AudioSense:
Enabling Real-time Evaluation of Hearing Aid Technology In-Situ

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Hearing Loss in US

- 35 million people in the US have hearing loss [1]

  - ⇒ leads to communication difficulties, depression & dementia

- Primary intervention is hearing aid amplification

  - only ≈ 50% of hearing aid users are satisfied with performance in noisy environments

[1] K.S. Marketrak VIII: 25-year trends in the hearing health market, Hearing Review '09

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Underlining causes of user dissatisfaction are poorly understood

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Challenge of evaluating hearing aids
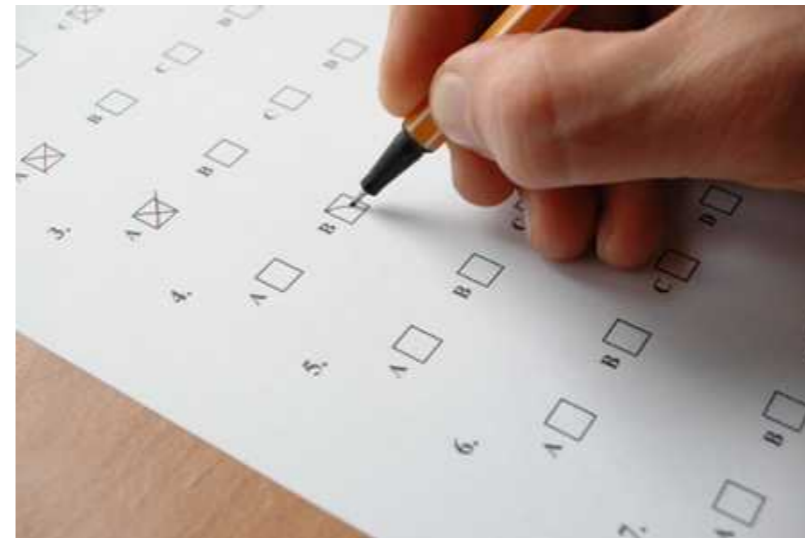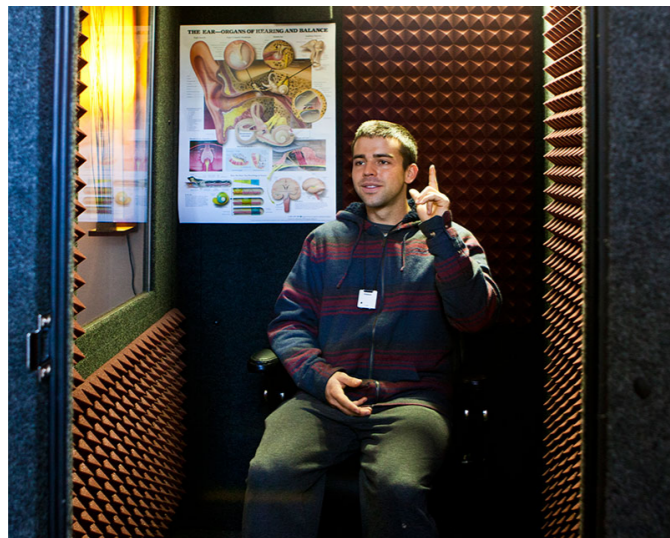
- Listening contexts

social context: speaker familiarity, number of speakers, visual cues

acoustic context: indoors vs. outdoors, noise/reverberation levels
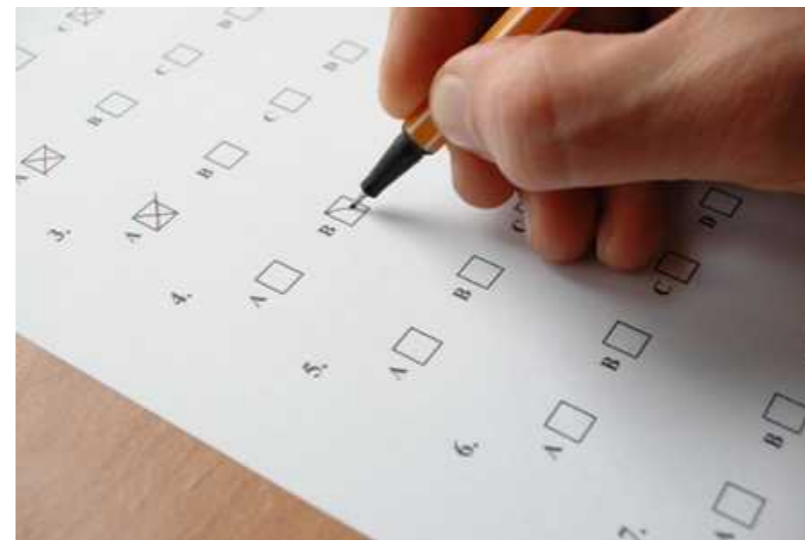
Existing Evaluation Methodologies

- Manual data collection: self-reports or diary methods
  - subjective, memory bias, scalability
- Speech-in-noise tests: assess aspects of hearing aid technology
  - not representative of real-world listening contexts

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Existing evaluation methods are poor predictors of real-world performance

AudioSense
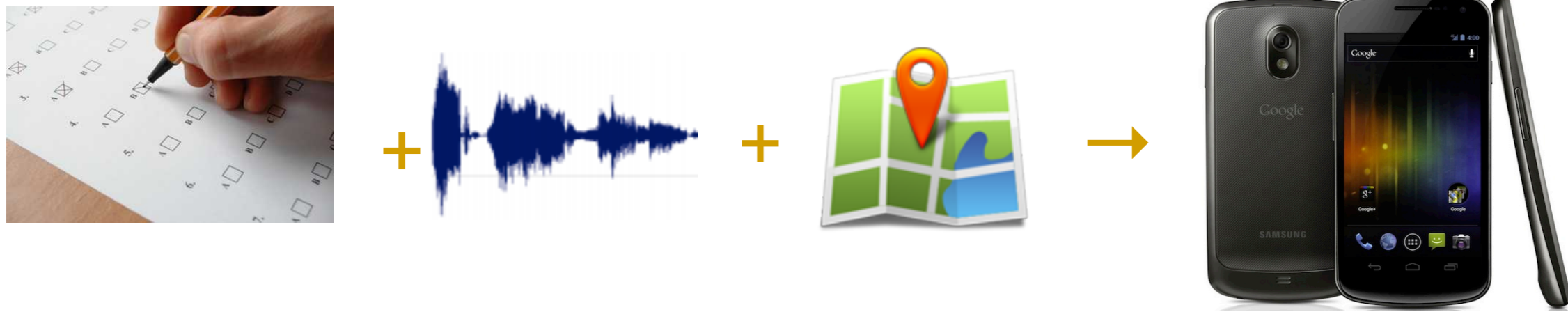
- Provides clinicians with subjective and objective measures of hearing aid performance and listening contexts

  - data is collected in real-time and in-situ

  - subjective: Ecological Momentary Assessment (EMA)

  - objective: measures derived from audio and GPS

- EMA has been previous used by Henry et. al.[1] and Galvez[2]

  - do not collect sensor data or track patients in real-time

[1] Henry et.al., Pilot study to evaluate ecological momentary assessment of tinnitus, *Ear Hear* '12
[2] Galvez et.al., Feasibility of ecological momentary assessment of hearing difficulties encountered by hearing aid users, *Ear Hear* '12

Architecture of AudioSense

Android Phones

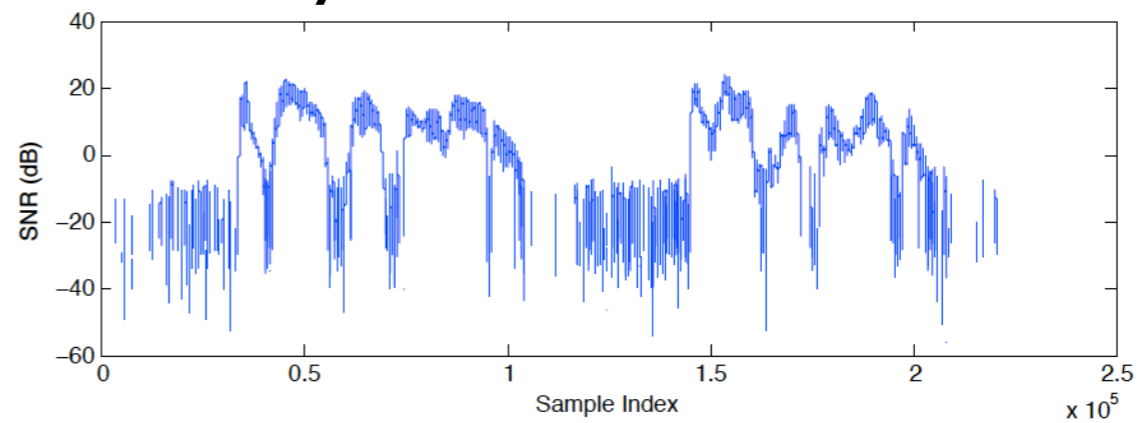**Web Server**
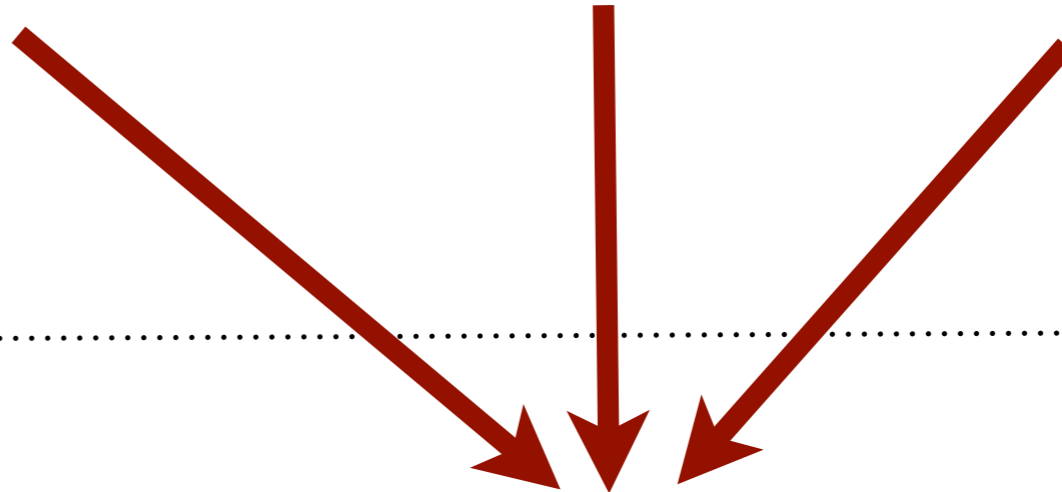
Web Interface

django

Condition	Last user survey	Last timer survey	Last log time	User count	Timer count	Compliance
55	June 12, 2013, 10:54 a.m.	June 11, 2013, 8:09 p.m.	June 12, 2013, 11:19 a.m.	7	7 / 63 (3 snooze)	11.67
33	June 12, 2013, 11:29 a.m.	June 12, 2013, 1:10 p.m.	June 12, 2013, 1:10 p.m.	1	2 / 5 (0 snooze)	40.00

Extensible Analysis Environment

MATLAB

6

Architecture of AudioSense

Android Phones

- EMA

- Extensible user interface and effective alarms

- Energy efficient data collection, high reliability

Web Server

- Real-time compliance information

- Extensible data analysis environment

- Scales to support multiple concurrent users

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EMA Component - Survey Delivery

- Surveys are alarm-triggered or user-initiated
- Alarm-triggered
  - randomized ($\mathtt{T_{offset}}$+$\mathtt{[0,T_{rand}]}$)
  - fixed ($\mathtt{T_{offset}}$)
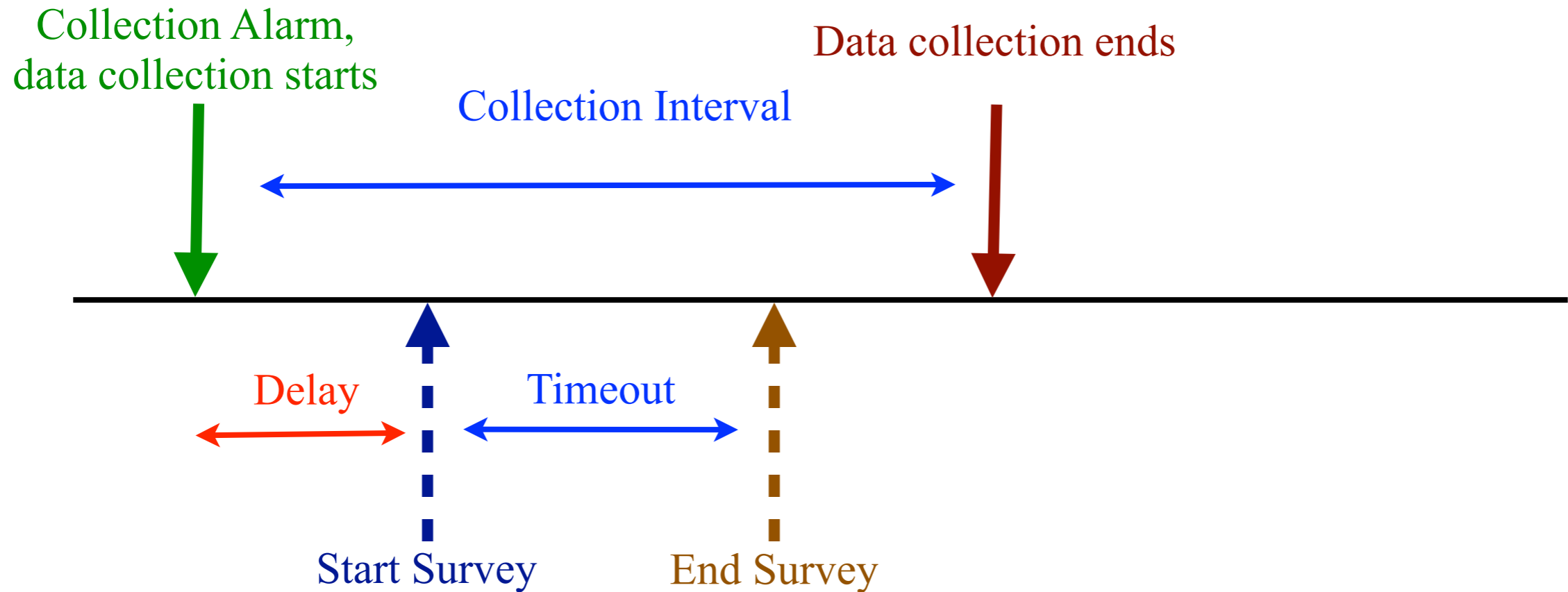- Delivery parameters are customized by clinicians

EMA Component - Survey Delivery

Collection Alarm,
data collection starts

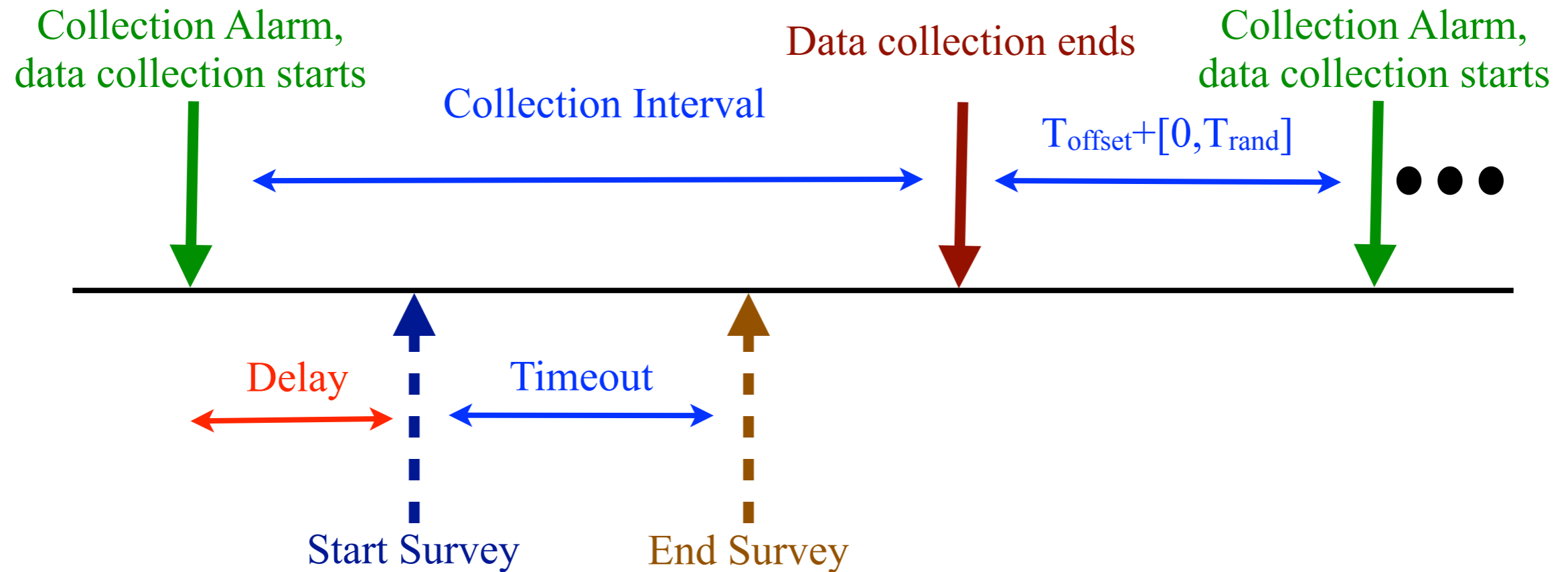- Surveys are alarm-triggered or user-initiated
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EMA Component - Survey Delivery

Delay

Start Survey

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EMA Component - Survey Delivery

Collection Alarm,
data collection starts

Data collection ends

Collection Interval

Delay

Timeout

Start Survey

End Survey

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User Interface Design
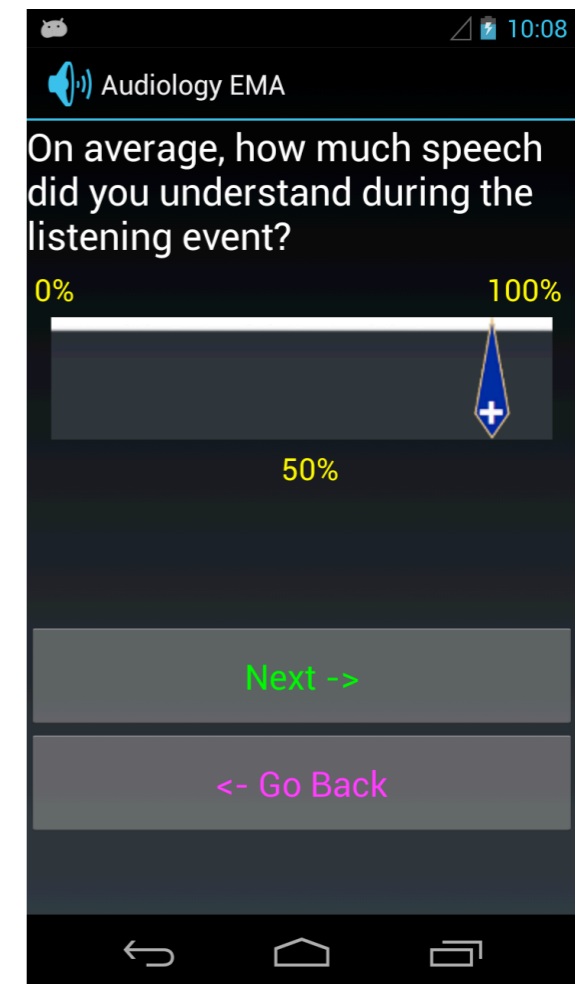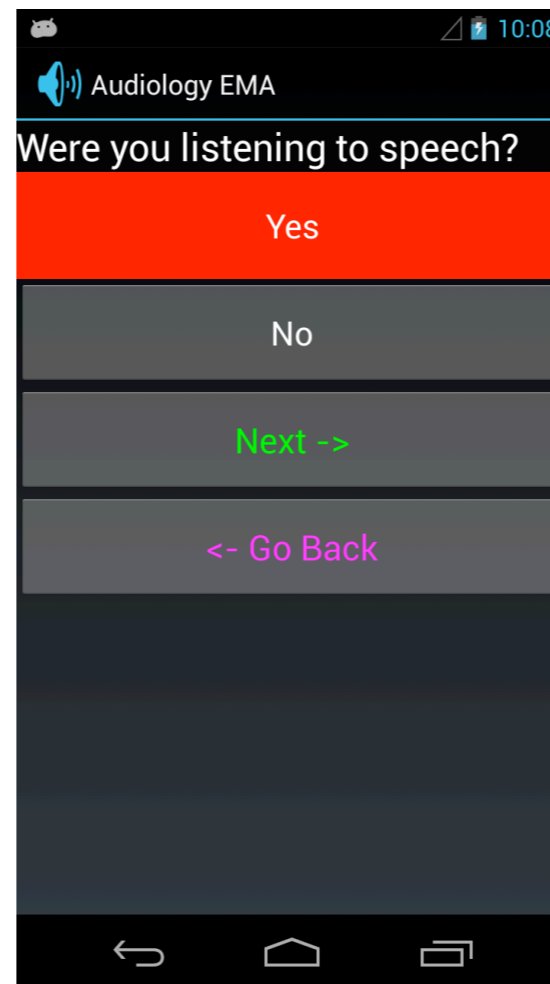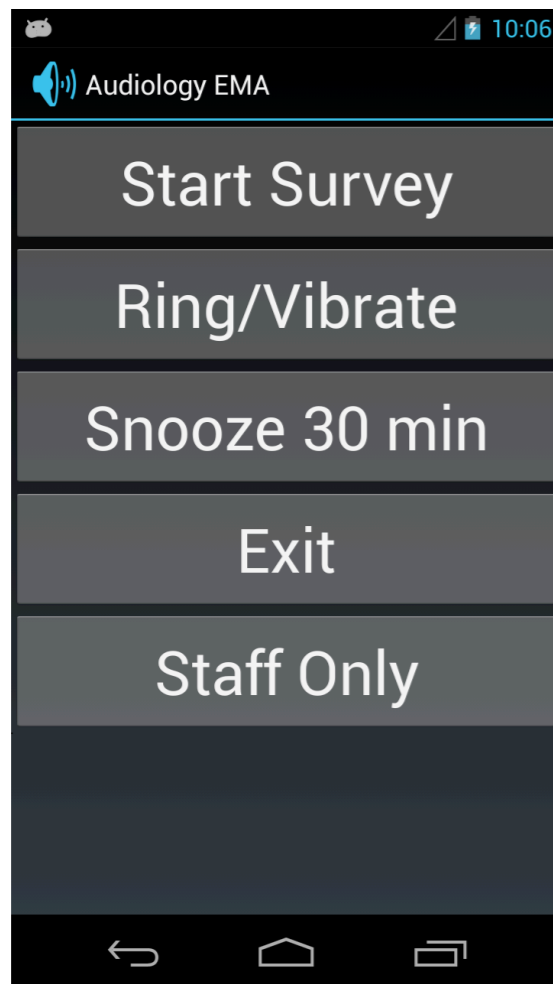
- Iterative design based on patient feedback

  - patients of hearing loss tend to be older, may have impaired vision ⇒ larger fonts, bigger buttons, contrasting colors

- Surveys are adaptive

Architecture of AudioSense

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- Extensible user interface and **effective alarms**
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Alarms

- Design refined over several iterations based on patient feedback

- Challenge: find sweet-spot between invasiveness and compliance

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Alarms not noticed by the subjects

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Alarms not noticed by the subjects

- loud ringtones, screen and camera flash blinking

- subjects can switch to vibration mode

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Energy Efficiency
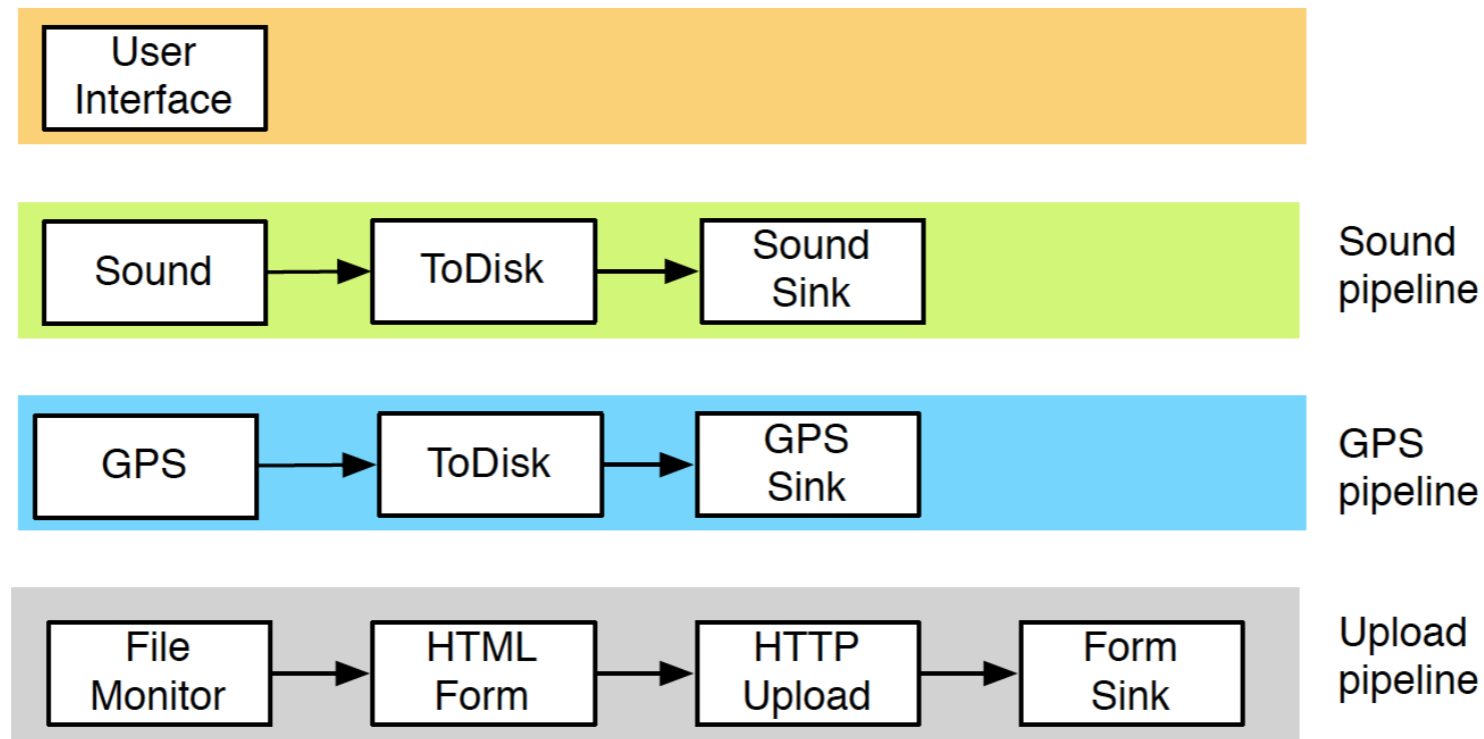
- Independent pipelines for processing sound, GPS, and uploading

- Shared buffering to mitigate impact of Garbage Collection
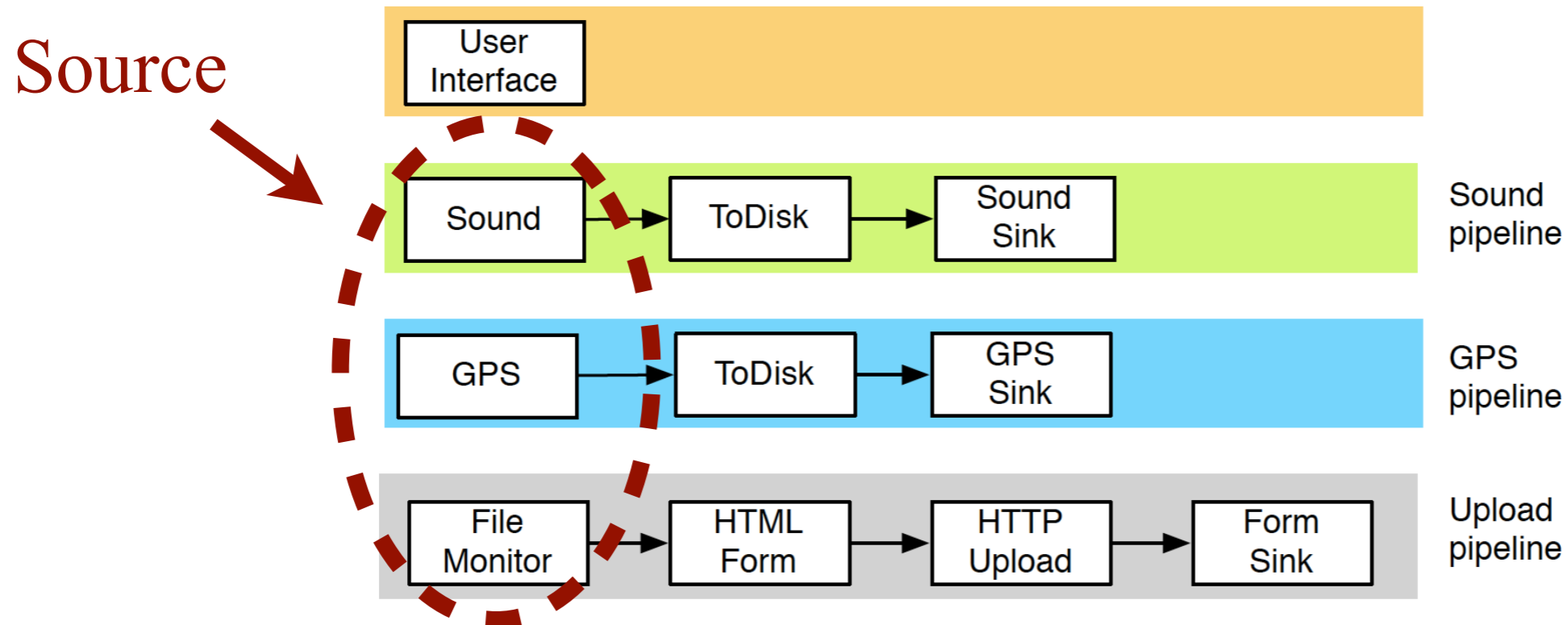
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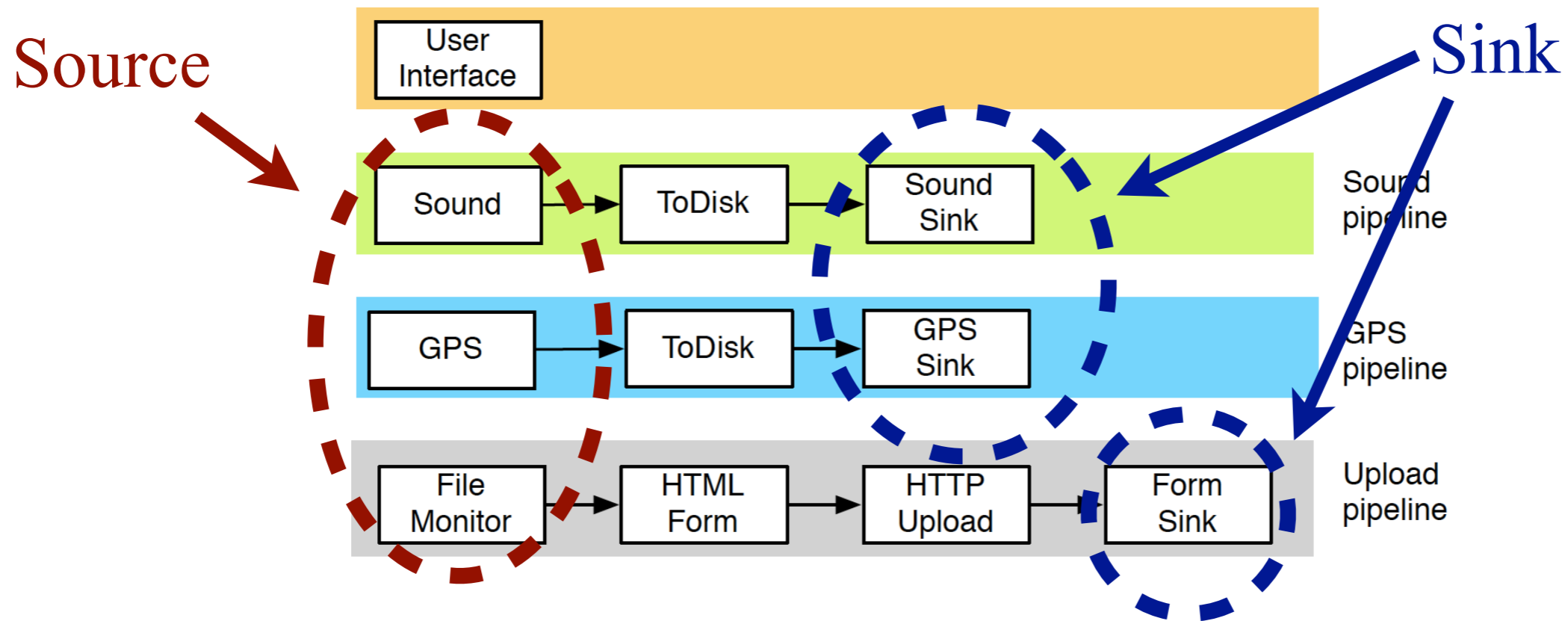
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Reliability

- Reliability in terms of uploading the data

- Issue: unreliable network connections
  - caching data locally until a connection is available
  - vast amounts of memory available
    - store several days worth of data

Performance Analysis

- Testing environment

  - surveys delivered every 5 min, sensors sampled for 3 min.

  - tested using WiFi at home to simulate natural environment
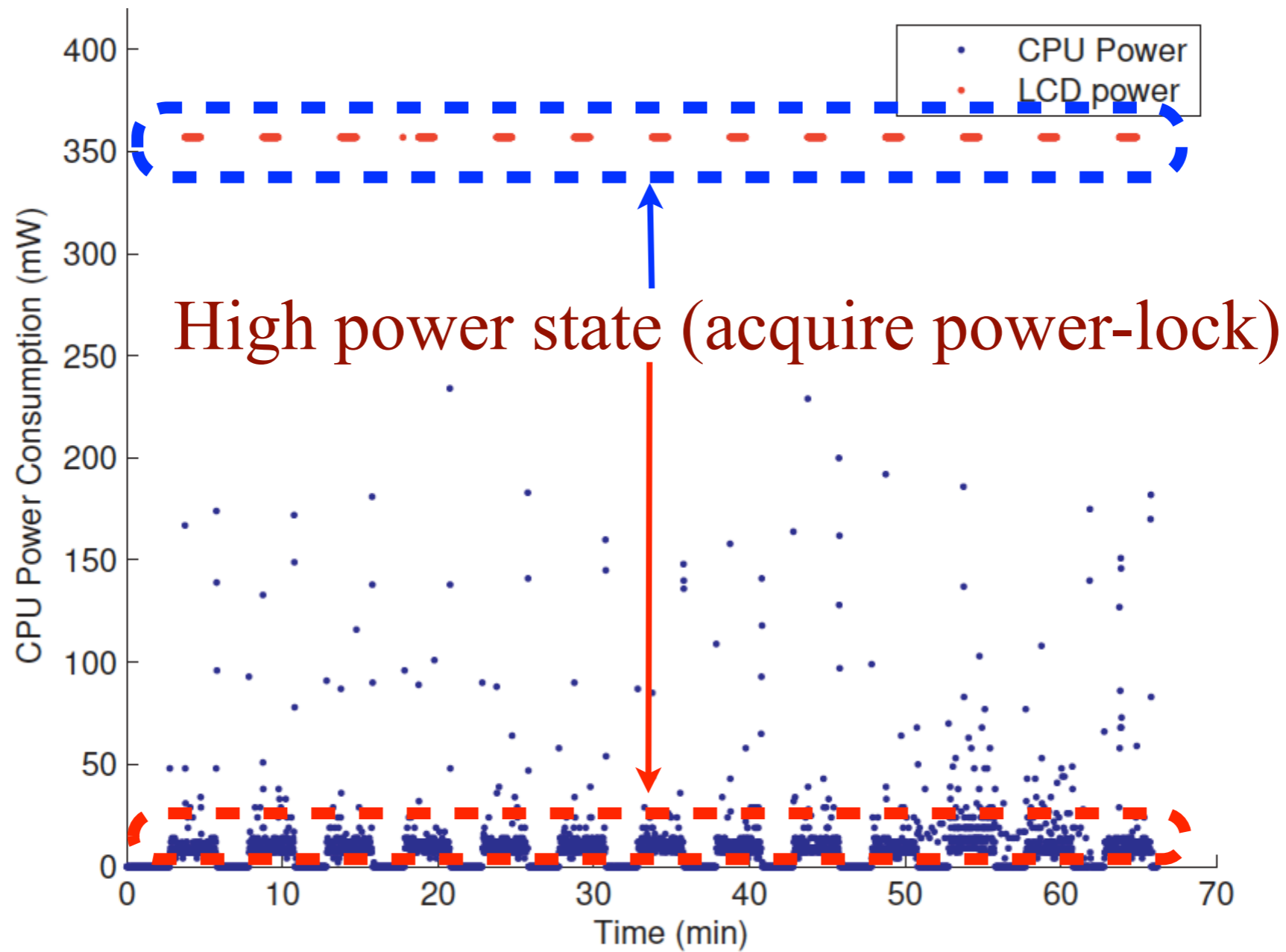
  - test run for 70 minutes

Reliability

Reliability

Reliability

all files uploaded

19
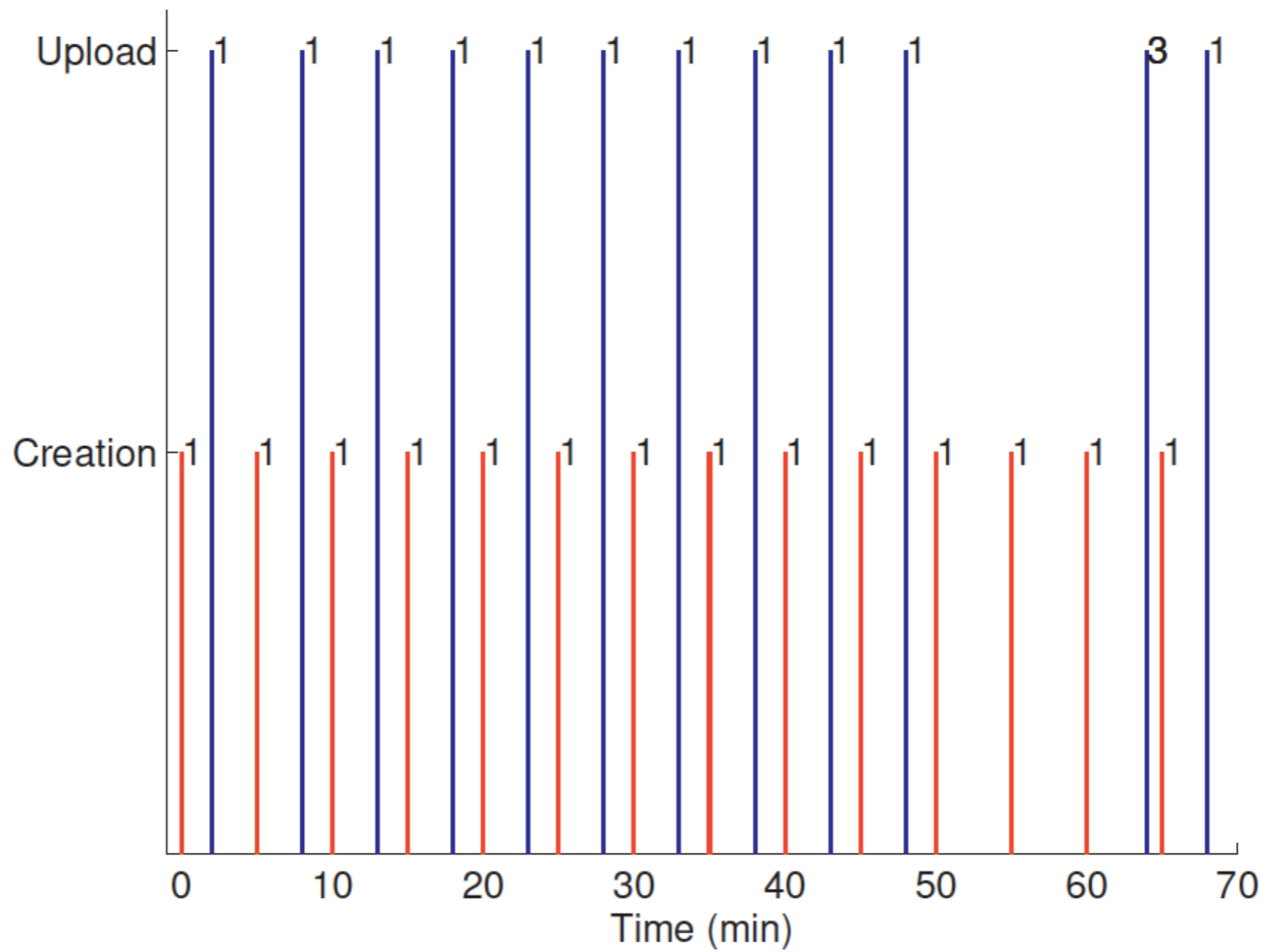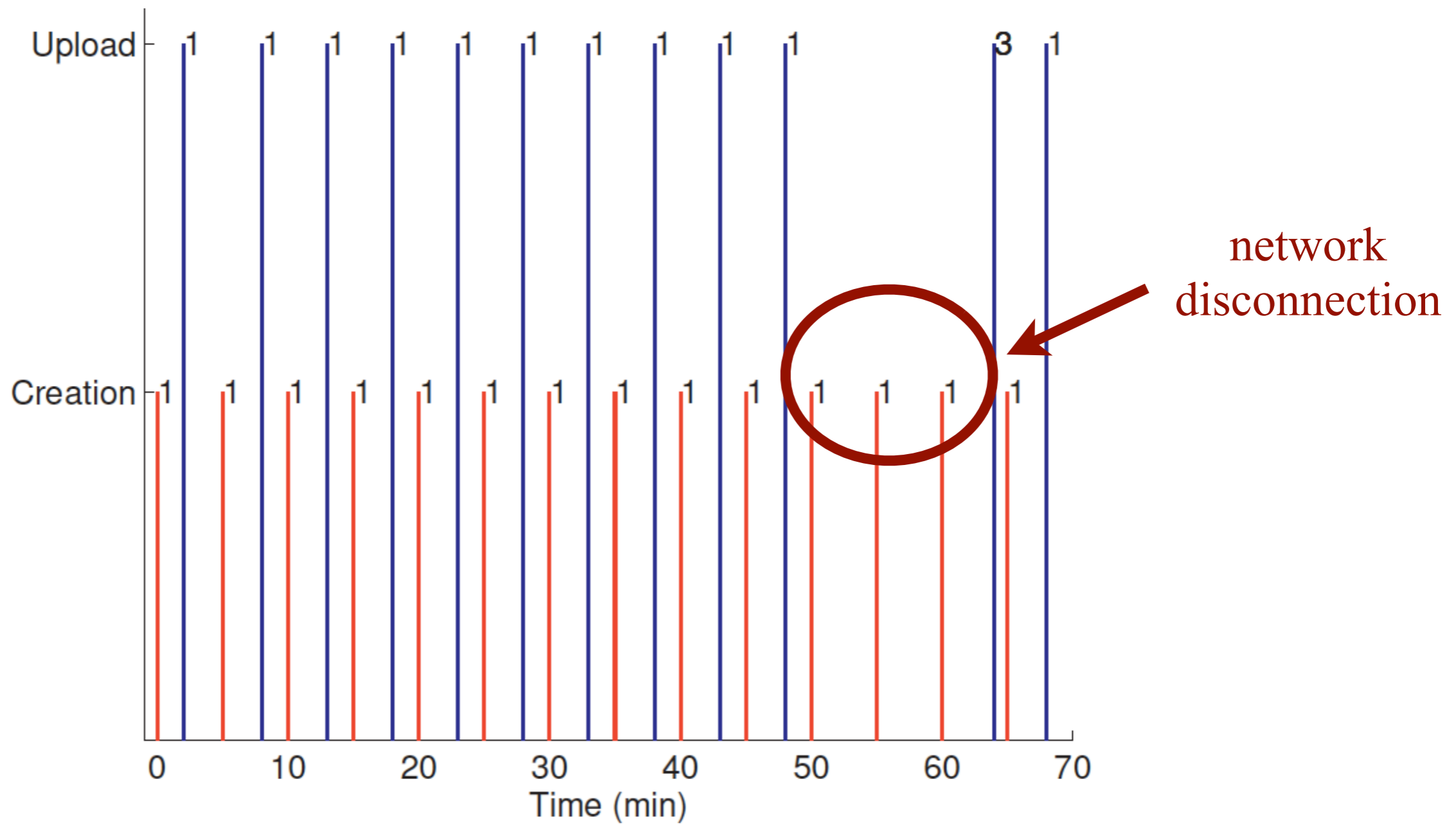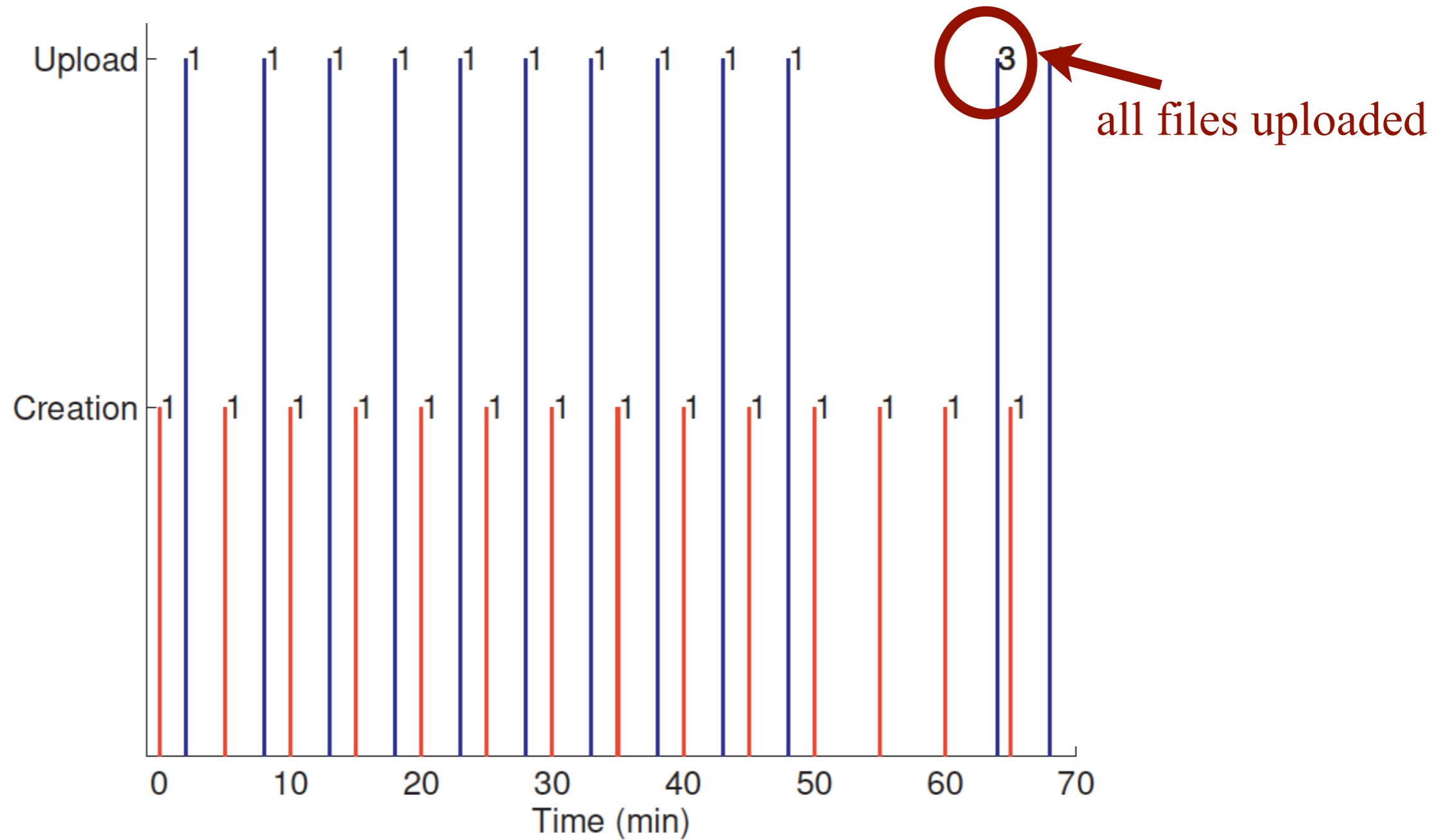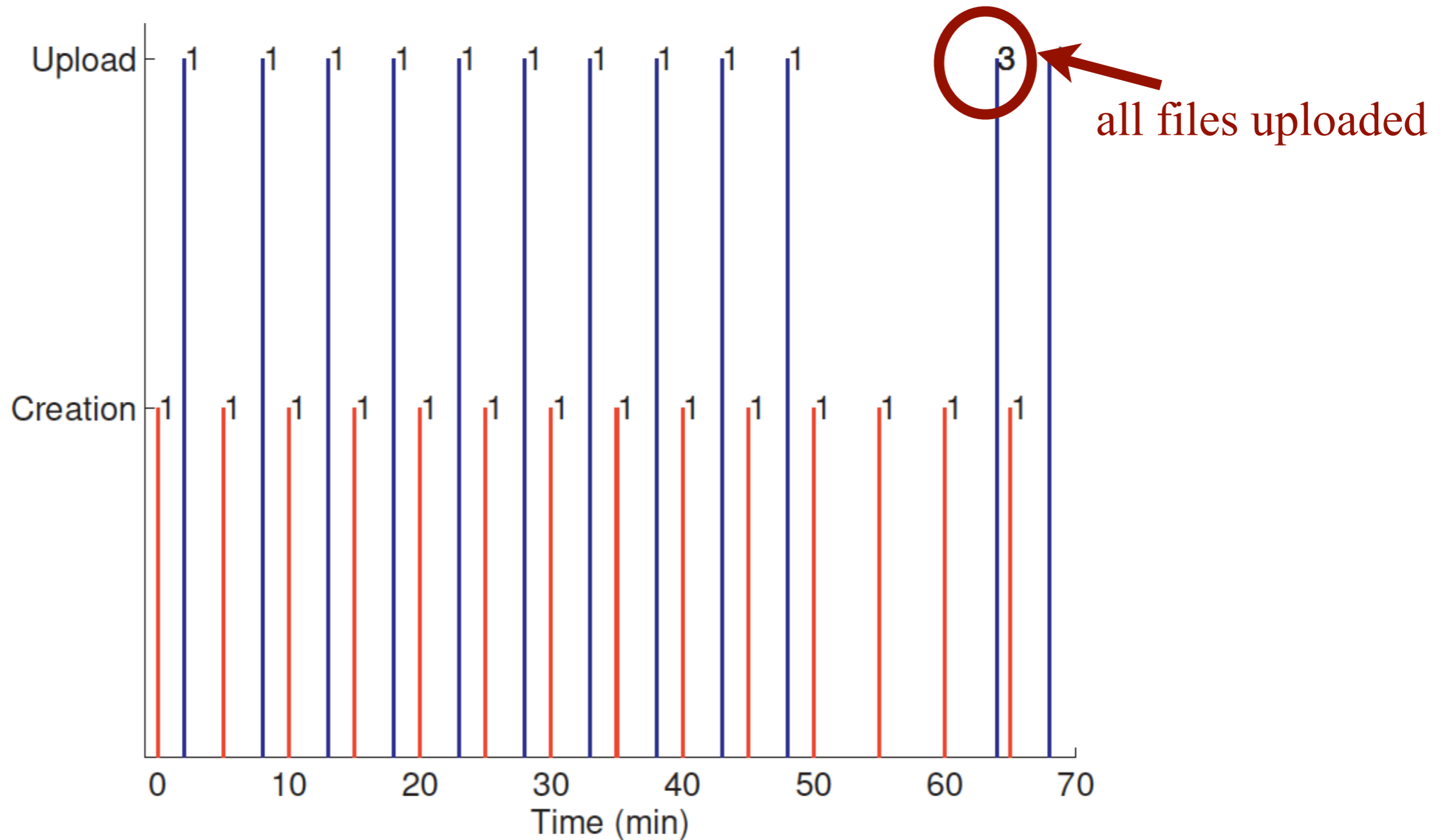
Reliability

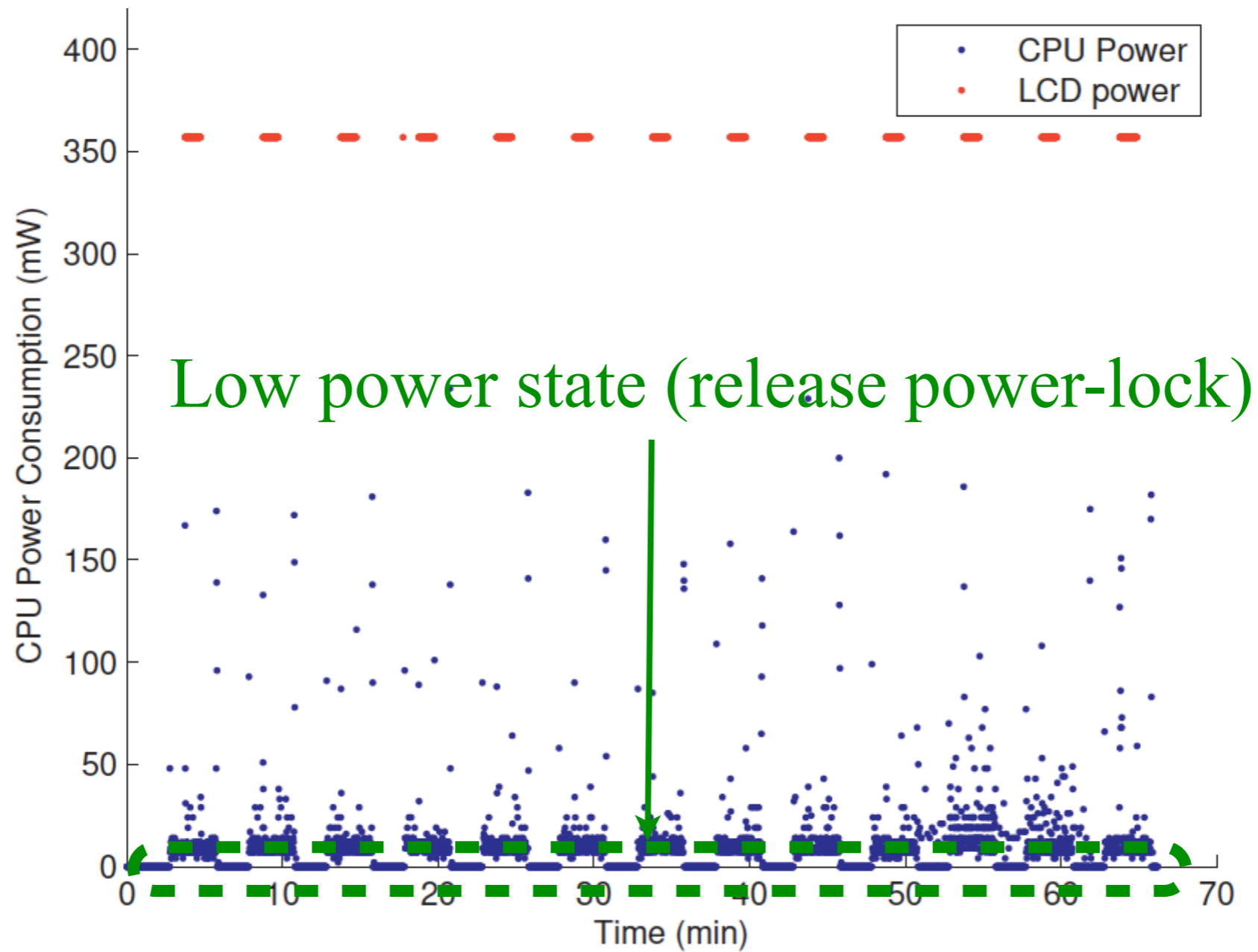Achieved 100% reliability in spite of network disconnections!
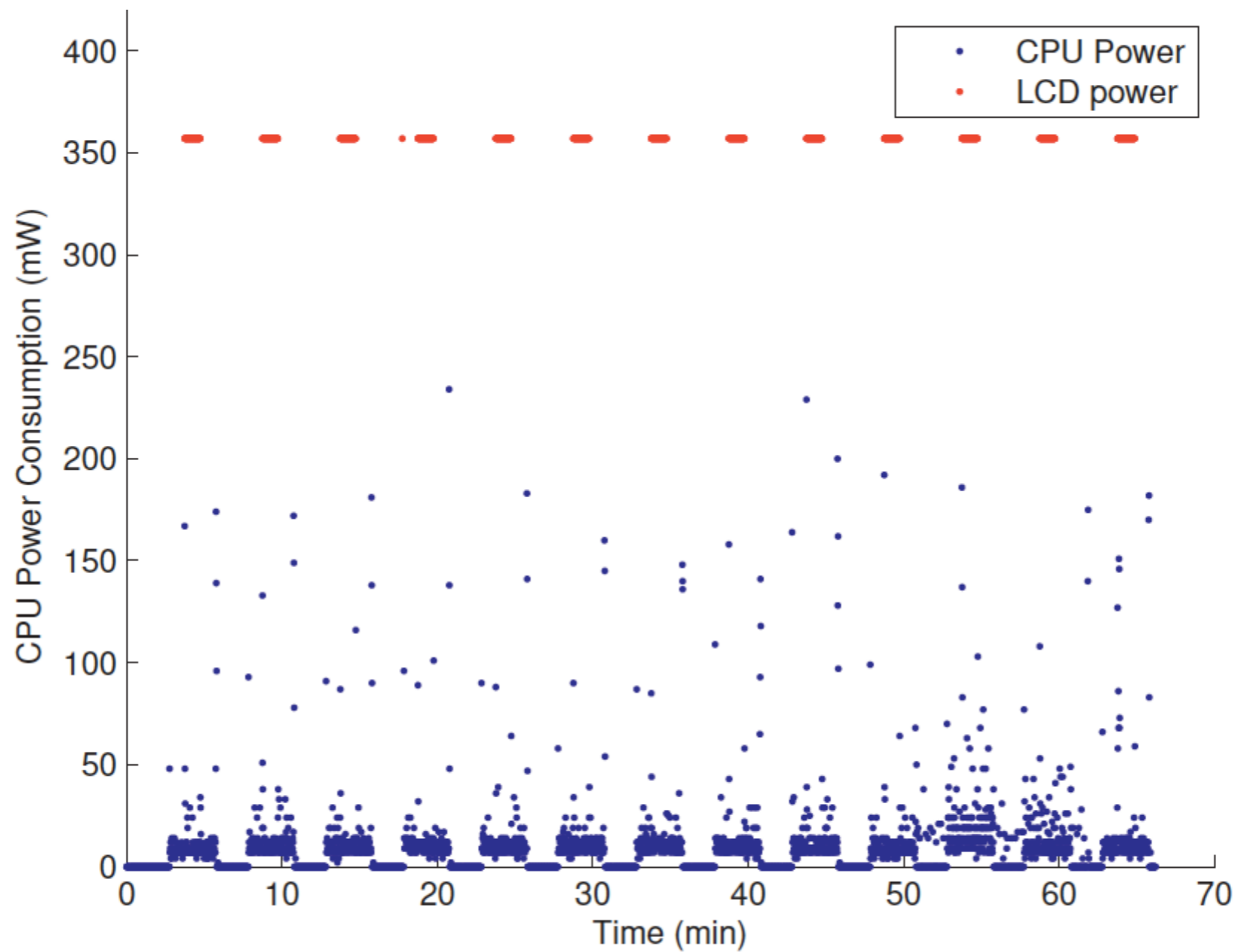
Power Consumption
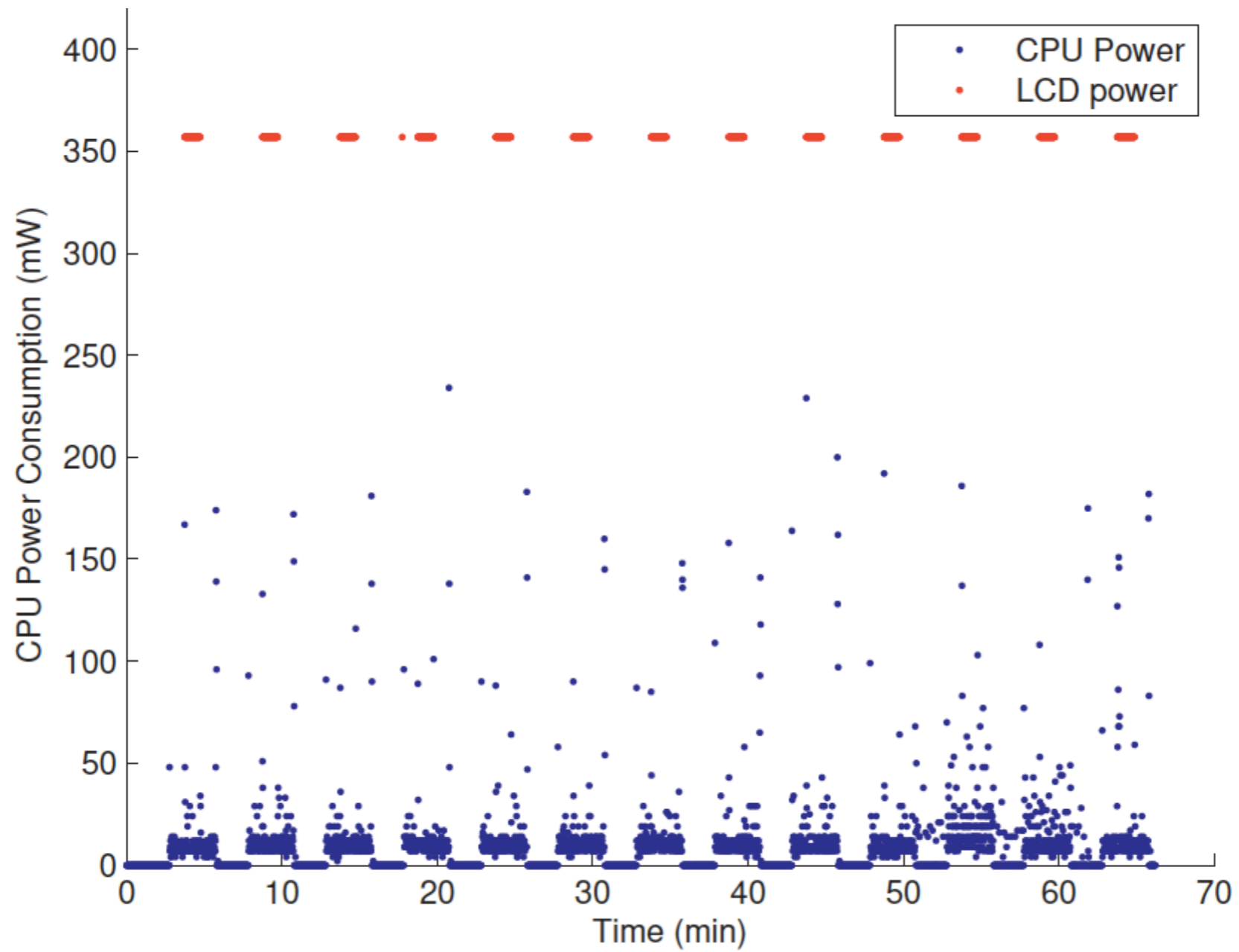
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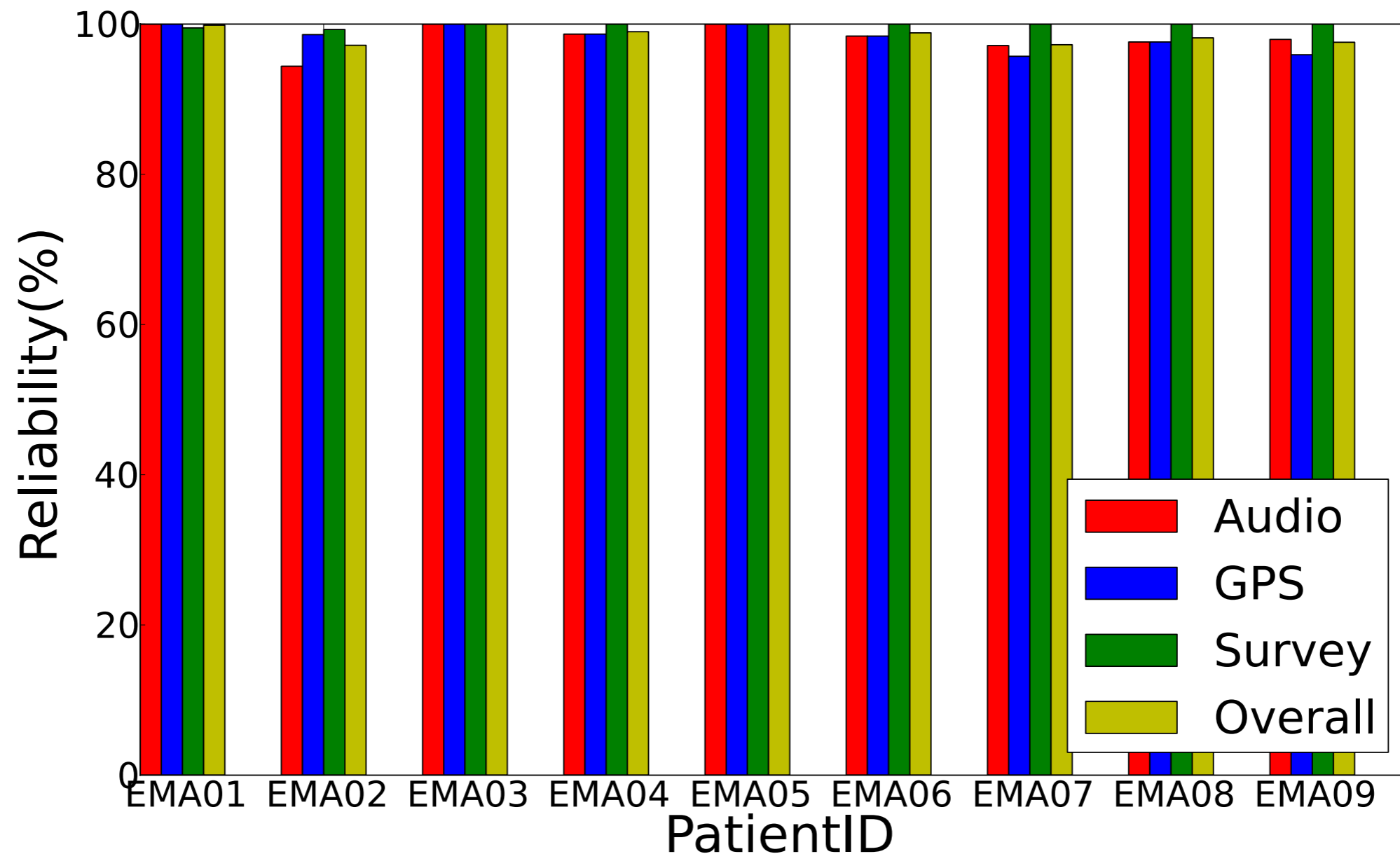# Power Consumption
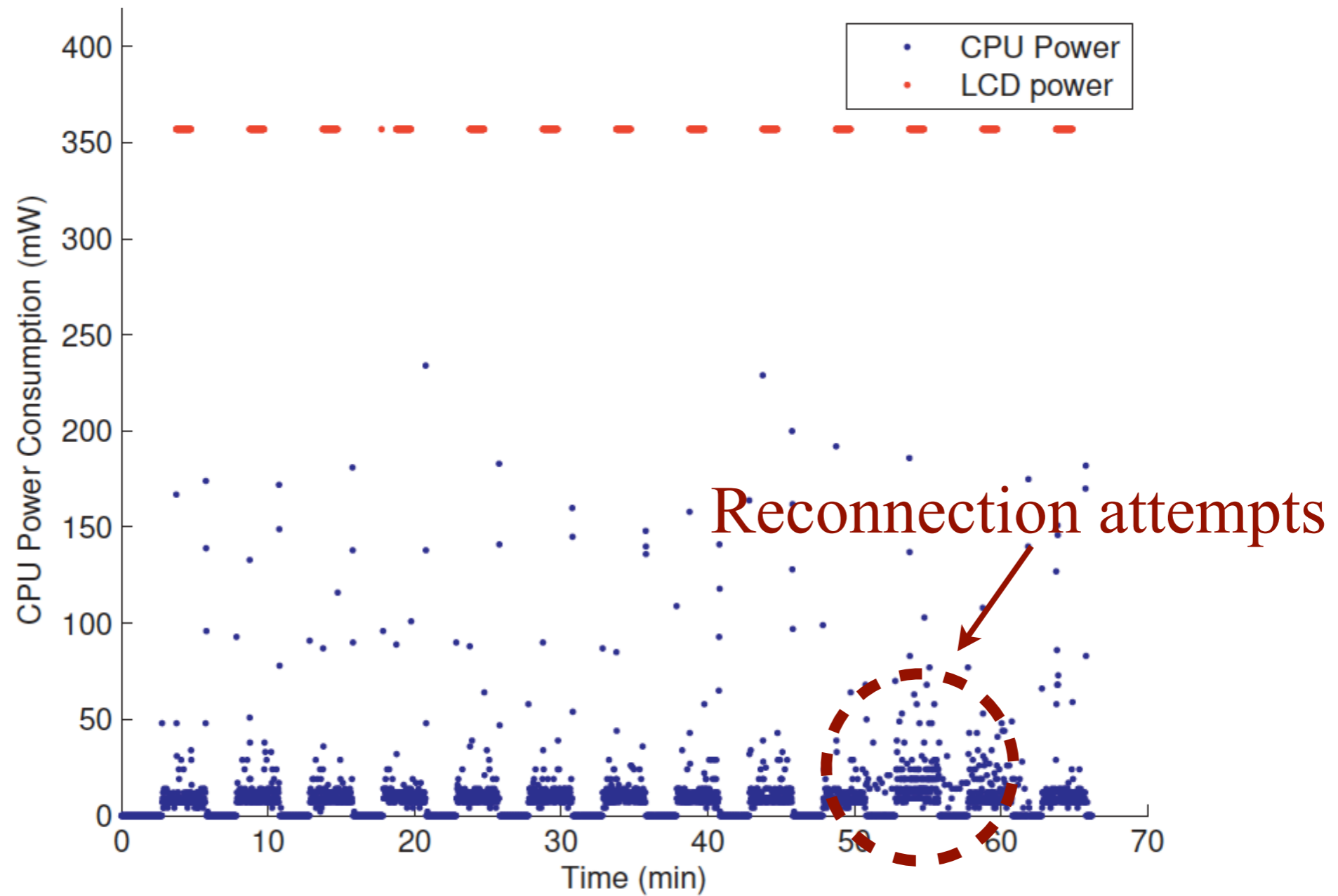
Power Consumption

Power Consumption

Lasted for 3 days without recharging

Recent Results for Reliability

98.7% reliable even in a clinical deployment

Conclusions and Future Directions

- AudioSense a new evaluation mechanism for hearing aids combines EMA and sensor data (audio + GPS)

  - in-situ, just-in-time, and scalable

  - patient compliance: real-time tracking, alarms design, and energy efficient

  - reliable and real-time data collection

- Future work:

  - evaluated through a 50 user clinical study

  - study correlations between:

    - listening contexts and patient compliance

    - measures listening context and hearing aid performance

Acknowledgements

- Audiology collaborator: Elizabeth Stangl

- National Science Foundation
  (grant # 1144664)

- National Institutes of Deafness and Other Communication
  Disorders - National Institutes of Health
 (grant # IR03DC012551-01)

Questions?

Server Backend

- Provides three components

  - web portal, database, and audio analysis environment

- Web portal + database

  - provides secure access to real-time data via web interface

  - built on Django+SQLite

  - serves multiple concurrent clients

- Audio analysis environment

  - invoked on each audio file submission

  - uses MATLAB $\Rightarrow$ extensible

    - e.g. SNR calculation

Server Backend
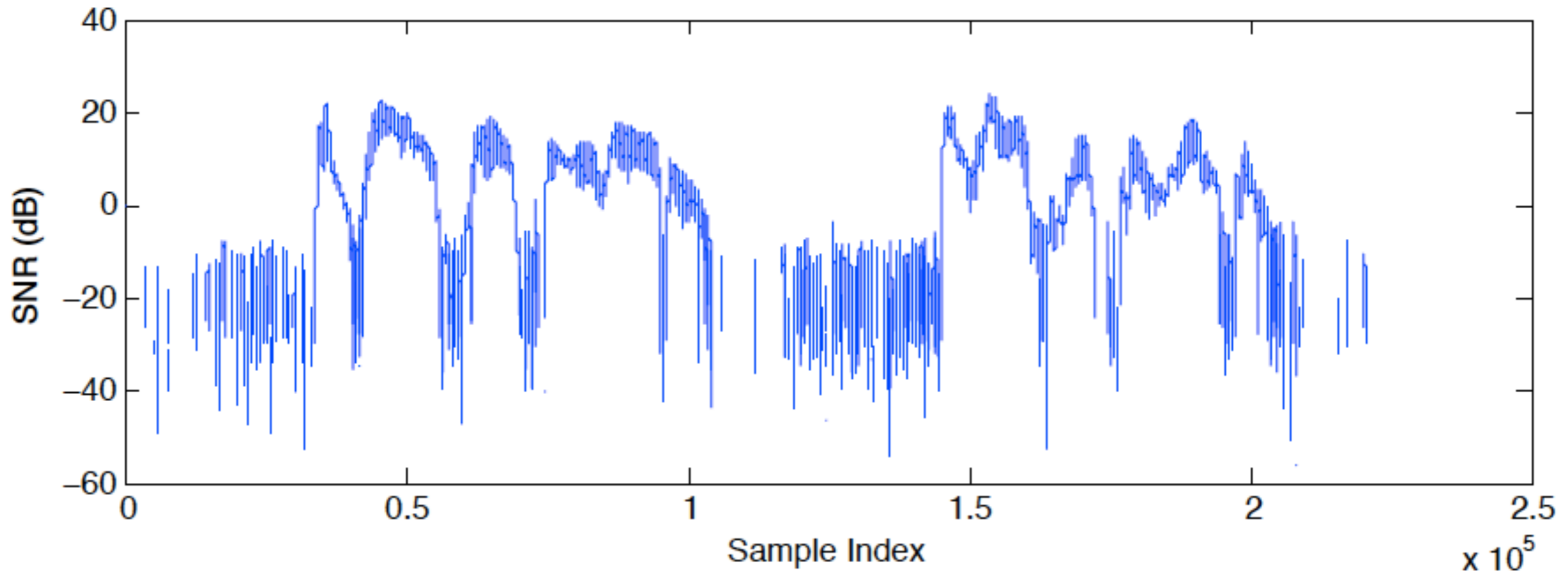
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Clinician's options