A period of suspended growth
accompanied by decreased metabolism in insects

Personalized Diapause:

Reducing Radio Energy Consumption of Smartphones by Network–Context Aware Dormancy Predictions

Yeseong Kim and Jihong Kim

Computer Architecture & Embedded Systems Lab.
Department of Computer Science and Engineering
Seoul National University

2012 Workshop on Power-Aware Computing and Systems
October 7, 2012

Radio Energy Consumption in Smartphones

- High radio energy consumption
  - About 30% of the total energy consumption in smartphones (3G Network)
- Radio energy consumption increasing
  - Network-dependent apps increasing (e.g., SNS apps)
  - Shift to high-energy-demand 4G LTE radio network



Apps

3G or 4G LTE



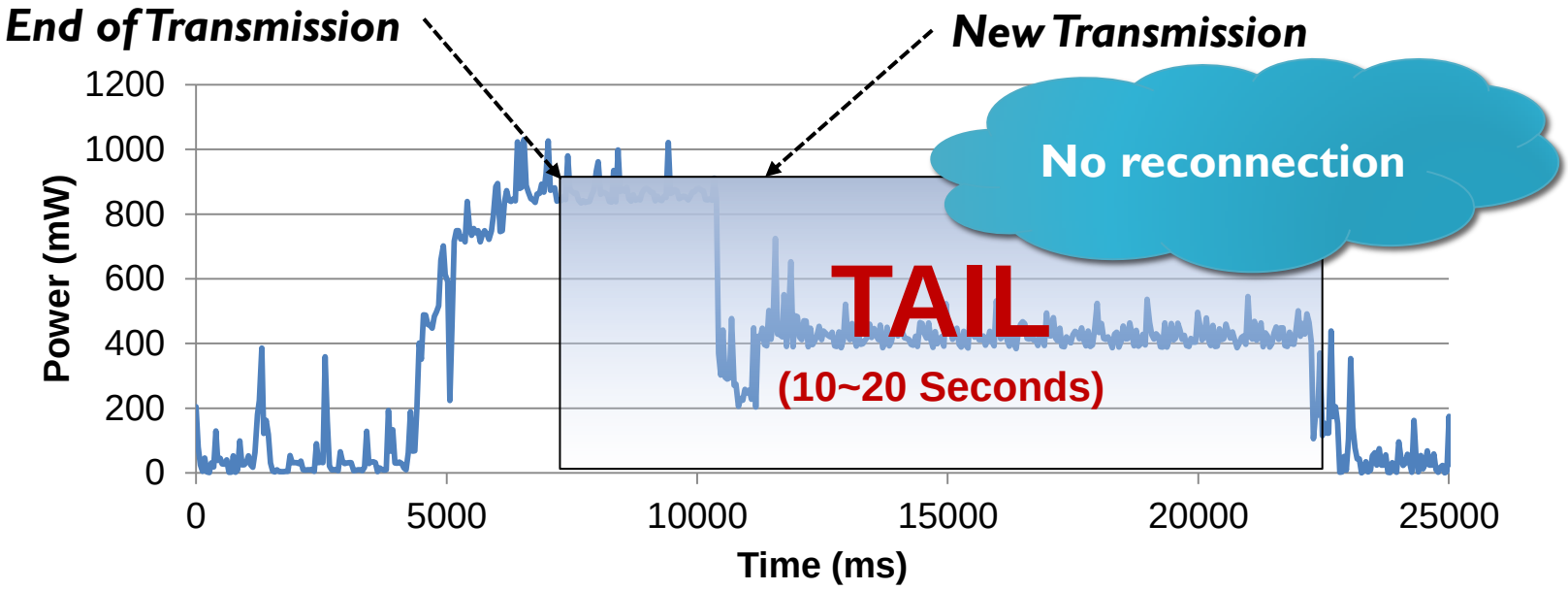


Mobile Network

Reducing radio energy consumption
is an important design issue of smartphones.

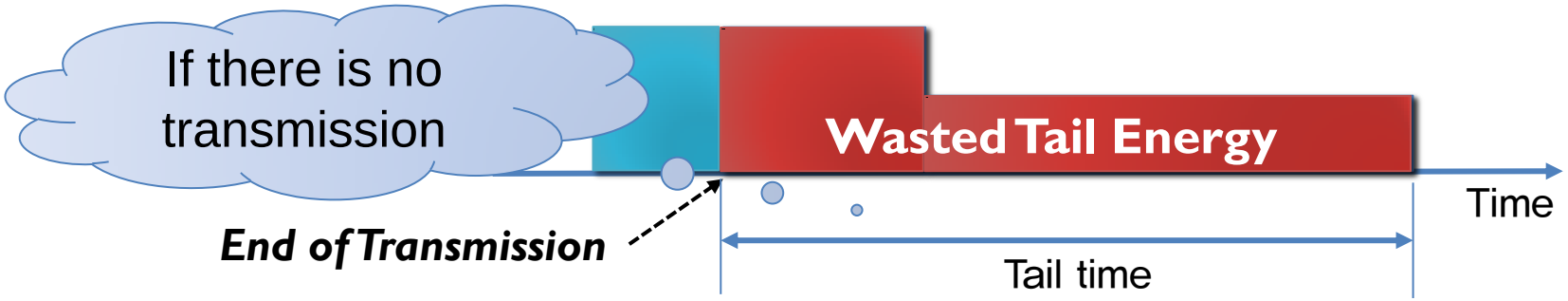
Radio Energy Consumption in Tail Time

- A significant portion of radio energy is consumed during "**tail time**"
  - After a packet transmission, a **high power level** is maintained expecting a subsequent transmission.

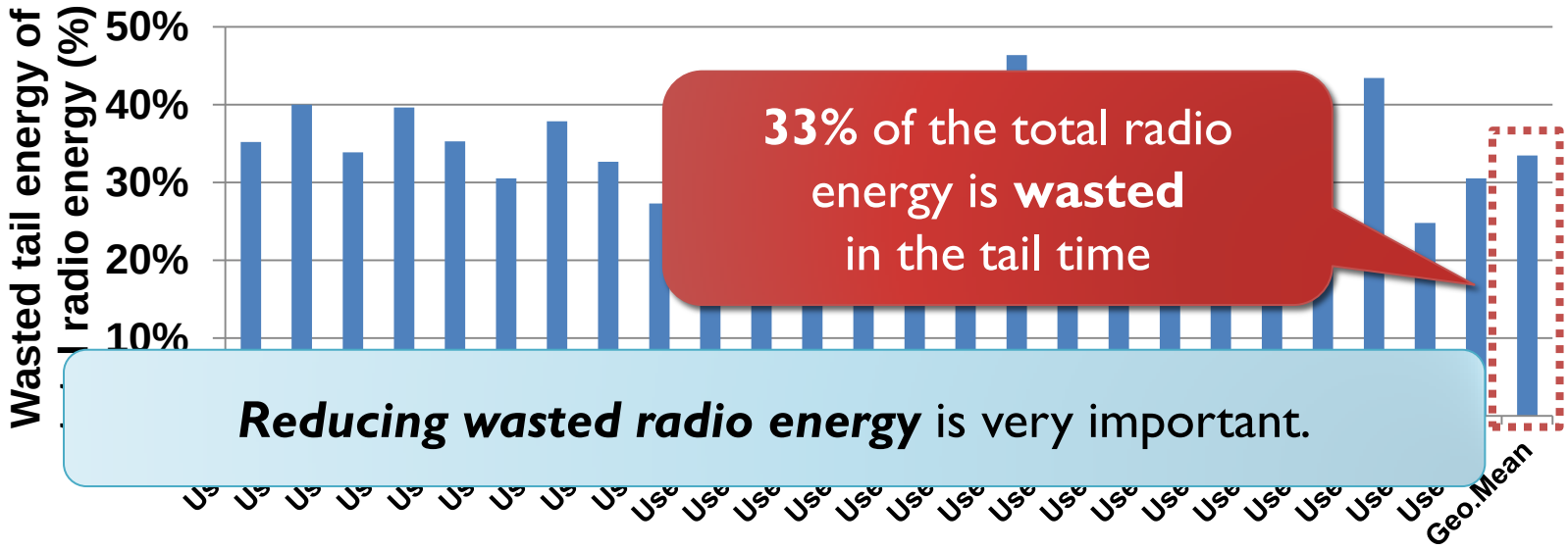


Wasted Radio Energy during Tail Time

- A significant radio energy is wasted during "**tail time**".



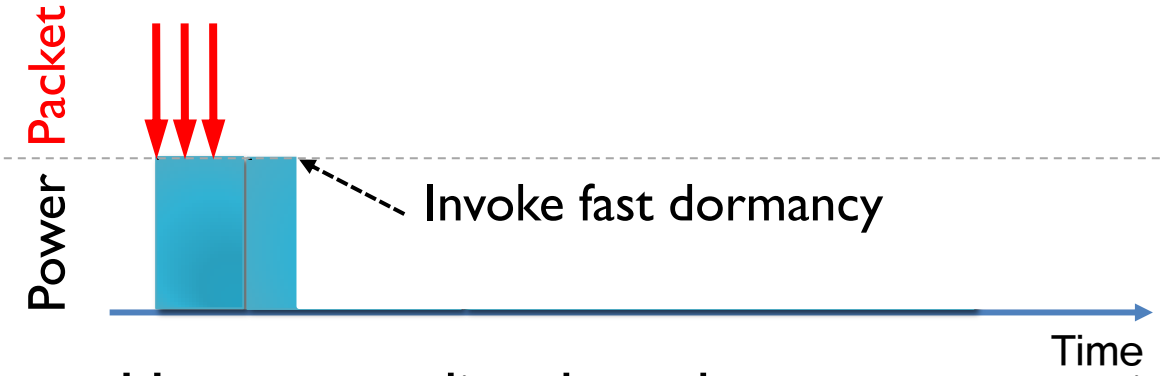
- From our measurement study of 25 smartphone users



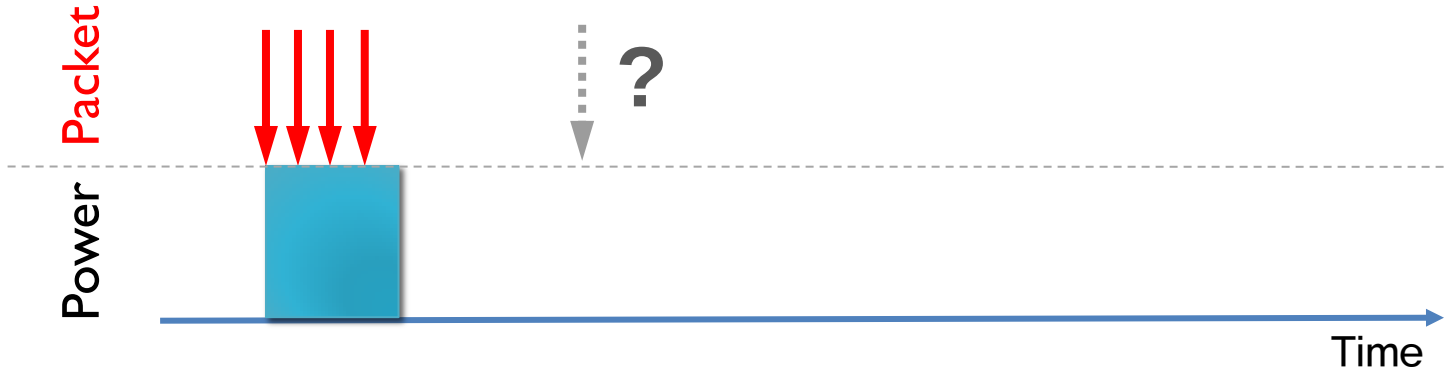
Reducing wasted radio energy is very important.

Fast Dormancy and Key Challenge

- The ***Fast Dormancy*** feature enables a smartphone radio module to ***release the radio connection***
  - to save the wasted energy during the tail time

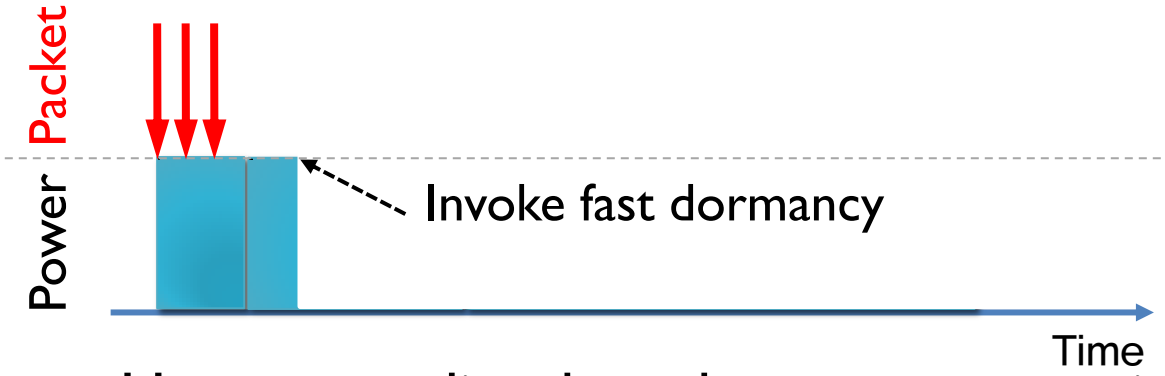


- Key Challenge: How to predict the subsequent transmission

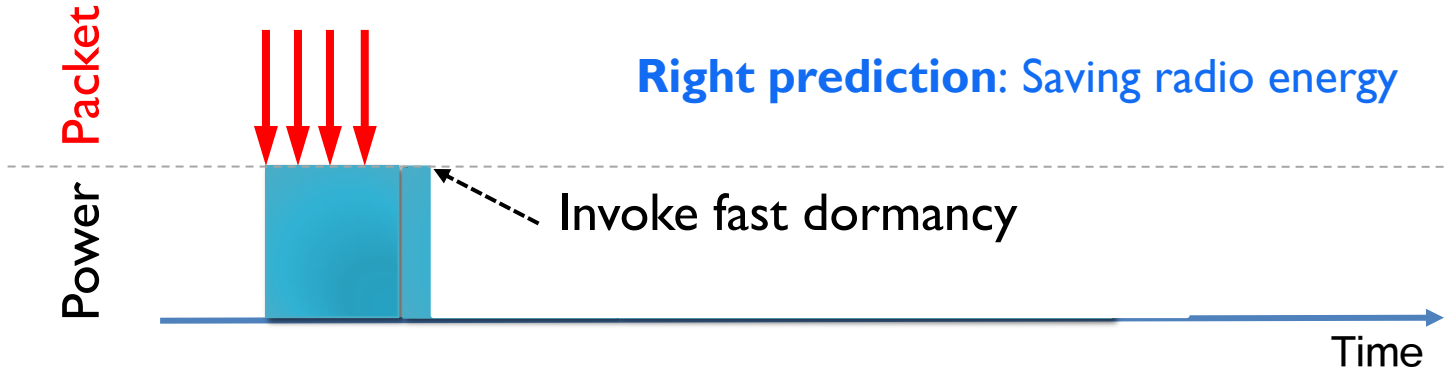


Fast Dormancy and Key Challenge

- The ***Fast Dormancy*** feature enables a smartphone radio module to ***release the radio connection***
  - to save the wasted energy during the tail time

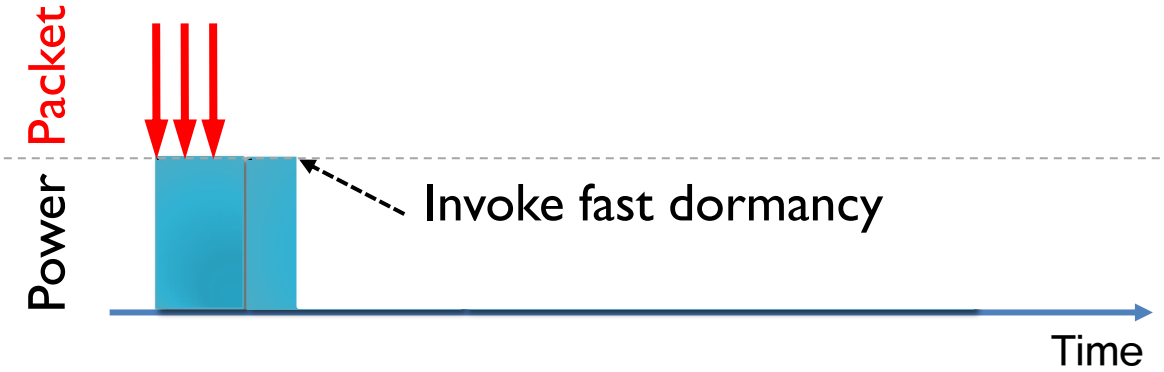


- Key Challenge: How to predict the subsequent transmission

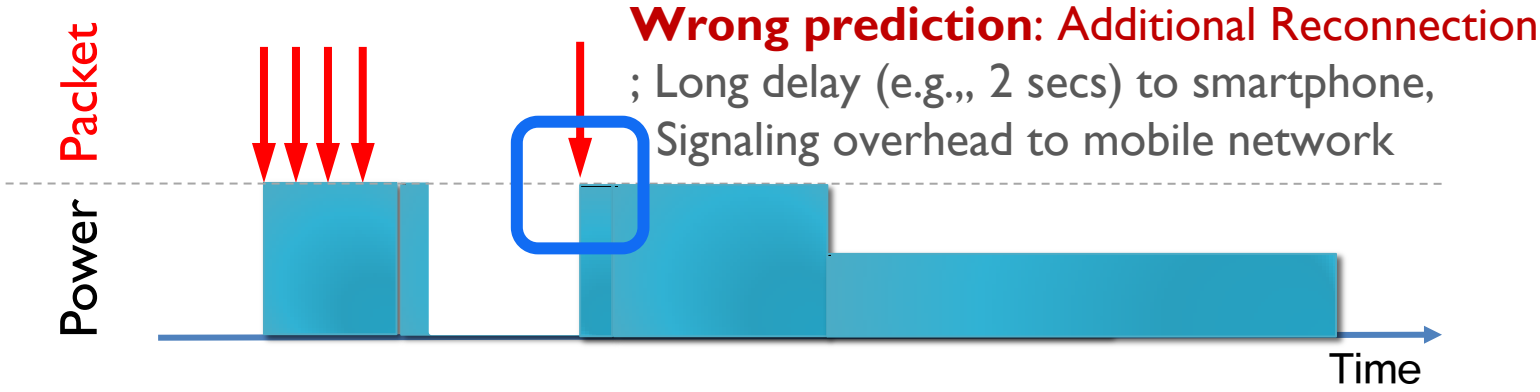


Fast Dormancy and Key Challenge

- The ***Fast Dormancy*** feature enables a smartphone radio module to ***release the radio connection***
  - to save the wasted energy during the tail time

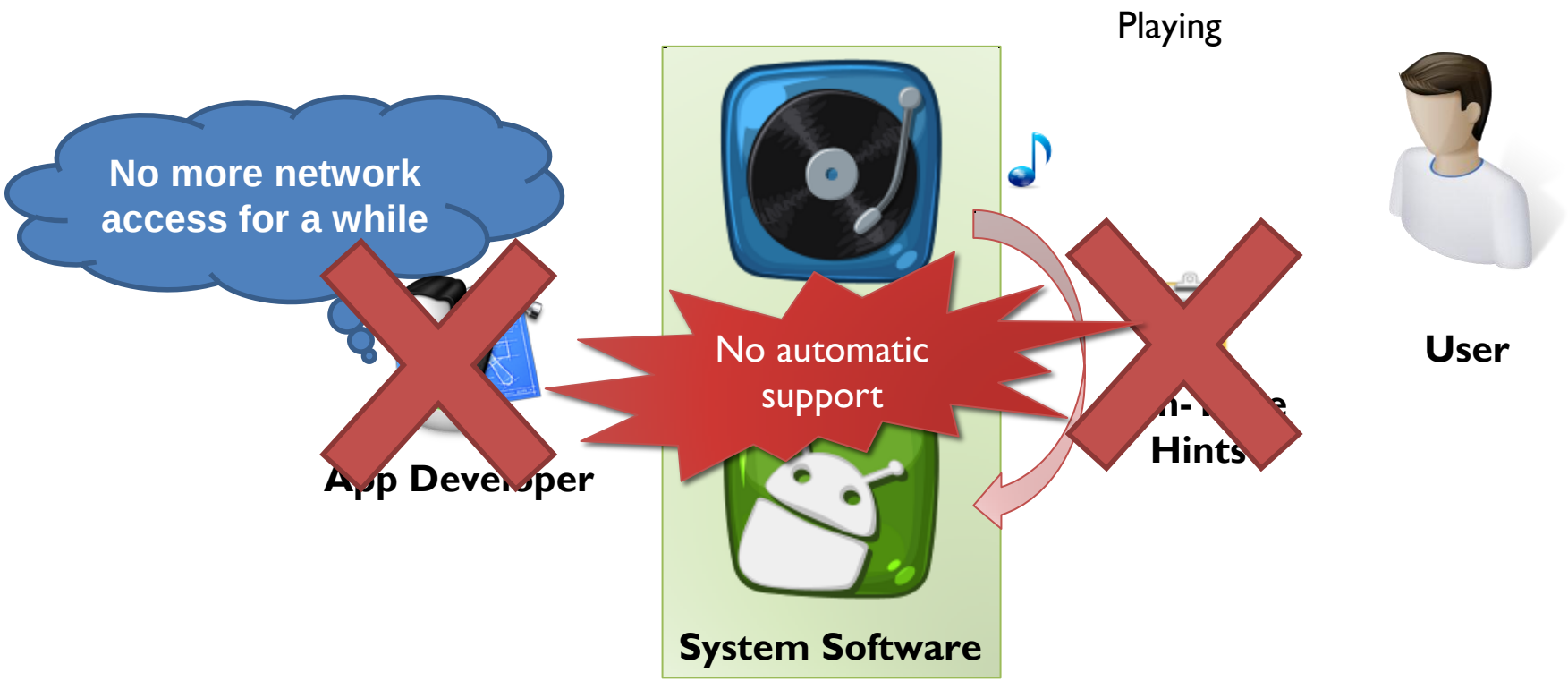


- Key Challenge: How to predict the subsequent transmission



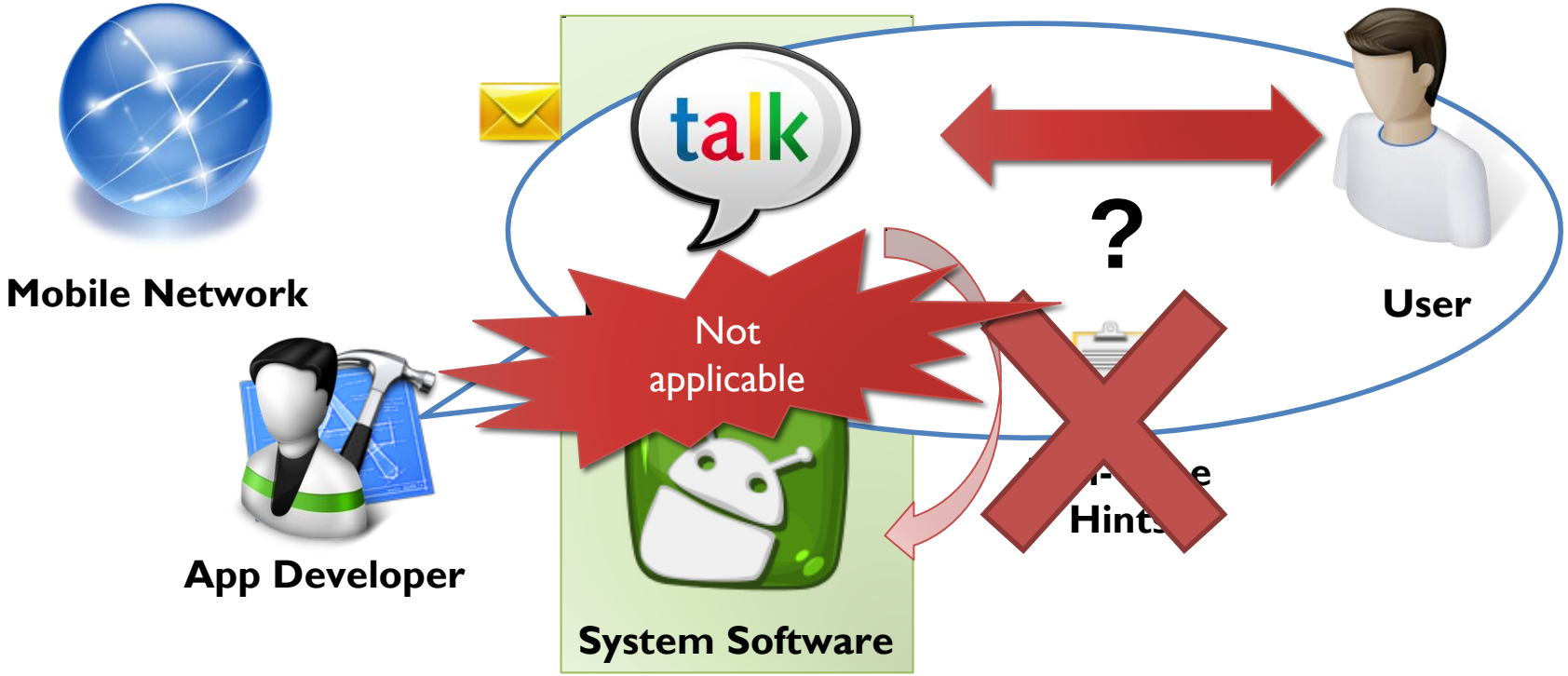
Problems of Existing Dormancy Technique

- Problem 1. Existing dormancy techniques are **app-centric.**
  - require ***app-assisted run-time hints*** on the next transmission
  - e.g., TOP [ICNP 10]



Problems of Existing Dormancy Technique

- Problem 2. Existing dormancy techniques are not applicable to **most interactive** apps.
  - It is very difficult to predict how ***a user interacts*** with interactive apps such as google talk and facebook app.



Contributions

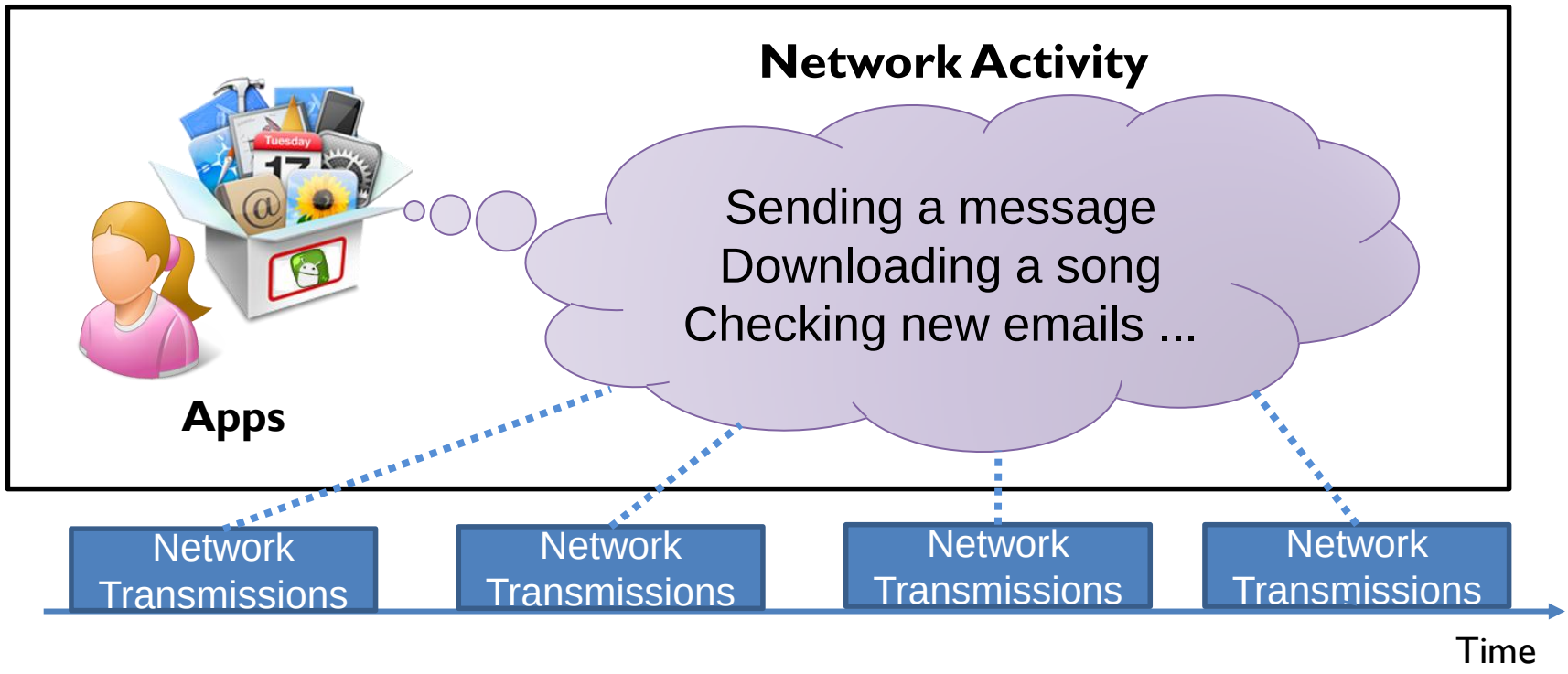
- We propose **Personalized Diapause,** a ***general-purpose automatic*** predictive dormancy technique for supporting the fast dormancy feature
  - Not depending on app-assisted future network usage hints
  - Applicable to most of apps with general network transmission patterns

- Personalized Diapause was implemented on Android 2.3 (Gingerbread) Nexus S smartphones
  - Radio energy consumption saving by up to 36% with 10% increase in the radio reconnection over when no fast dormancy feature is used.

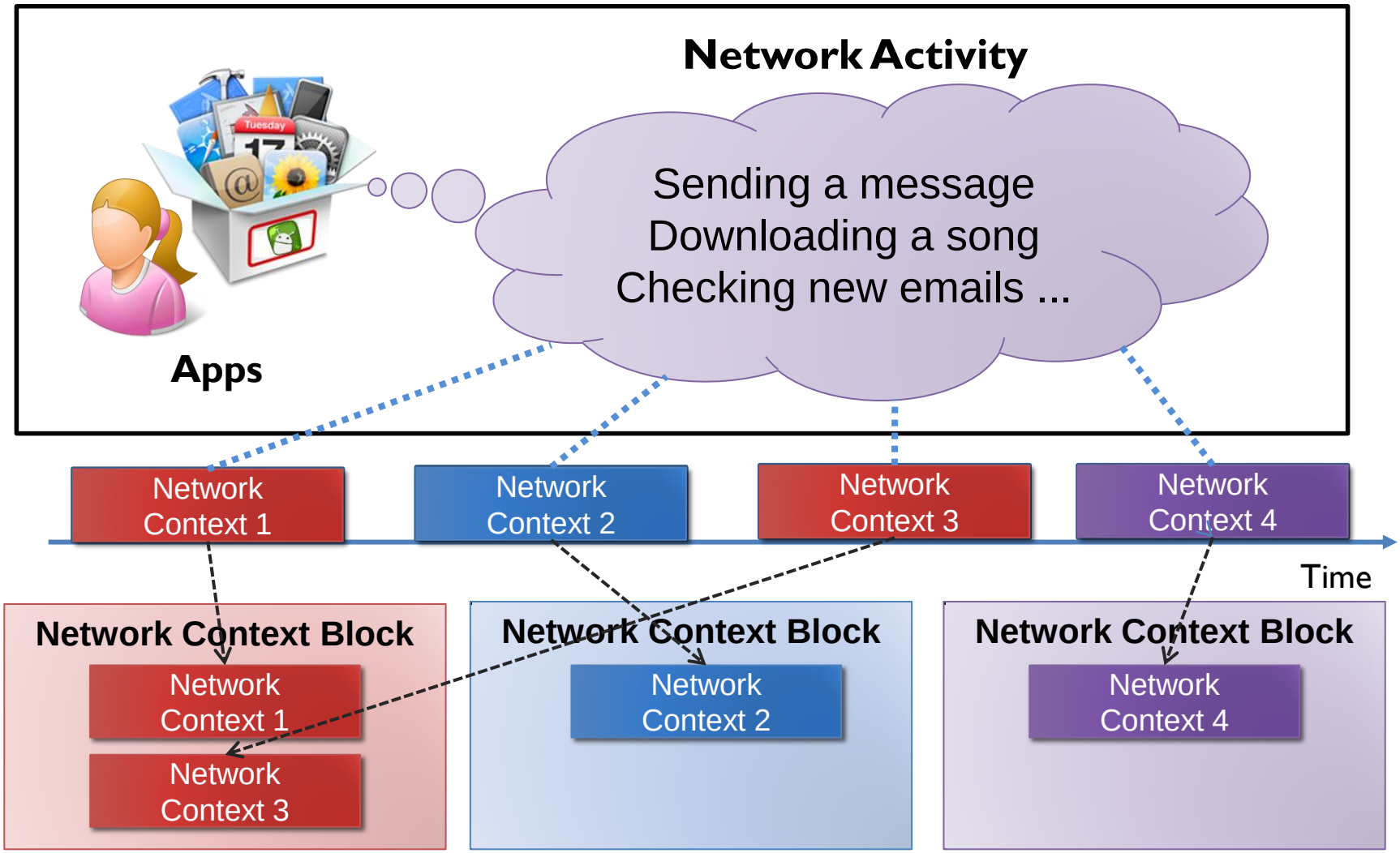
Outline

- Introduction
- **Overview of Personalized Diapause**
- Key Steps of Personalized Diapause
  - Extraction of Network Context
  - Estimation of Network Transmission Trend
  - Predictive Dormancy Analysis
- Experimental Results
- Conclusion

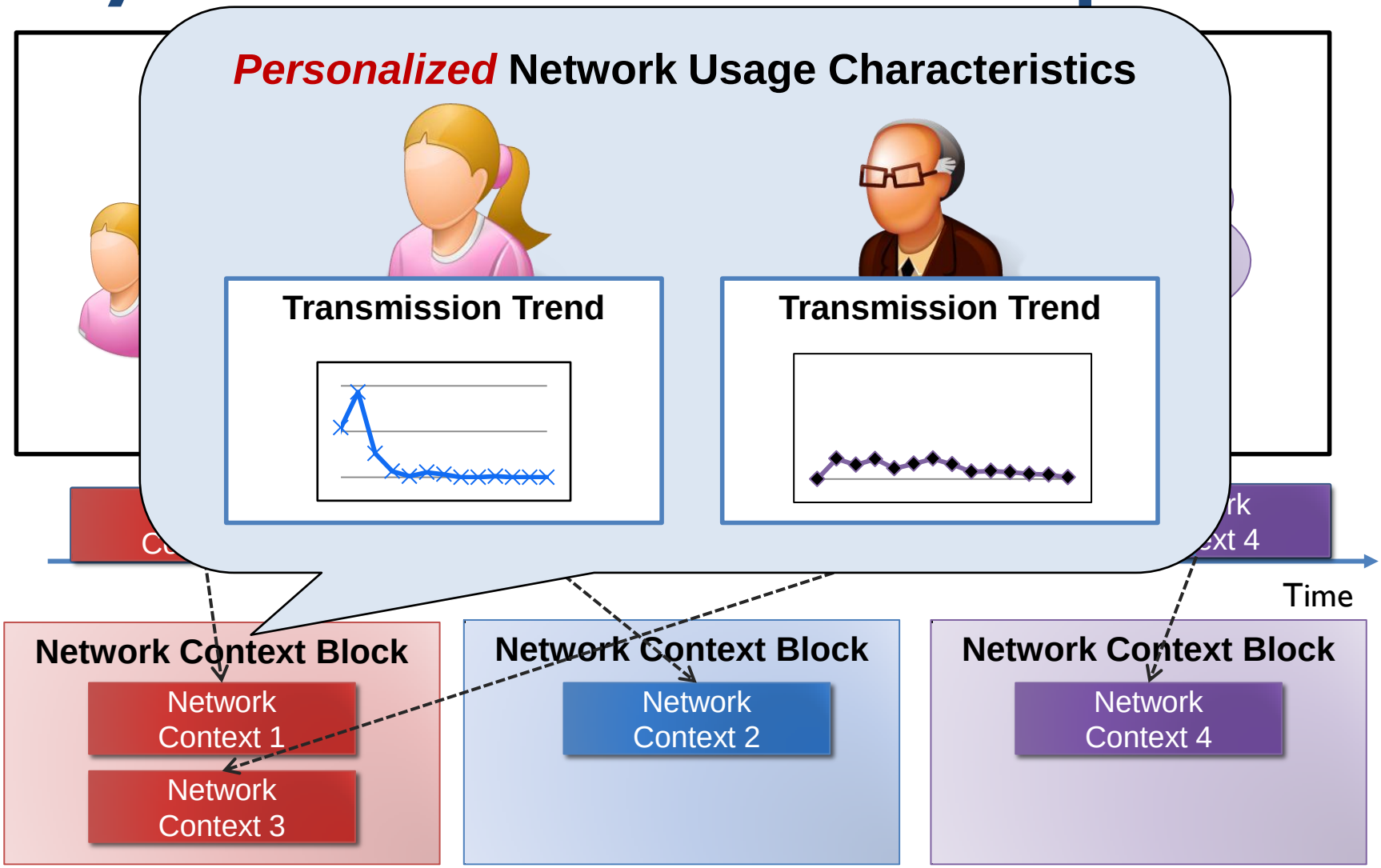
Key Idea of Personalized Diapause



Key Idea of Personalized Diapause



Key Idea of Personalized Diapause



Overview of Personalized Diapause

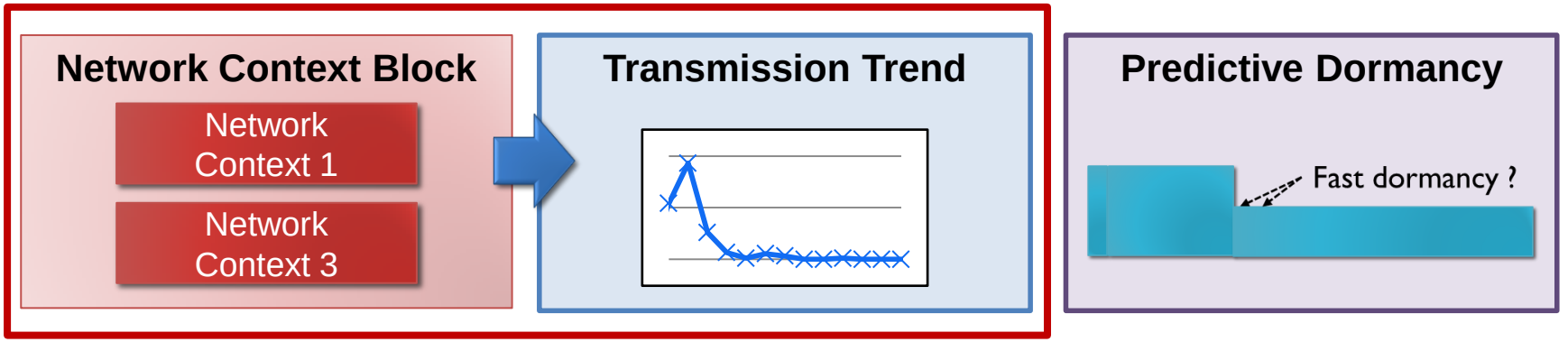
- Key steps of Personalized Diapause

Extracting semantically ***equivalent*** network activities

+

Estimating ***transmission trends*** of network activities

Predictive dormancy analysis

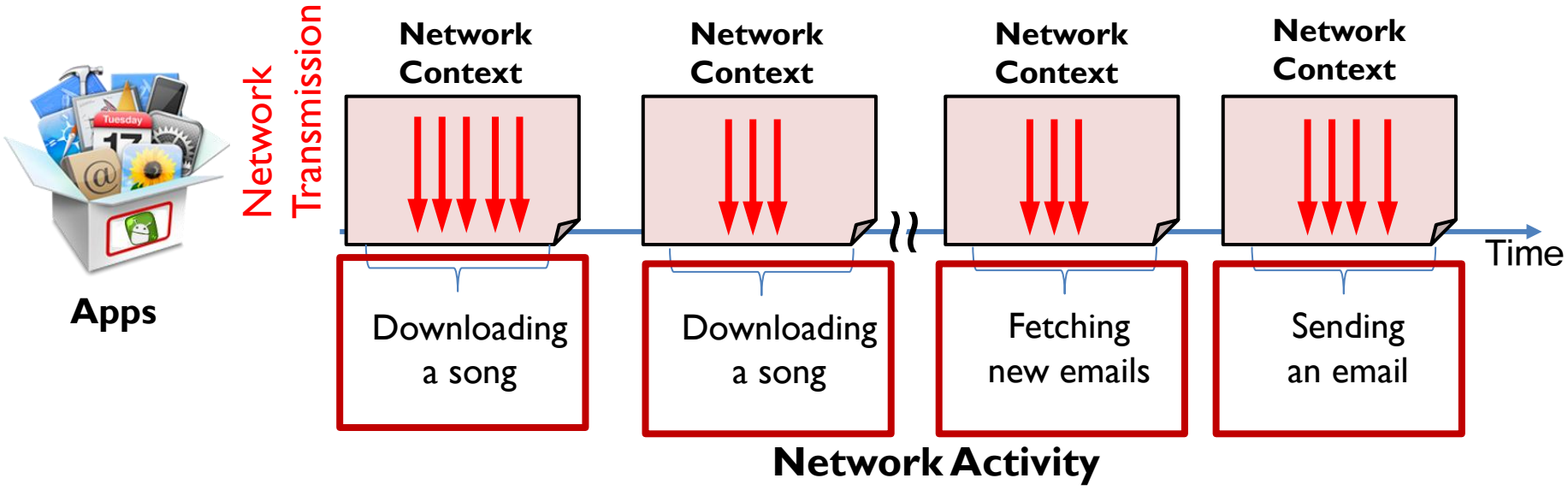


Outline

- Introduction
- Overview of Personalized Diapause
- **Key Steps of Personalized Diapause**
  - Extraction of Network Context
  - Estimation of Network Transmission Trend
  - Predictive Dormancy Analysis
- Experimental Results
- Conclusion

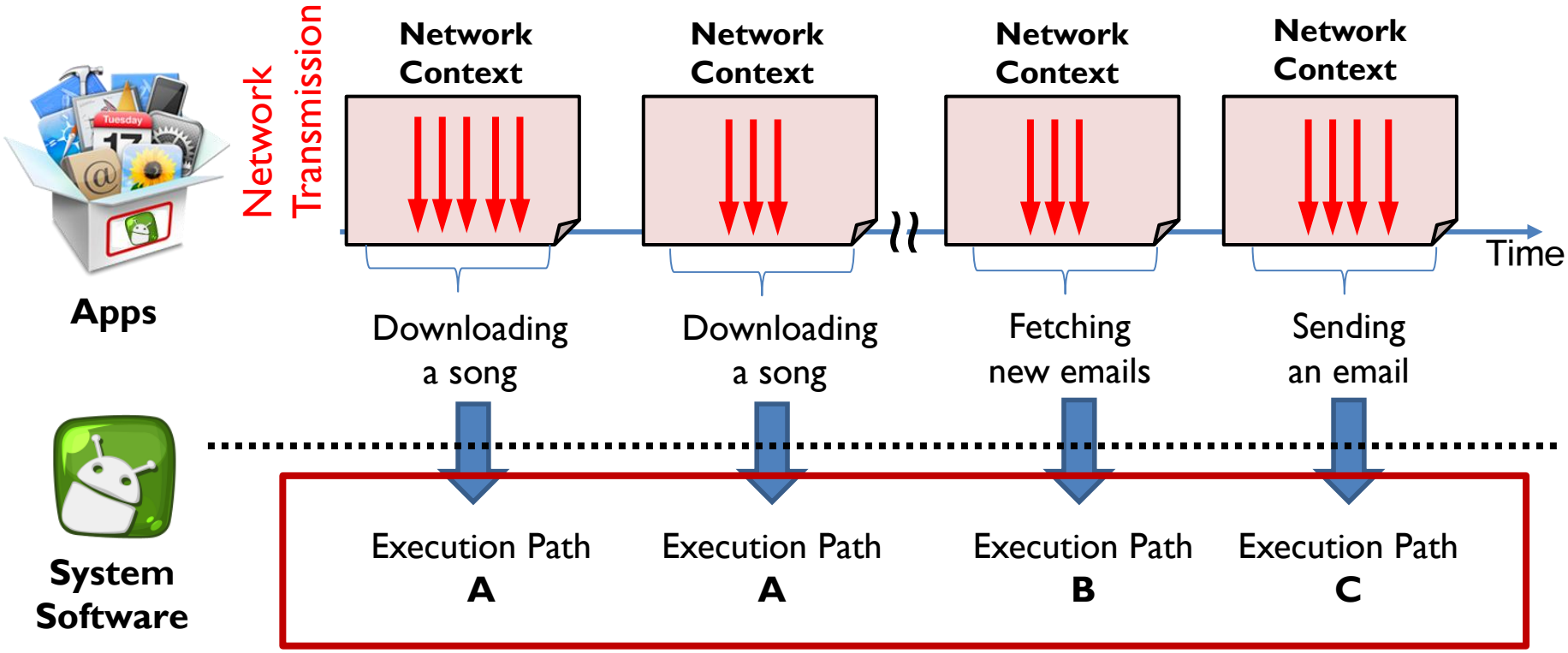
Step 1. Extraction of Network Context

- Network Transmissions are transferred due to **network activities**.



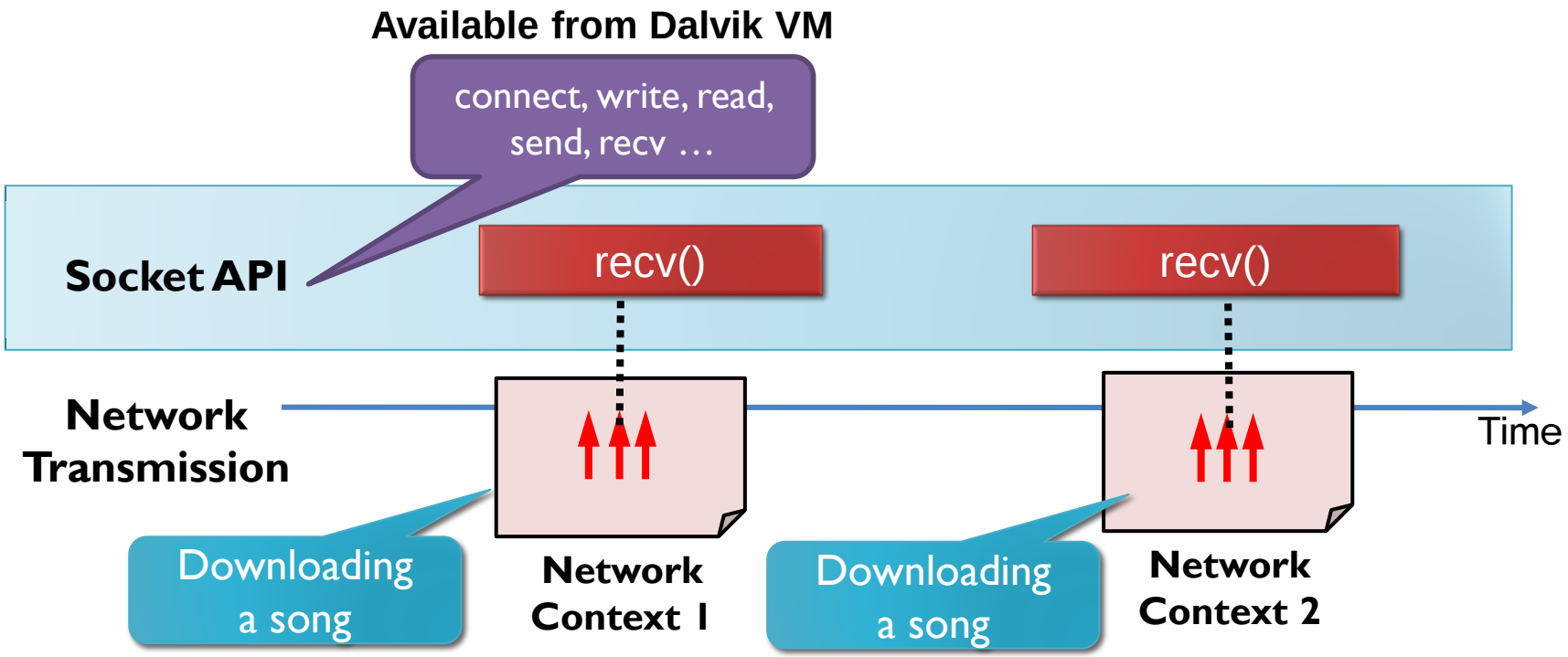
Step 1. Extraction of Network Context

- Network Transmissions are transferred due to **network activities**.

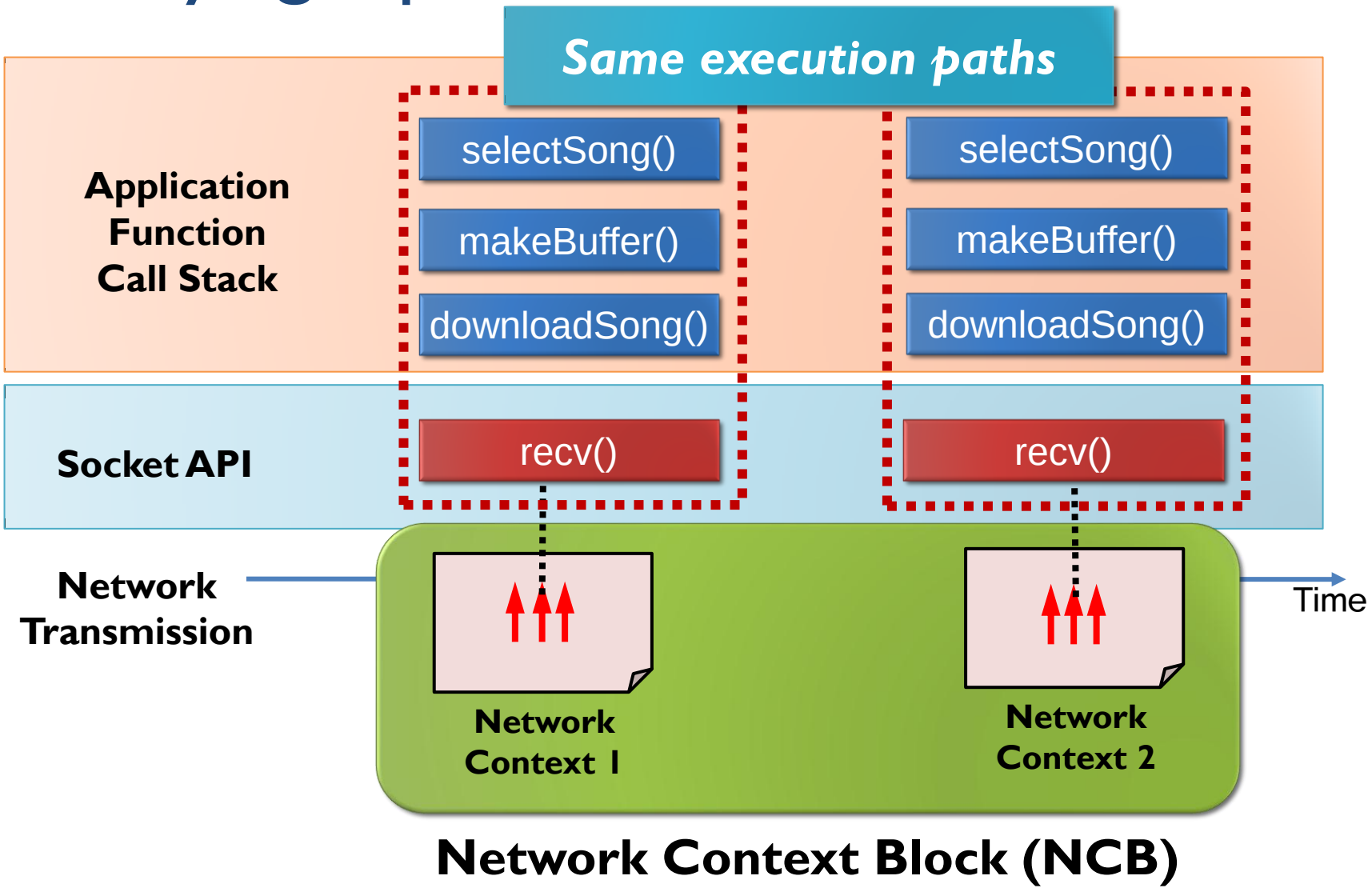


The network activities can be systematically distinguished from their **execution paths**.

Identifying Equivalent Network Context

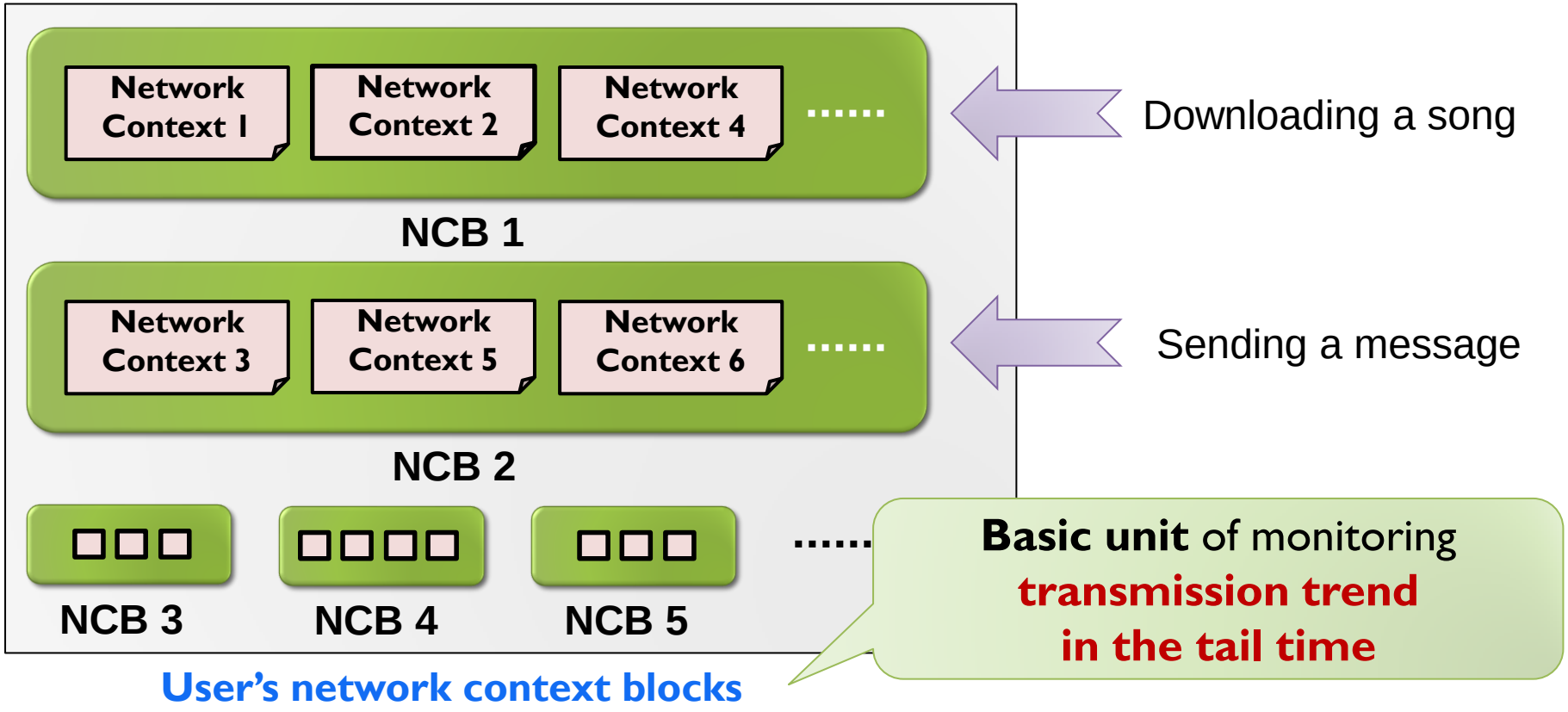


Identifying Equivalent Network Context



Network Context Block (NCB)

- Network contexts in the **same Network Context Block** are assumed to perform same **network activity**.



Key steps of Personalized Diapause

Step 1.

Extracting semantically ***equivalent*** network activities

\+

Step 2.

Estimating ***transmission trends*** of network activities

Step 3.

Predictive dormancy analysis

Personalized Transmission Trend

- ***Claim 1.***
  Different users differently behave even for same network activity.
  - Talk via messenger apps





Mr. Every10Seconds

A transmission is **likely** to occur in the tail time





Prof. EveryHour

A transmission is **unlikely** to occur in the tail time

Must consider ***personalized transmission trends***.

Transmission Trend of Network Activities

- ***Claim 2.***
  Different Network Activities have different transmission trends.

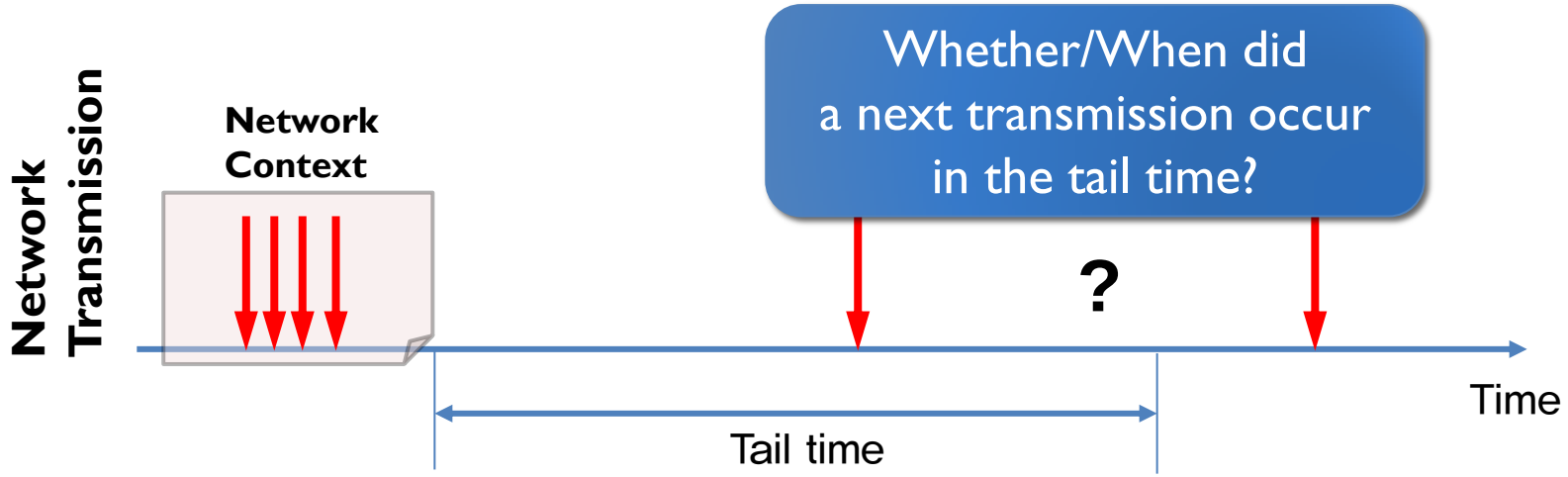


Checking system update	Browsing a web page	Sending a message	Checking new emails
Transmission Trend	Transmission Trend	Transmission Trend	Transmission Trend

Must consider ***different network activity characteristics***.

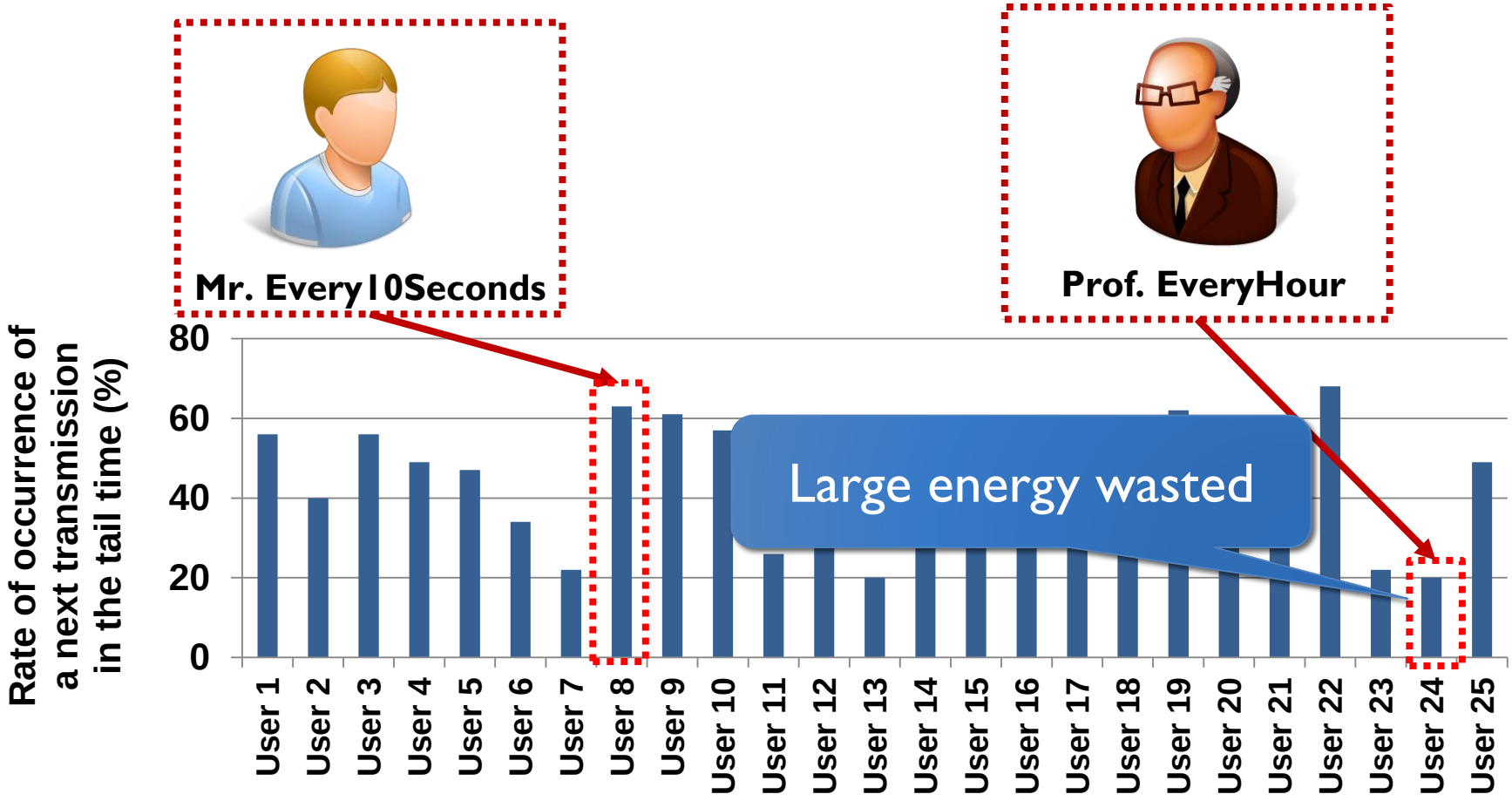
Validation Study of Smartphone Network Usage

- **Subject:** 25 active smartphone users
  - Aged 20~40
  - College students, graduate students, bankers, kindergarten teachers …
- **Study Period:** during two weeks
- **Method:** using a modified Dalvik VM
  - For logging network contexts with call stack information



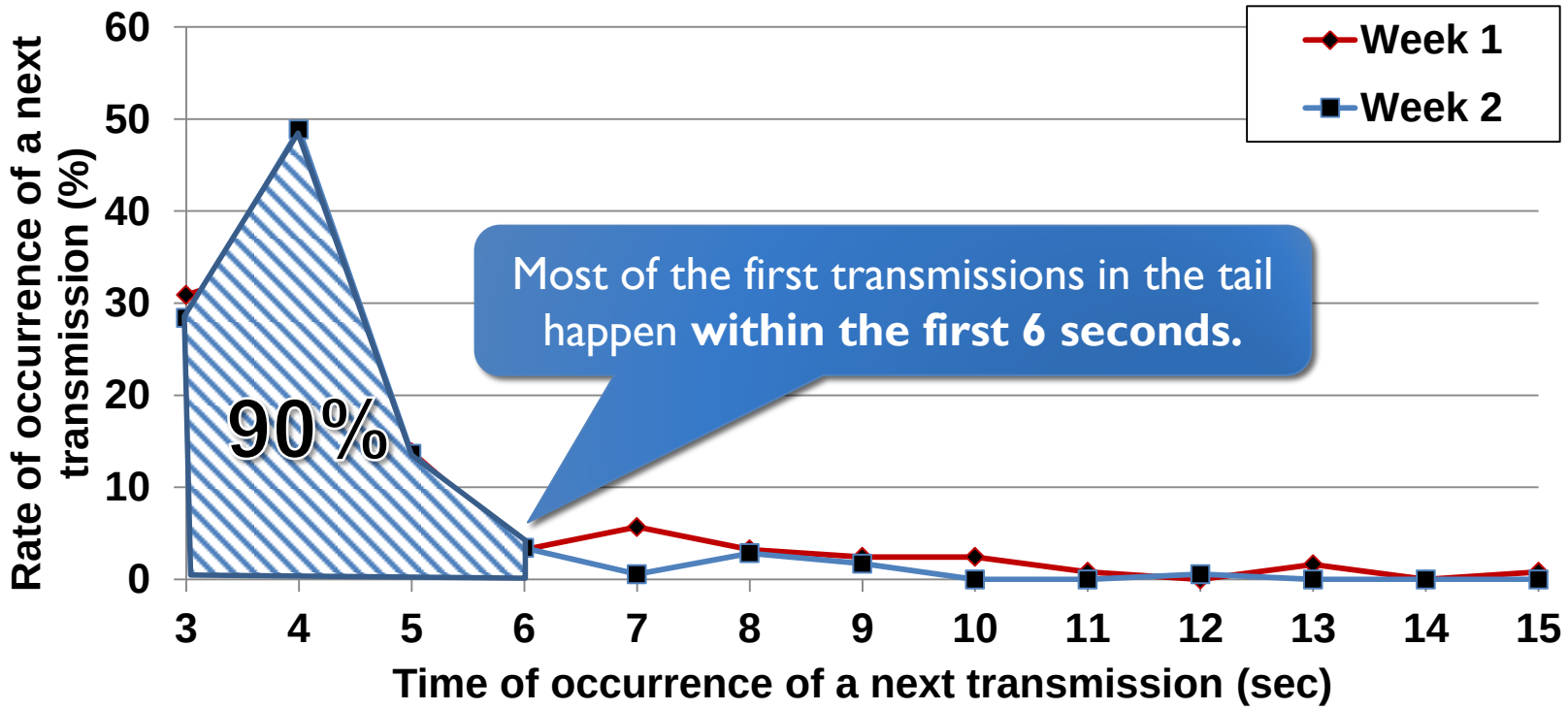
Personalized Network Usage Tendency

- Strong ***personalized*** network usage tendency



Skewed Transmission Distribution

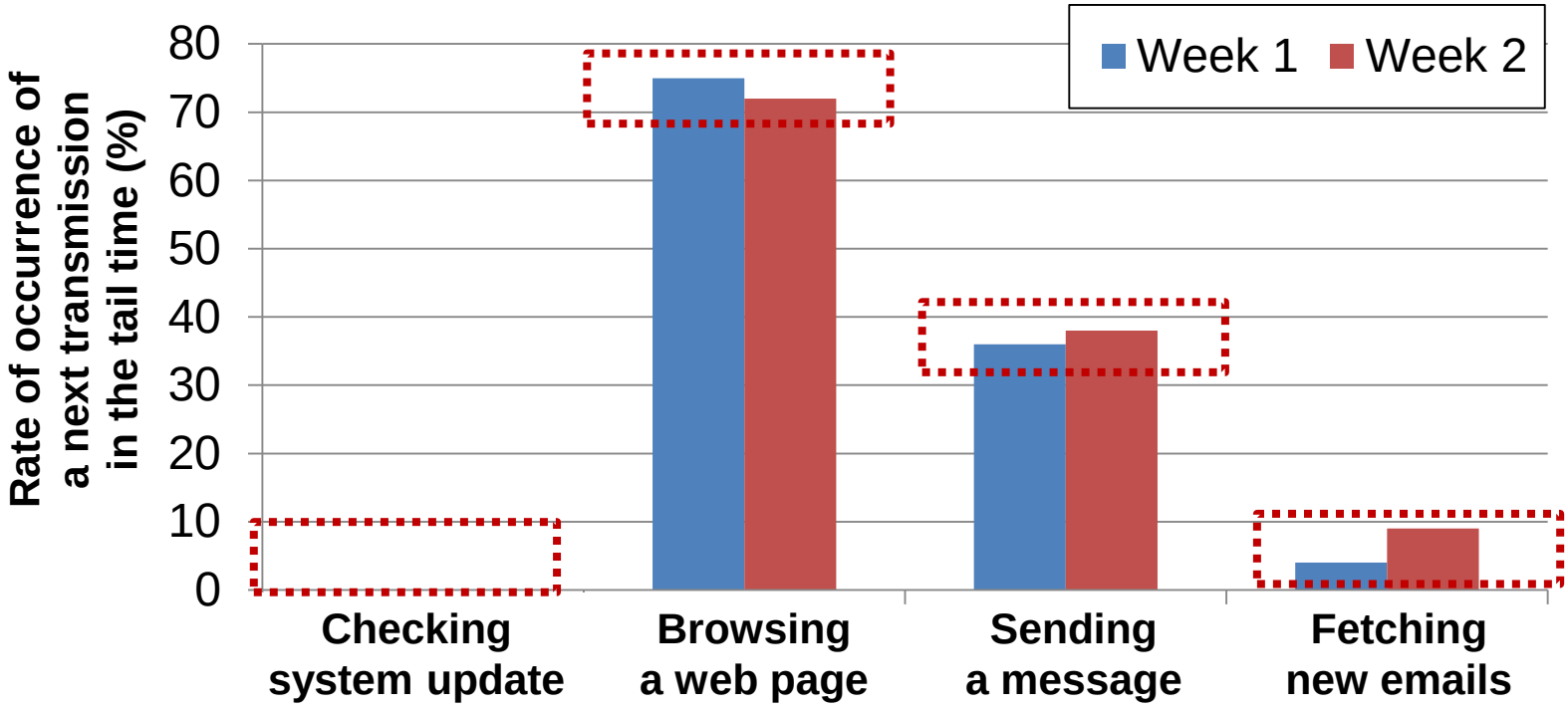
- User's behavior for transmissions is quite ***skewed***.



These ***persistent right-skewed distribution***
can be exploited to apply the fast dormancy feature.

Transmission Characteristics for Different Network Activities Per User

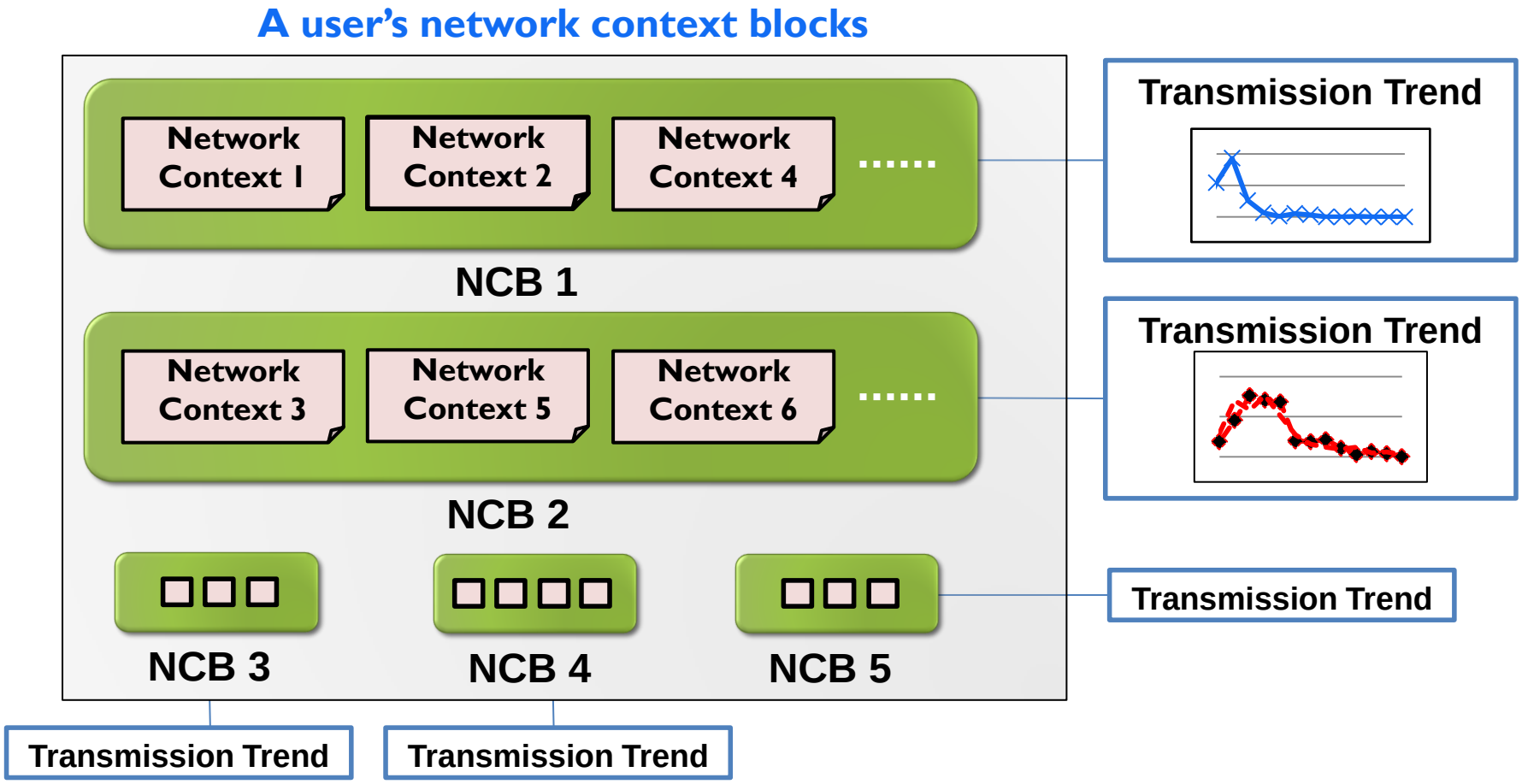
- ***Different transmission characteristics*** for different network activities
  - The transmission trend of each NCB **persists over long time**.



Exploiting these ***persistent*** transmission trends ***over different NCBs*** ,we can **estimate** transmissions in the tail time.

Step 2.
Estimating Transmission Trend of Network Activity

- We estimate when/whether a transmission will occur in the tail time based on the ***skewed transmission distribution*** of **each NCB.**



Key steps of Personalized Diapause

Step 1.

Extracting semantically ***equivalent*** network activities

+

Step 2.

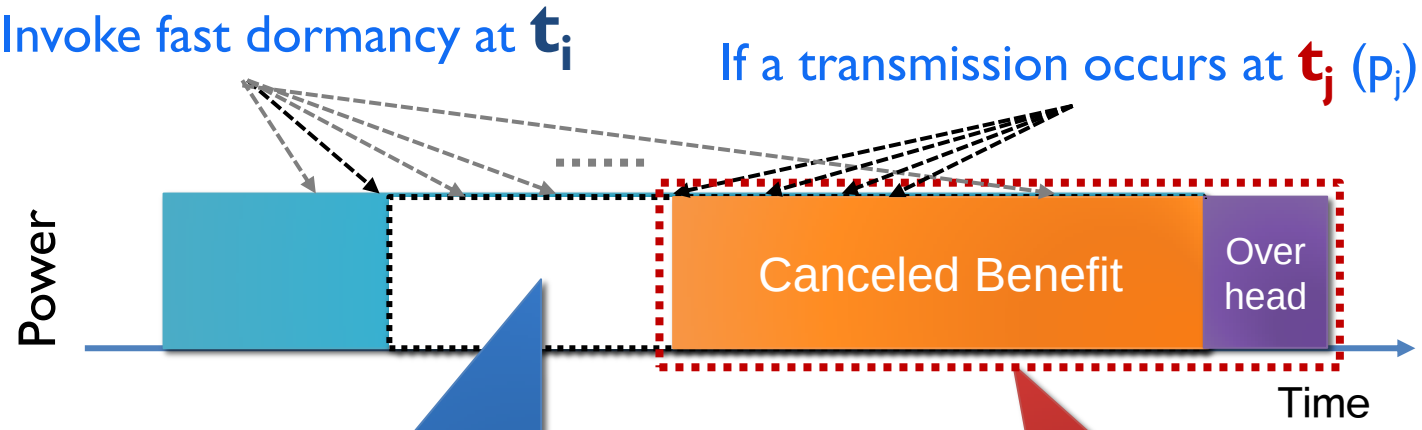
Estimating ***transmission trends*** of network activities

Step 3.

Predictive dormancy analysis

Step 3. Predictive Dormancy Analysis

- To determine when to invoke the fast dormancy feature
  - Considering cost-benefit tradeoff

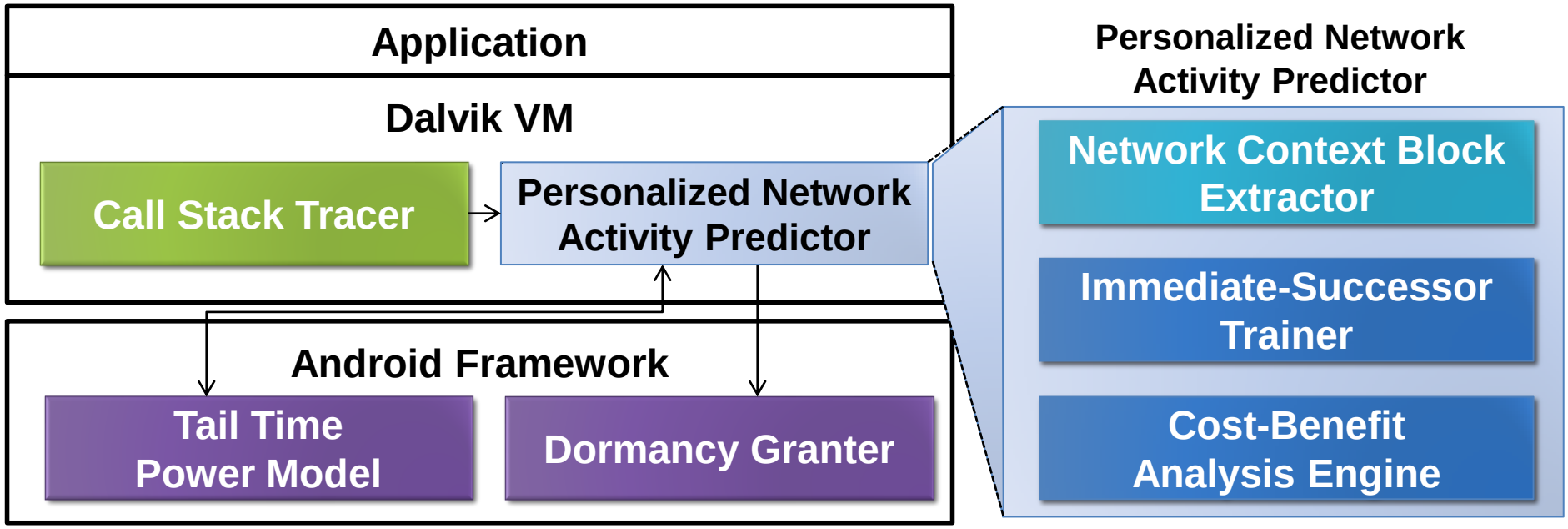


$$\text{Gain } (G_i) = \text{Expected Energy Benefit } (B_i) - \sum_j (\text{Energy Cost } (C_j) \times \text{Probability } (p_j))$$

  - Intuitively, choosing the best moment (t_i) to invoke fast dormancy
    - Consider t_k's only where the probability of retransmissions after t_k is less than a given upper bound threshold
    - (See our paper for a detail description of the decision procedure)

Architectural Overview of Personalized Diapause

- The key steps are implemented as additional modules to the Dalvik VM and Android framework.

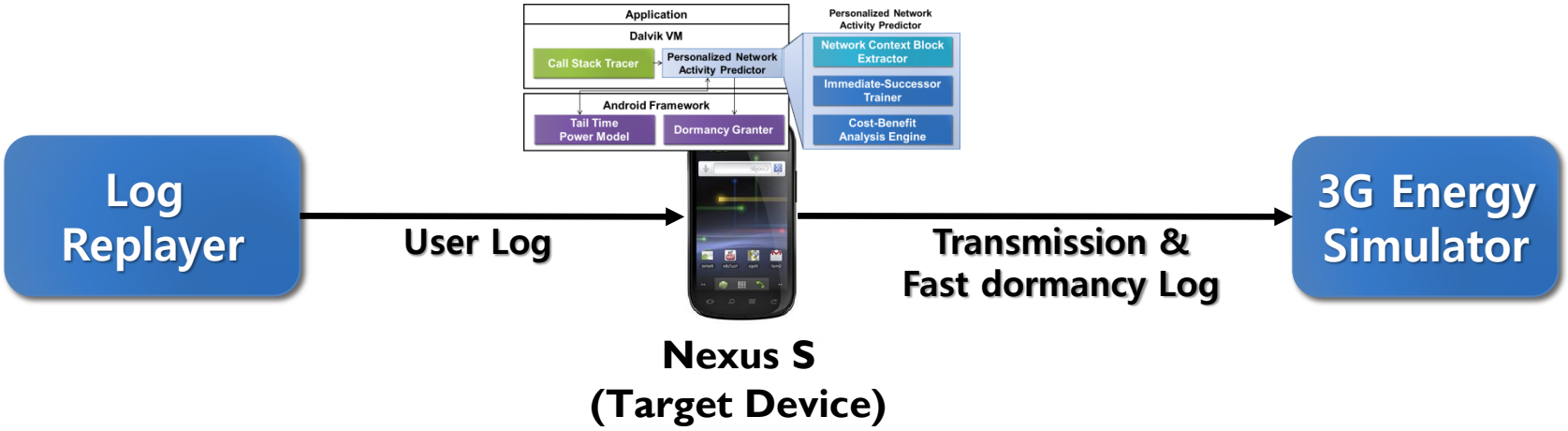


Outline

- Introduction
- Overview of Personalized Diapause
- Key Steps of Personalized Diapause
  - Extraction of Network Context
  - Estimation of Network Transmission Trend
  - Predictive Dormancy Analysis
- **Experimental Results**
- Conclusion

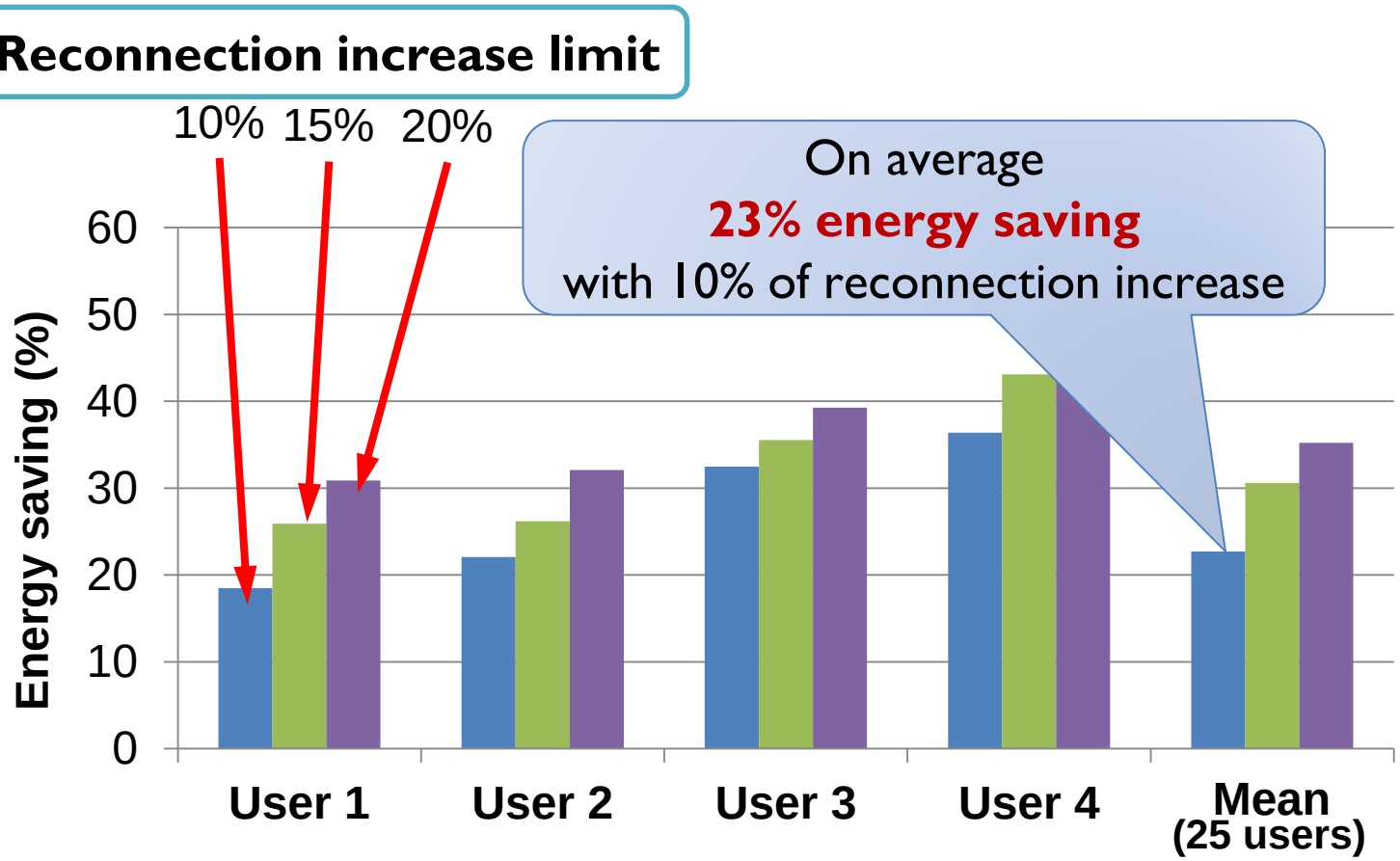
Experimental Environment

- Implemented the Personalized Diapause (PD) technique on ***Nexus S Android reference smartphones***
  - Running Android 2.3 (Gingerbread)
  - To Dalvik VM and Android framework
- Using the collected network transmission logs from 25 users
  - A custom log replayer tool reproduced network contexts logs.
  - A 3G energy simulator was used for energy consumption comparison.



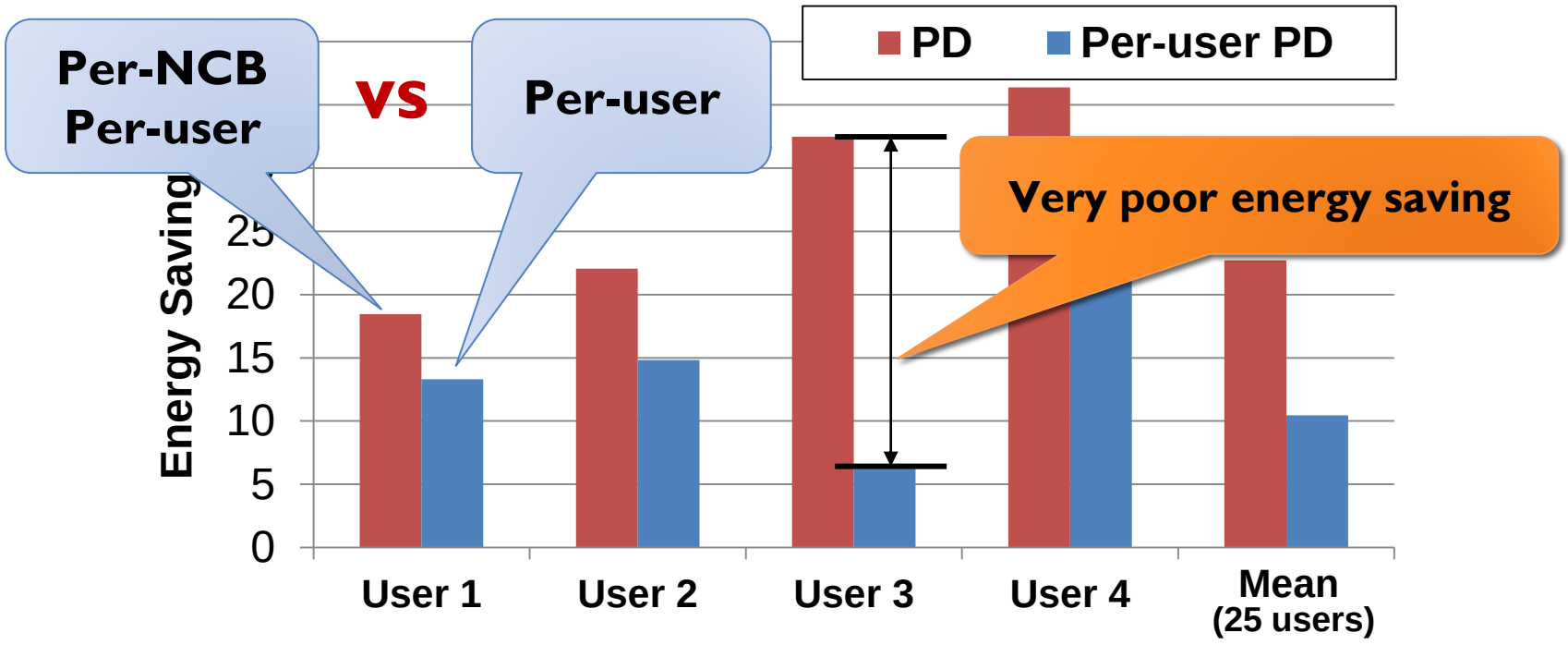
Impact of PD on Energy Consumption Saving

- Energy saving of Personalized Diapause
  - No-fast-dormancy support as a baseline



Impact of NCB Classification Technique

- Comparison with **Per-user PD**
  - Assuming that all network contexts are classified to a single NCB.



The ***fine-grained NCB separation*** based on semantic differences is important in achieving a high energy efficiency.

Conclusions

- We presented a general-purpose automatic predictive dormancy technique, Personalized Diapause.
  - Optimizing the radio energy consumption of smartphones with the fast dormancy feature
- Personalized Diapause takes advantages of personalized network context usage in deciding when to release a radio connection.
  - Based on an automatic extraction technique of meaningful network activities
- Future work
  - Extend for other types of system optimizations using other useful information available from the network context.

Thank you