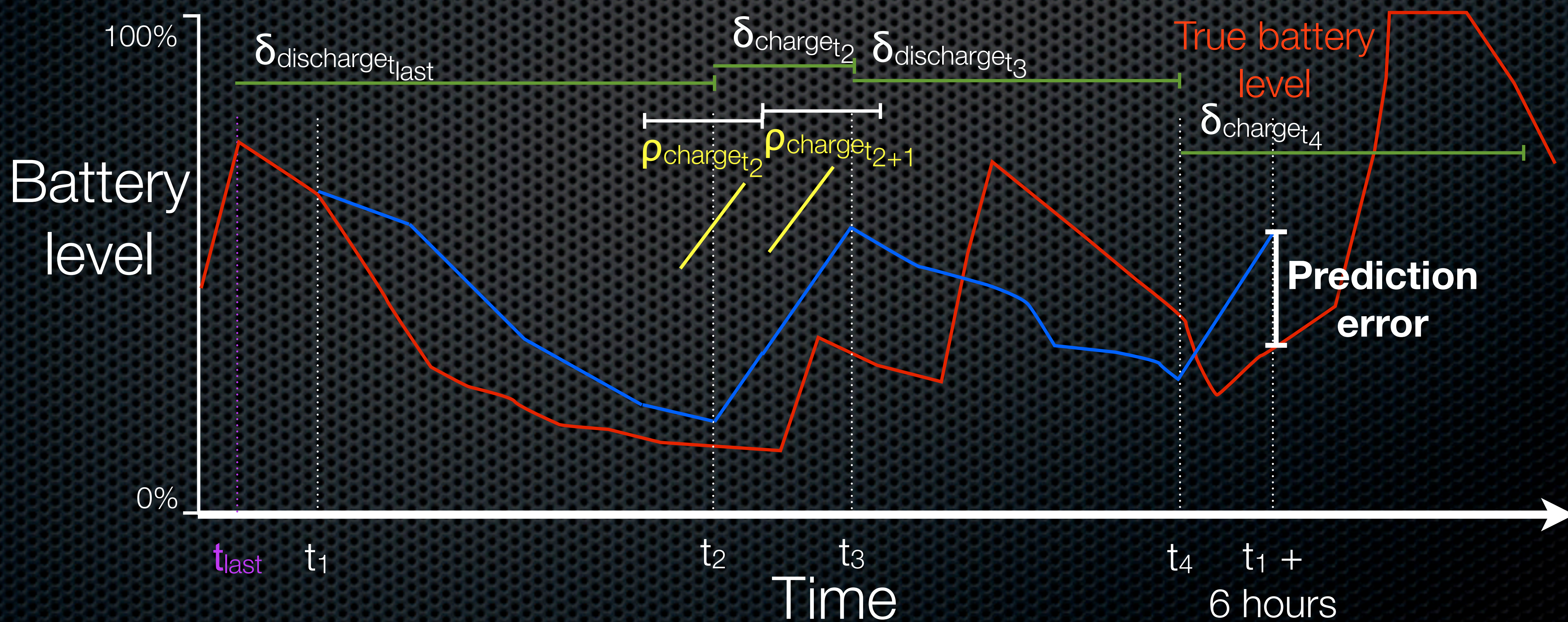

User classification

- Cluster by device
- Cluster by energy consumption/replenishment characteristics
  - Which set of characteristics are best?
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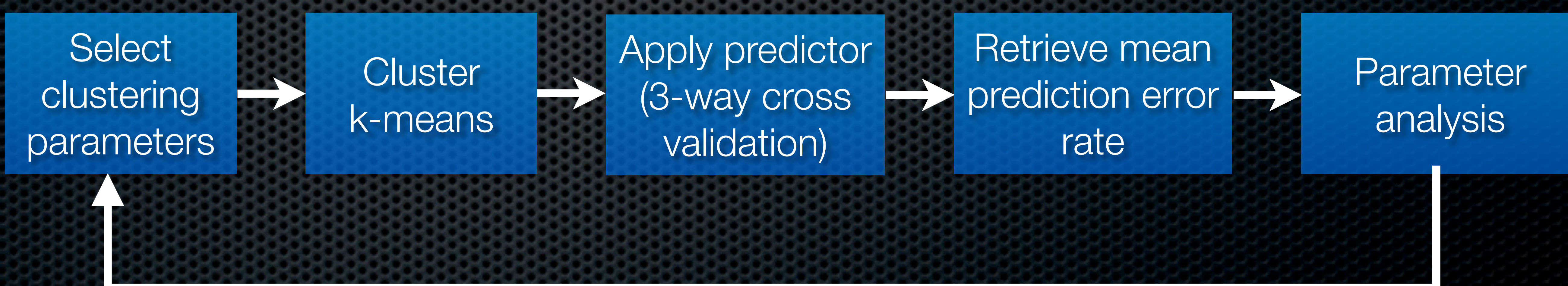
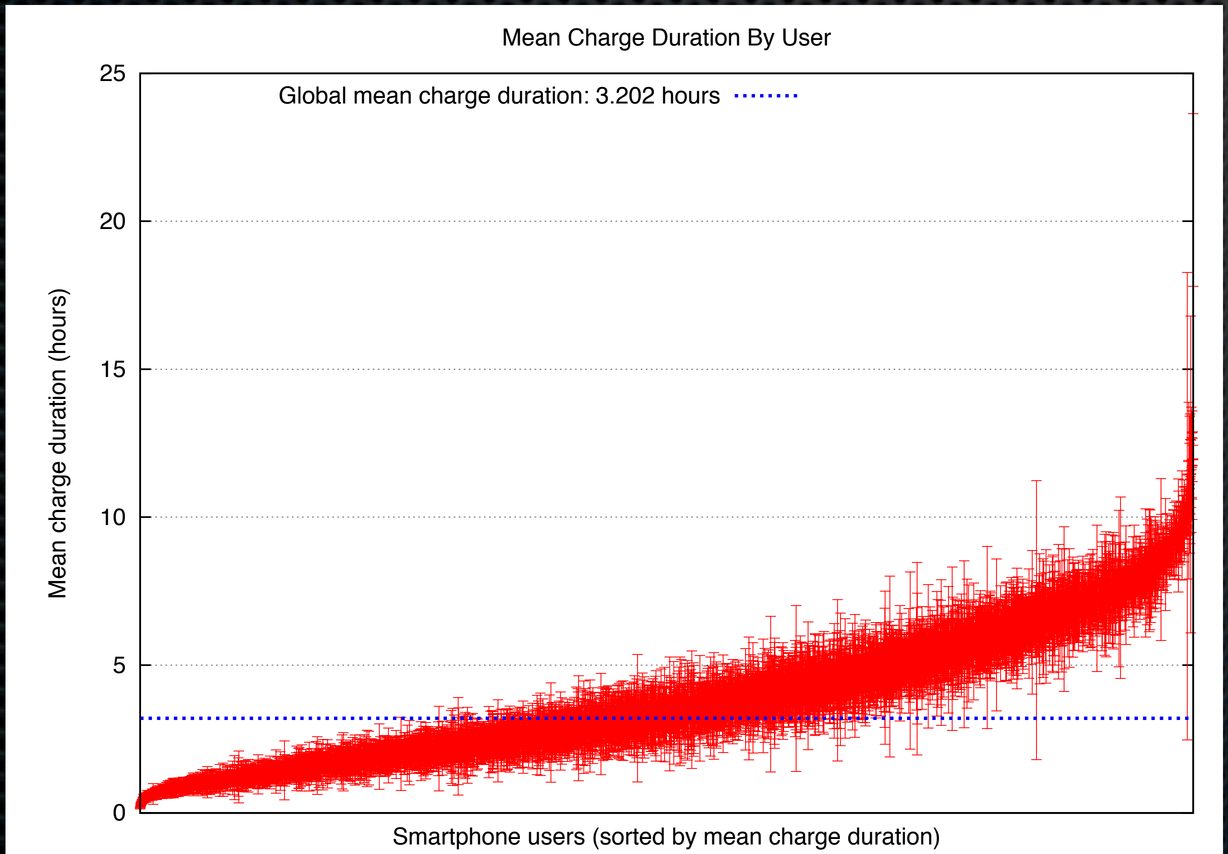


Clustering parameters

$$\left\{\begin{array}{r}\text{Mean charge duration}\\ \text{Mean discharge duration}\end{array}\right\} \times \left\{\begin{array}{r}\text{weekday}\\ \text{weekend}\end{array}\right\}$$

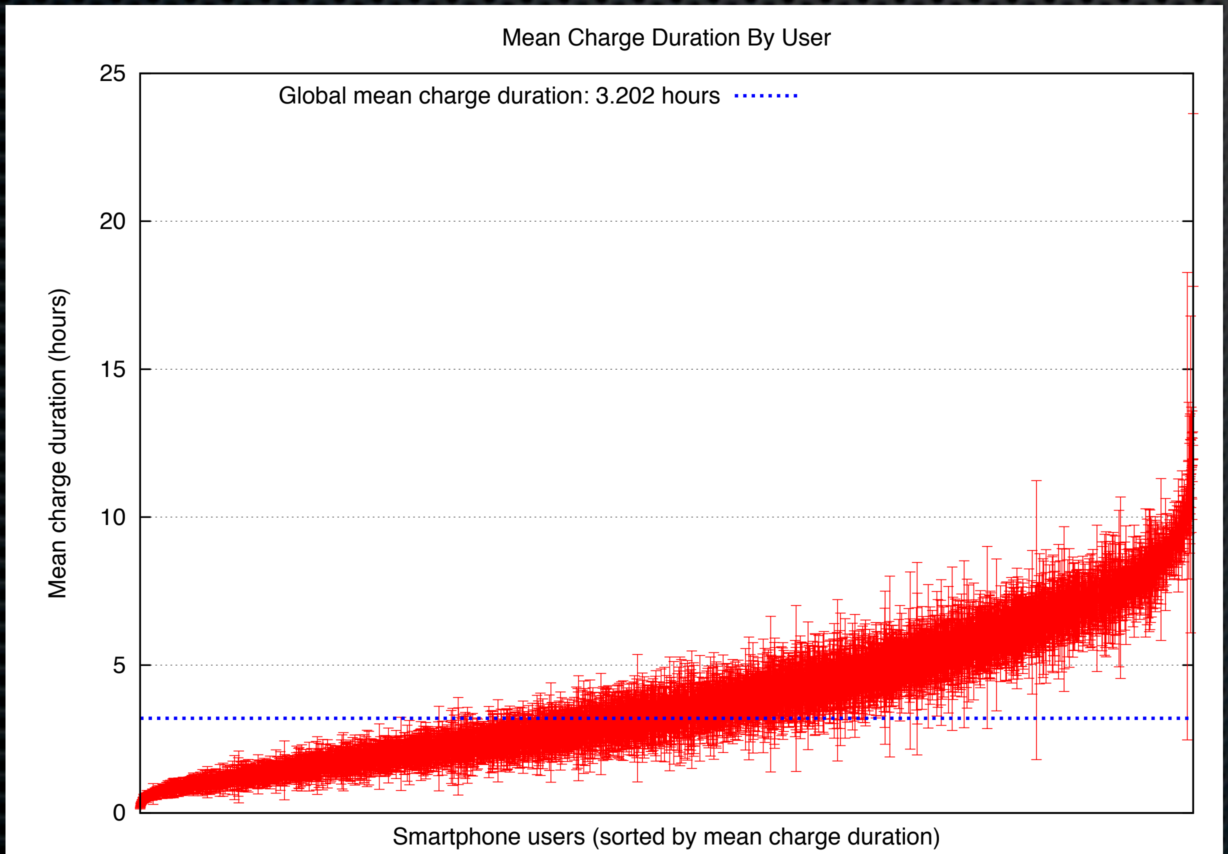
Clustering parameters

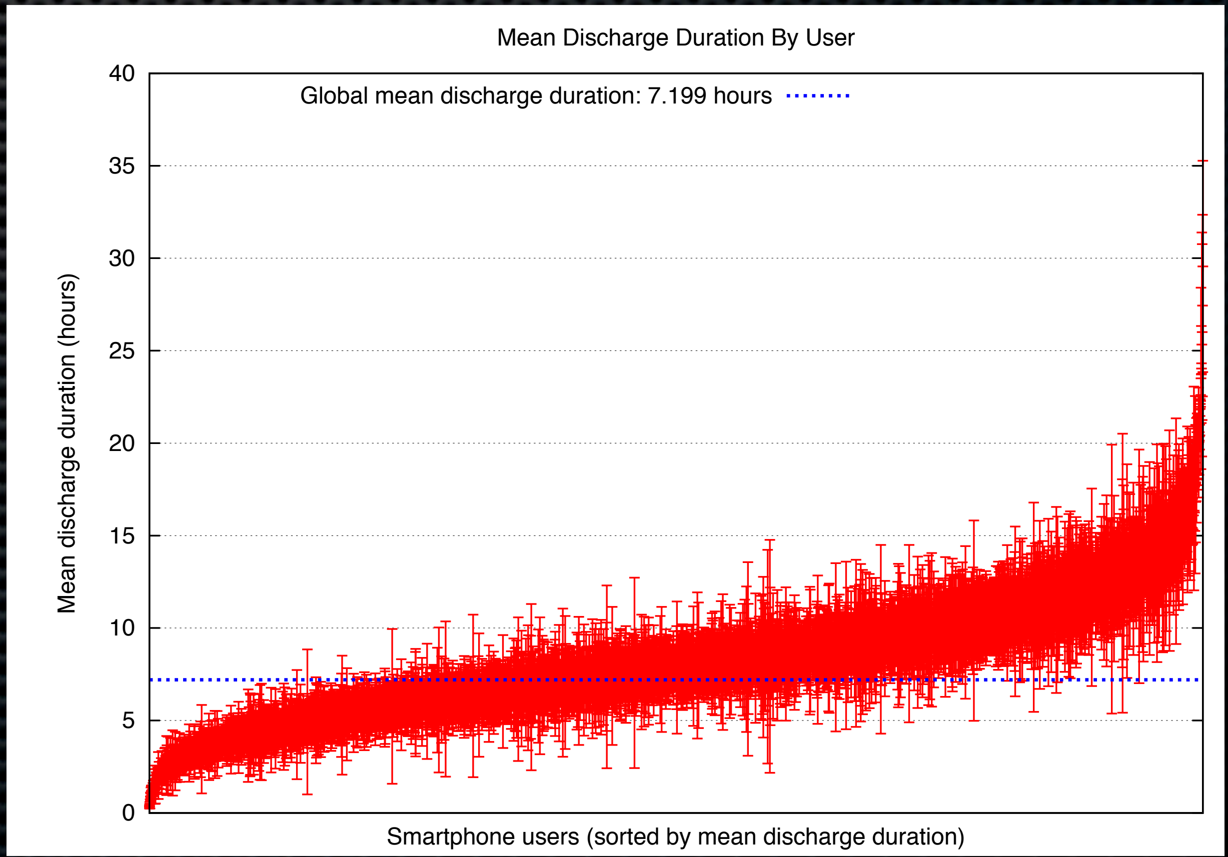
$$\begin{Bmatrix} \text{Mean charge duration} \\ \text{Mean discharge duration} \end{Bmatrix} \times \begin{Bmatrix} \text{weekday} \\ \text{weekend} \end{Bmatrix}$$



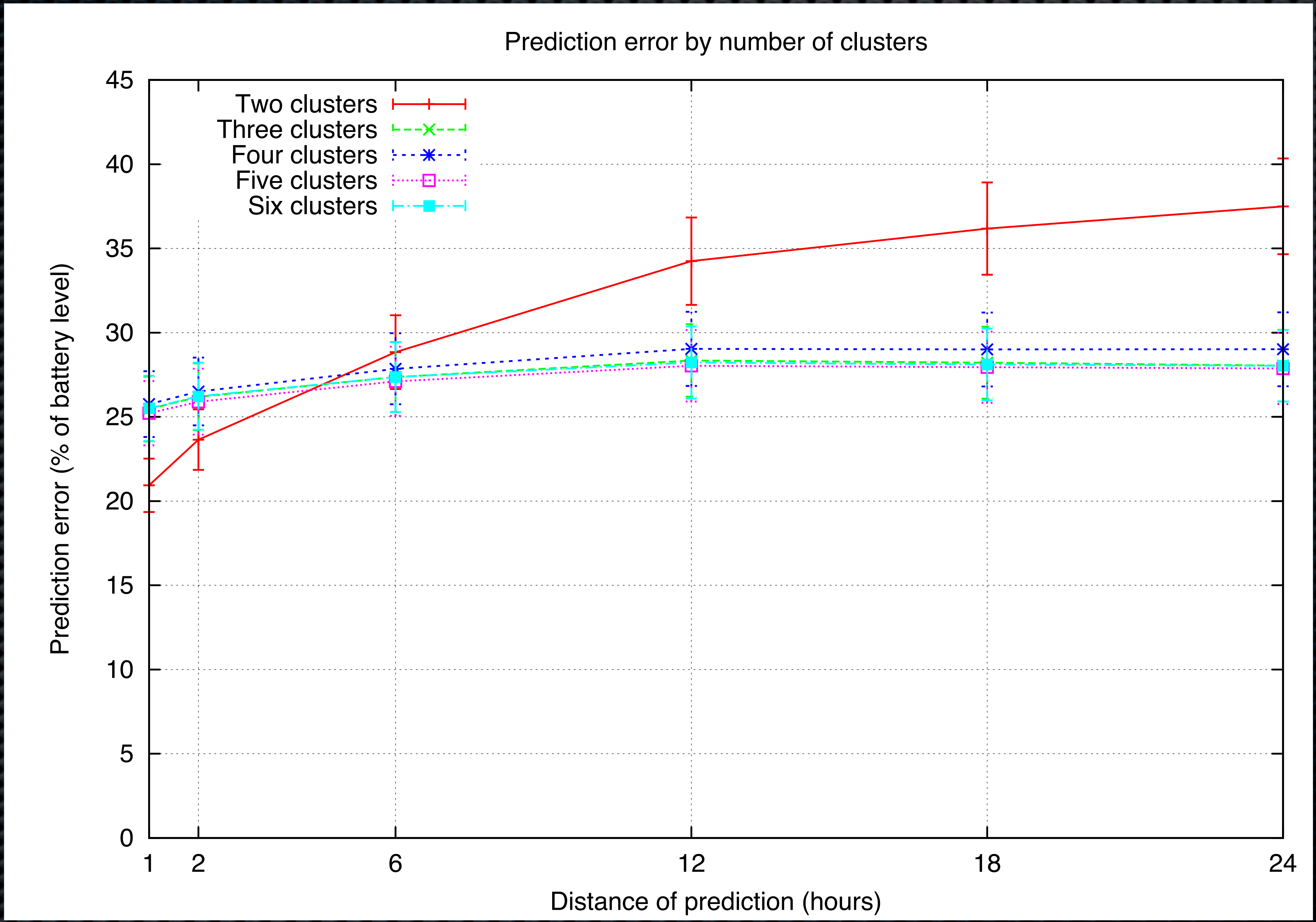
Clustering parameters

$$\left\{\begin{array}{r}\text{Mean charge duration}\\ \text{Mean discharge duration}\end{array}\right\} \times \left\{\begin{array}{l}\text{weekday}\\ \text{weekend}\end{array}\right\}$$

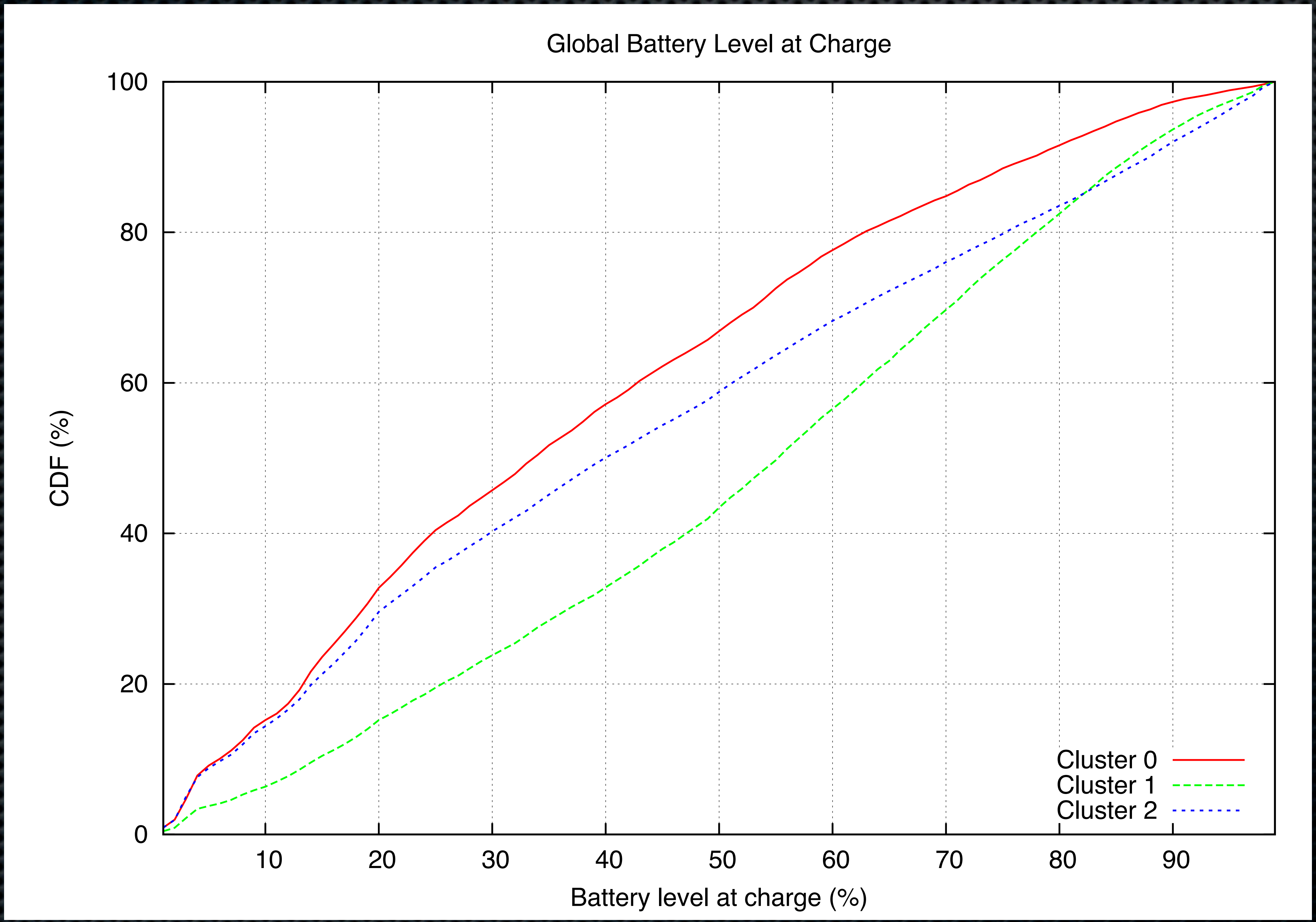




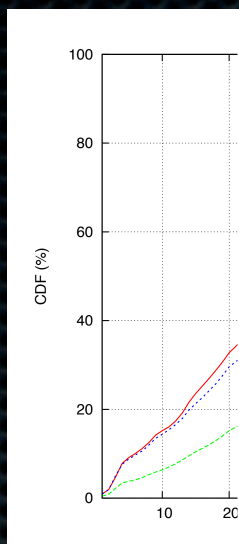
User classification

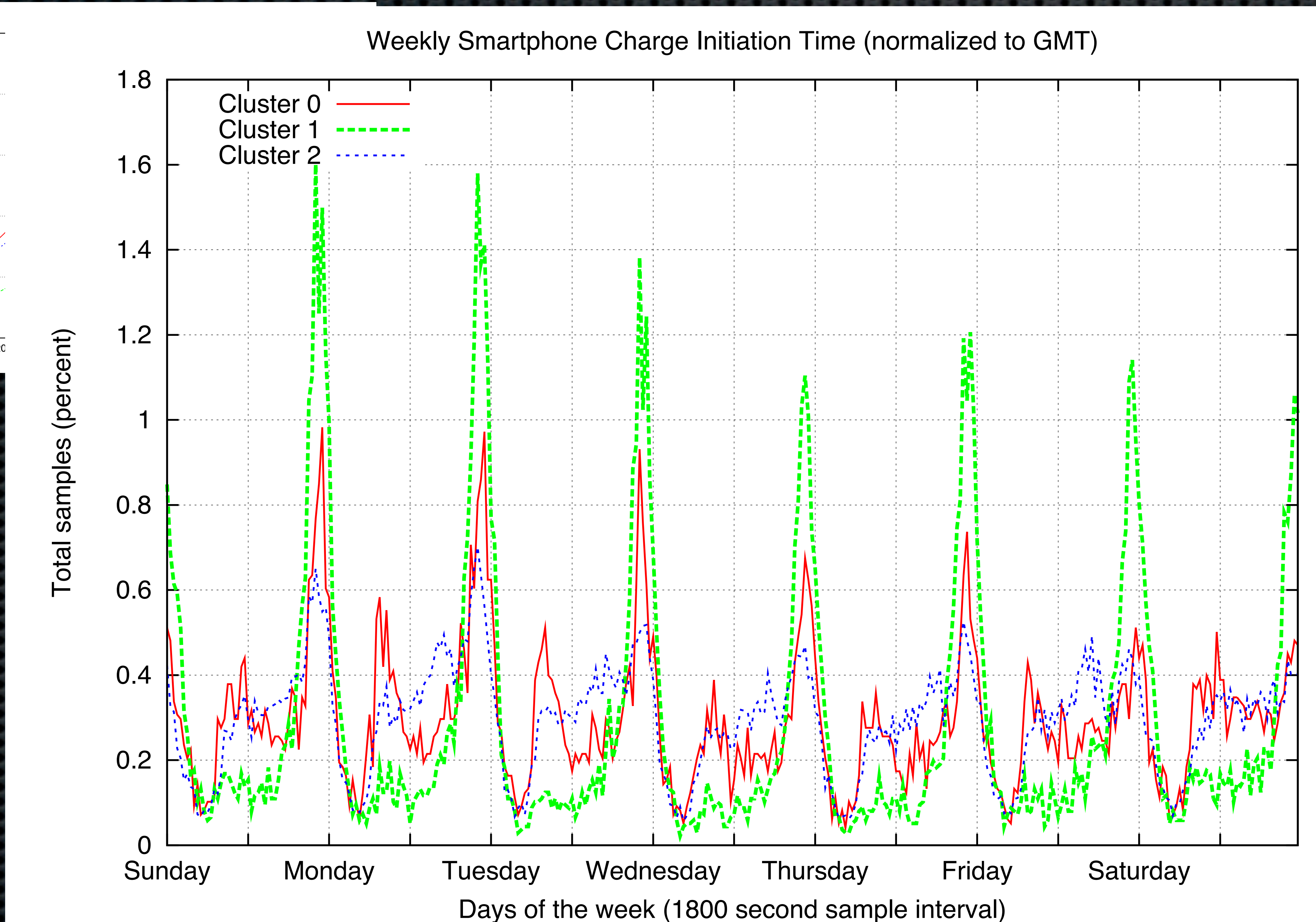


User classification

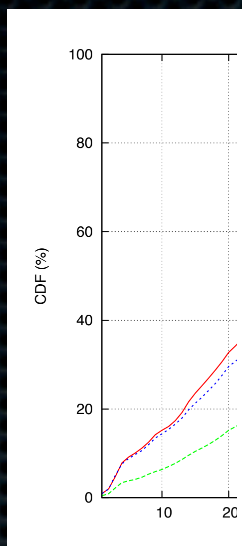


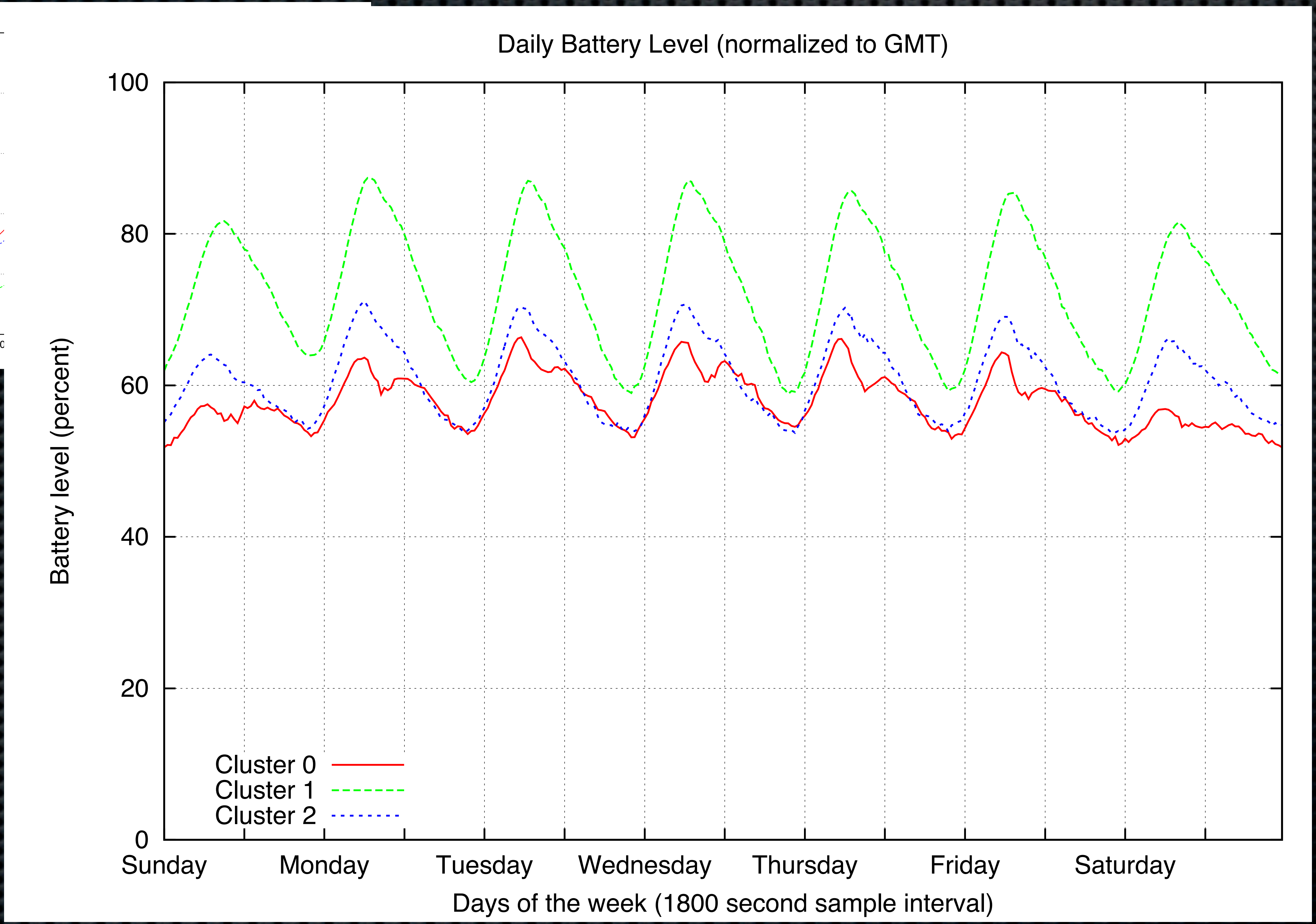
User classification



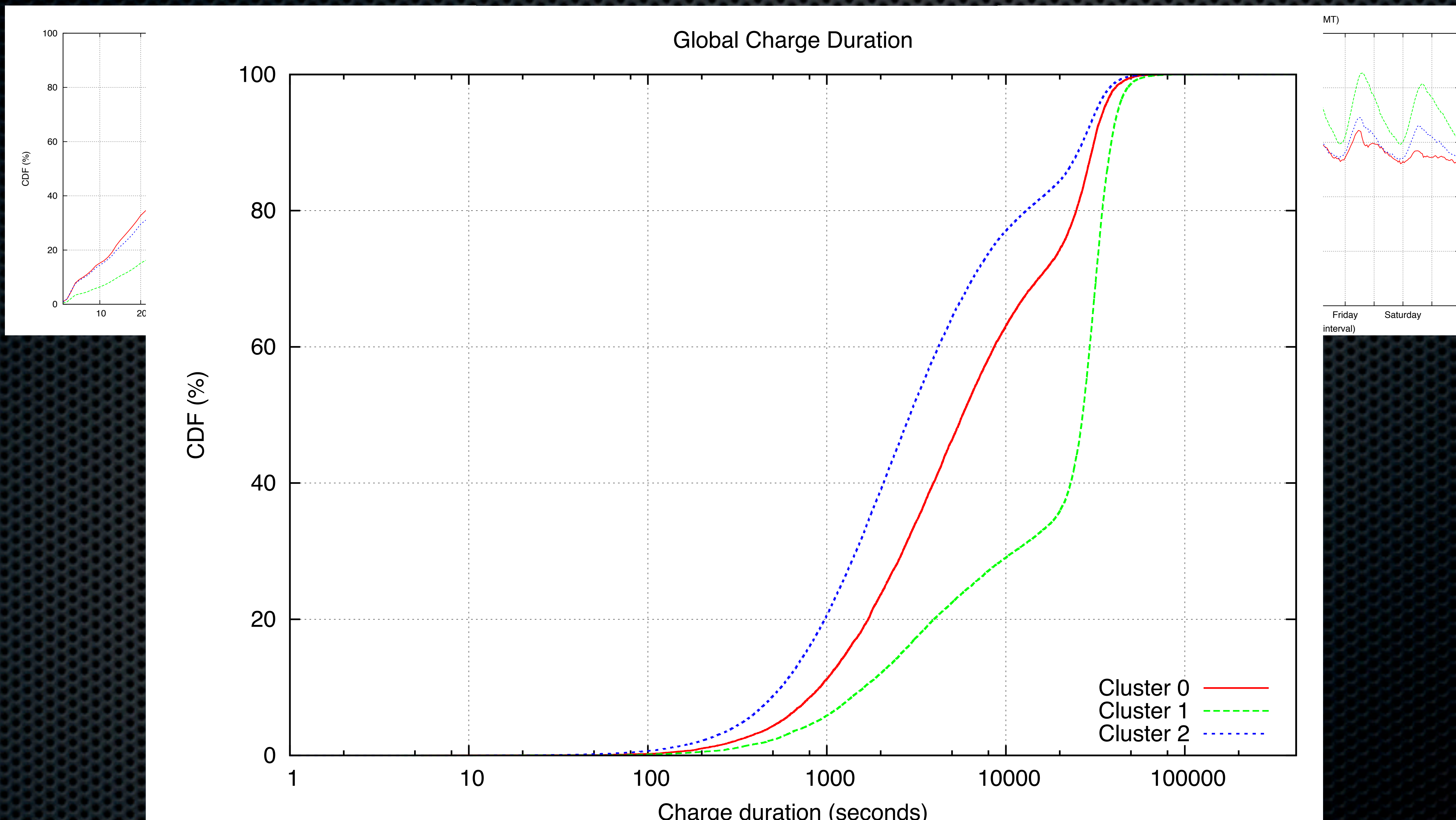


User classification

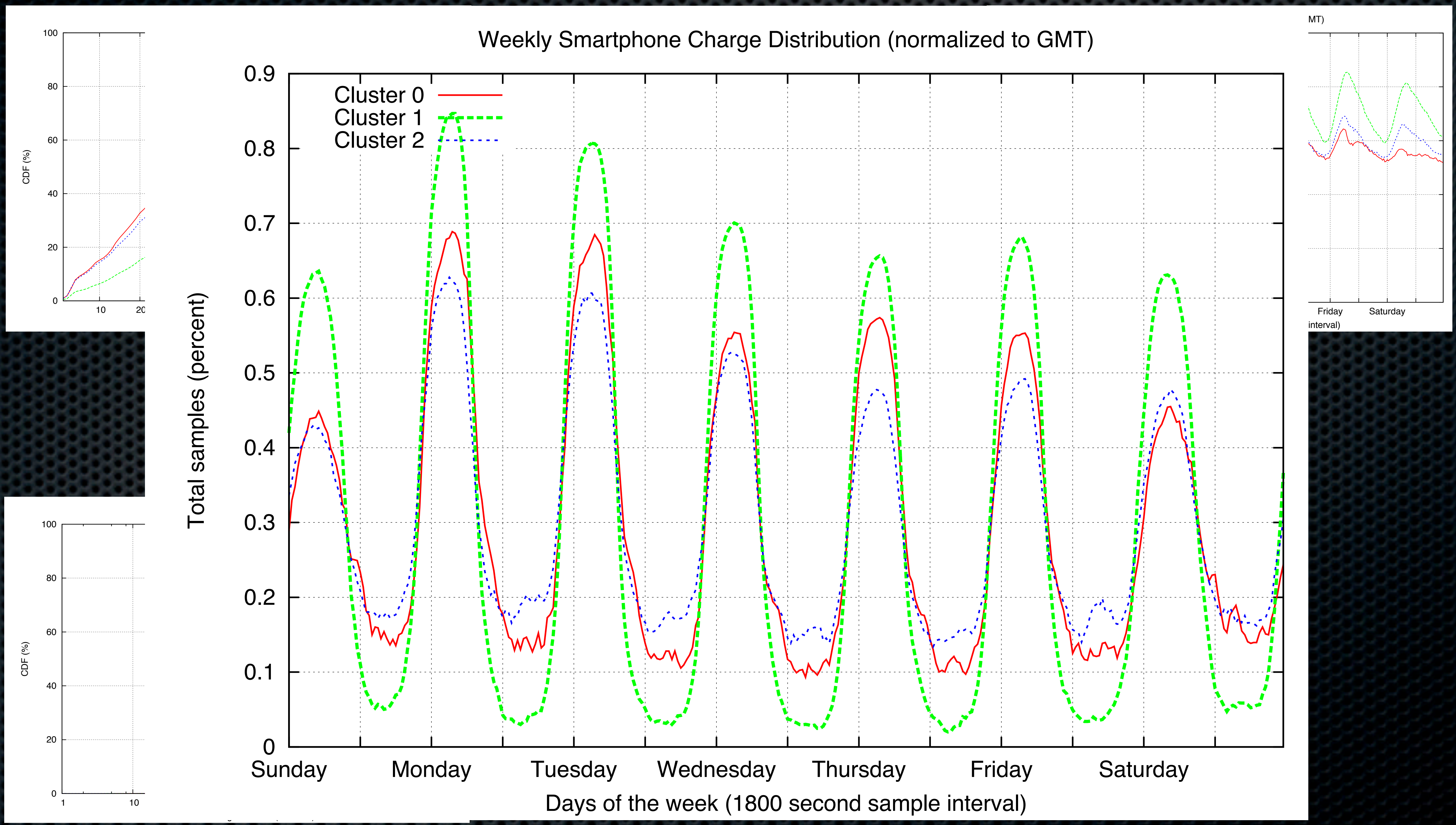




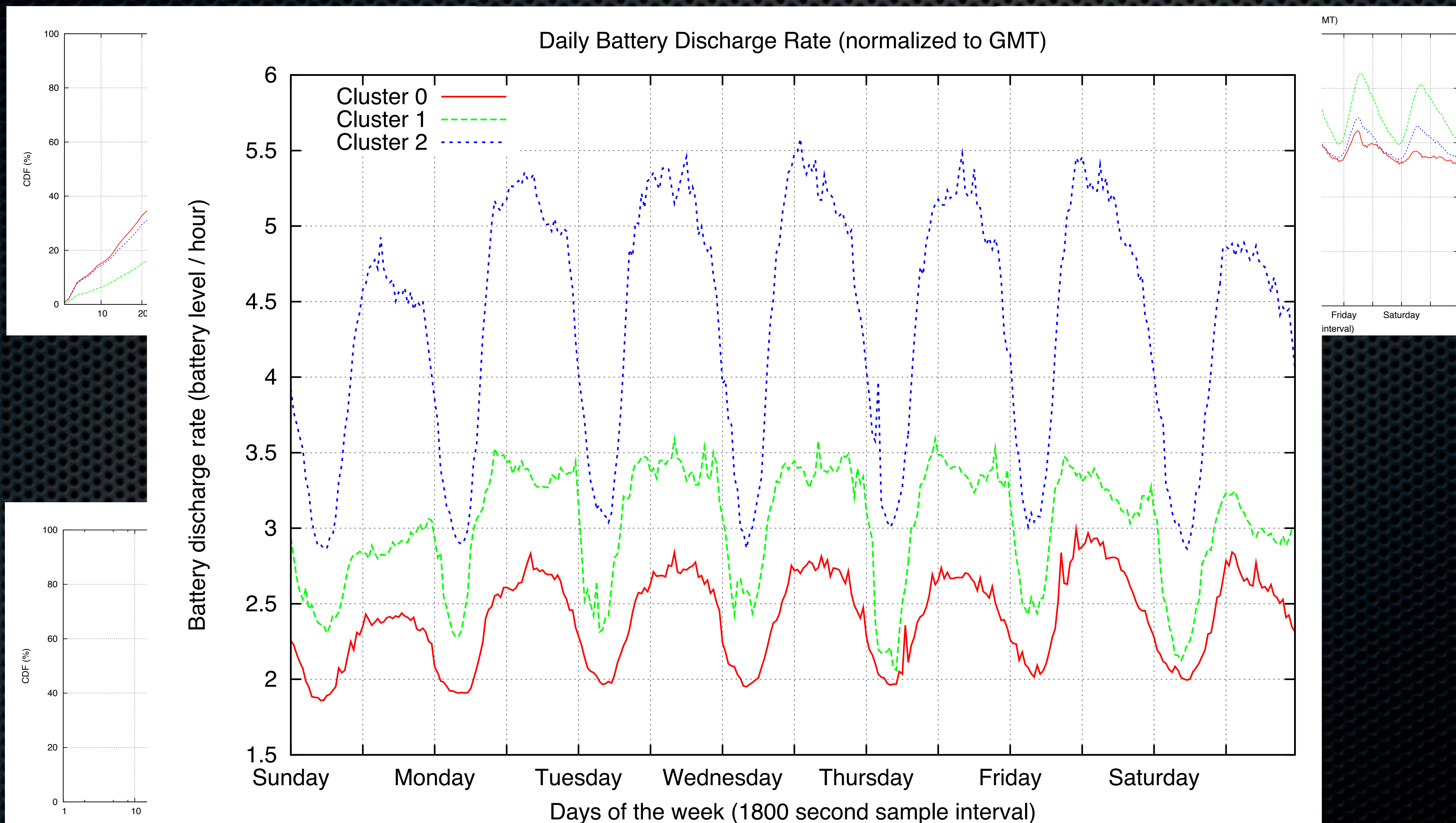
User classification



User classification

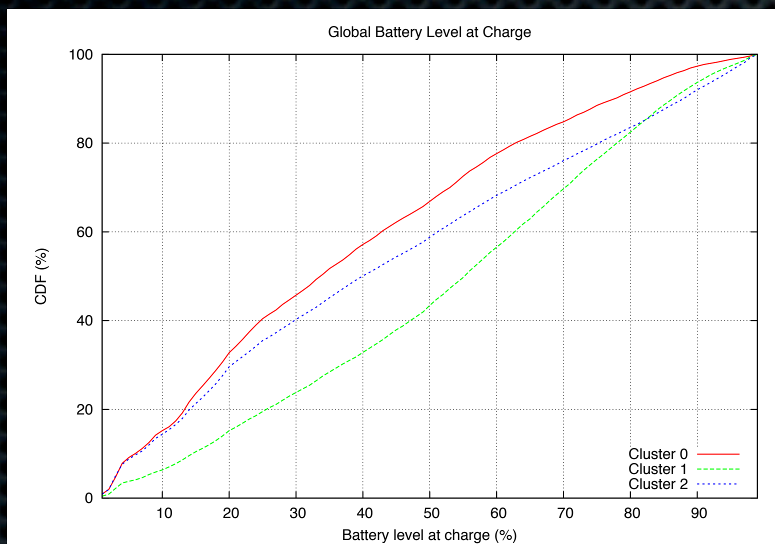


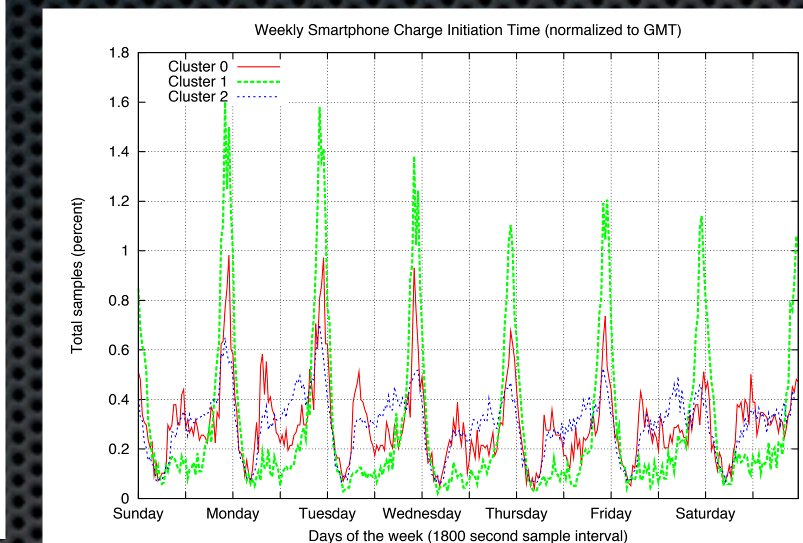
User classification

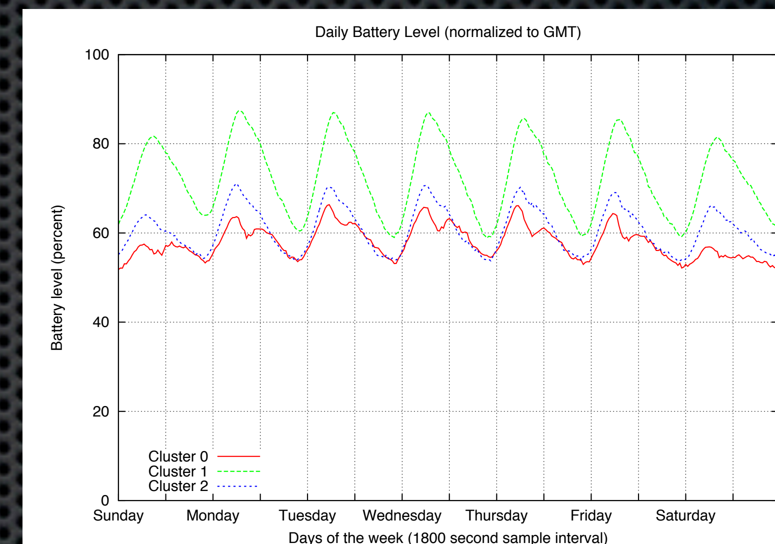


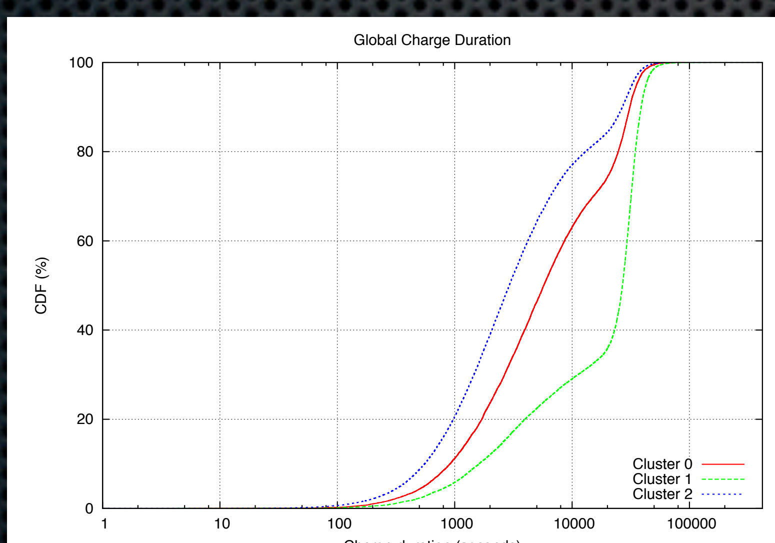
Tuesday, September 14, 2010

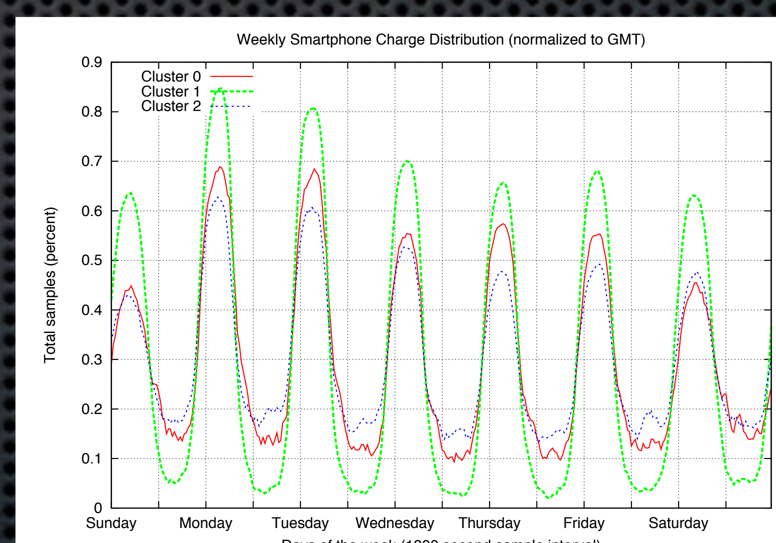
User classification

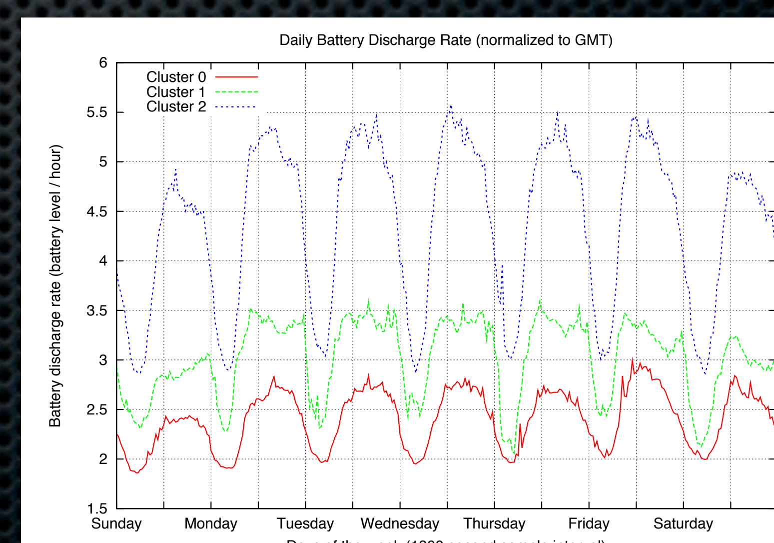




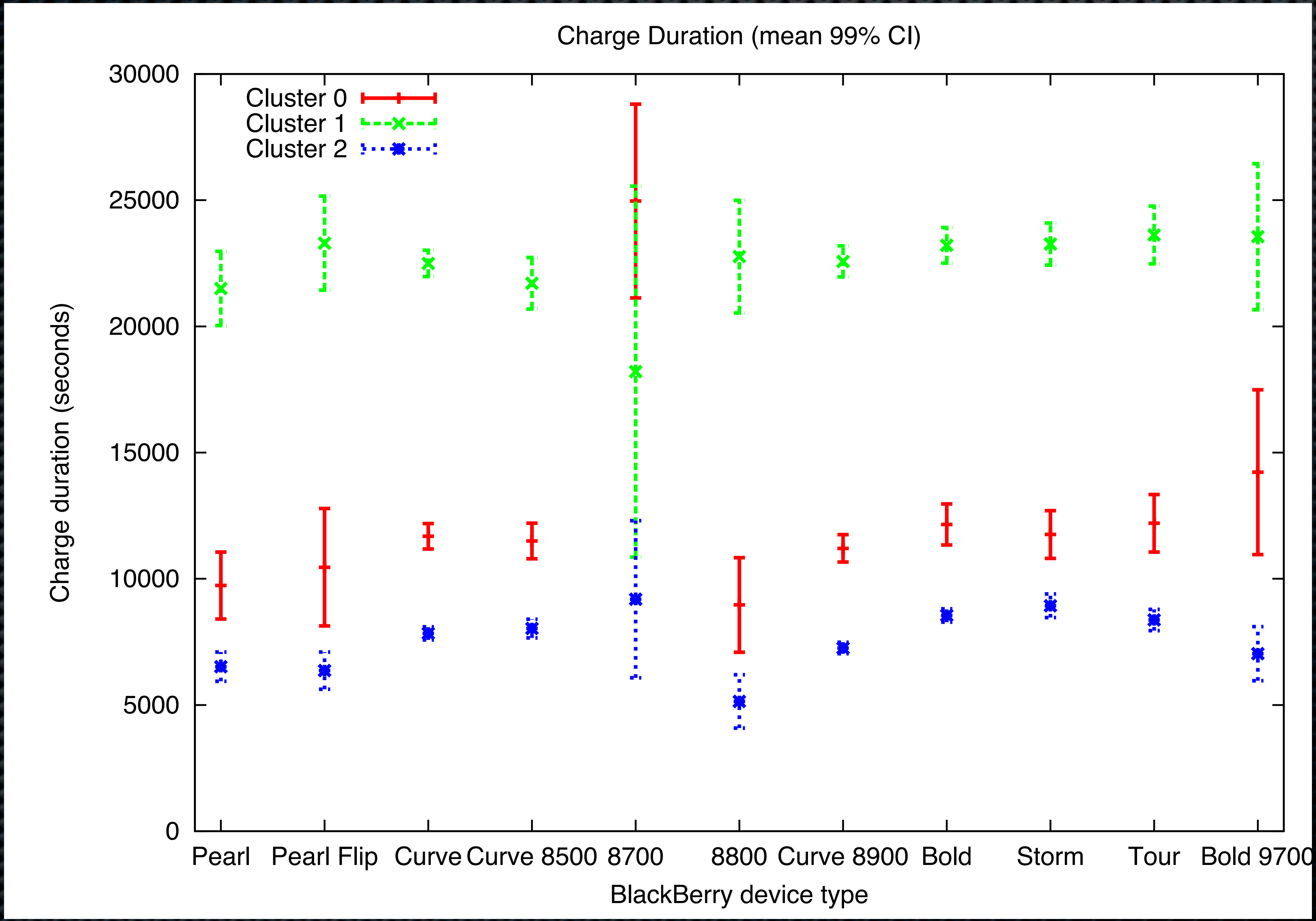




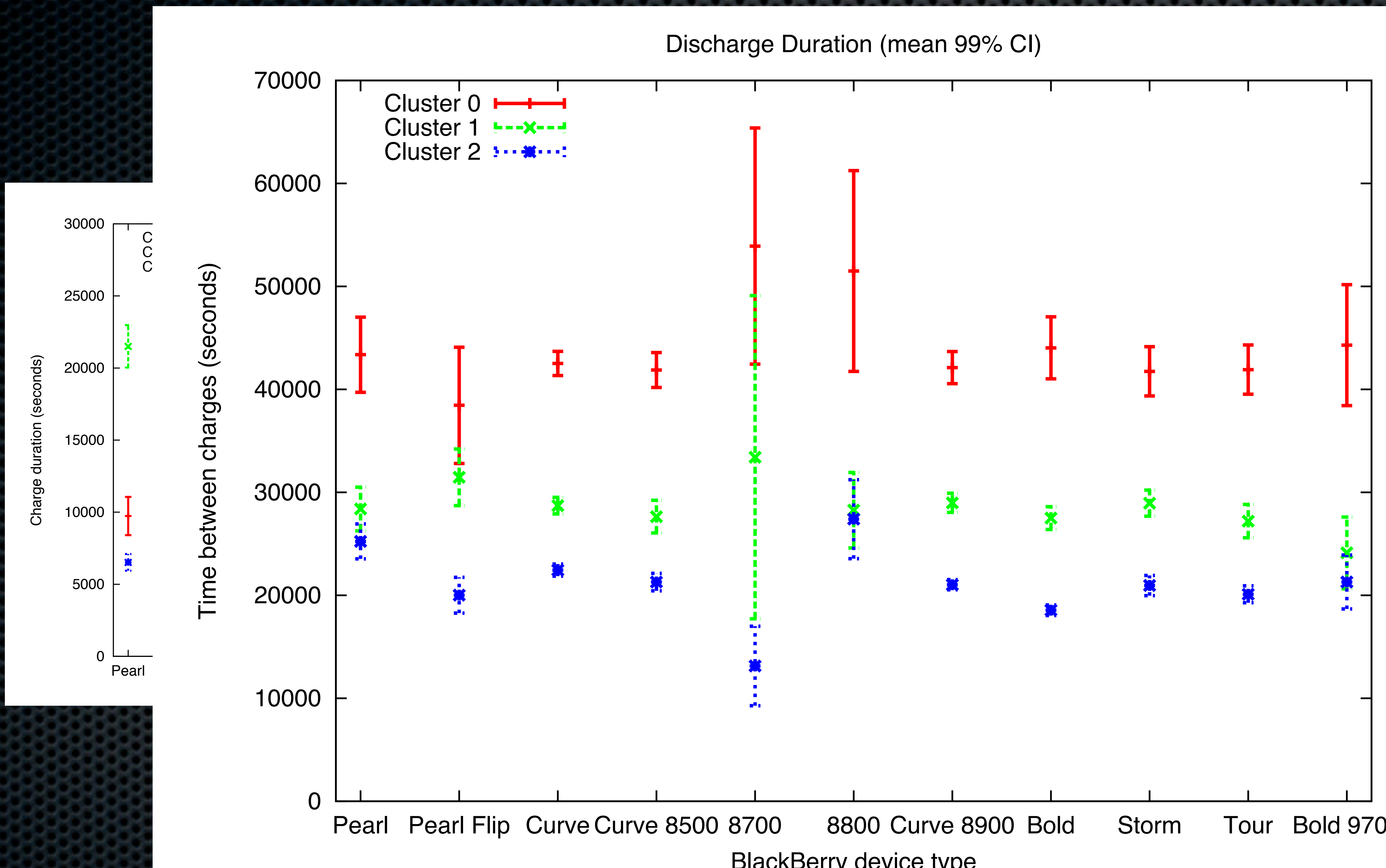




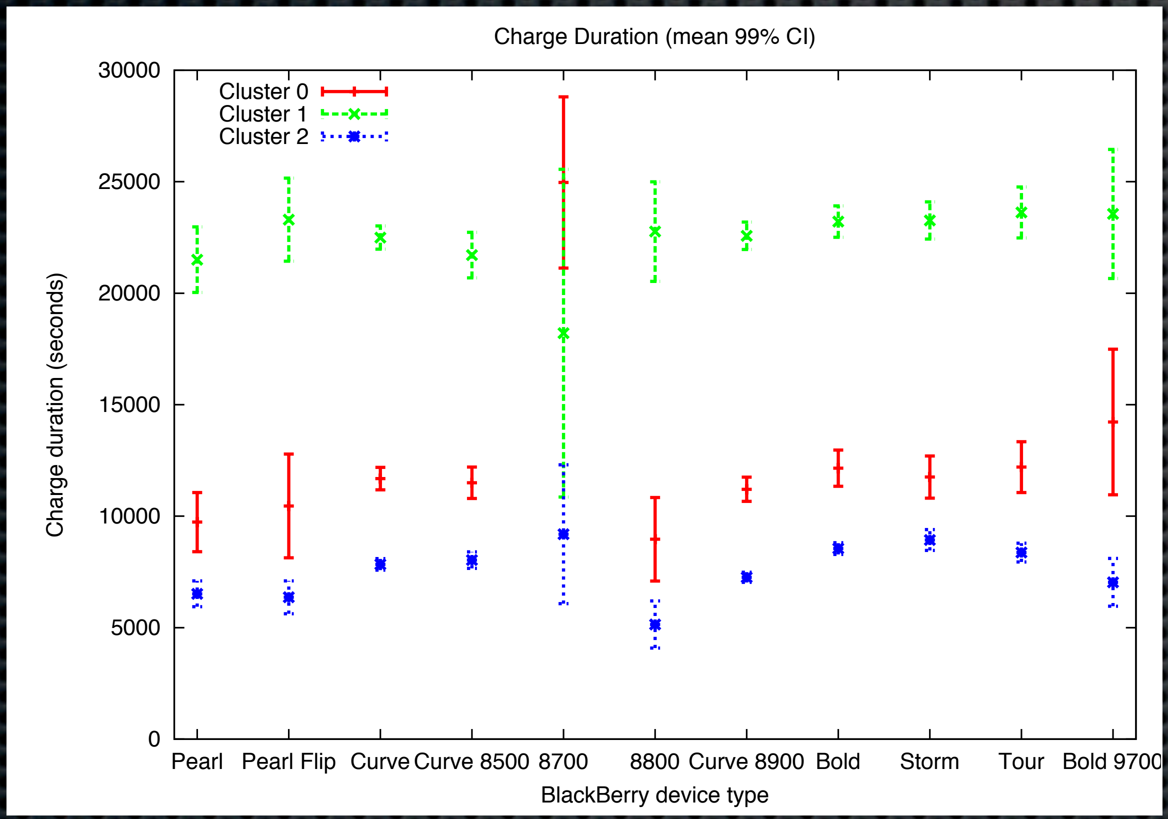
User/device classification

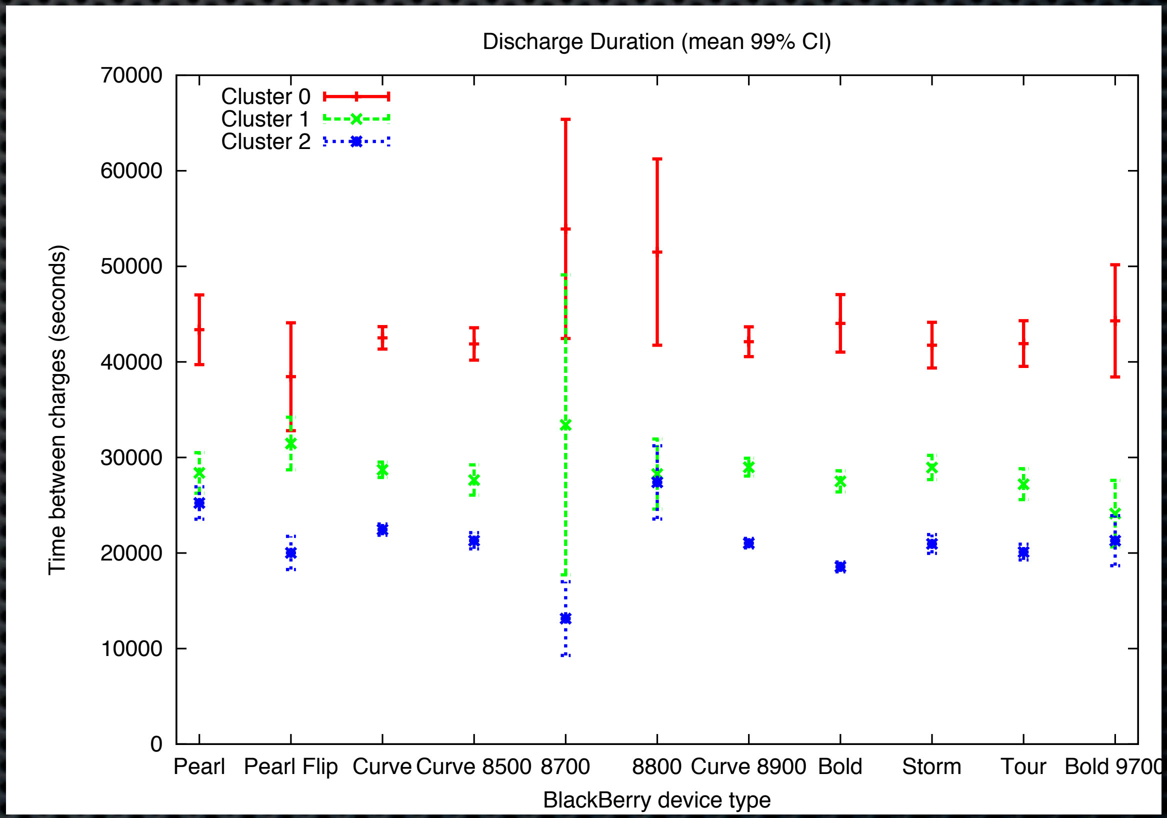


User/device classification



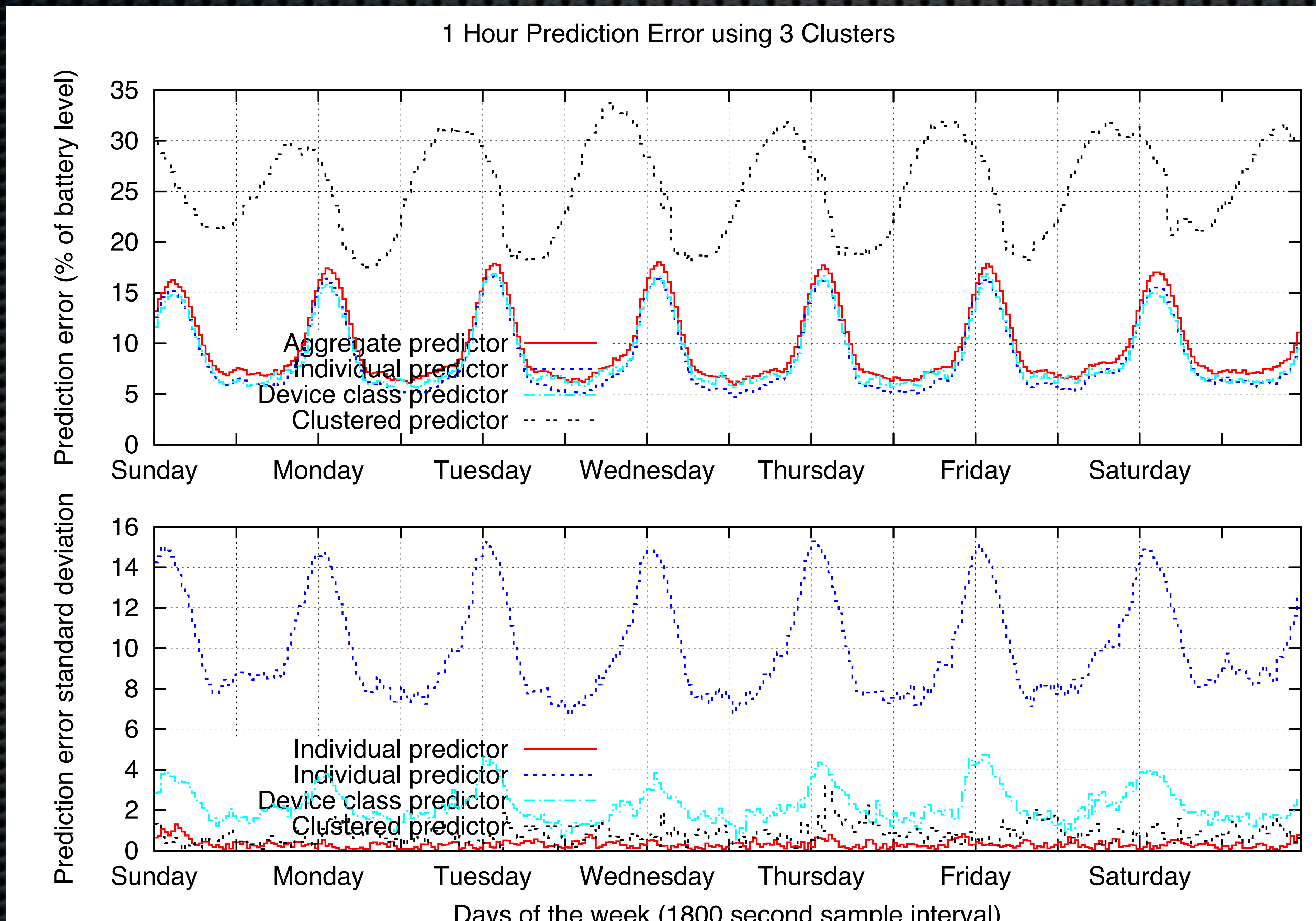
User/device classification



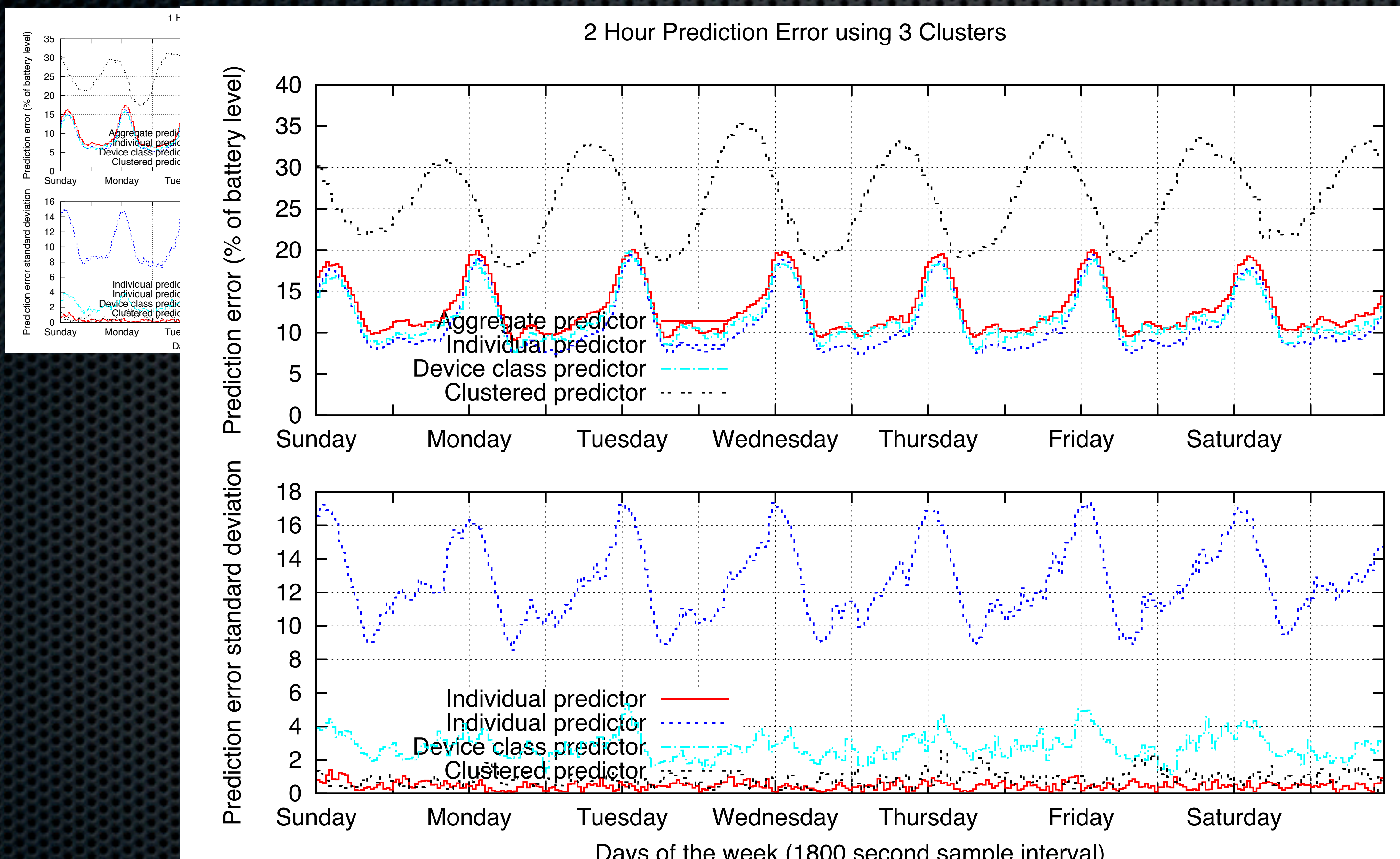


- Can you guess which user type has the most predictable battery level?

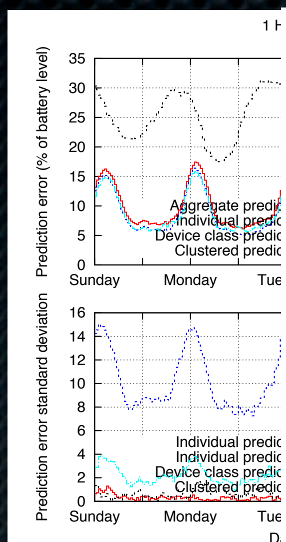
Battery prediction rate

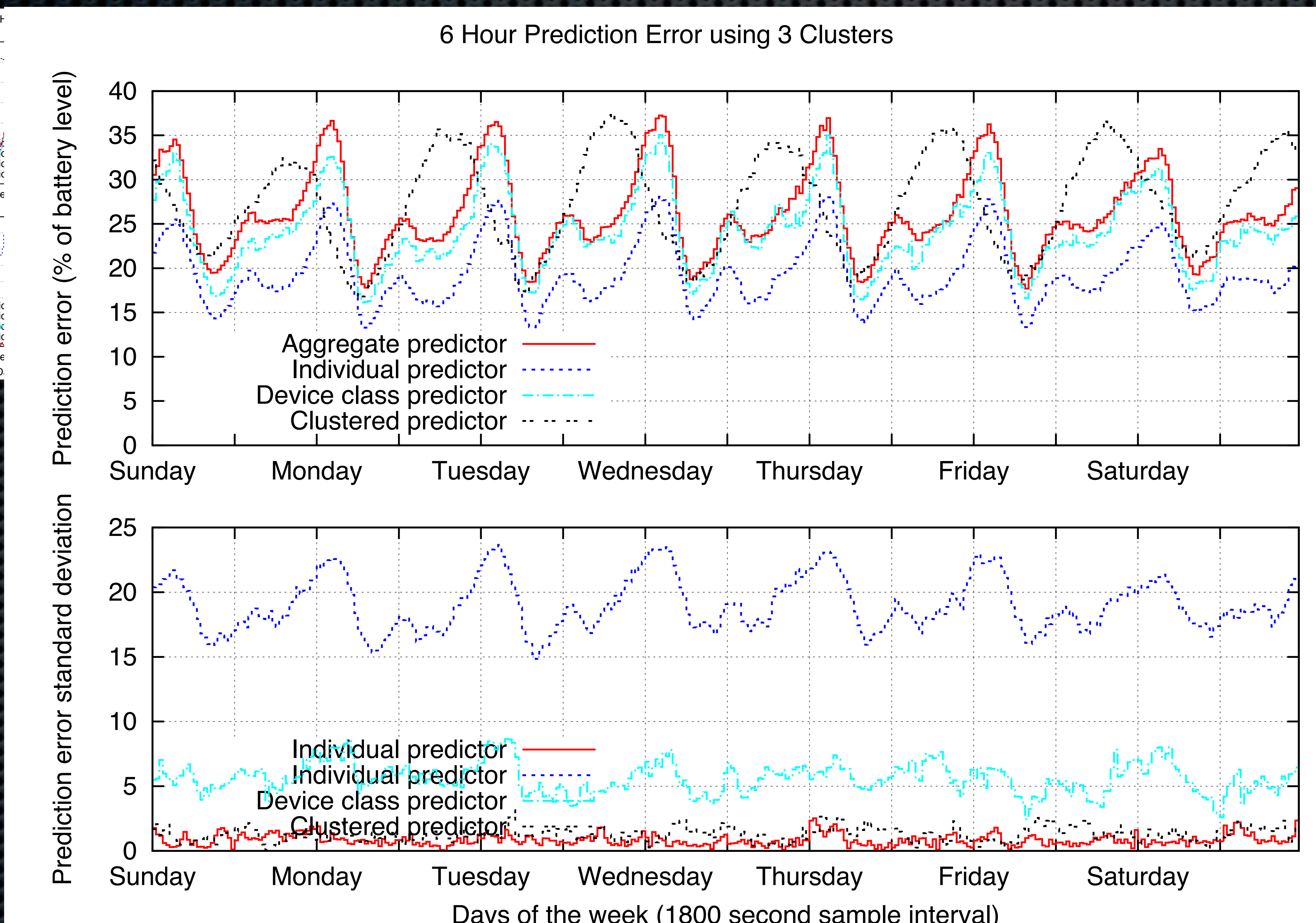


Battery prediction rate



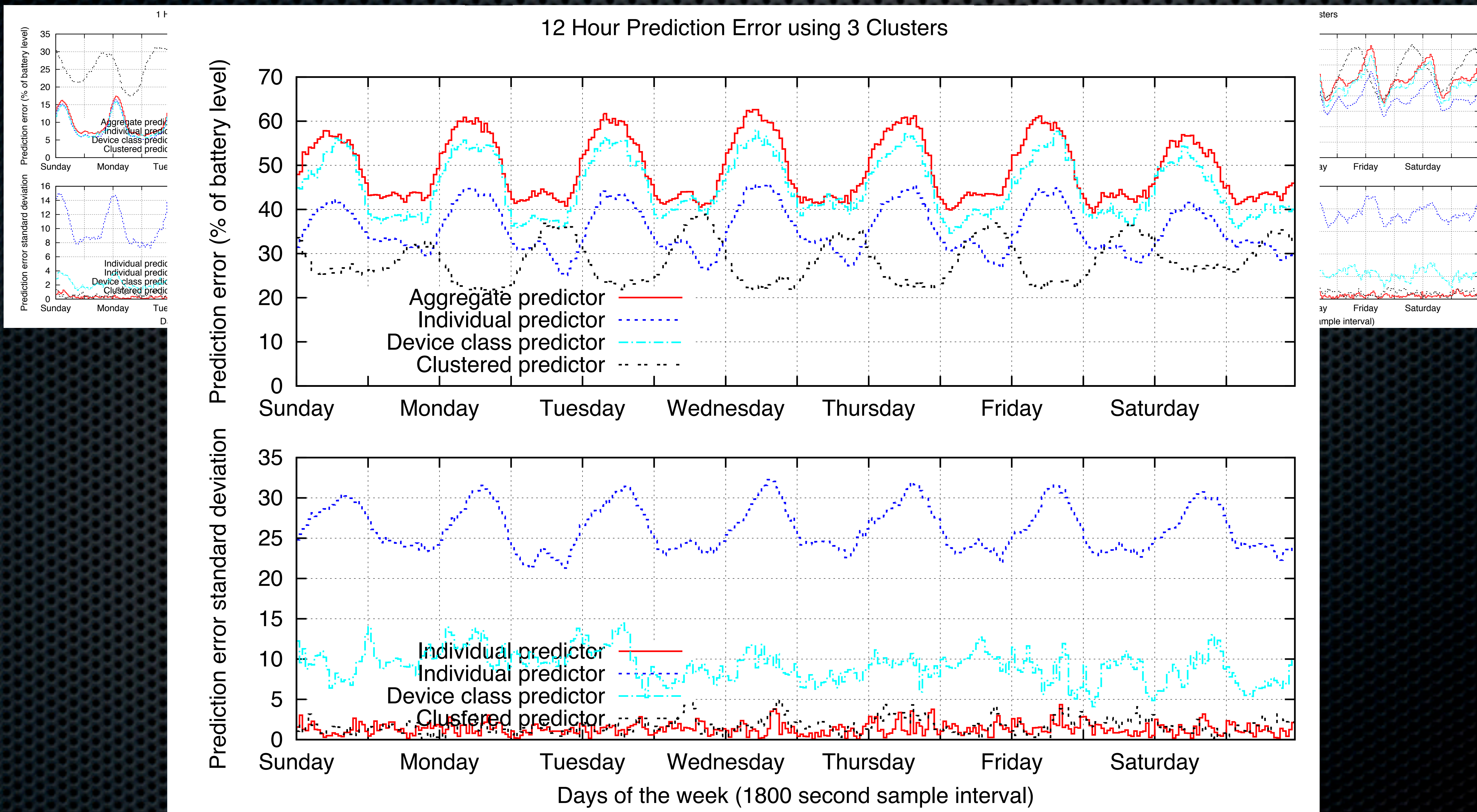
Battery prediction rate



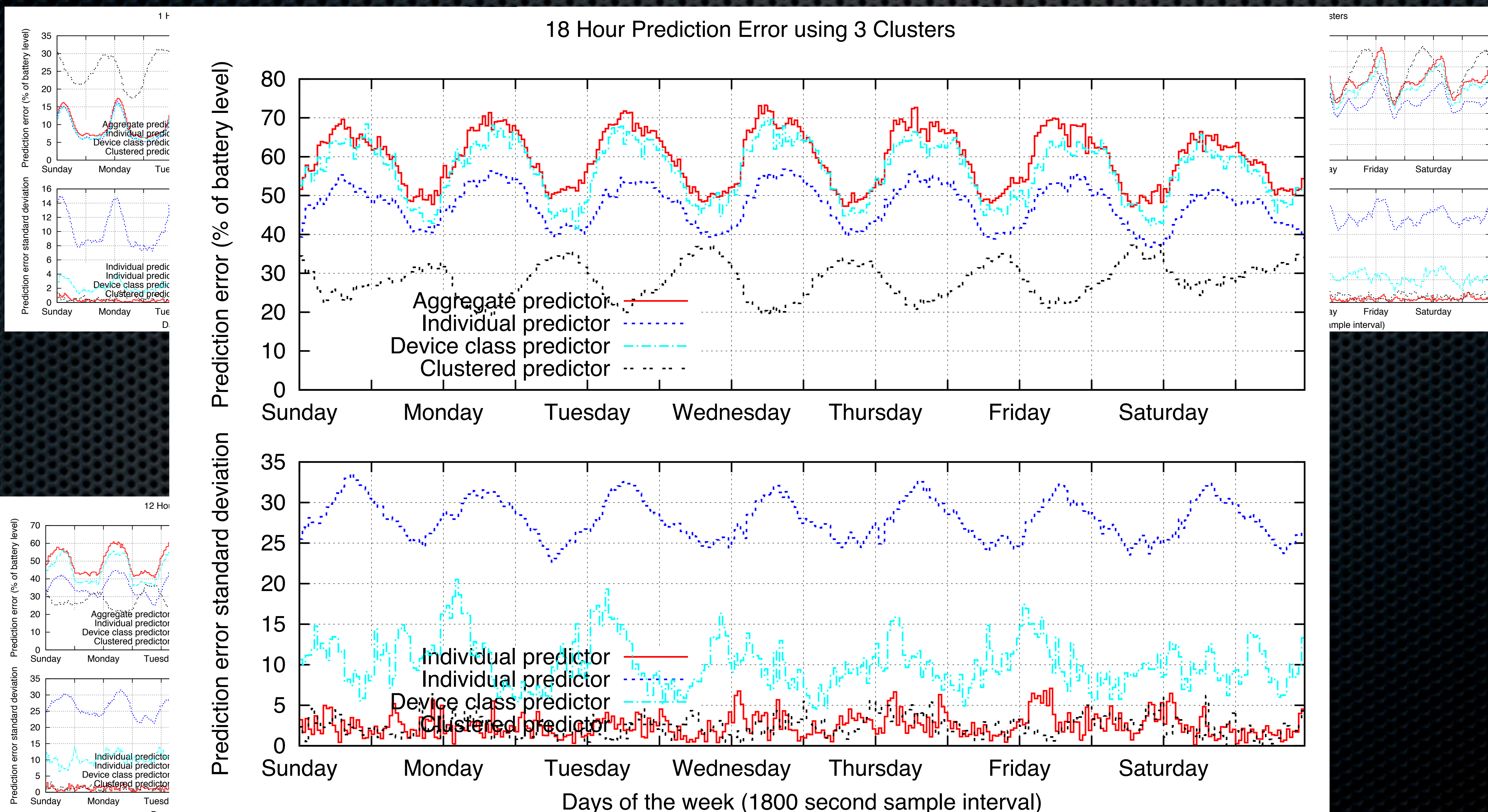


Tuesday, September 14, 2010

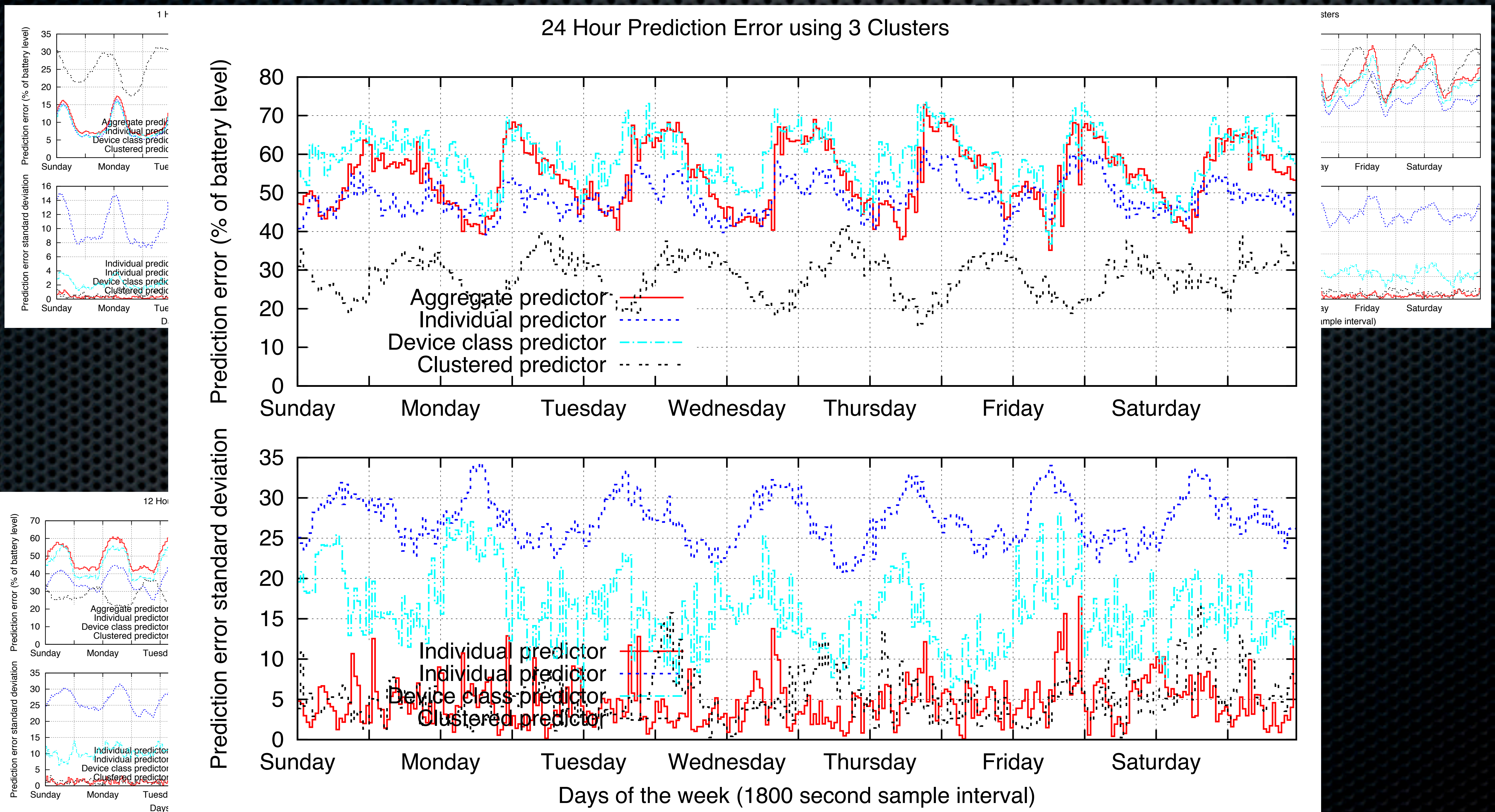
Battery prediction rate



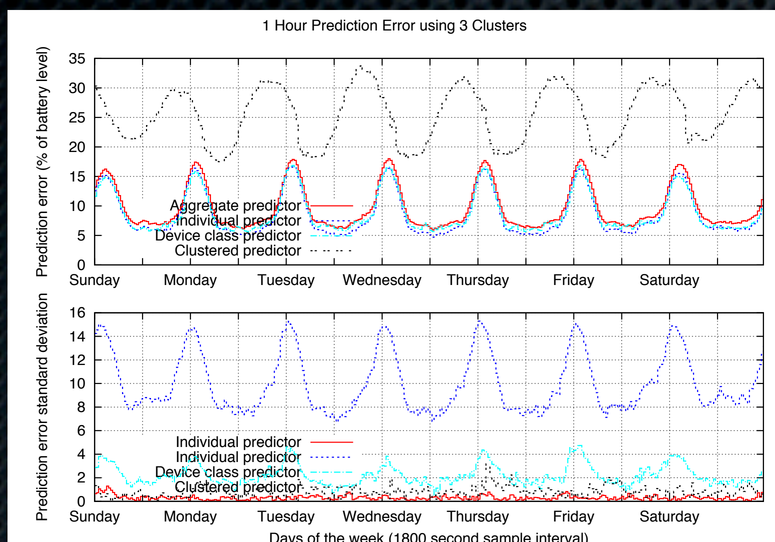
Battery prediction rate

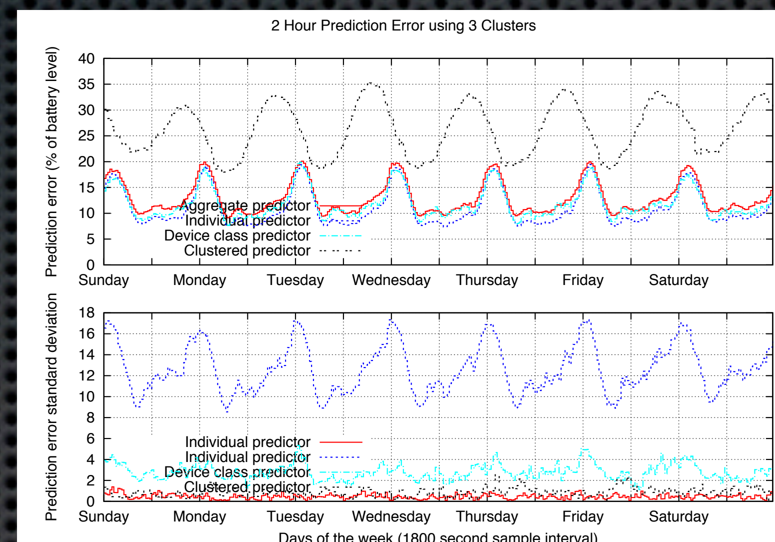


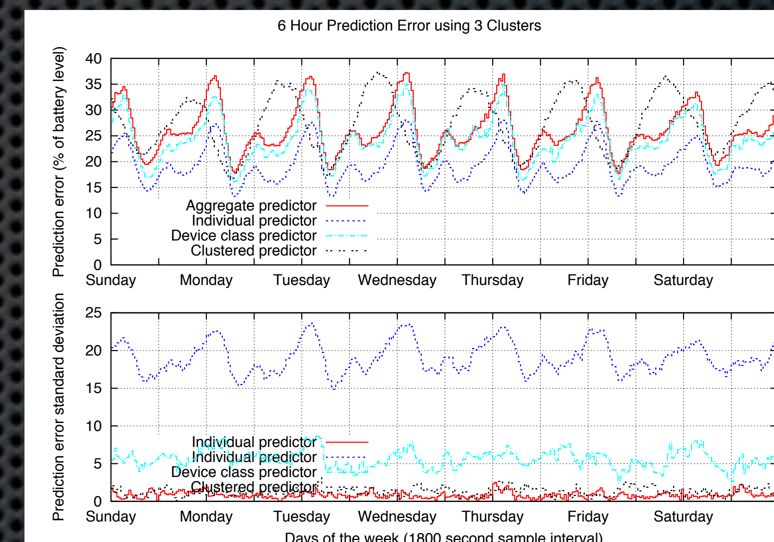
Battery prediction rate

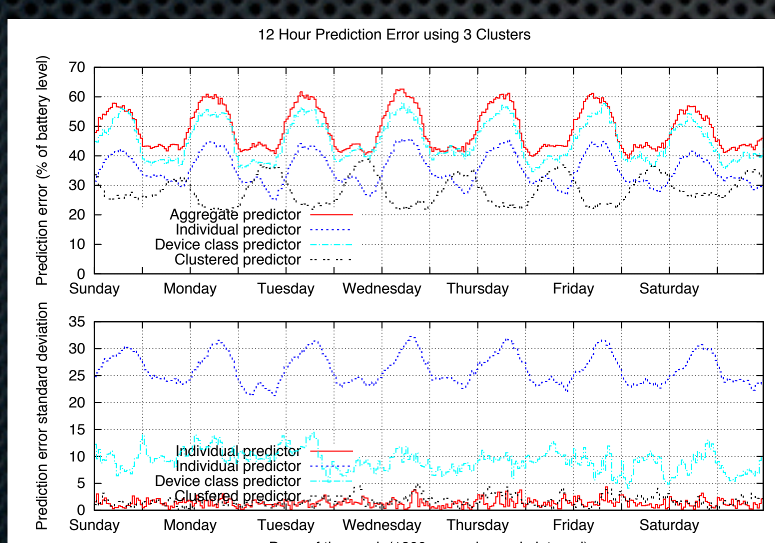


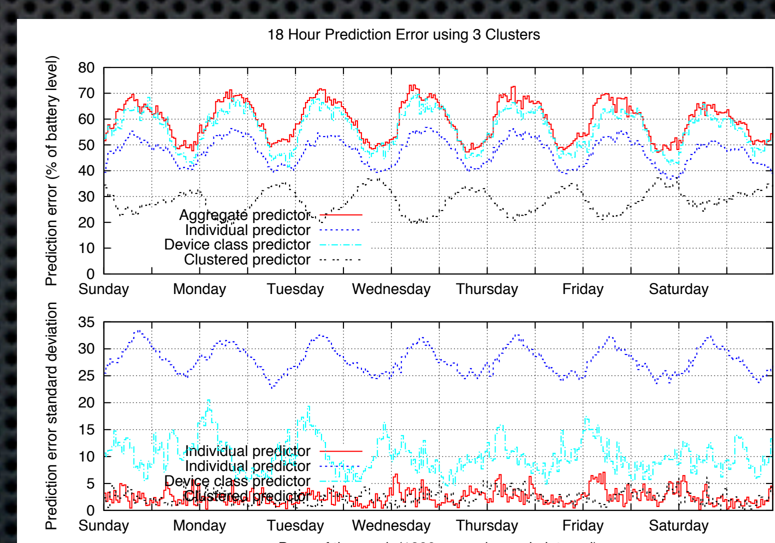
Battery prediction rate

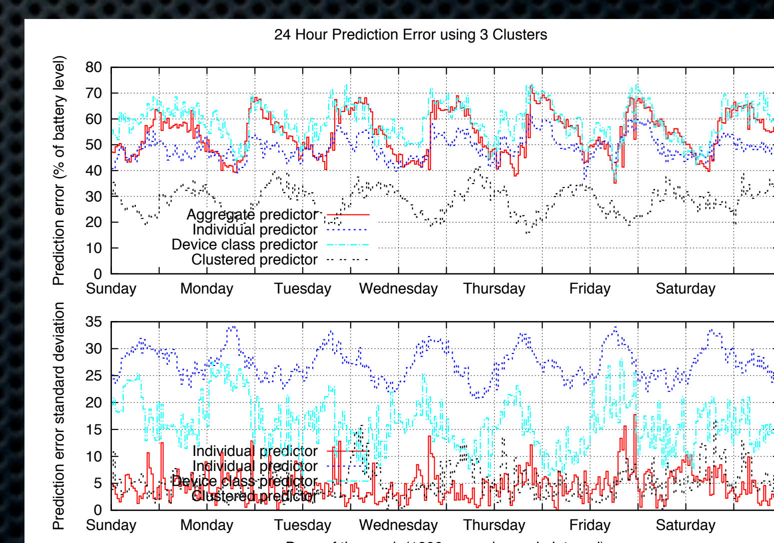




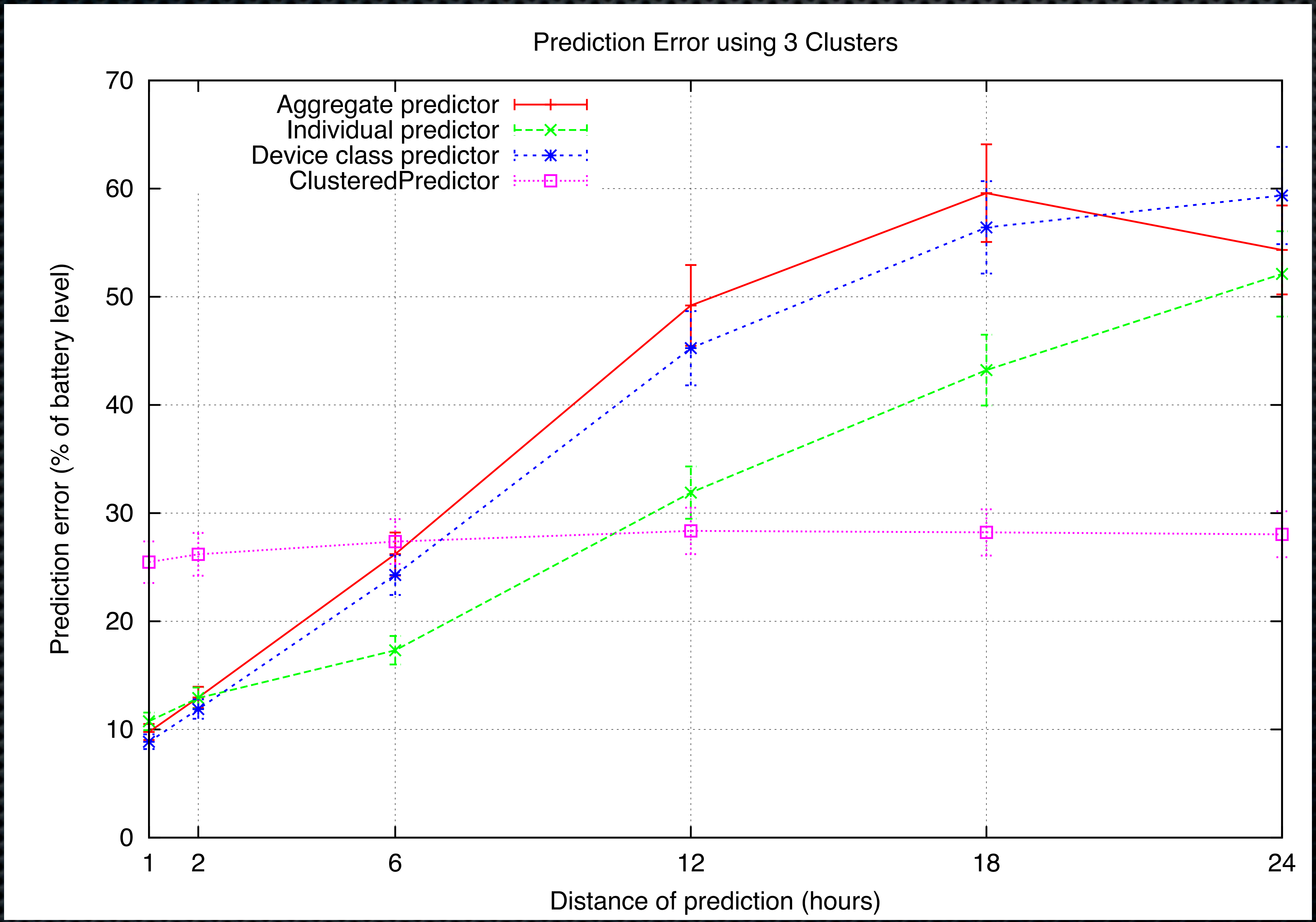




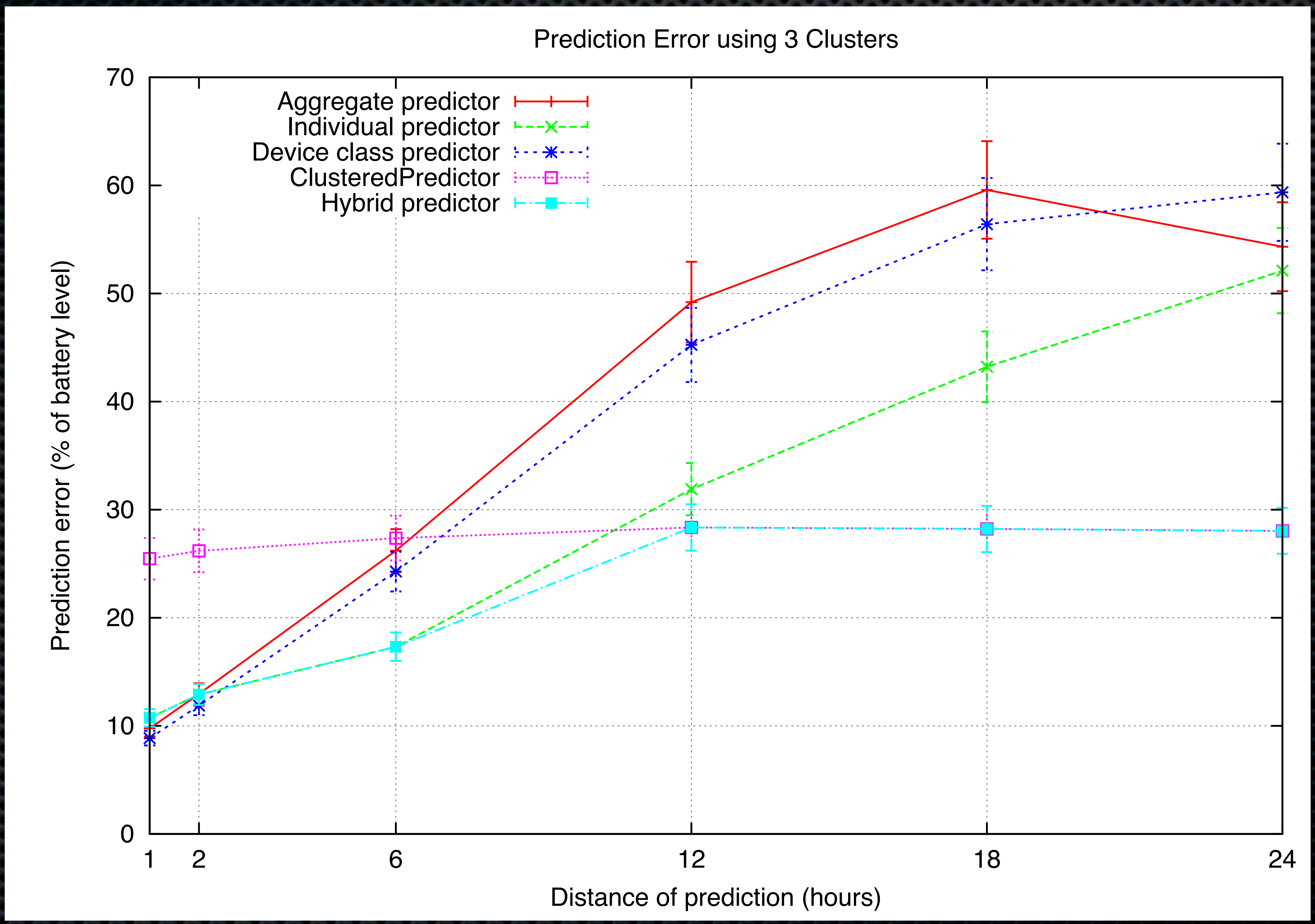




Battery prediction rate



Hybrid battery predictor



Successful execution prediction

Successful execution prediction

- Built **App-Predict** tool to simulate an application's execution against known traces.

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- Predictions over:

Successful execution prediction

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- Predictions over:
  - entire population

Successful execution prediction

- Built **App-Predict** tool to simulate an application’s execution against known traces.
- Predictions over:
  - entire population
  - specific device classes

Successful execution prediction

- Built **App-Predict** tool to simulate an application's execution against known traces.
- Predictions over:
  - entire population
  - specific device classes
  - specific user types

Use of App-Predict

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

- Energy capacities of all devices in the dataset are 'known'

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

- Energy capacities of all devices in the dataset are ‘known’
- Measured the energy consumption of basic applications

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

- Energy capacities of all devices in the dataset are ‘known’
- Measured the energy consumption of basic applications
  - Bluetooth scanning

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

- Energy capacities of all devices in the dataset are ‘known’
- Measured the energy consumption of basic applications
  - Bluetooth scanning
  - WiFi data transfer (from memory and file)

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

- Energy capacities of all devices in the dataset are ‘known’
- Measured the energy consumption of basic applications
  - Bluetooth scanning
  - WiFi data transfer (from memory and file)
  - File I/O

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

- Energy capacities of all devices in the dataset are ‘known’
- Measured the energy consumption of basic applications
  - Bluetooth scanning
  - WiFi data transfer (from memory and file)
  - File I/O
  - Video playback

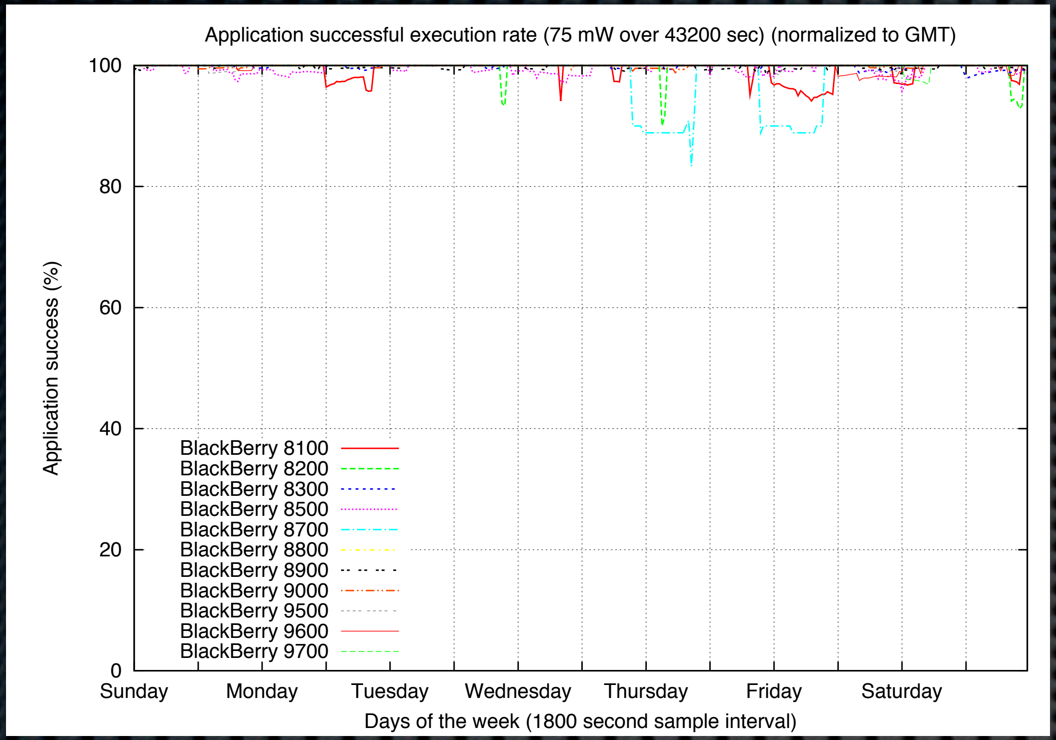
Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

Use of App-Predict

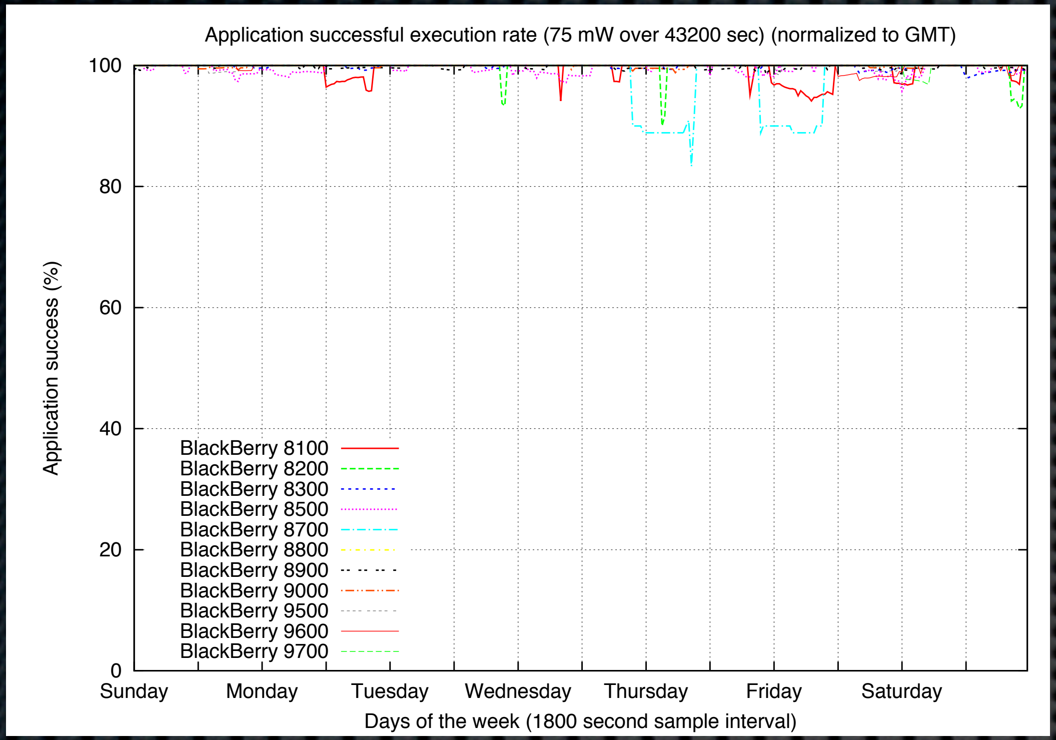
- Energy capacities of all devices in the dataset are 'known'
- Measured the energy consumption of basic applications
  - Bluetooth scanning
  - WiFi data transfer (from memory and file)
  - File I/O
  - Video playback
  - GSM phone calls

Device	Capacity	Voltage
8100	900 mAh	3.7V
8200	900 mAh	3.7V
8300	1100 mAh	3.7V
8500	1150 mAh	3.7V
8700	1000 mAh	3.7V
8800	1400 mAh	3.7V
8900	1400 mAh	3.7V
9000	1500 mAh	3.7V
9500	1400 mAh	3.7V
9600	1400 mAh	3.7V
9700	1500 mAh	3.7V

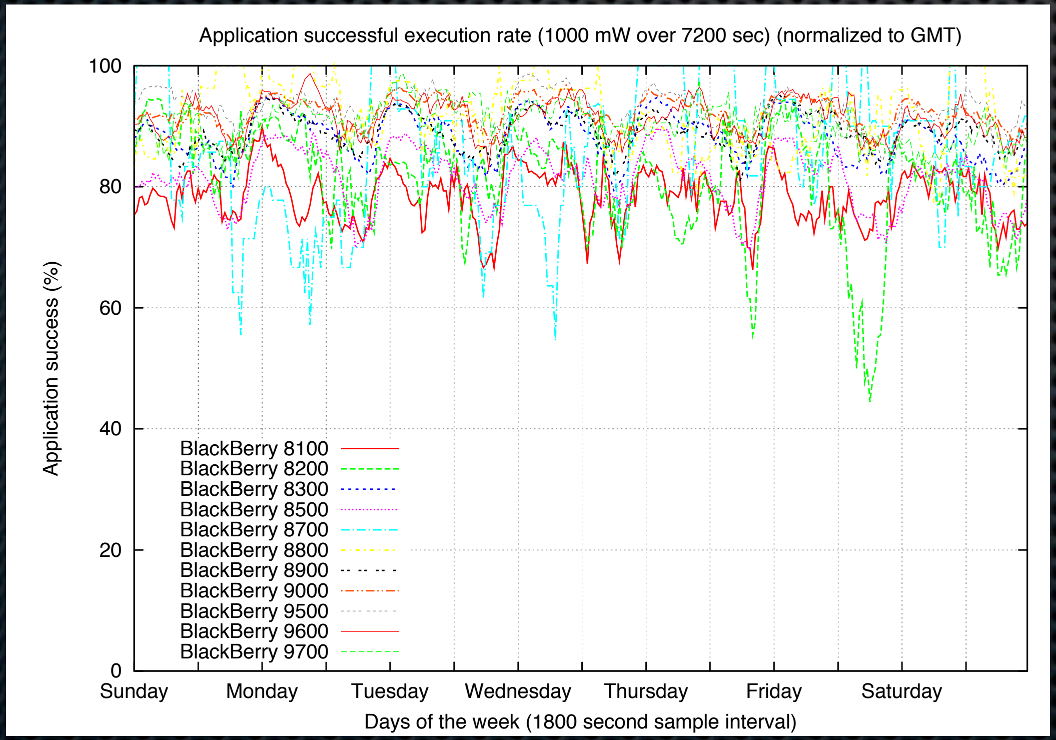
Examples


Application successful execution rate (75 mW over 43200 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

Examples

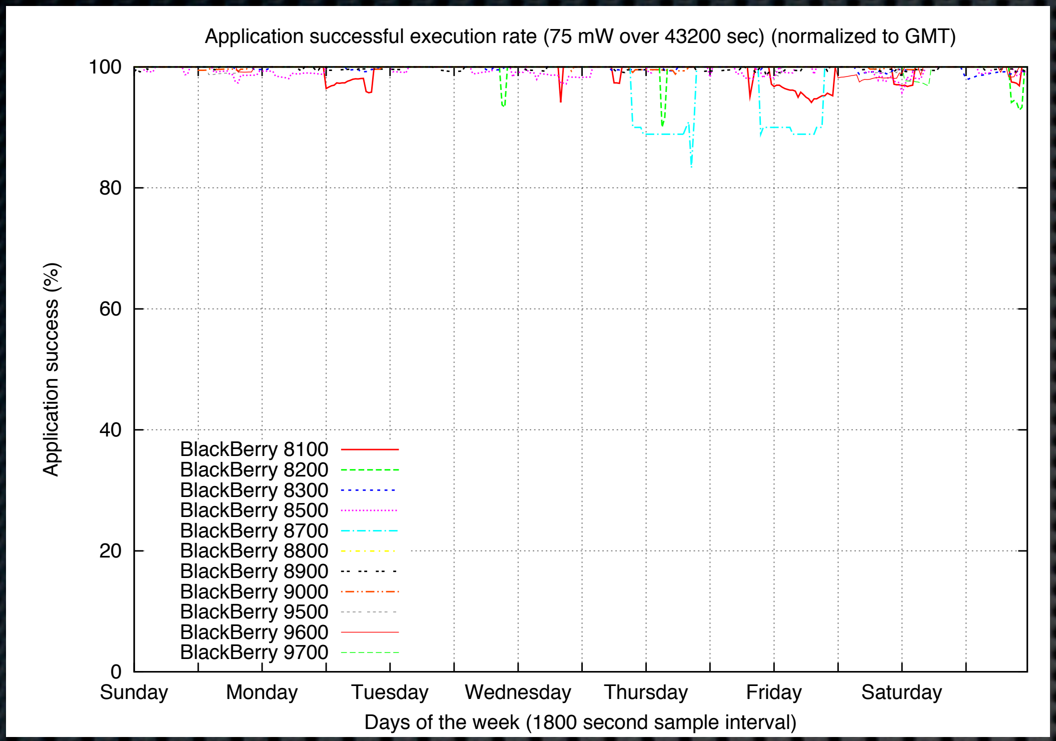


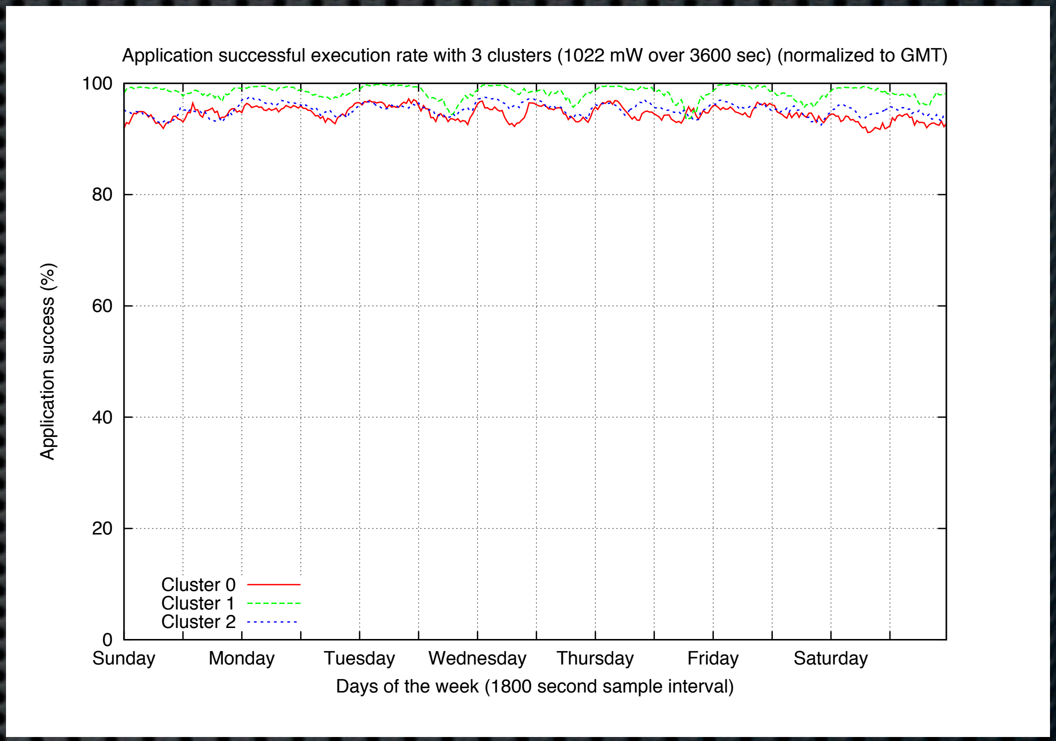
Application successful execution rate (75 mW over 43200 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

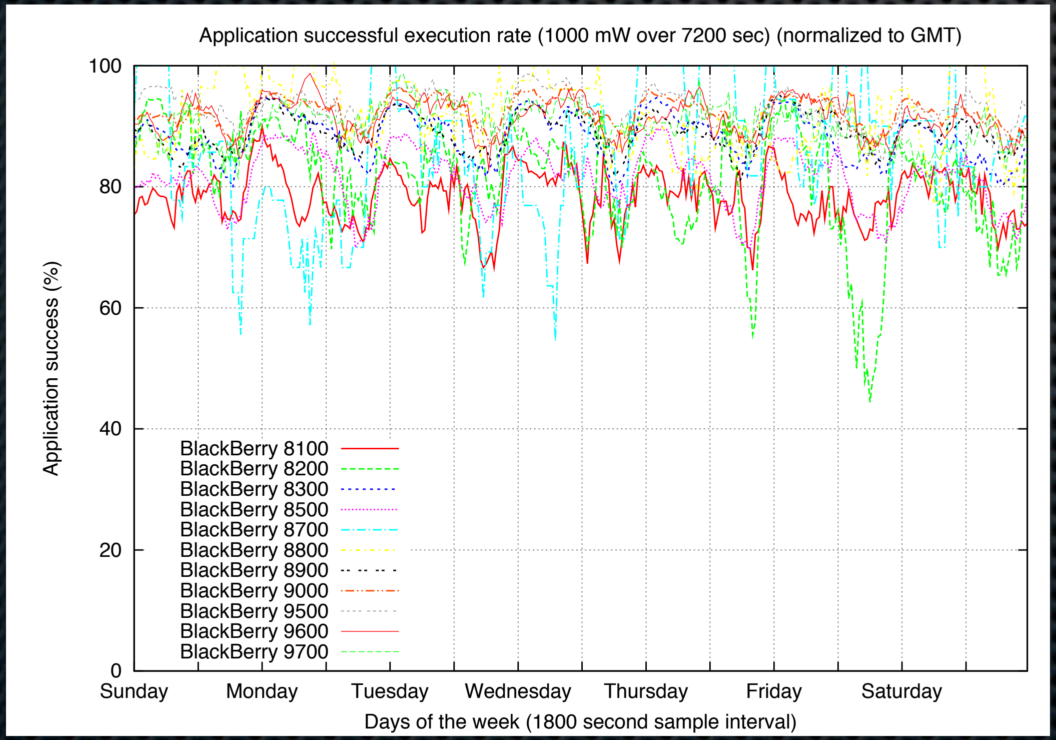


Application successful execution rate (1000 mW over 7200 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

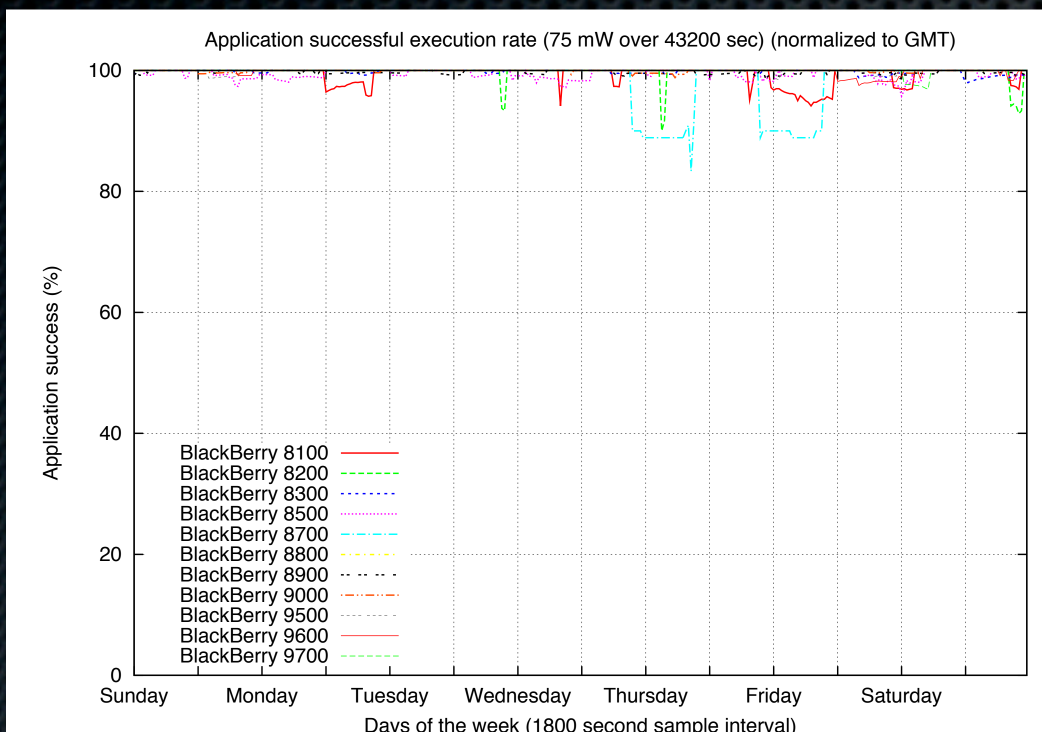
Examples

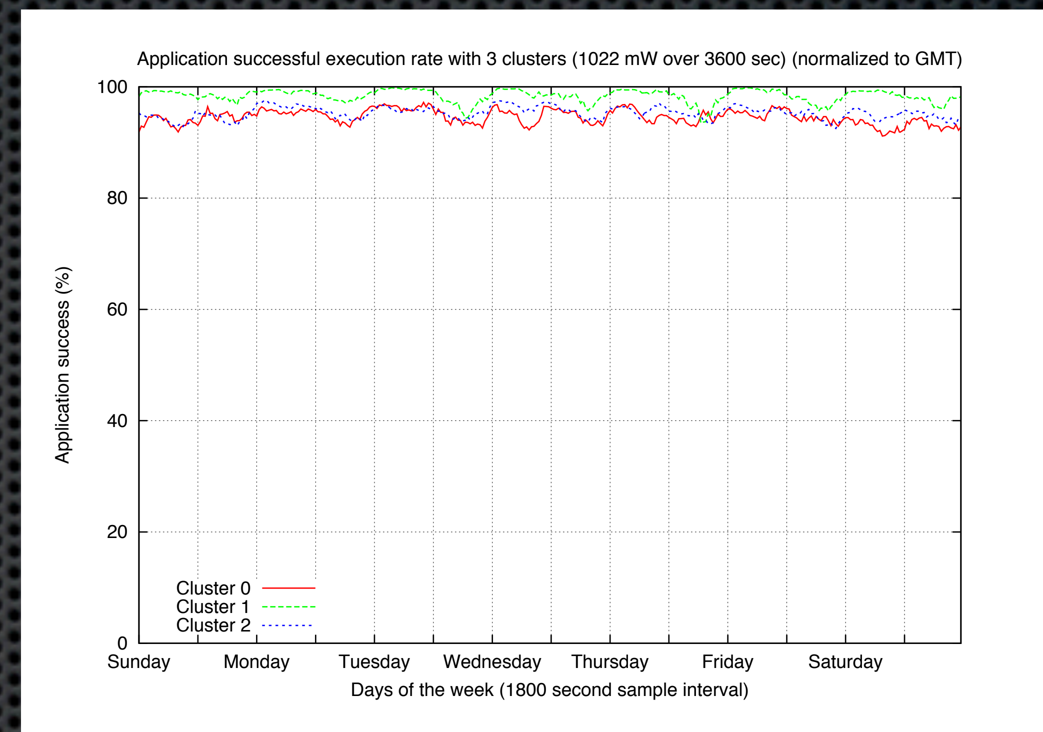

Application successful execution rate (75 mW over 43200 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

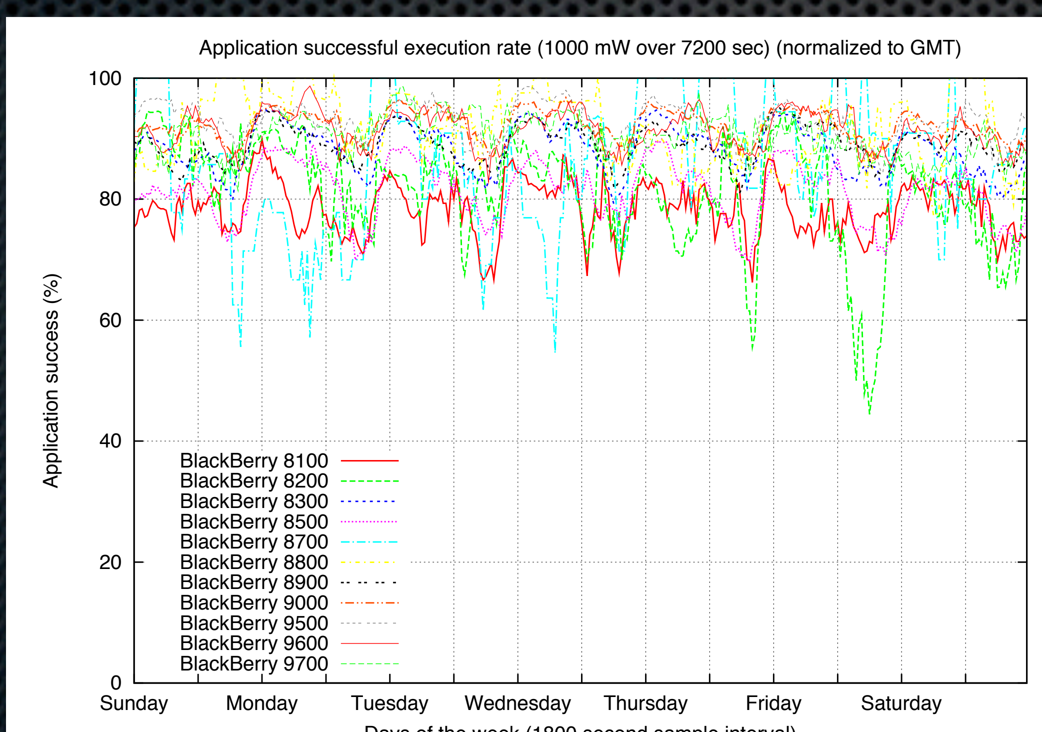

Application successful execution rate with 3 clusters (1022 mW over 3600 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
Cluster 0
Cluster 1
Cluster 2
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

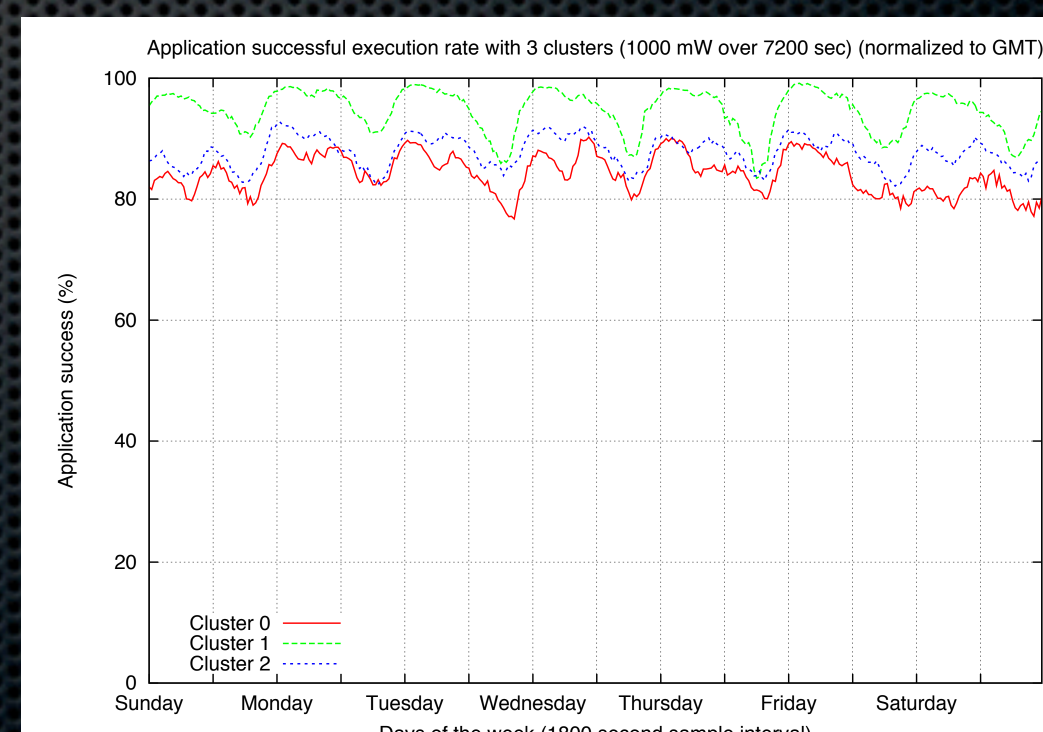

Application successful execution rate (1000 mW over 7200 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

Examples


Application successful execution rate (75 mW over 43200 sec) (normalized to GMT)
Application success (%)
Days of the week (1800 second sample interval)
Sunday Monday Tuesday Wednesday Thursday Friday Saturday
0 20 40 60 80 100
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700


Application successful execution rate with 3 clusters (1022 mW over 3600 sec) (normalized to GMT)
Application success (%)
Days of the week (1800 second sample interval)
Sunday Monday Tuesday Wednesday Thursday Friday Saturday
0 20 40 60 80 100
Cluster 0
Cluster 1
Cluster 2


Application successful execution rate (1000 mW over 7200 sec) (normalized to GMT)
Application success (%)
Days of the week (1800 second sample interval)
Sunday Monday Tuesday Wednesday Thursday Friday Saturday
0 20 40 60 80 100
BlackBerry 8100
BlackBerry 8200
BlackBerry 8300
BlackBerry 8500
BlackBerry 8700
BlackBerry 8800
BlackBerry 8900
BlackBerry 9000
BlackBerry 9500
BlackBerry 9600
BlackBerry 9700


Application successful execution rate with 3 clusters (1000 mW over 7200 sec) (normalized to GMT)
Application success (%)
Days of the week (1800 second sample interval)
Sunday Monday Tuesday Wednesday Thursday Friday Saturday
0 20 40 60 80 100
Cluster 0
Cluster 1
Cluster 2

More complex scenarios

More complex scenarios

- Scenario 1

More complex scenarios

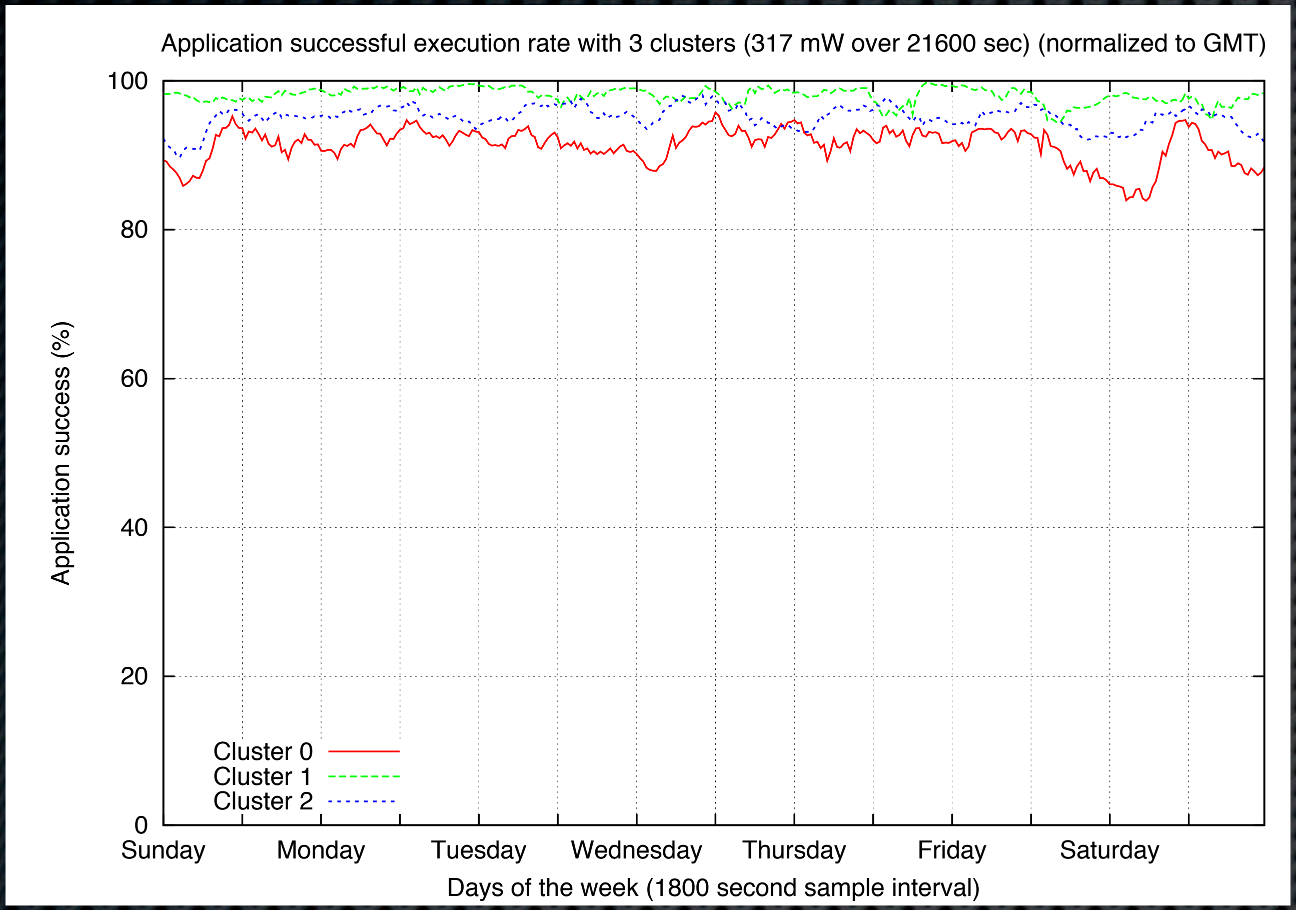
- Scenario 1
  - Scan for neighbouring Bluetooth device every minute

More complex scenarios

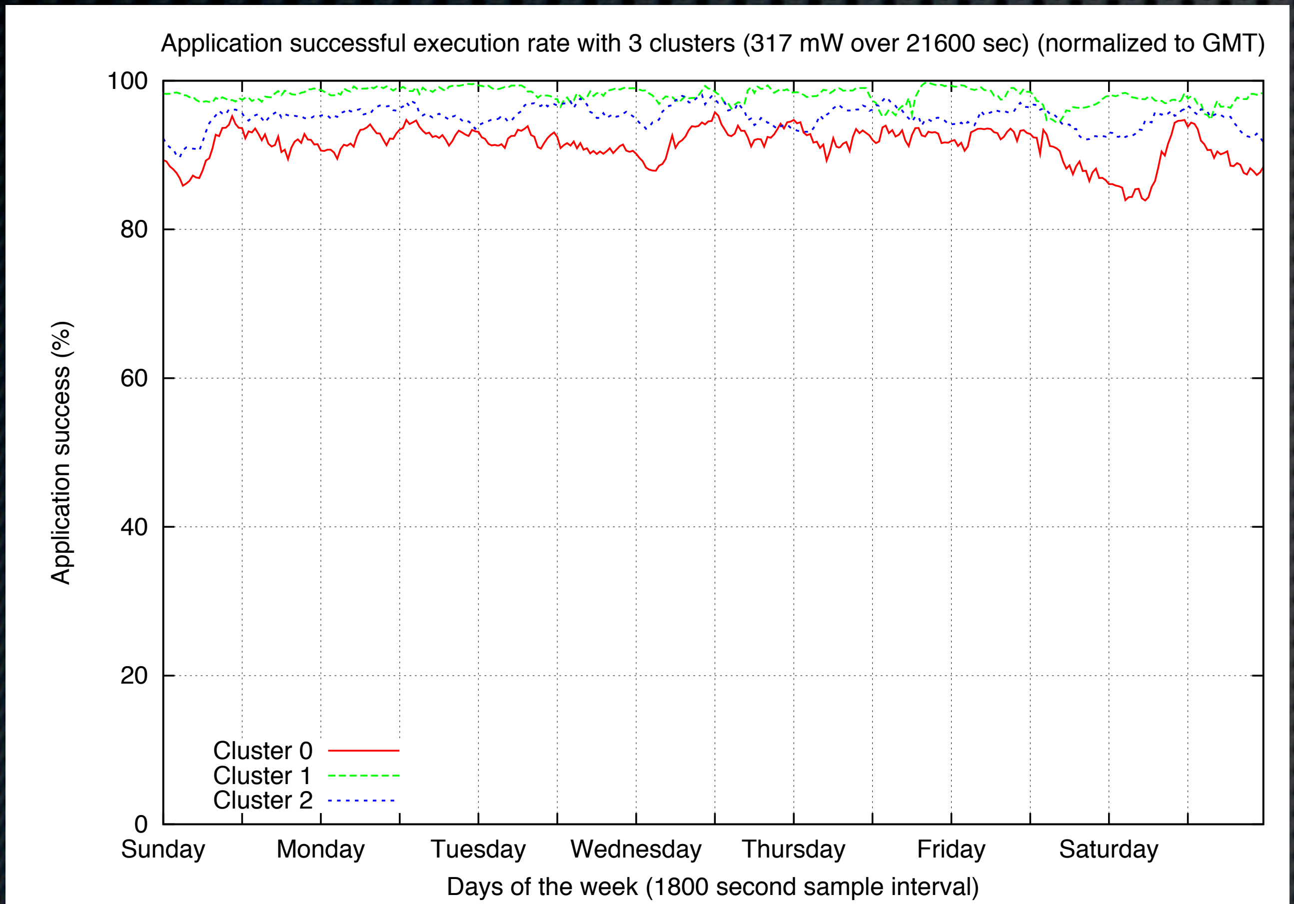
- Scenario 1
  - Scan for neighbouring Bluetooth device every minute
  - Upload 50 KB of memory resident data over WiFi after every scan.

More complex scenarios

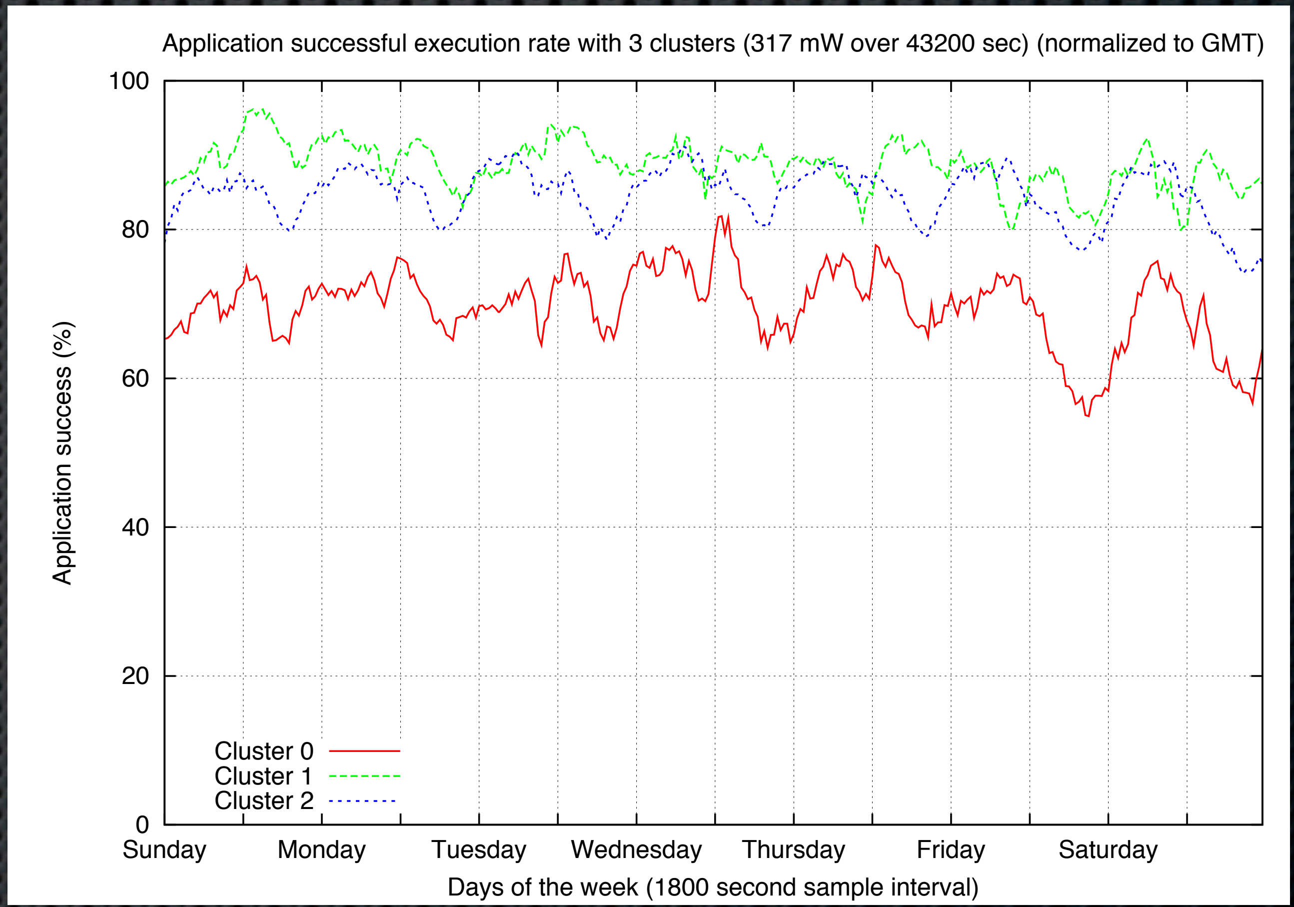
- Scenario 1
  - Scan for neighbouring Bluetooth device every minute
  - Upload 50 KB of memory resident data over WiFi after every scan.
  - Upload 100 MB of Flash-resident data over WiFi once per hour.



Application successful execution rate with 3 clusters (317 mW over 21600 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
Cluster 0
Cluster 1
Cluster 2
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)



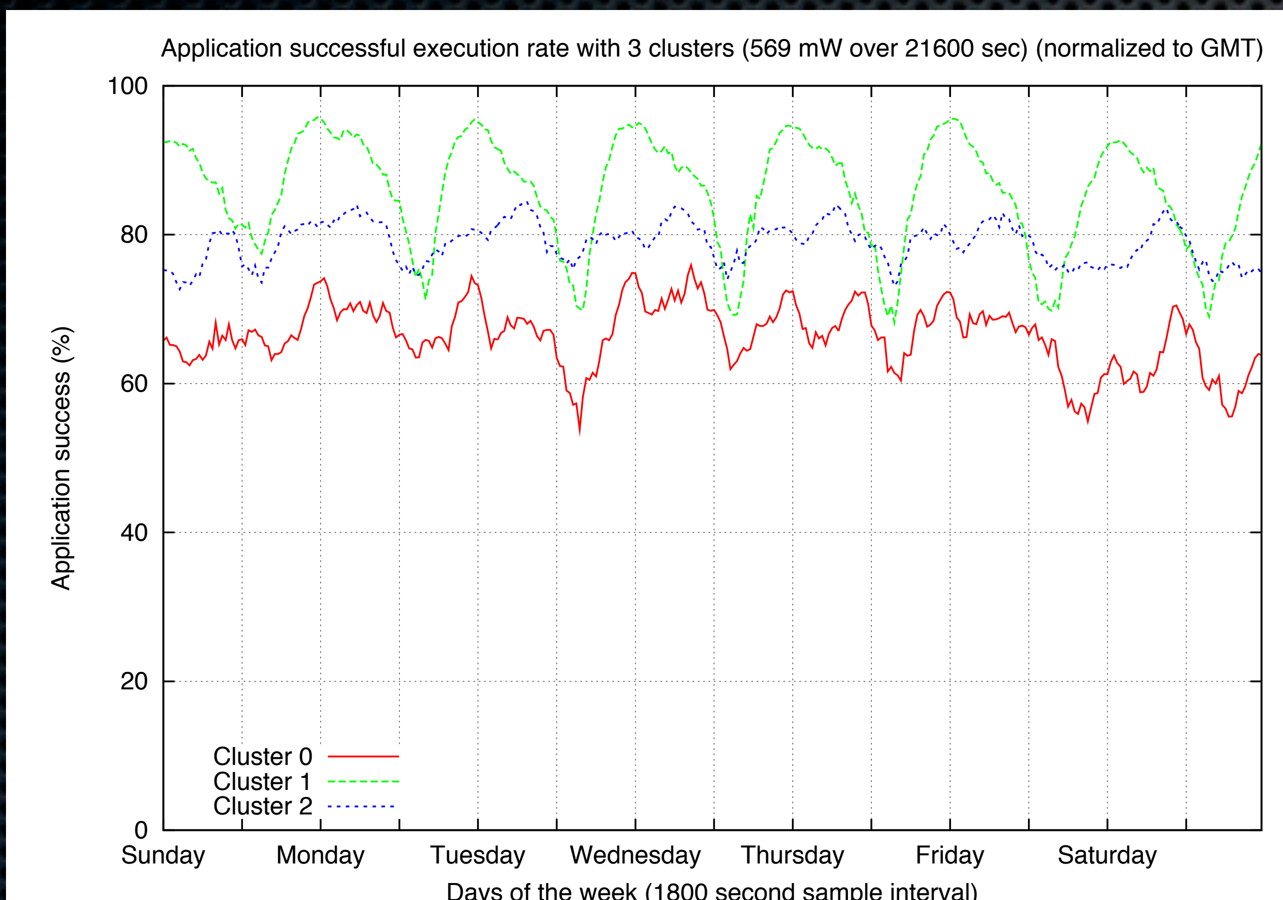
Application successful execution rate with 3 clusters (317 mW over 21600 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
Cluster 0
Cluster 1
Cluster 2
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

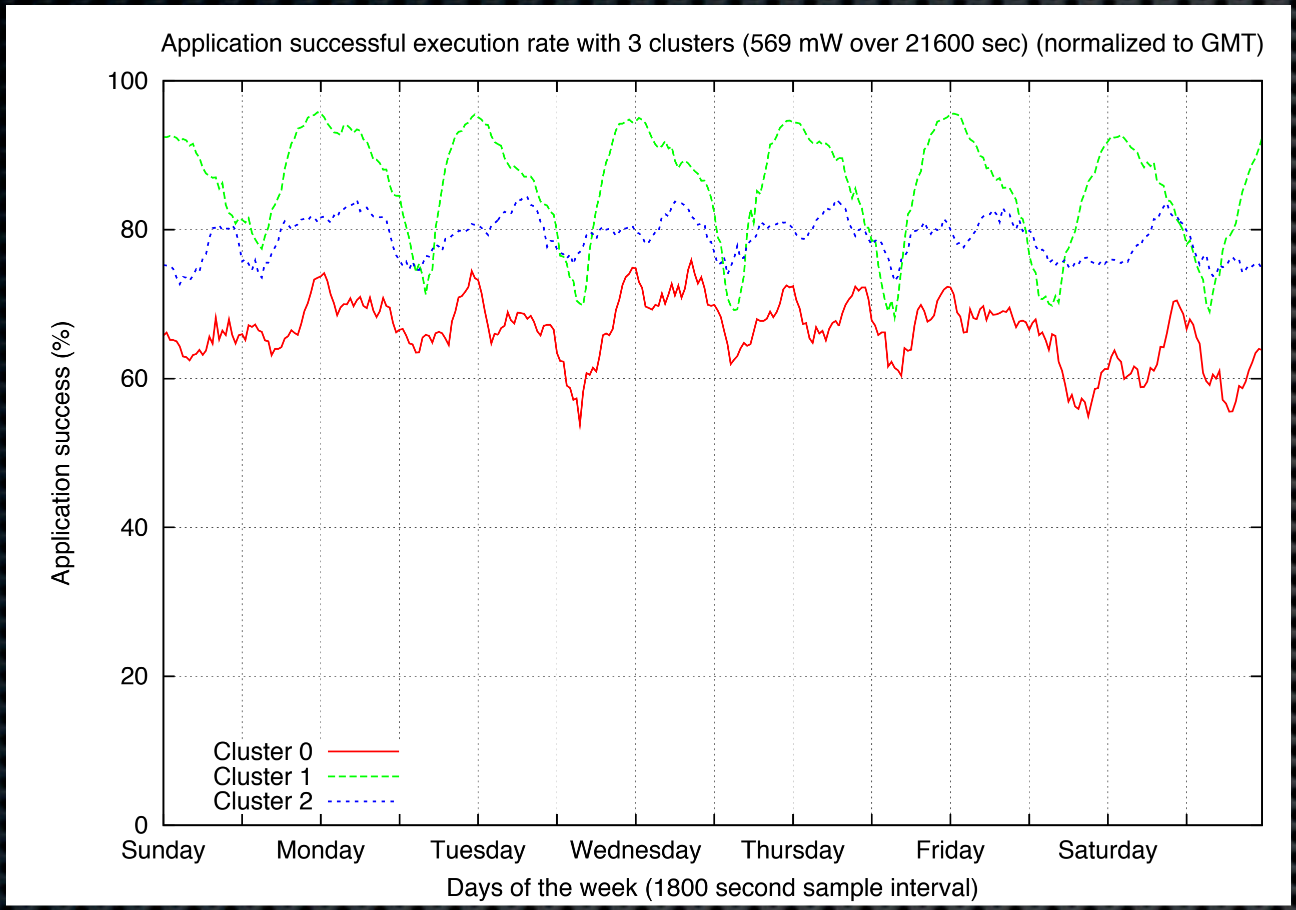


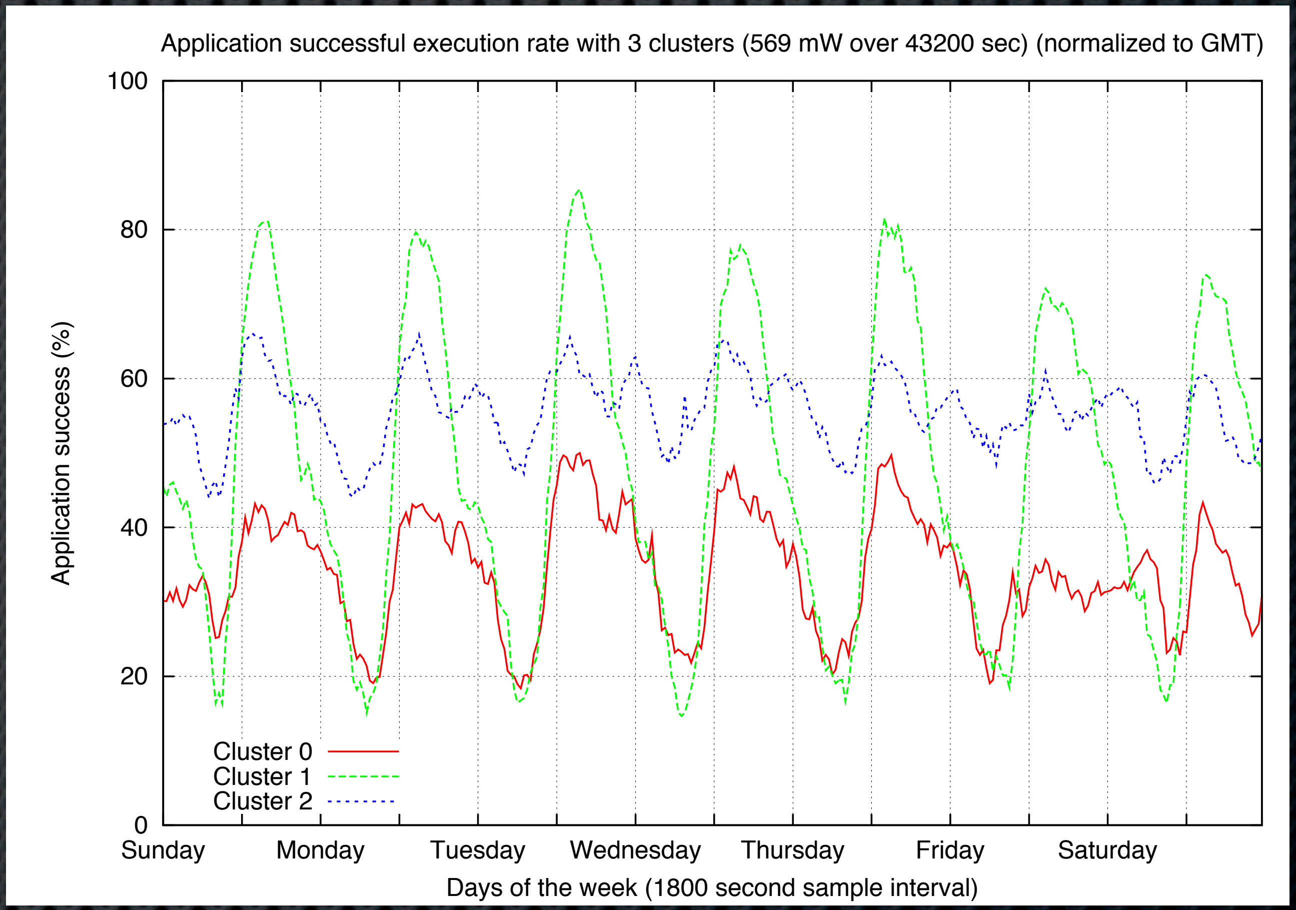
Application successful execution rate with 3 clusters (317 mW over 43200 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
Cluster 0
Cluster 1
Cluster 2
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)

- Scenario 2
  - Scan for neighbouring Bluetooth device every minute
  - Upload 50 KB of memory resident data over WiFi after every scan.
  - Upload 100 MB of Flash-resident data over WiFi once per hour.

- Scenario 2
  - Scan for neighbouring Bluetooth device every minute
  - Upload 50 KB of memory resident data over WiFi after every scan.
  - Upload 100 MB of Flash-resident data over WiFi once per hour.
  - Download 100 MB of data over WiFi once per hour and write it to Flash.


Application successful execution rate with 3 clusters (569 mW over 21600 sec) (normalized to GMT)
Application success (%)
100
80
60
40
20
0
Cluster 0
Cluster 1
Cluster 2
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Days of the week (1800 second sample interval)





Tuesday, September 14, 2010

Future work

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- Runtime profiling of applications' energy consumption.

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- Creation of an energy supervisor

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- Runtime profiling of applications' energy consumption.
- Creation of an energy supervisor
  - Uses future predicted battery level to enable/disable energy intensive applications to preserve device usability.

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- Clustering users by energy consumption characteristics can improve battery level prediction by ~***54%*** over long durations.
- ***App-Predict*** tool to simulate the successful execution rate of energy intensive mobile applications.

Questions?

Trivia questions