A Case for Battery Charging-Aware Power Management and Deferrable Task Scheduling in Smartphones

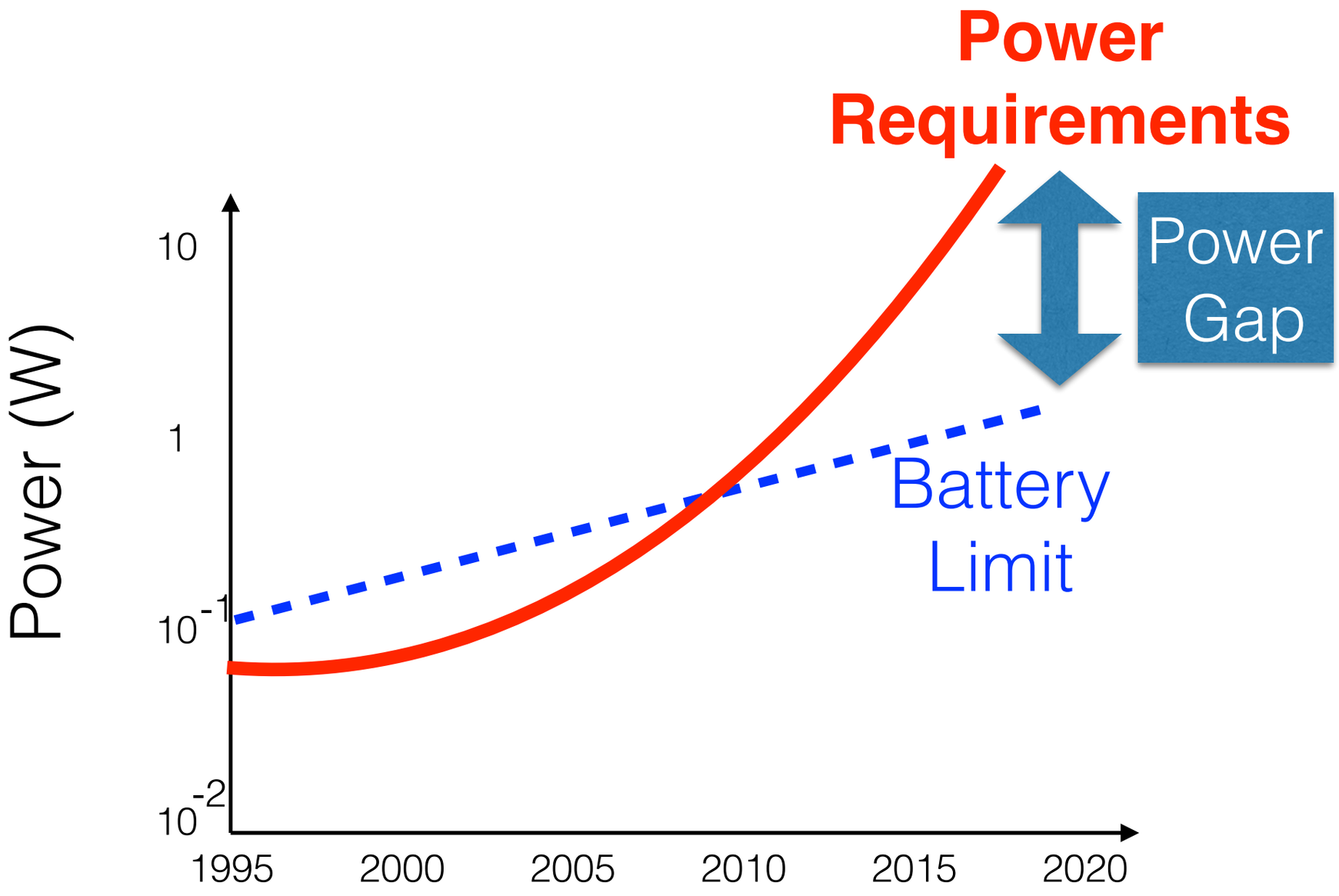
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NanoCAD Laboratory
University of California, Los Angeles

NanoCAD LAB

Networked & Embedded Systems Laboratory

Motivation



Courtesy of PREETI GUPTA, “RTL Design-for-Power In Mobile SoCs”.

Power gap - Device Availability

Maximizing lifetime alone does not completely satisfy user's needs

"Availability": the proportion of time the system can deliver the subjective user-desired functionality.

Net Energy Stored ~= Availability

Device Availability

How to increase the device availability?

Discharging Process

- power management techniques in the OS.
- power management in applications especially the perpetual sensing apps

Device Availability

How to increase the device availability?

Discharging Process

- power management techniques in the OS.
- power management in applications especially the perpetual sensing apps

Charging Process

- battery related hardware (supply, charger controller, battery characteristics)
- user's behavior
- power load (running applications

Is it possible we can control the charging process in a way to increase the net energy gained by the end of the charging event?

Charging Process

Battery-related hardware

- Battery Characteristics
- Power Supply
- Charger Controller

Software

- Tasks run during the charging process
- Schedule of different tasks through the charging duration

User behavior

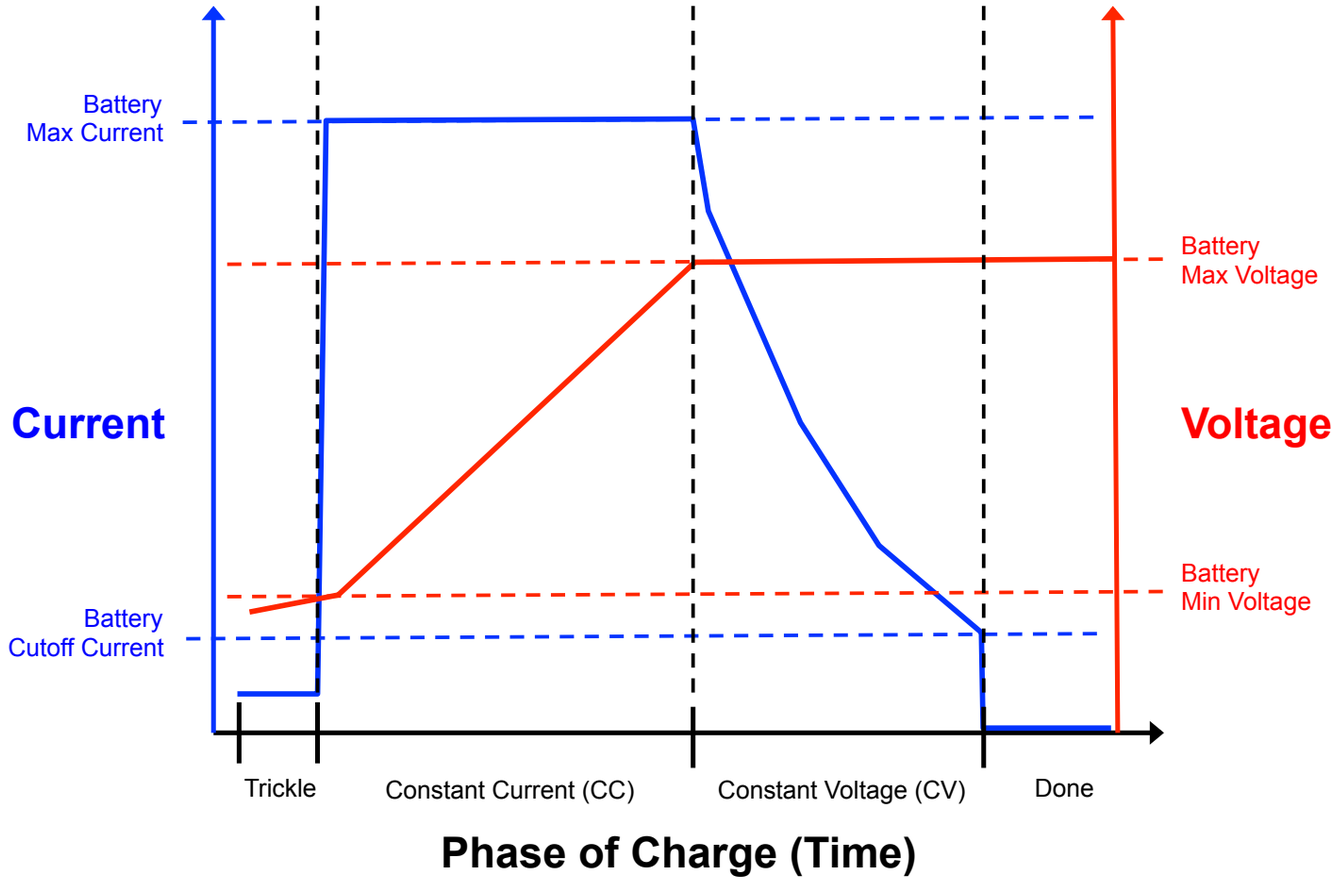
- How long they stay plugged in?
- What is the state of charge (SOC) at plug-in event?
- What is the SOC at the unplug event?

Part 1:
Battery Related Hardware (Charging Characteristics)

Li-Ion Charging (Battery Characteristics)

Charging process from 0% to 100% SOC is divided into two main phases:

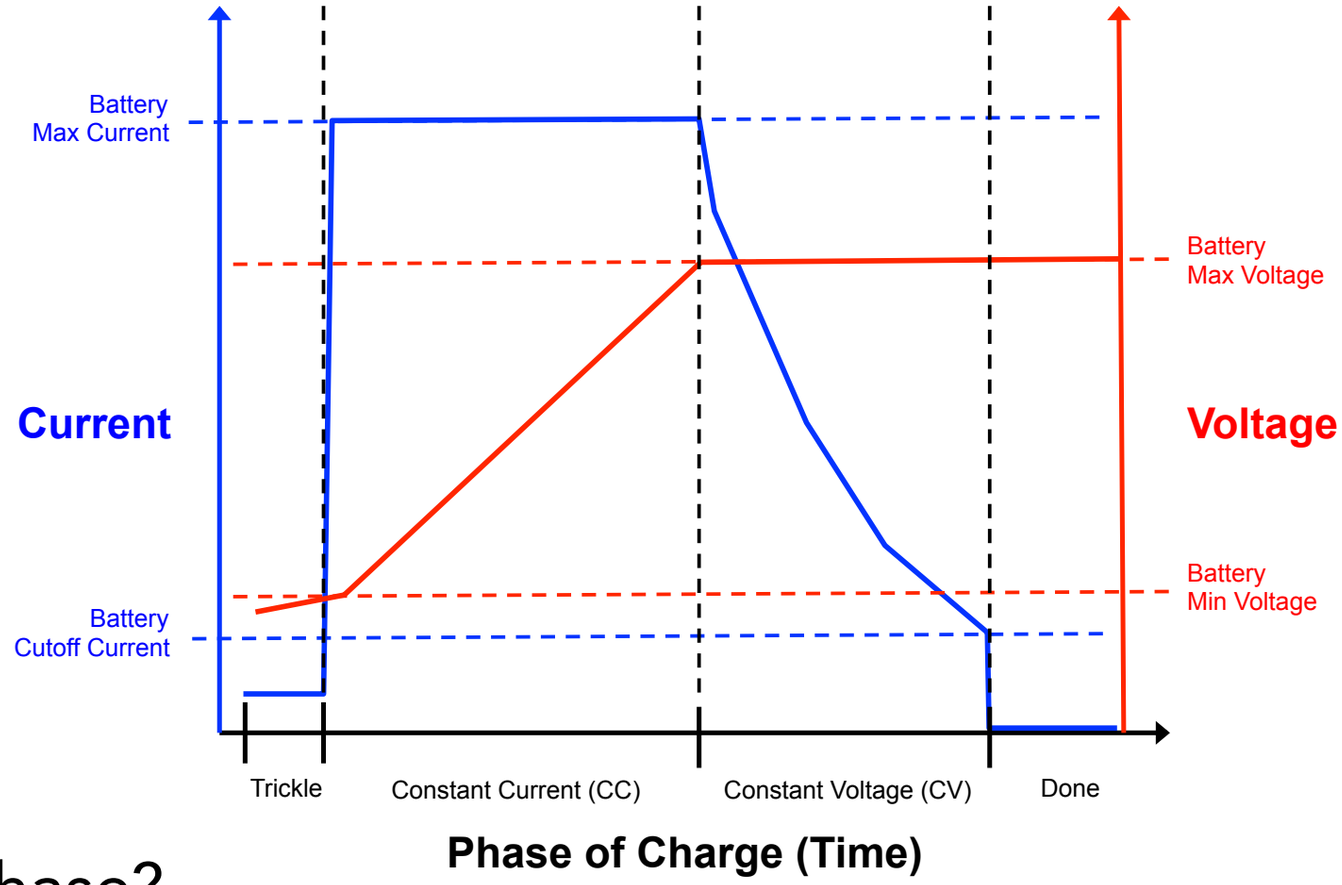
1. Constant Current Phase (CC)
2. Constant Voltage Phase (CV)



Li-Ion Charging (Battery Characteristics)

Charging process from 0% to 100% SOC is divided into two main phases:

1. Constant Current Phase (CC)
2. Constant Voltage Phase (CV)



Quantification:

1. How much time spent in each phase?
2. What is the SOC at each phase?
3. Can we benefit from this behavior?

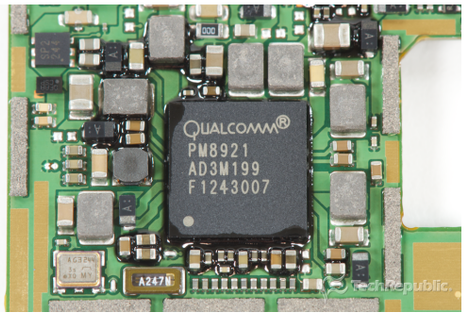
Smartphone Charging Profile



USB charger



AC adapter charger



Charger Controller Circuit
(Qualcomm PM8921)



Supply Side → Controller Side → Battery

* Qualcomm chip image is courtesy of Bill Detwiler - techRepublic

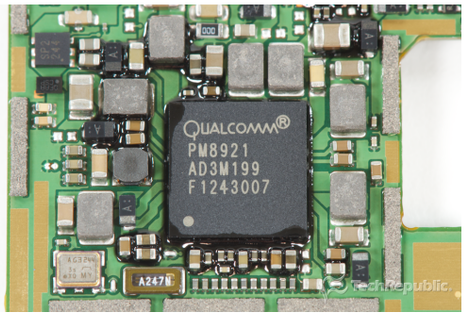
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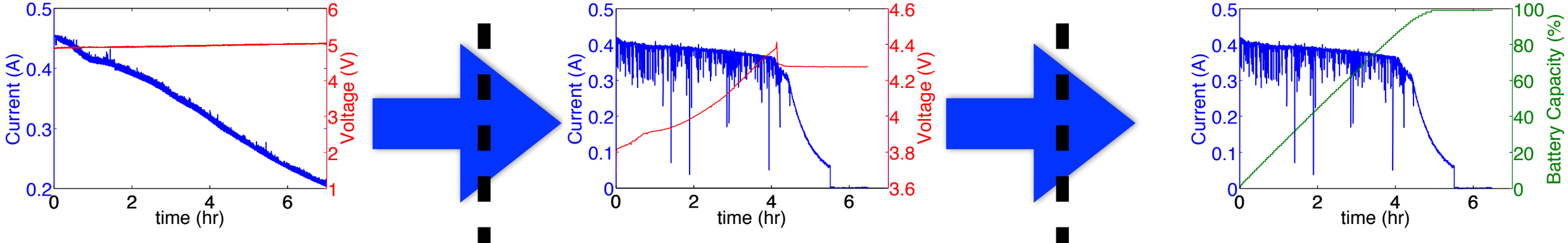


Measure (I-V)
SMU

Report (I-V)
Android HAL

* Qualcomm chip image is courtesy of Bill Detwiler - techRepublic

Smartphone Charging Profile (USB cable)



USB charger

- 5 volt supply
- Current drops to maintain conservation of power flow (Power in = Power out)

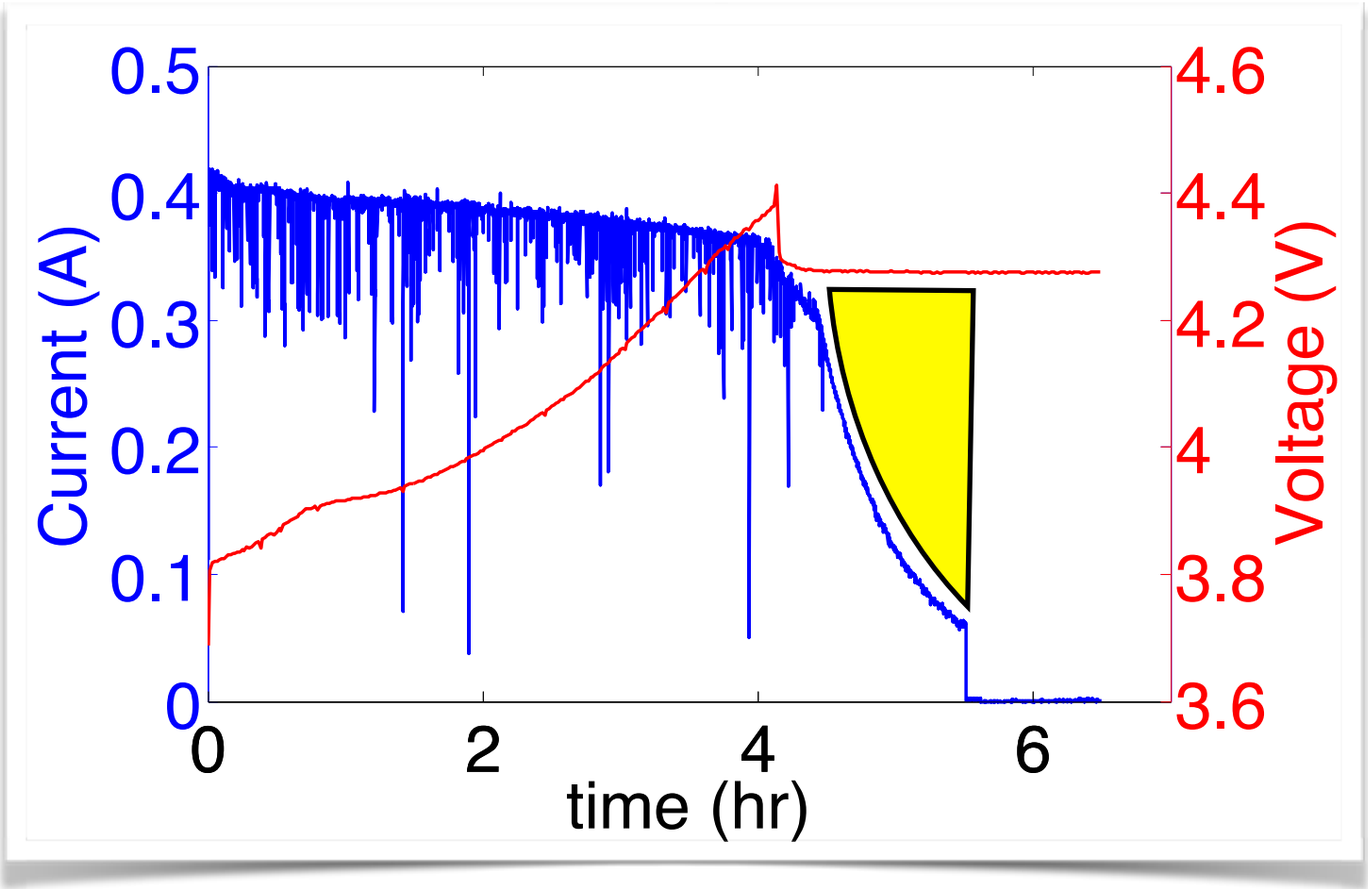
Charger Controller Circuit (Qualcomm PM8921)

- The current drawn is approximately 400 mA during the CC phase, being limited by the USB 500 mA restriction. (USB restriction)
- CV phase starts after about 4.2 hours
- The time spent in the CV phase is approximately 1.3 hours.

- SOC is approximately 85% when CV starts

Is there an opportunity to increase availability from the charging profile?

Power Headroom



- Power drawn by the battery while charging depends on the phase of charge.
- The maximum power of the 5 VDC supply is ***not*** drawn throughout the entire charging process.

Power Headroom

The maximum power that the supply can deliver minus the maximum power that the battery can absorb

- **What if this headroom can be used to do useful work for the system load without impacting the energy gained by the battery during charging?**
- **Under what condition will the users benefit from this power headroom?**
- **What is the portion of users that will benefit from this headroom?**

Charging Process

Battery-rela
hardware

Existence of Power Headroom

tery Characteristics
wer Supply
arger Controller

Software

- Tasks run during the charging process
- Schedule of different tasks through the charging duration

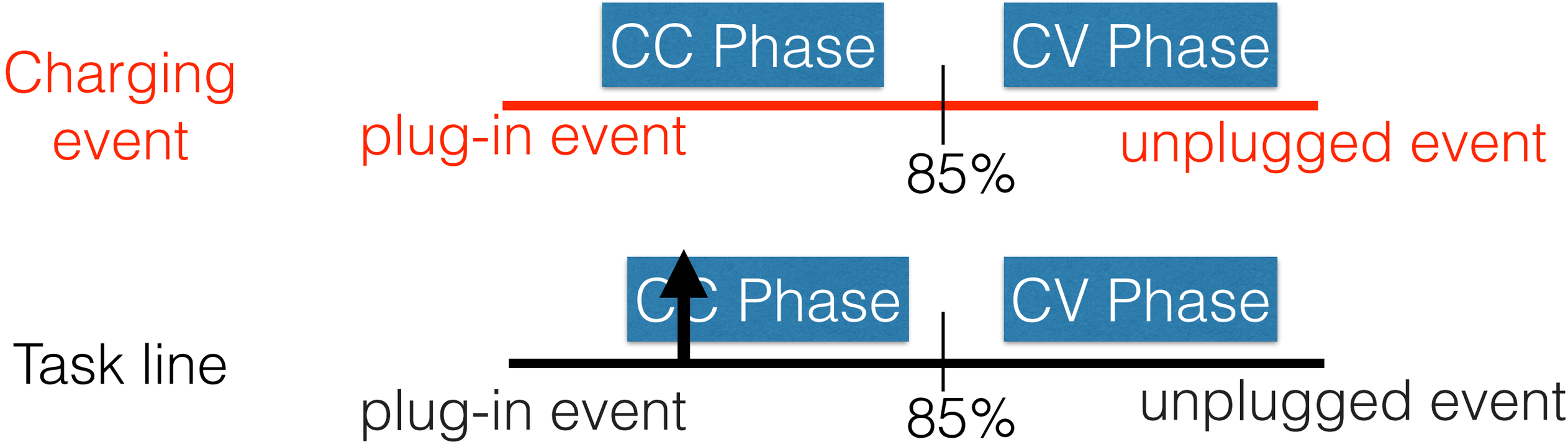
User behavior

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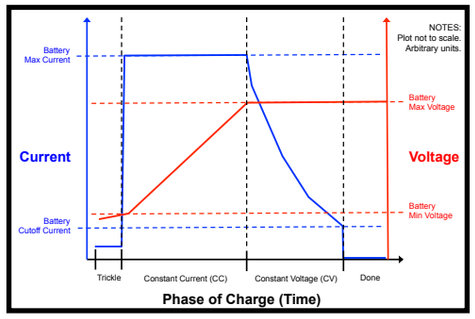
Part 2:
Software:
Opportunities for Task Deferral

Opportunities for Task Deferral





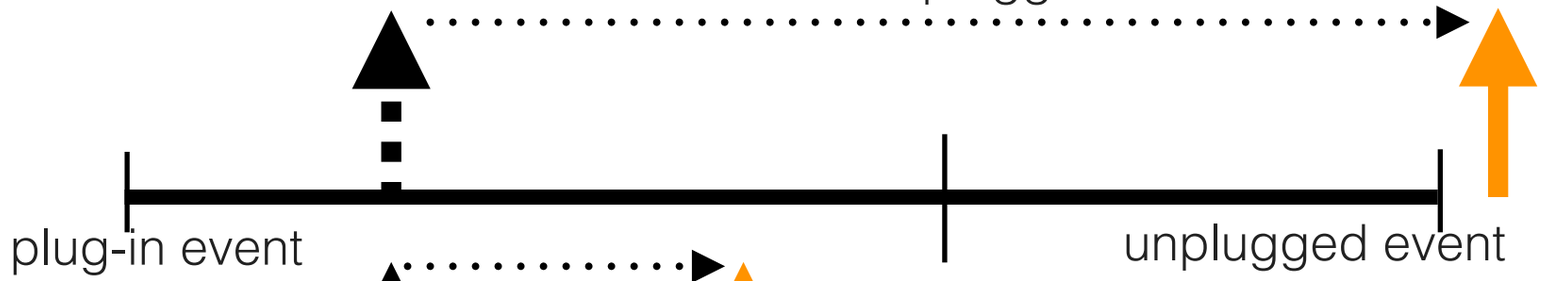
Scheduling Policies



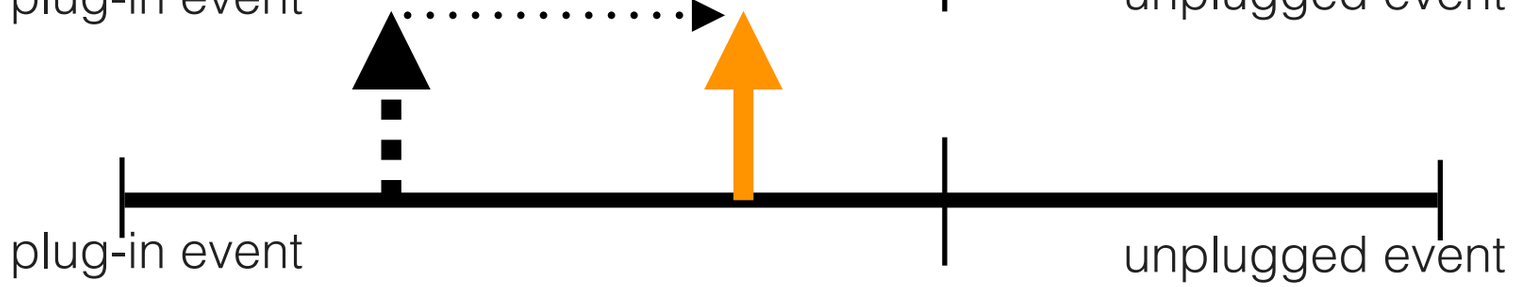
original scheduler



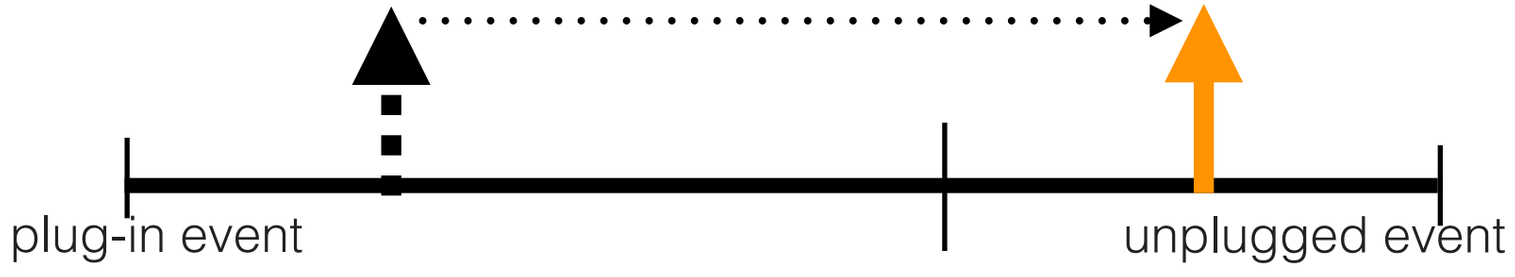
1- Schedule tasks after unplugging



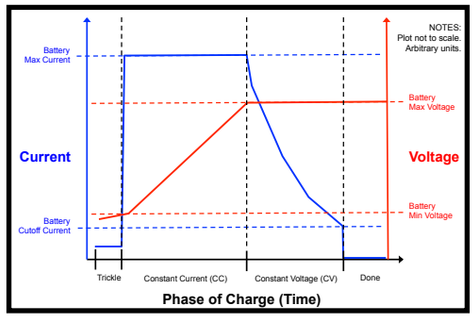
2- Schedule tasks within the CC Phase

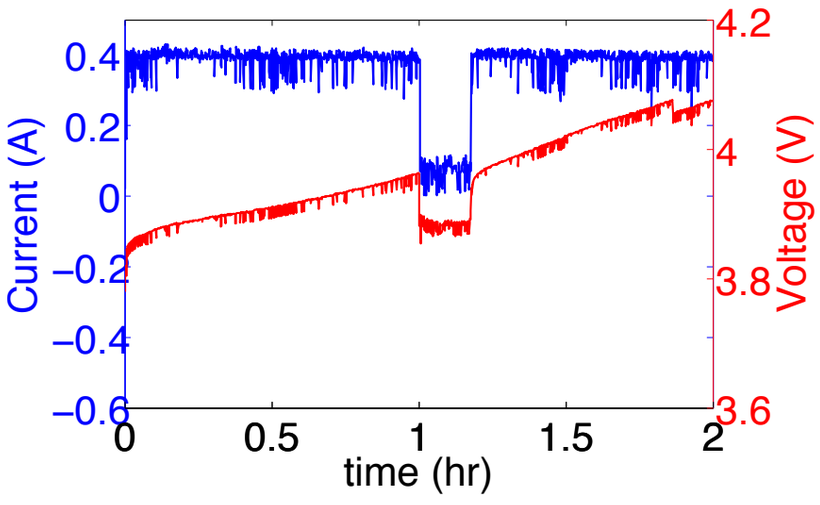


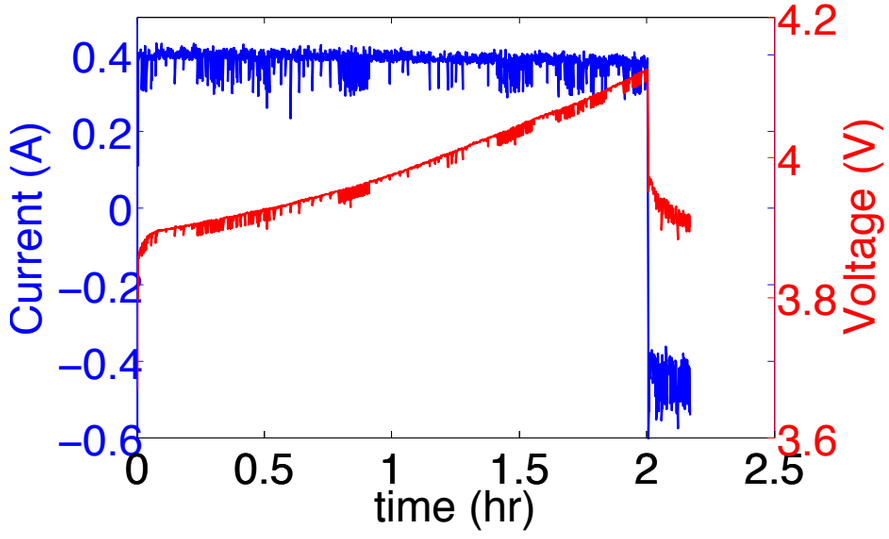
3- Schedule tasks in the power headroom

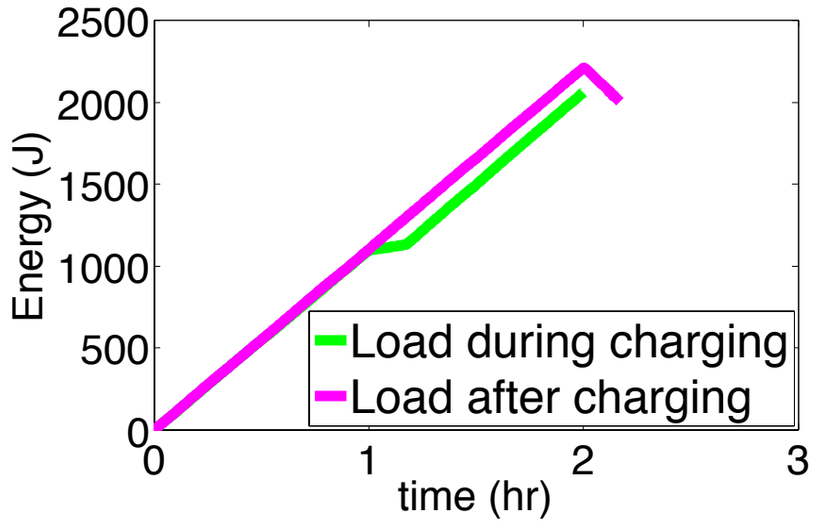


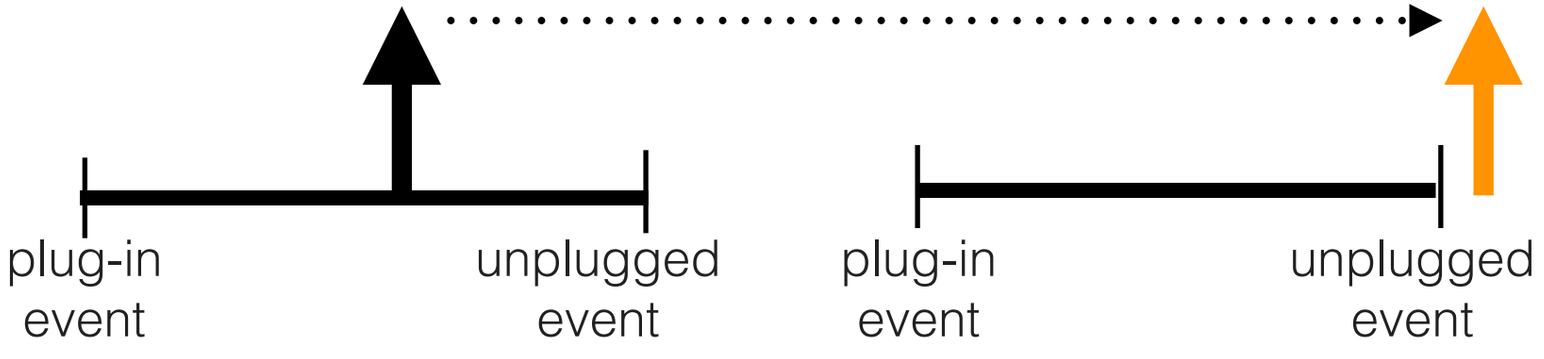
Schedule Tasks After Unplugging



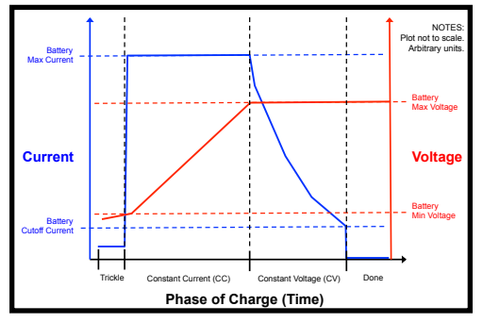


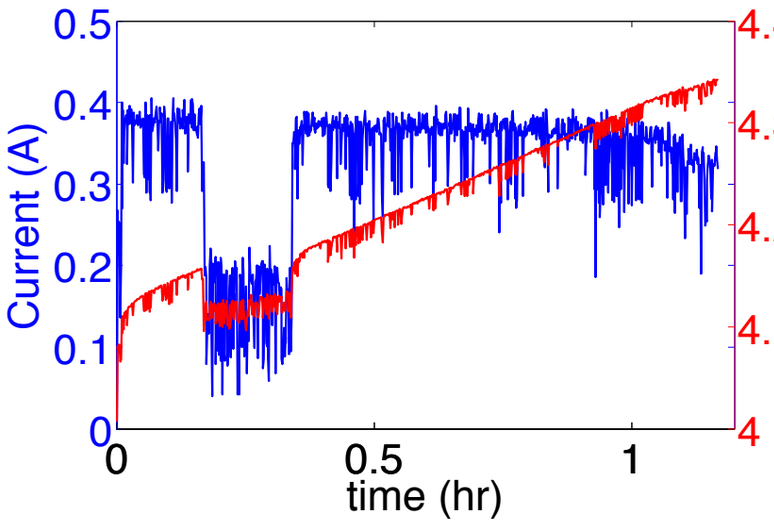


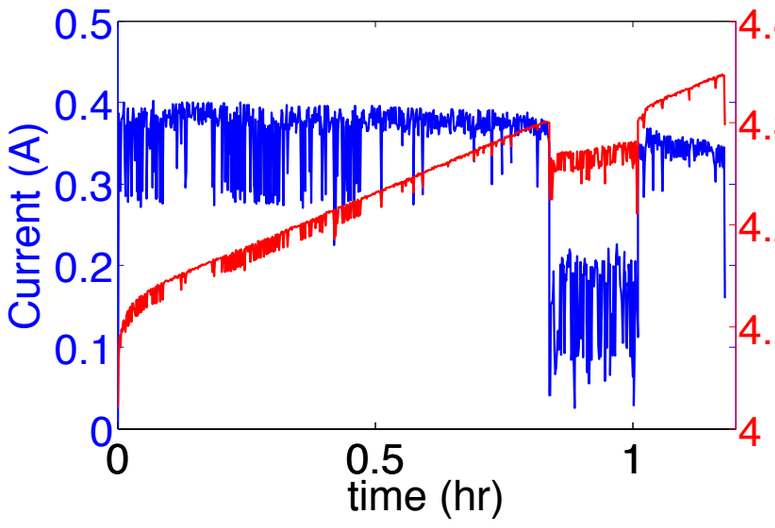


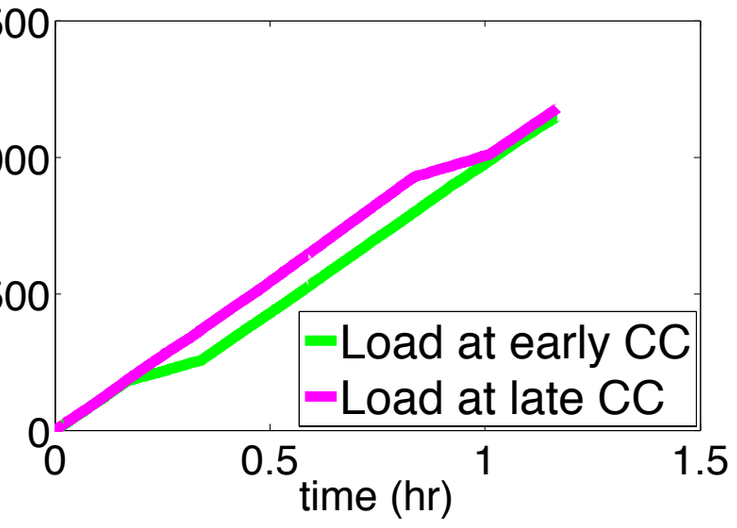


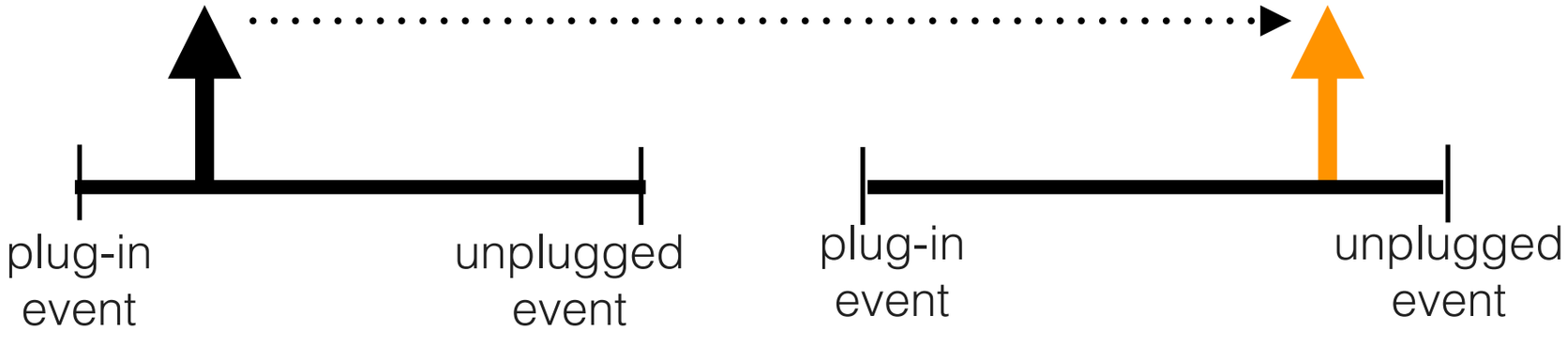
Schedule Tasks Within the Constant Current Phase



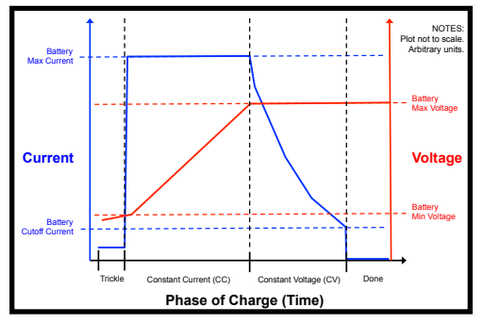


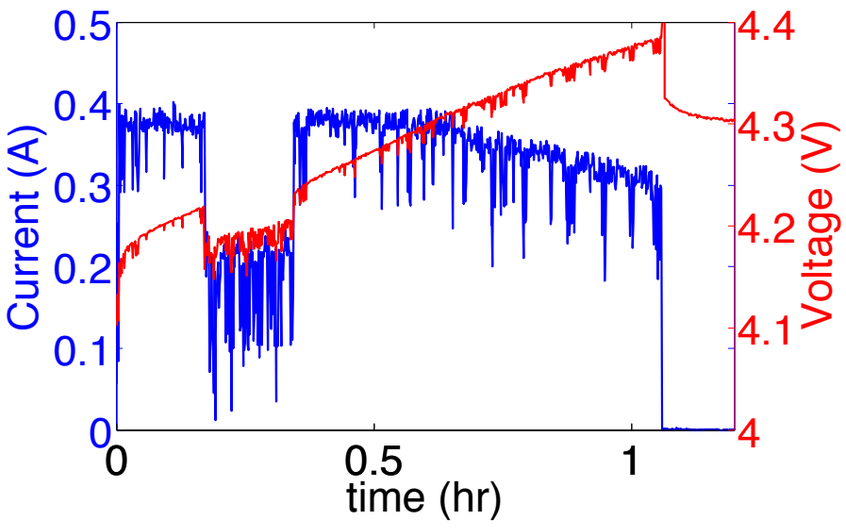


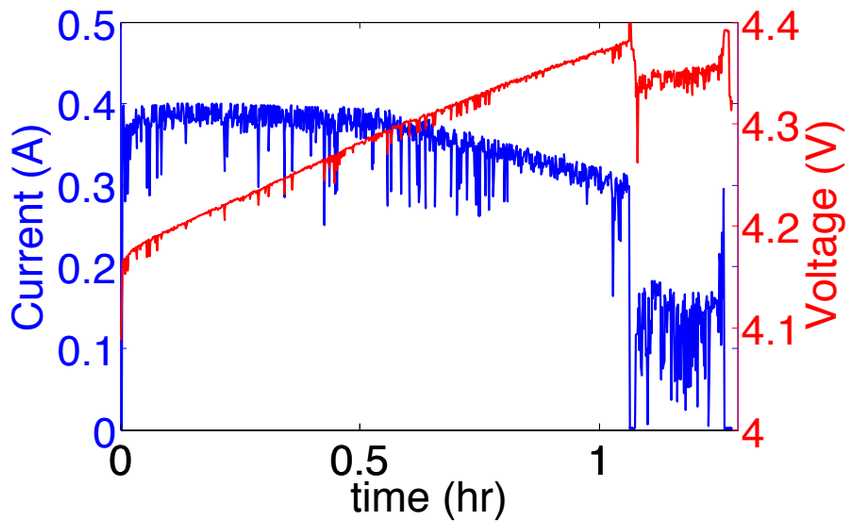


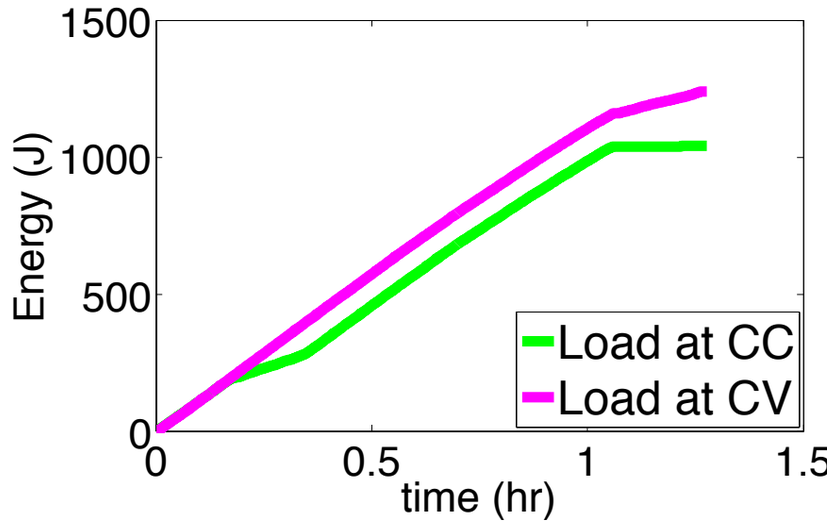


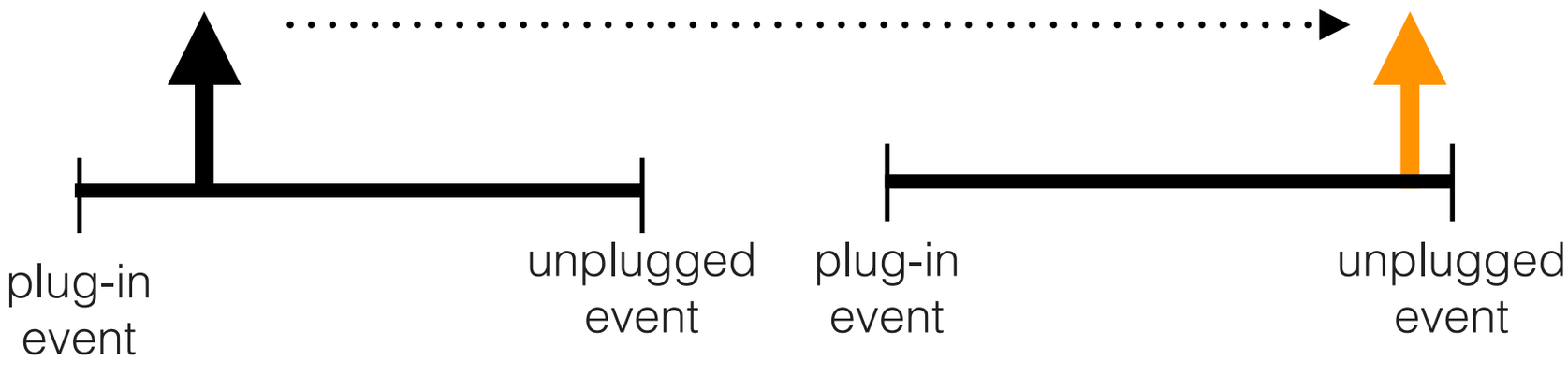
Schedule Tasks in the Power Headroom





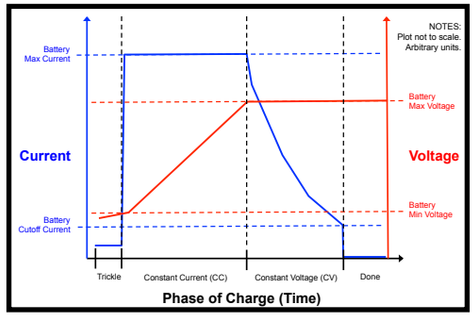


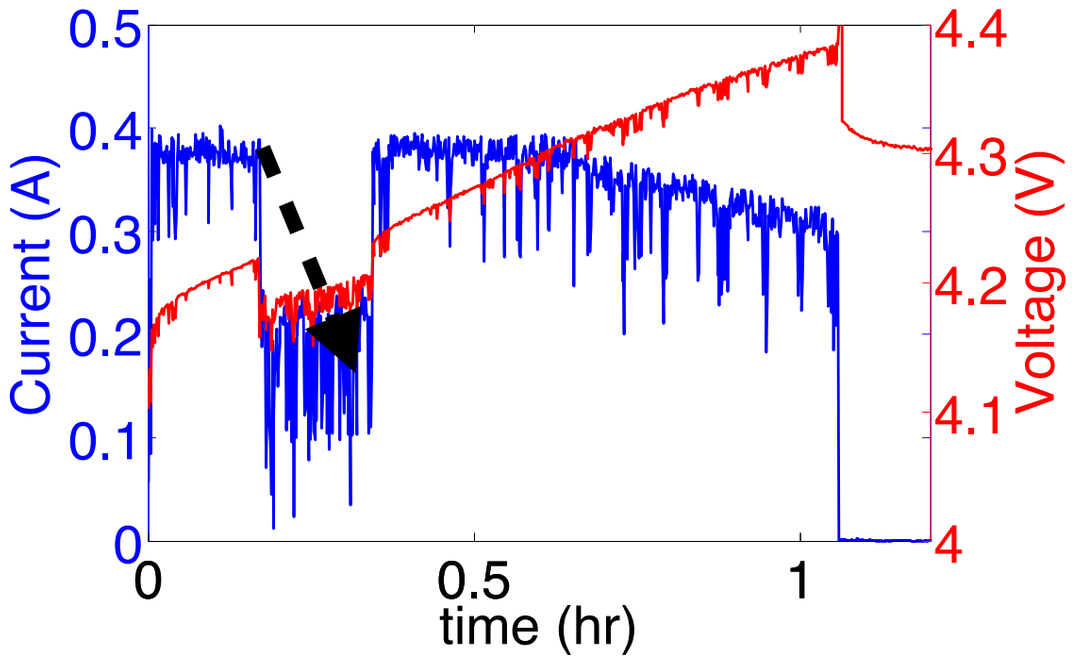




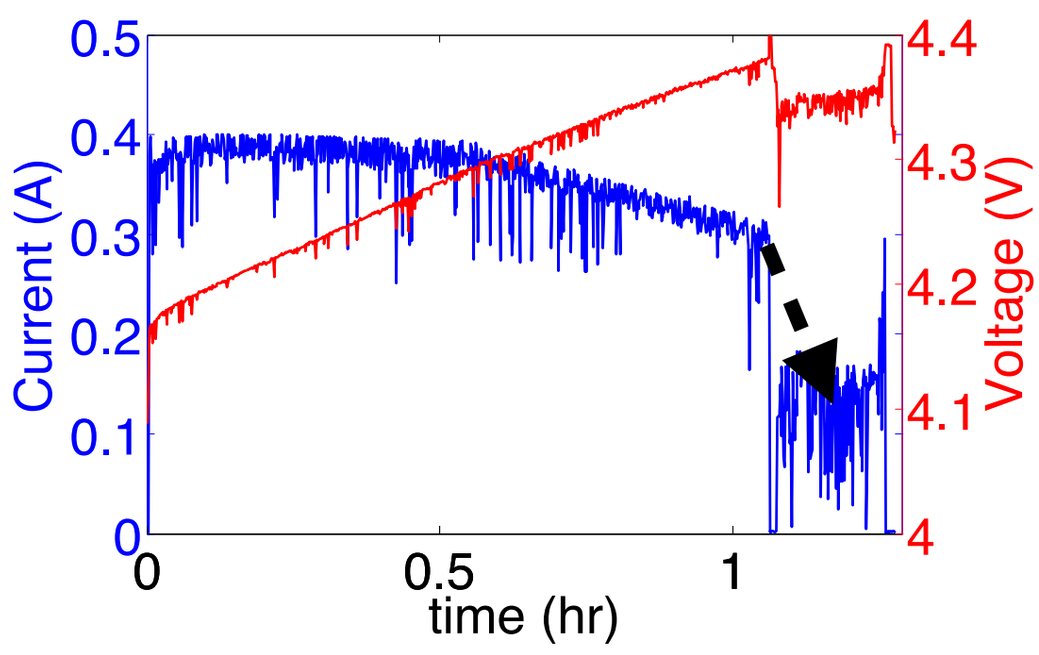
18.9% increase in energy

Schedule Tasks in the Power Headroom





Current drops from approximately 400 mA to 150 mA



Current drops from approximately 300 mA to 100 mA

Charging Process

Battery-rela
hardware

Existence of Power Headroom

tery Characteristics
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arger Controller

Software

Deferring tasks to Power headroom can increase availability

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User behavior

- How long they stay plugged in?
- What is the state of charge (SOC) at plug-in event?
- What is the SOC at the unplug event?

Part 3:
USER CHARGING BEHAVIOR
(Users progress through CC and CV phases)

Quantifying User Charging Behavior

A user's charging behavior can be quantified as the answer to the following statistical questions:

1. What is the **SOC when the device is plugged** into the supply, irrespective of when it is unplugged?

2. What is the **charging duration** for each unique plug-to-unplug charging event?

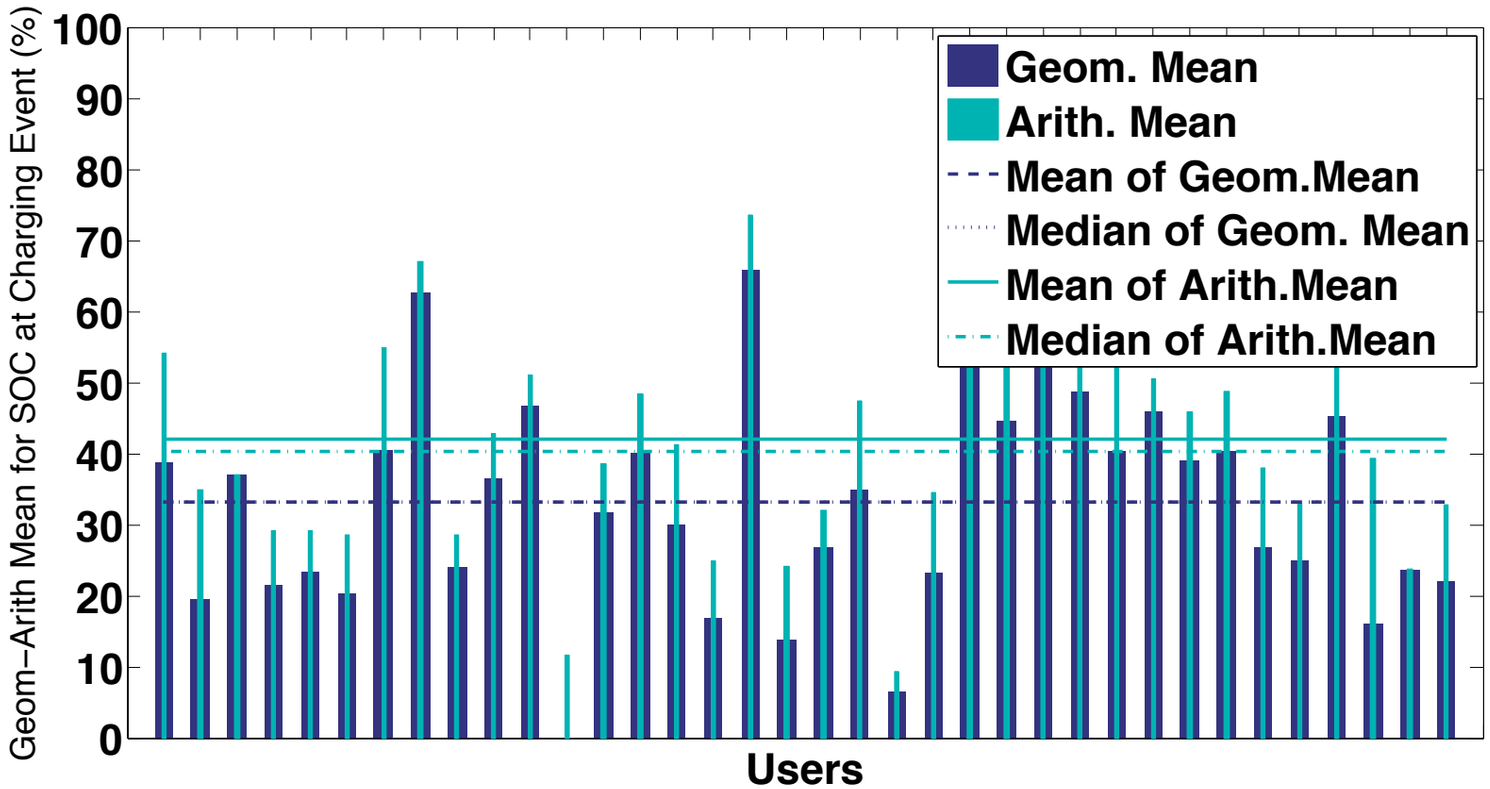
3. What is the **SOC when the device is unplugged**, irrespective of when it was plugged?

User Data Set

- We study the user charging behavior of **40** randomly chosen and anonymous Nexus 4 users over a period of roughly **six months** using the Device Analyzer*

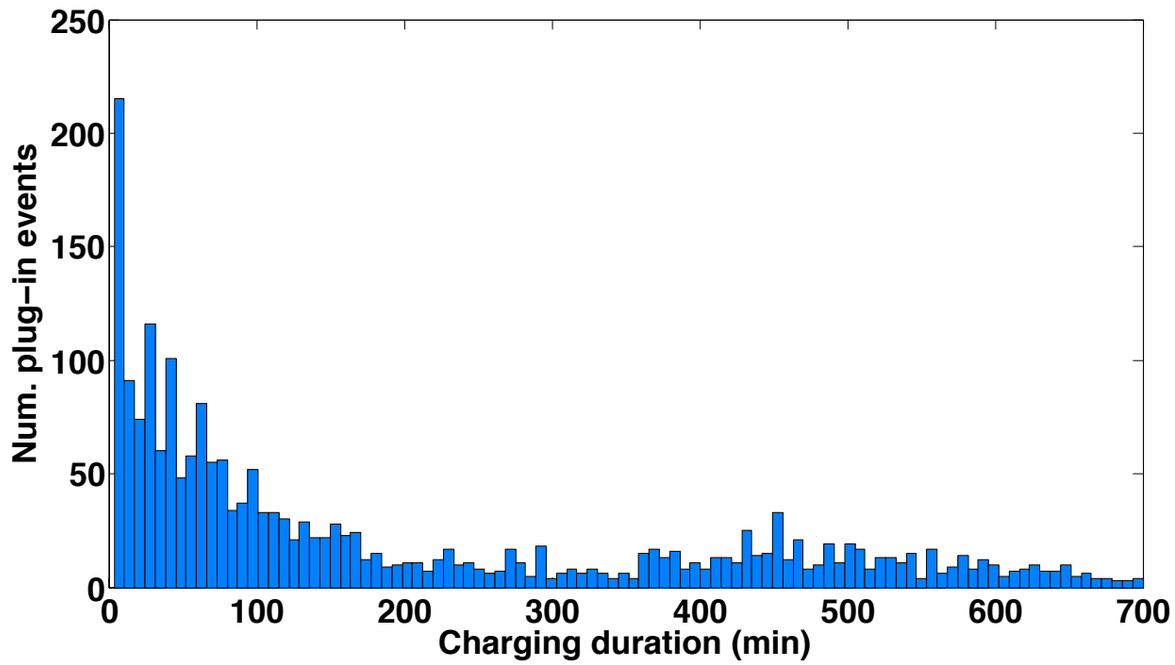
* WAGNER, D. T., RICE, A., AND BERESFORD, A. R. Device Analyzer: Understanding smartphone usage. In Proceedings of the International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (Tokyo, Japan, 2013), ACM.

1- SOC when the device is plugged



- The global arithmetic **mean for SOC when plug-in** events occur is **47%**.
- Three Classes:
  1. at **high SOC** (60-100%)
  2. **around the mean** SOC (40-60%), and
  3. at **low SOC** (0-40%)

2- Charging duration



- The global arithmetic mean of the charging durations across all users is 120 minutes

- The correlation coefficient between the SOC at plug-in with the charging duration is below 0.06.

3- SOC when the device is unplugged?

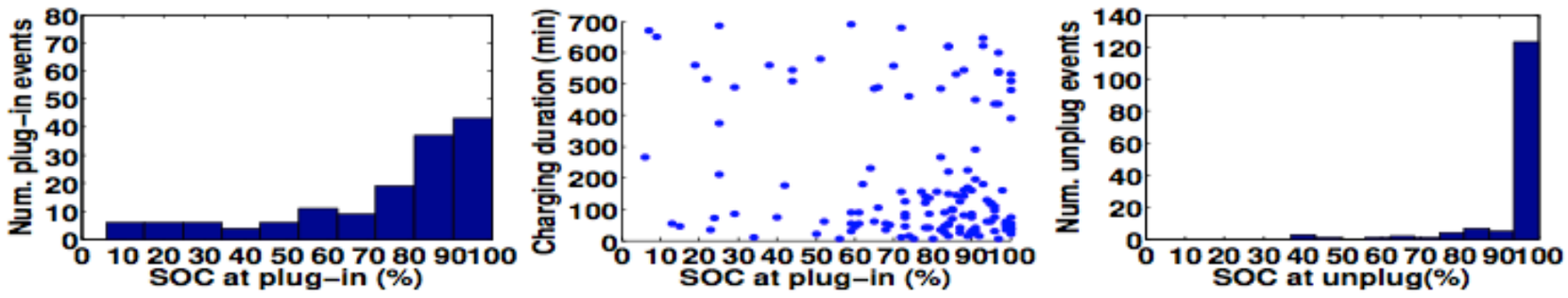
- We observe that typically either the users let their phone charge until complete or it coincidentally completes because the charging duration happens to be long enough.

- The charging duration is not correlated with SOC when plugged-in, which implies that charge completion is not necessarily the primary goal for users).

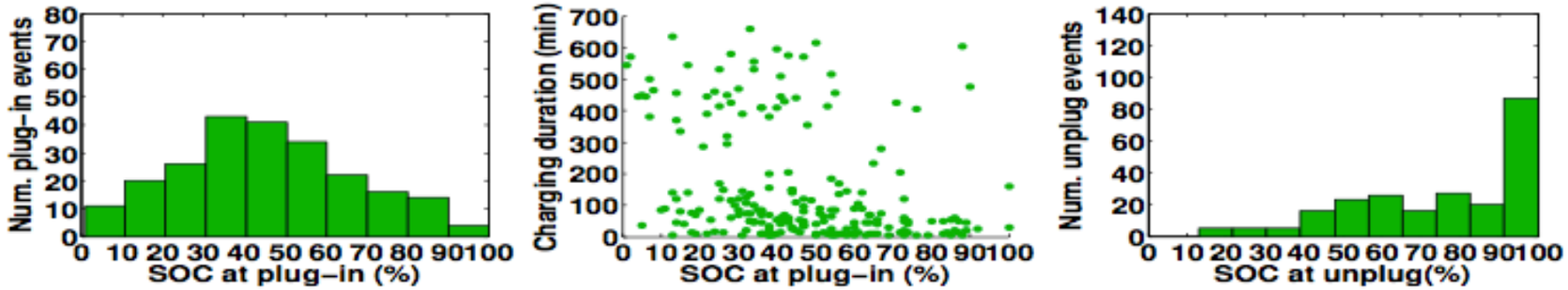
- We find that in general, all three classes types have similar unplugging behavior. Hence, we conclude that using the SOC when un-plugged as a parameter does not affect the charging behavior classification of users.

User Classification

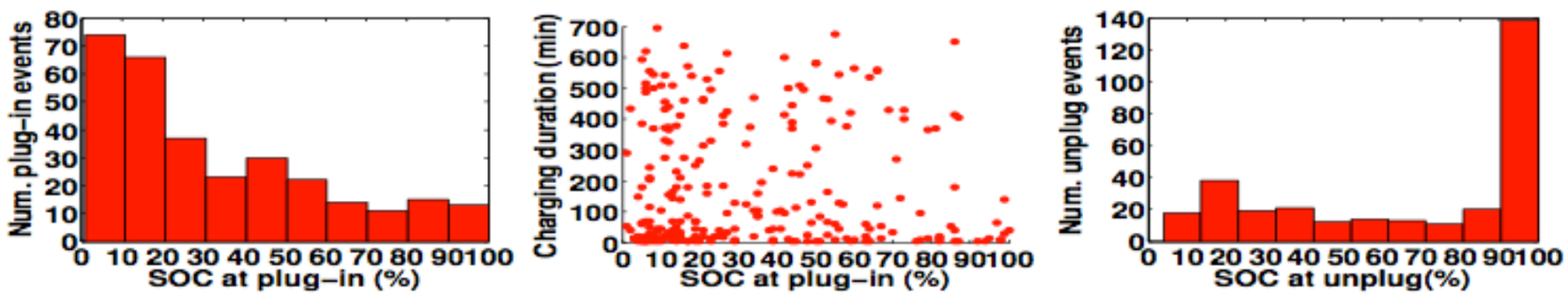
Class 1



Class 2

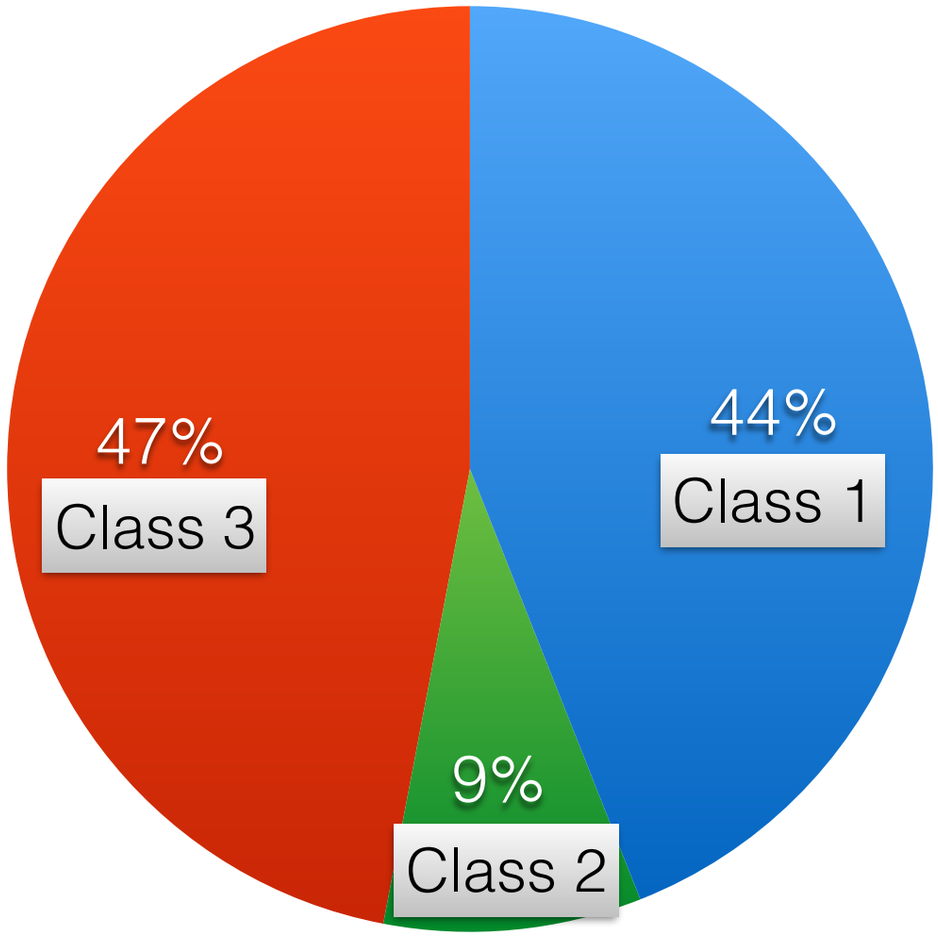


Class 3



User Classification

- Determine which users progress through the CC and CV phases
- Classify users based on their SOC at plug-in event.
- Users of class 2 and 3 (Medium and High SOC) is around 53%



Charging Process

Battery-rela
hardware

Existence of Power Headroom

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User behav

53% of users likely progress through the power headroom

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What is the SOC at the unplug event?

Conclusion

- We present a case for battery charging-aware power management and deferrable task scheduling to **improve overall device availability**.

- Our study on Nexus 4 smartphone user charging behavior shows that most users tend to charge their phone **for less than 120 minutes**, and that the **charging duration is largely independent of the SOC** when the smartphone is plugged in or unplugged.

- We estimate that around **53% of users** could benefit from battery charging-aware software policies.

- We find that **deferring tasks to the CV phase** can **improve** the **net energy** gained by the battery by approximately **18.9%**.

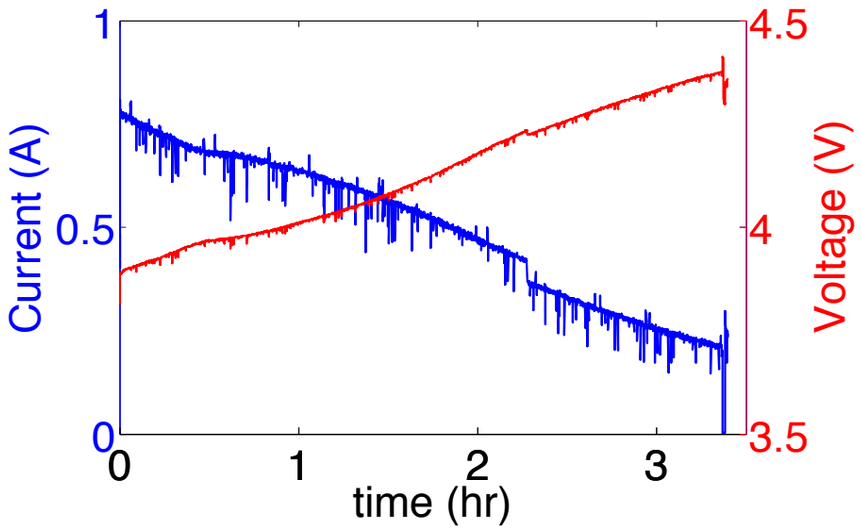
Future Work

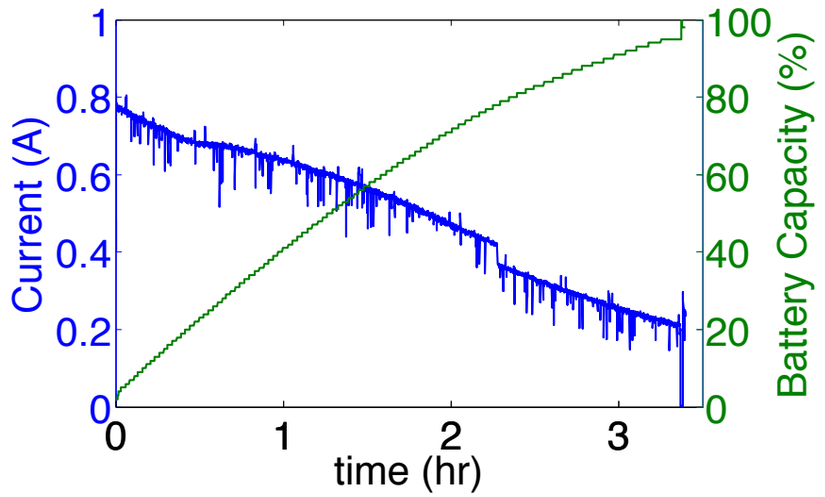
- **Quantifying power headroom** based on the battery characteristics and the stage of the charging process to determine the number and type of tasks to be deferred based on their predicted energy requirements.

- **User-specific models** to predict whether a given user during some charging event is likely to reach a period with greater power headroom.

Thanks

Smartphone Charging Profile (AC adapter)





Charger Controller Circuit (Qualcomm PM8921)

- The current drawn is approximately 800 mA being limited by the ability of the battery to absorb current (battery restriction)
- No CC behavior is observed:
  current decays to maintain a smooth rise in battery voltage

- The battery is fully charged in 3.4 hours compared to 5.5 hours using USB