Fine Grained Power Modeling For Smartphones Using System Call Tracing

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Smartphone is Energy Constrained

- Energy: One of the most critical issues in smartphones
  - Limited battery lifetime

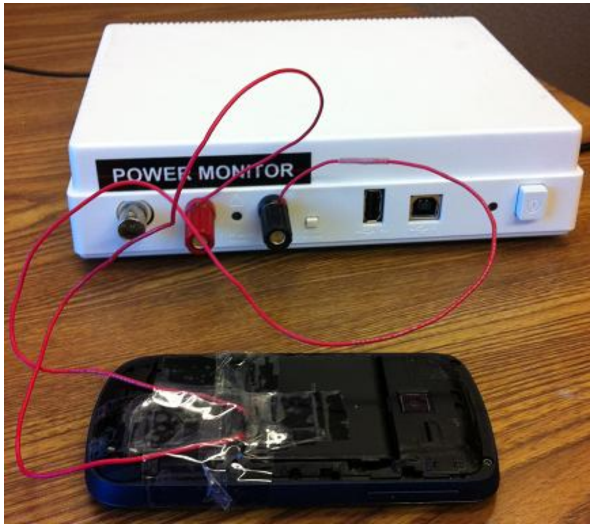
- Battery energy density only doubled in last 15 yrs

- Smartphone capability has increased drastically
  - Multiple Components: GPS, 3G, retina display, ...

Towards Understanding Energy Drain

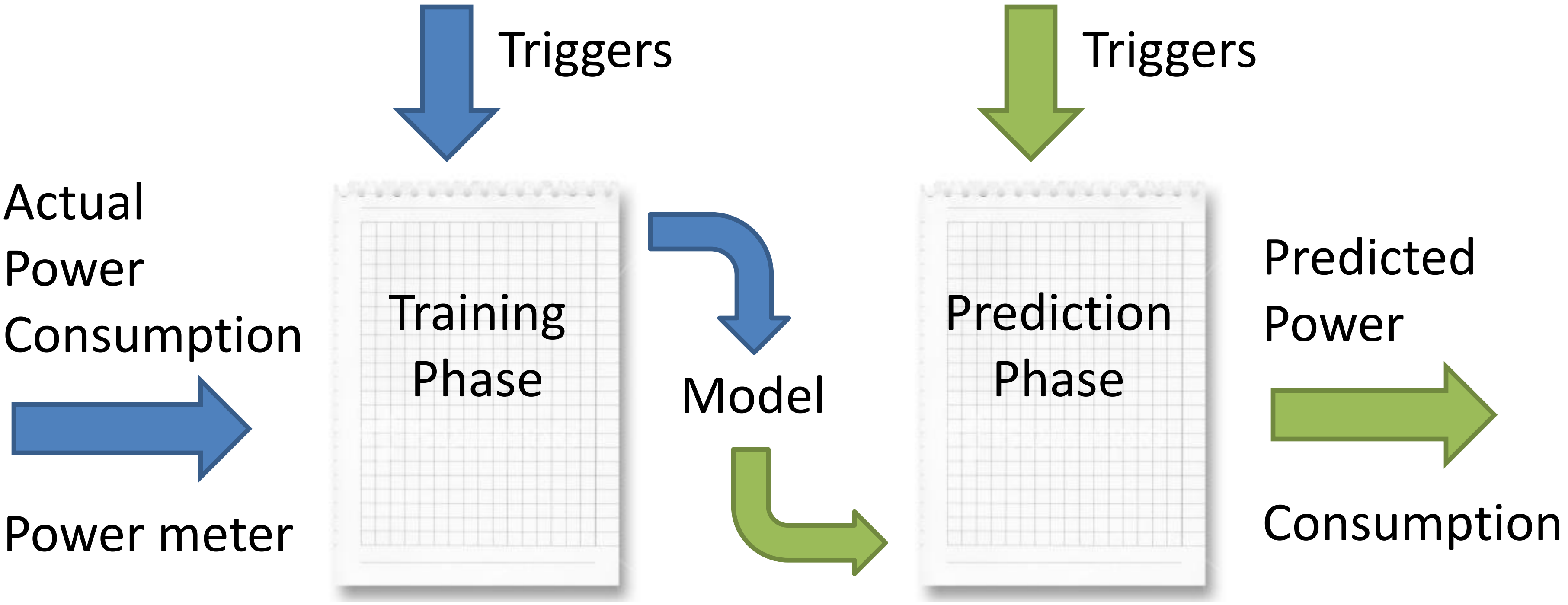
- Key Question: Where is energy being spent?
  - Which component/process/thread/function(?)

- Approach 1: Use Power Meter
  - Buy an expensive equipment ($770)
  - Problems:
    - Only reports entire device energy consumption

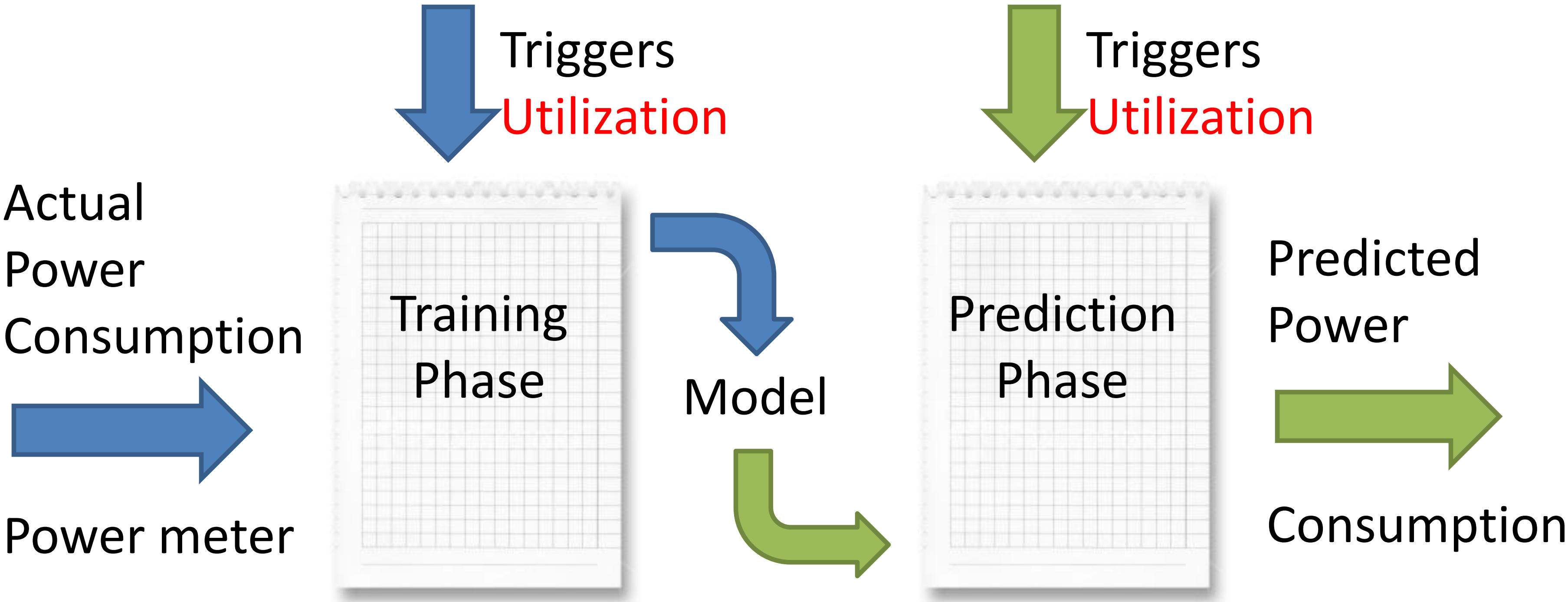


- Approach 2 : Develop Online Power Models

Generic Power Modeling



Smartphone Power Modeling State-of-Art: Utilization Based (1/2)



Linear Regression (LR) and Superimposition

$$\text{Model} = (\text{Util}_{\text{Net}})^{*}\ E_{\text{Net}} + (\text{Util}_{\text{CPU}})^{*}\ E_{\text{CPU}} + (\text{Util}_{\text{Disk}})^{*}\ E_{\text{Disk}}$$

Smartphone Power Modeling State-of-Art: Utilization Based (2/2)

$$\text{Model} = (\text{Util}_{\text{Net}}) * E_{\text{Net}} + (\text{Util}_{\text{CPU}}) * E_{\text{CPU}} + (\text{Util}_{\text{Disk}}) * E_{\text{Disk}}$$

Fundamental (yet intuitive) assumption

(Only active) Utilization => power consumption

Second assumption

Energy scales linearly with amount of work

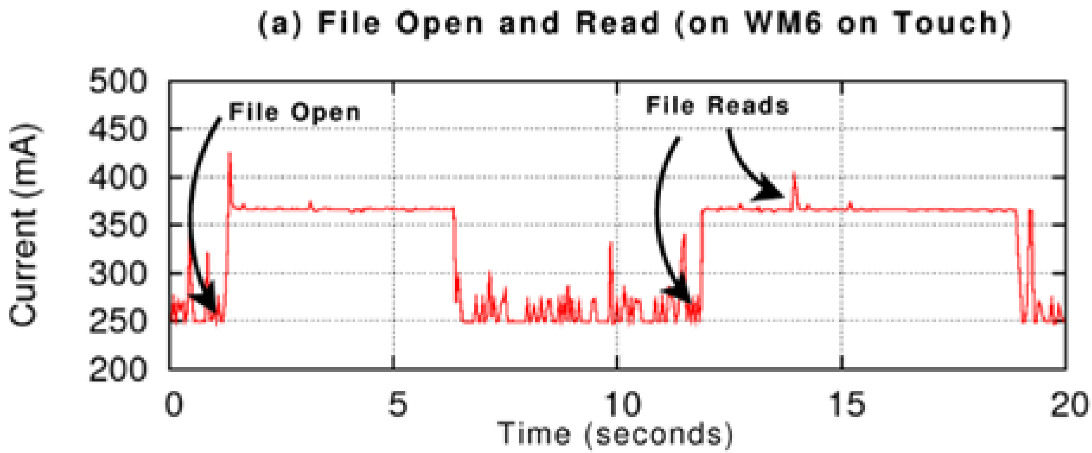
Third assumption

Components power consumption add linearly

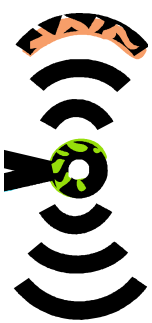
Desired Feature

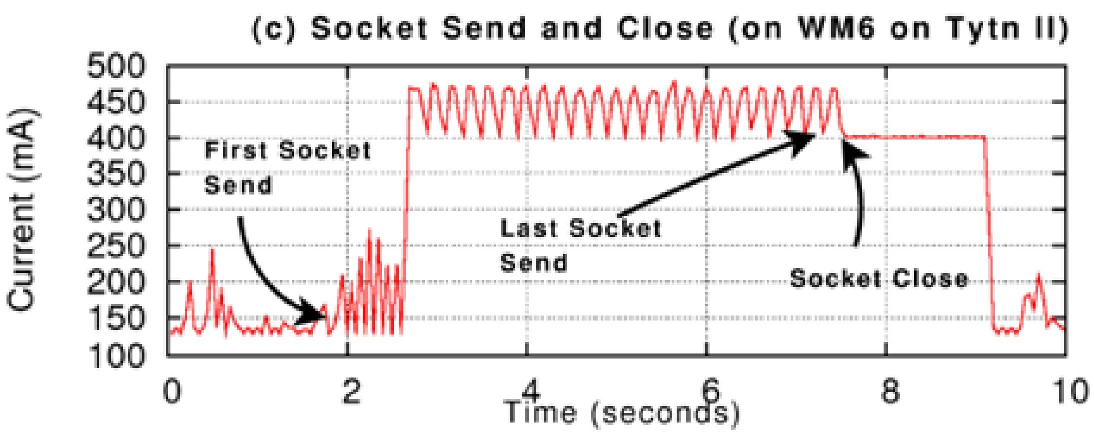
Which process/thread/function? Hard to correlate

(Only active) Utilization => Power Consumption



File open/delete/close/create change power state

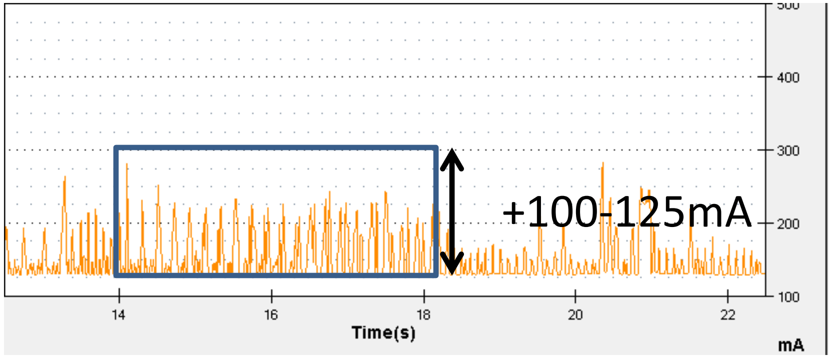


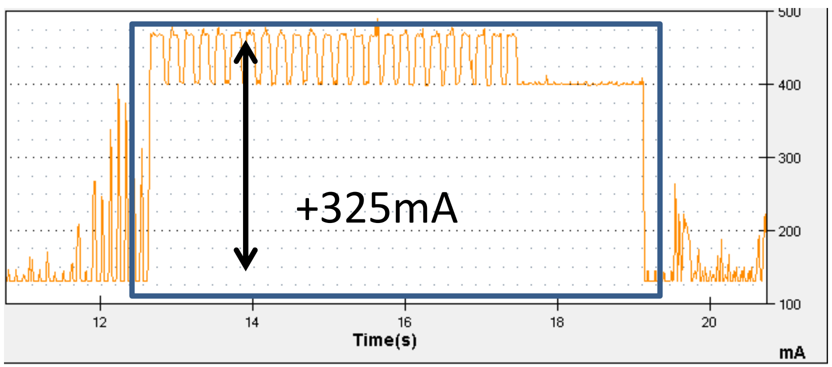


Several components have tail states (3G, disk, wifi, gps)

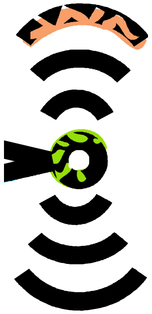
Energy scales linearly with amount of work

WM6.5 on Tytn II





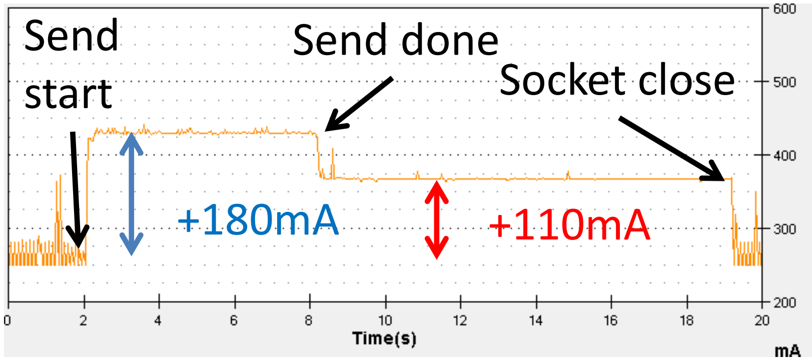
(1) Send packets @ < 50pkts/s

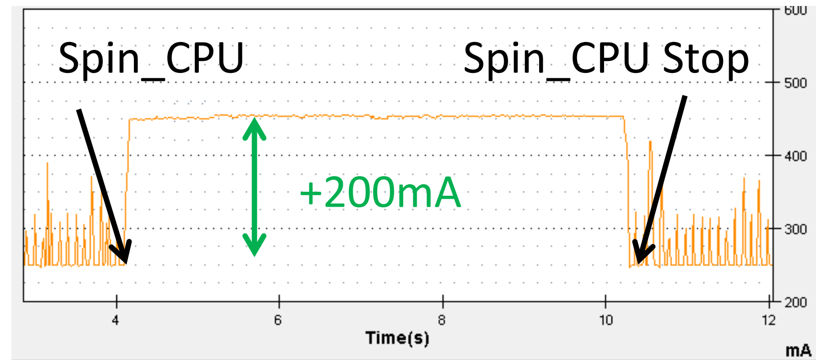


(2) Send packets @ > 50pkts/s

Components power consumption add linearly

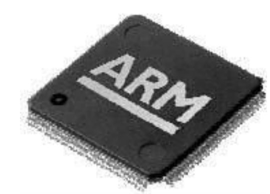
WM6.5 on HTC Touch





(1) Send(10mb);
sleep();
Socket.close();

(2) Spin_CPU(10M);

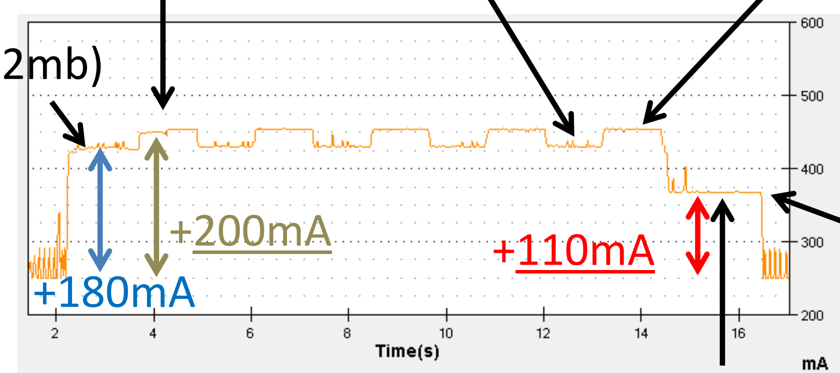


Spin_CPU(2M)
(i = 1)

Send(2mb)
(i = 5)

Spin_cpu(2M)
(i = 5)

Send(2mb)
(i = 1)



Socket close

Network tail

(3)
for (i in 1 to 5){
Send(2mb);
Spin_CPU(2M);
}
Sleep();
Socket.close();

What have we learnt so far?

Simple (state-of-art) energy modeling assumptions are wrong

There exits a notion of power states

What have we hinted so far?

Device drivers have intelligent power control rules

System calls play a role in power consumption

Challenges in fine-grained power modeling?

Device drivers are closed source (no code/no information)

System Calls As Power Triggers

Key observation: System call is the interface through which an application communicates with the underlying system (hardware) and outside world (Internet, GPS, etc.)

Key Idea: Use System Calls as triggers in power modeling

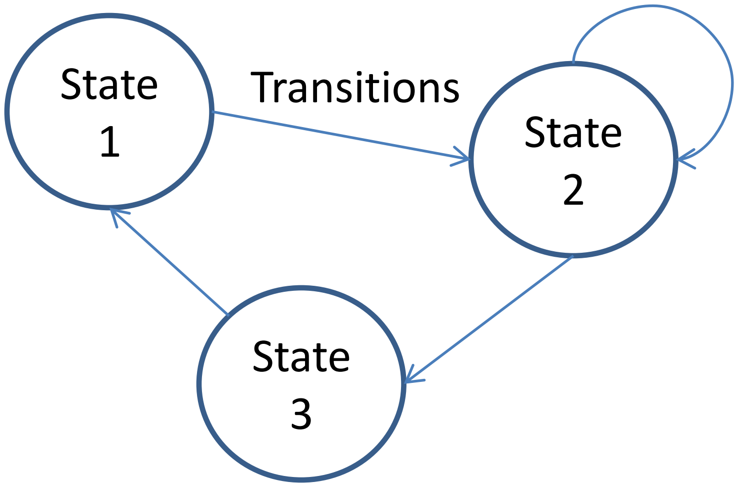
Advantages:

- Encapsulates utilization based triggers
  - Parameters of system calls
- Captures power behavior of ones that do not necessarily imply utilization
- Can be traced back to process, thread, function
  - Eases energy accounting

Finite-State-Machine (FSM) as Power Model Representation

We Use Finite-State-Machine (FSM)

- Nodes: Power states
  - Base State: No activity on phone
  - Productive state: Actual utilization
  - Tail state: No-useful work
- Edges: Transition rules
  - System calls (start/completion)
  - Workload (Ex: 50 pkts/sec)
  - Timeout



FSM Power Model Construction

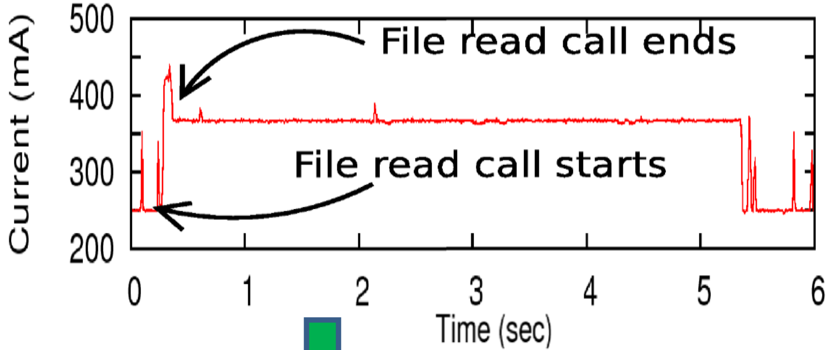
- Systematic ‘Brute Force’ Approach
  - Step 1 : Model Single System Call
  - Step 2 : Model Multiple System Calls for Same Component
  - Step 3 : Model Multiple Components (Entire Phone)
- Requires domain knowledge
  - Semantics of system calls

Step 1: Single System Call FSM

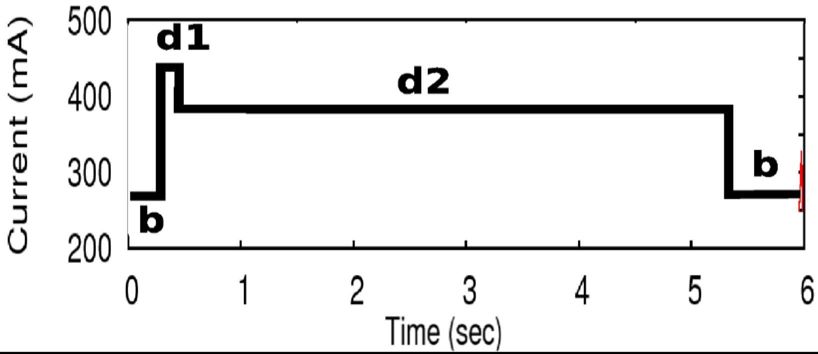
WM6.5 on HTC Touch

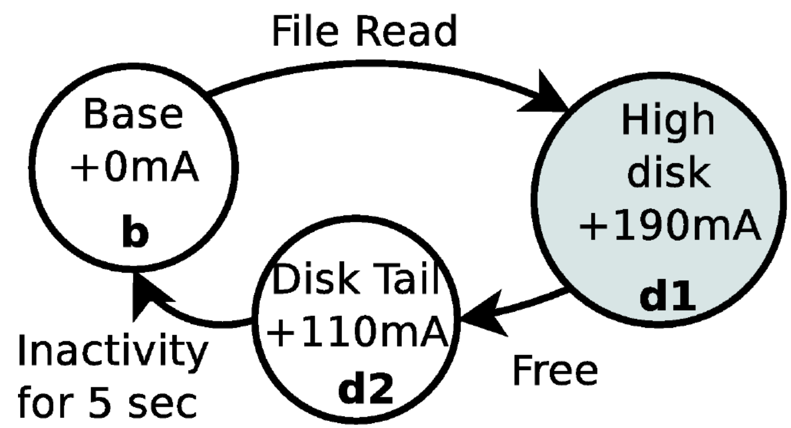
System call: **read** (fd, buf, size);

Measured power consumption + system calls (trigger)



Modeled power consumption





FSM

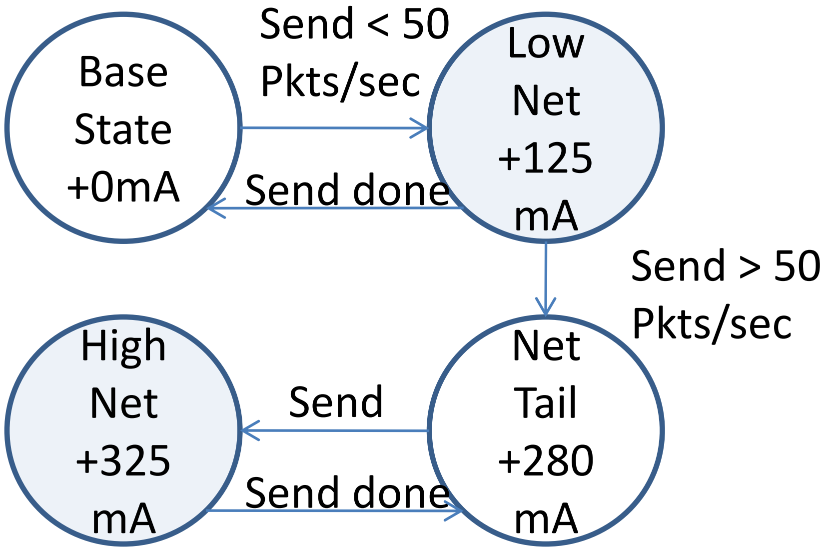
Step 2: Modeling Multiple System Calls of Same Component

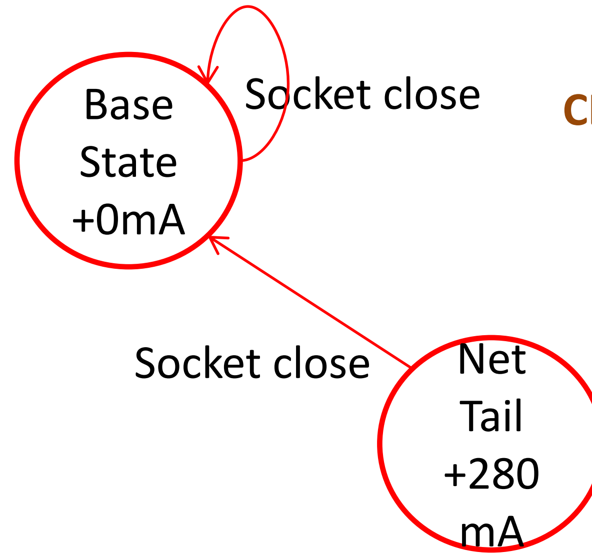
- Observation: A component can only have a small finite number of power states
- Methodology
  - Identify and merge similar power states
  - Obey programming order
  - Model concurrent system calls

Step 2: WiFi NIC

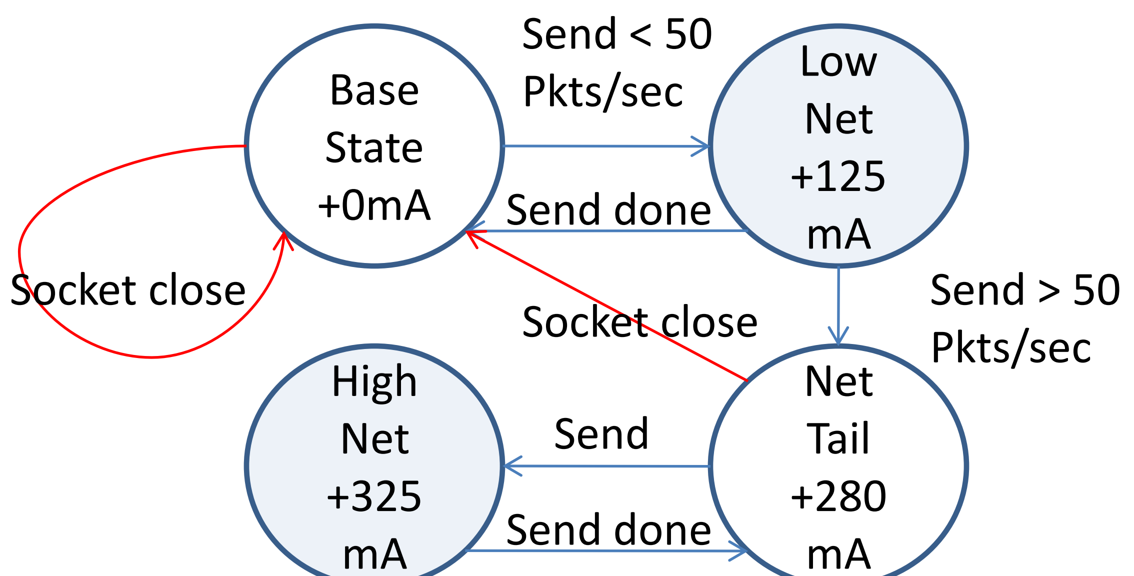
WM6.5 on HTC Tytn II

SEND





CLOSE



Step 3: Modeling Multiple Components

- Observation: Different components may interact with each other's power consumption

- Methodology
  - Try to reach different combination of states
  - Construct new states and transitions in FSM

Implementation

- Windows Mobile 6.5
  - Extended CeLog
- Android
  - System Tap: Logs kernel events
  - Android debugging framework: Custom logging in Dalvik VM

Evaluation: Handsets Used

HTC Tytn II

Win 6.5 (CE 5.2)

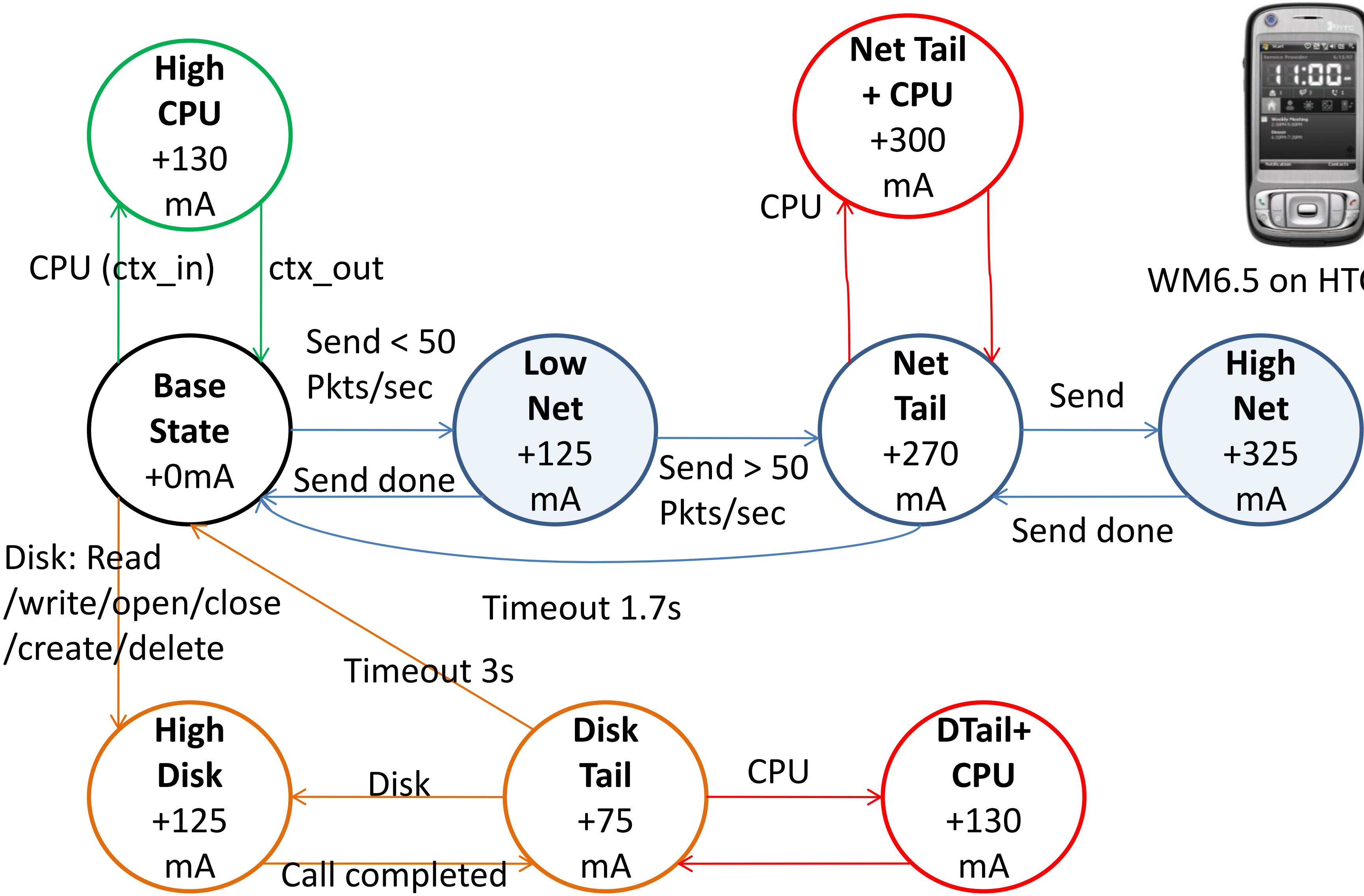
HTC Touch

Win 6.5 (CE 5.2)

HTC Magic

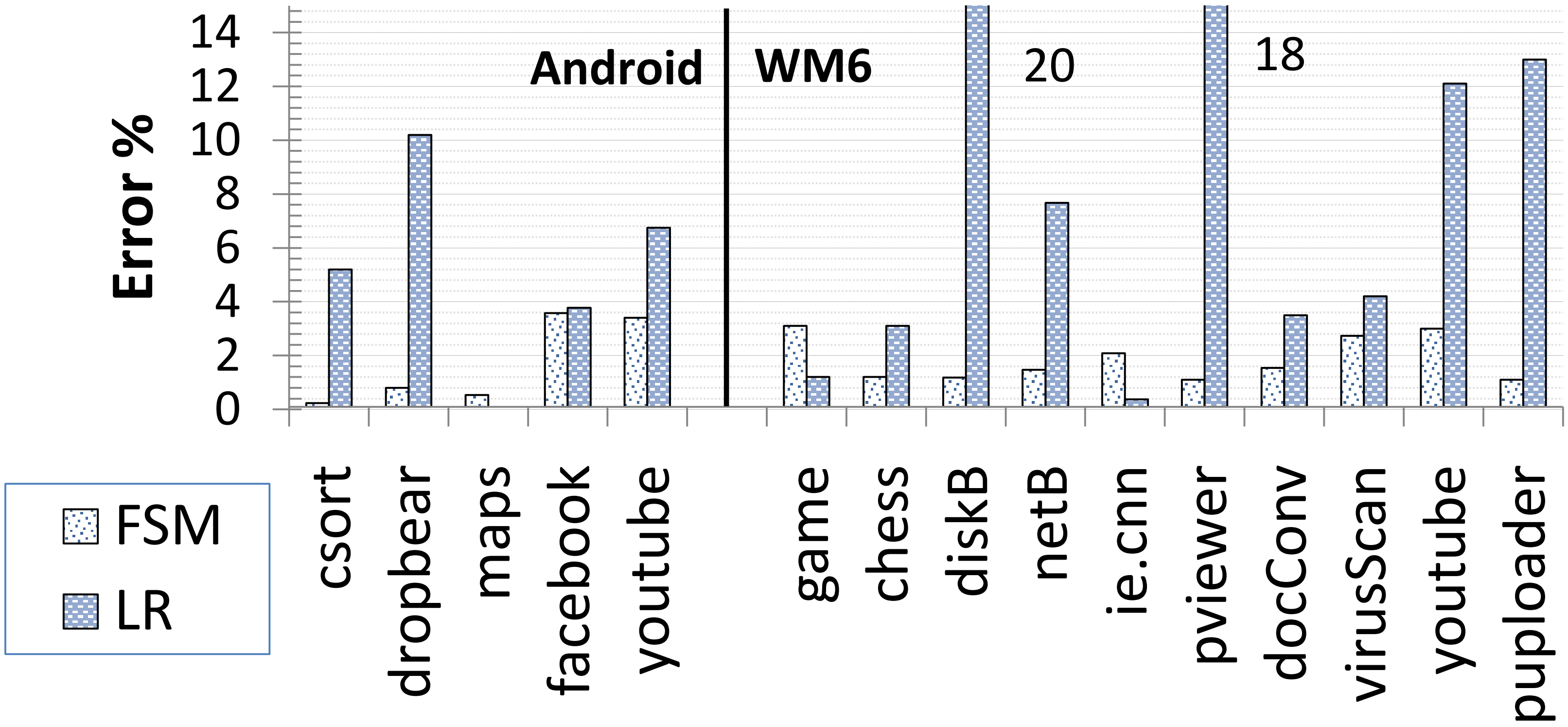
Android (Linux 2.6.34)

Snapshot of FSM for Entire Phone



WM6.5 on HTC Tytn II

End-To-End Energy Estimation Error

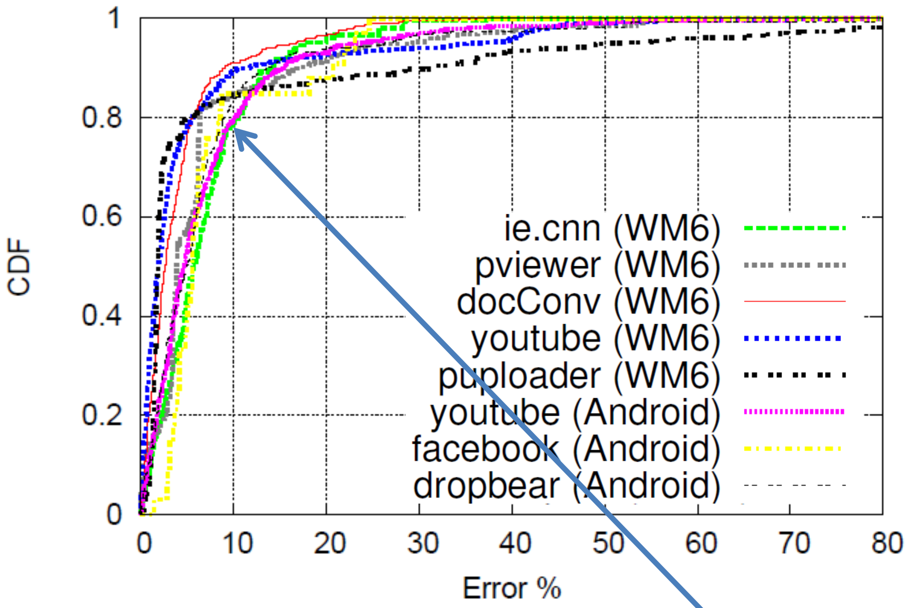


FSM: under 4%

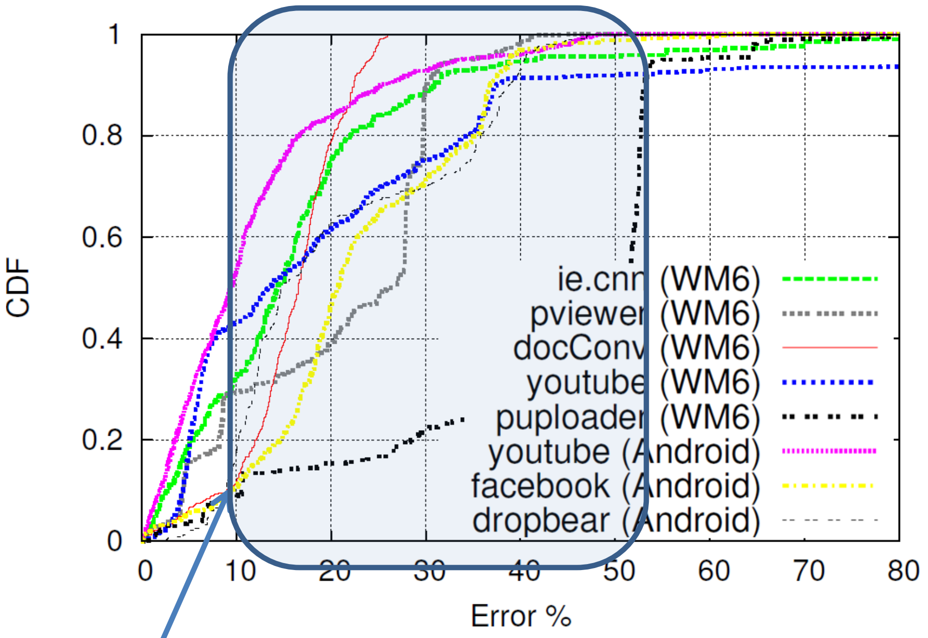
LR: 1% – 20%

Fine-Grained Energy Estimation

CDF of energy estimation error per 50ms time interval



FSM based on System calls



Linear Regression (State-of-art)

FSM: 80th percentile error less than 10% for all apps
LR: 10th percentile error less than 10% for all apps

Paper Contains ...

- Detailed FSM construction
  - Handling special cases (CPU Frequency, WiFi Signal Strength)
  - FSM for 3 smartphones

- Detailed Accuracy Results
  - Why our model performs better than state-of-art

- Logging Overhead
  - Under 10% overhead on both the OSes

- Application: Energy Profiler
  - Call-Graph Energy profiler for smartphone apps
  - Generates source code heat map

Main Contributions

- Developed fine-grained energy modeling: Predicts fine grained energy consumption using FSM of mobile applications
- Implemented on Windows Mobile 6.x and Android
- Demonstrated improved accuracy in fine-grained energy estimation over state-of-art utilization based models