Mobile Communication

Special Topics in Mobile Systems (FC5260)

Instructor: Venkat Padmanabhan

Note: includes slides generously made available by the authors of the papers being discussed

This Lecture: Mobile Communication

- Papers to be critiqued:
  - "*Energy Consumption in Mobile Phones: A Measurement Study and Implications for Network Applications*", IMC 2009
  - "*Bartendr: A Practical Approach to Energy-aware Cellular Data Scheduling*", Mobicom 2010
- Other papers to read:
  - "*A Close Examination of Performance and Power Characteristics of 4G LTE Networks*", MobiSys 2012

Energy Consumption in Mobile Phones: A Measurement Study and Implications for Network Applications

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This work was supported in part by NSF CNS-0845855 and the Center for Intelligent Information Retrieval at UMass Amherst.

Motivation

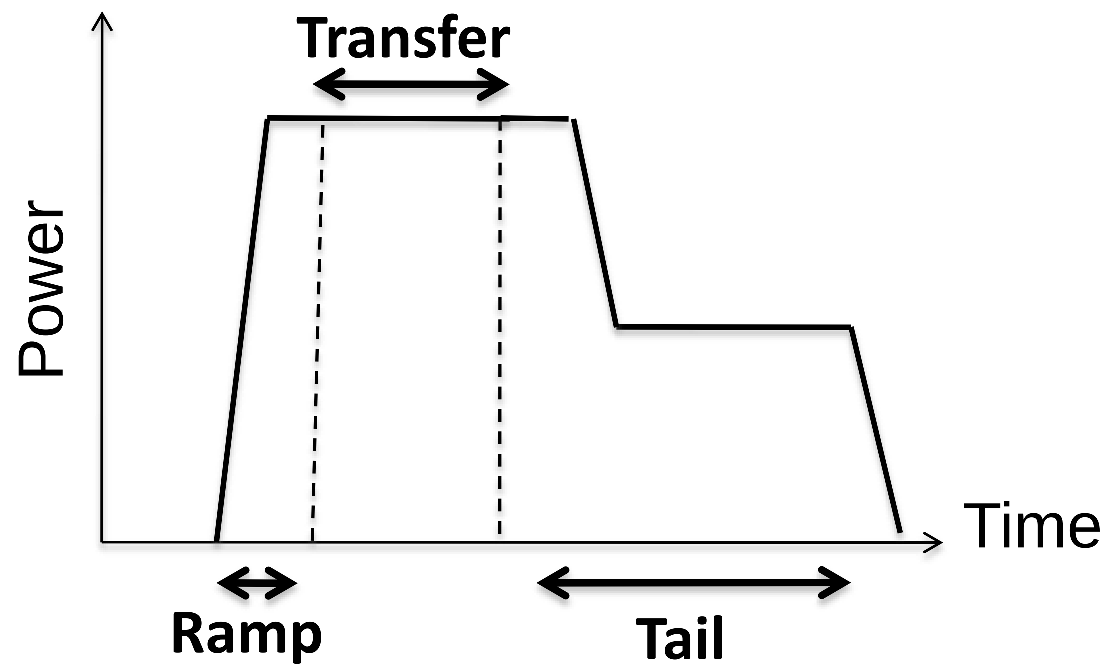
- Network applications increasingly popular in mobile phones
  - 50% of phones sold in the US are 3G/2.5G enabled
  - 60% of smart phones worldwide are WiFi enabled

- Network applications are huge power drain and can considerably reduce battery life

How can we reduce network energy cost in phones?

3G/2.5G Power consumption (1 of 2)

Power profile of a device corresponding to network activity



3G/2.5G Power consumption (2 of 2)

- **Ramp energy:** To create a dedicated channel
- **Transfer energy:** For data transmission
- **Tail energy**: To reduce signaling overhead and latency
  - Tail time is a trade-off between energy and latency [Chuah02, Lee04]

The tail time is set by the operator to reduce latency. Devices do not have control over it.

WiFi Power consumption

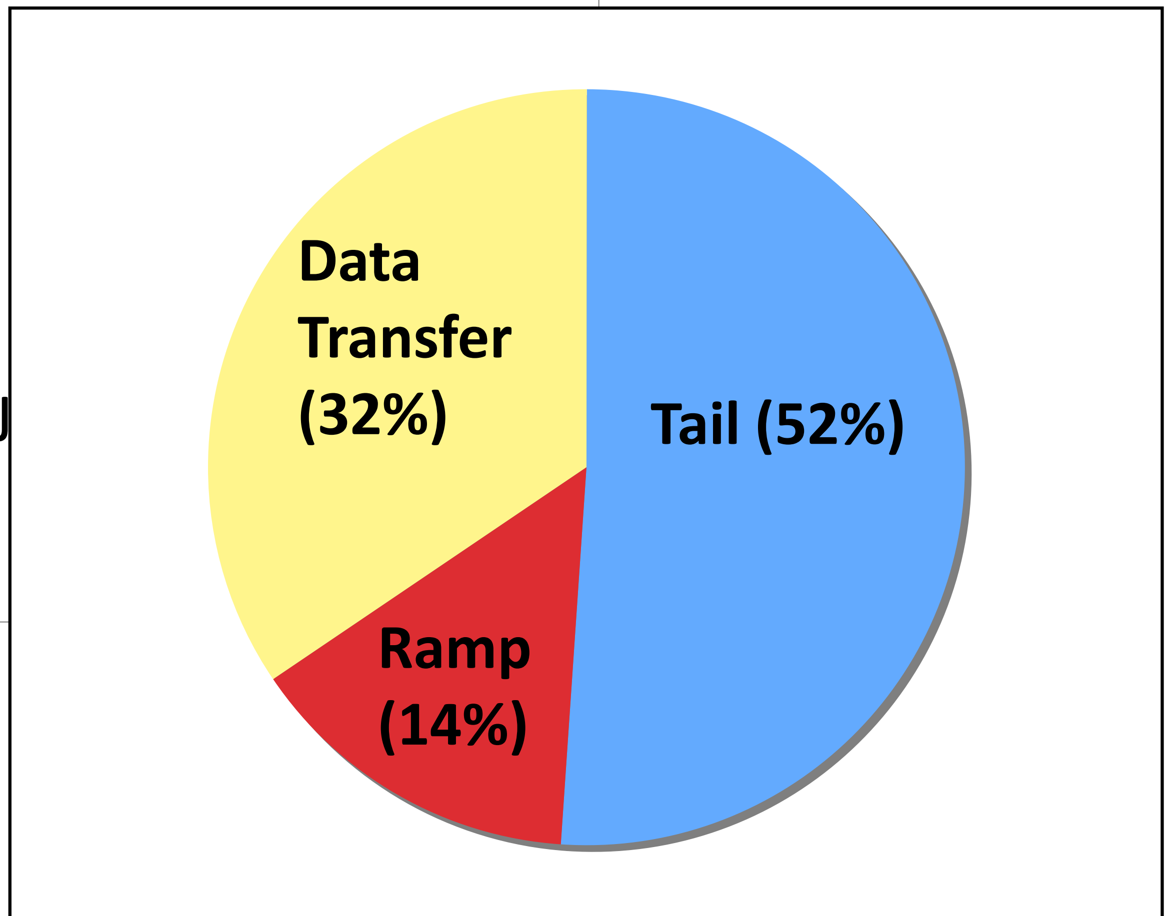
- Network power consumption due to
  - Scan/Association
  - Transfer

3G Energy Distribution for a 100K download

Total energy= 14.8J

Tail time = 13s

Tail energy = 7.3J

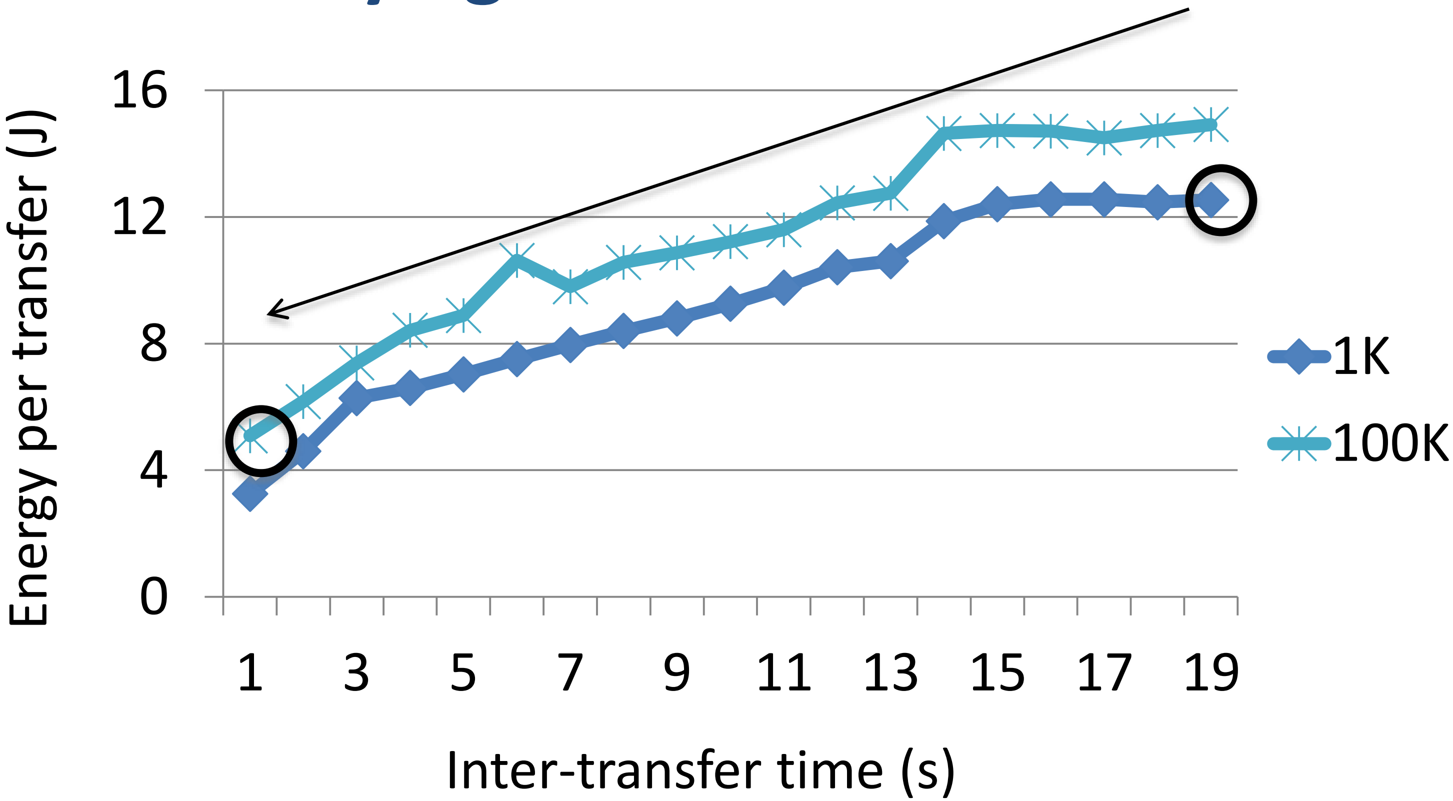


100K download: GSM and WiFi

- GSM
  - Data transfer = 74%
  - Tail energy= 25%

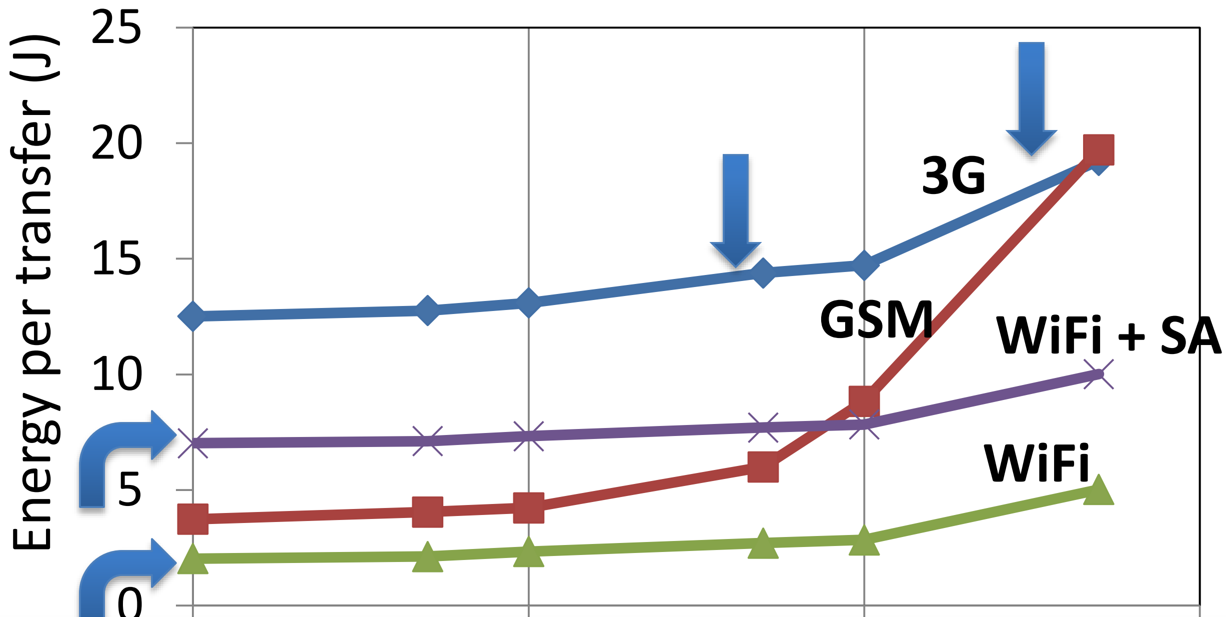
- WiFi
  - Data transfer = 32%
  - Scan/Associate = 68%

3G: Varying inter-transfer time



This result has huge implications for application design!!

Comparison: Varying data sizes

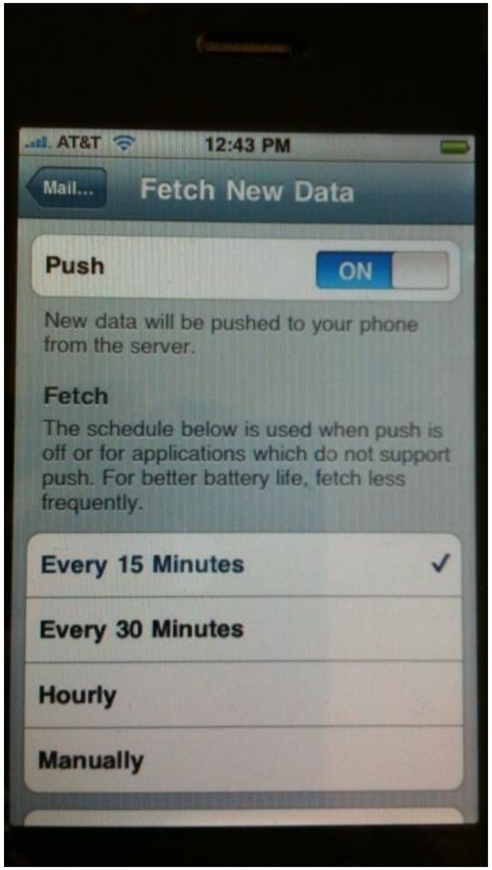


In the paper:
Present model for 3G, GSM and WiFi energy as a function of data size and inter-transfer time

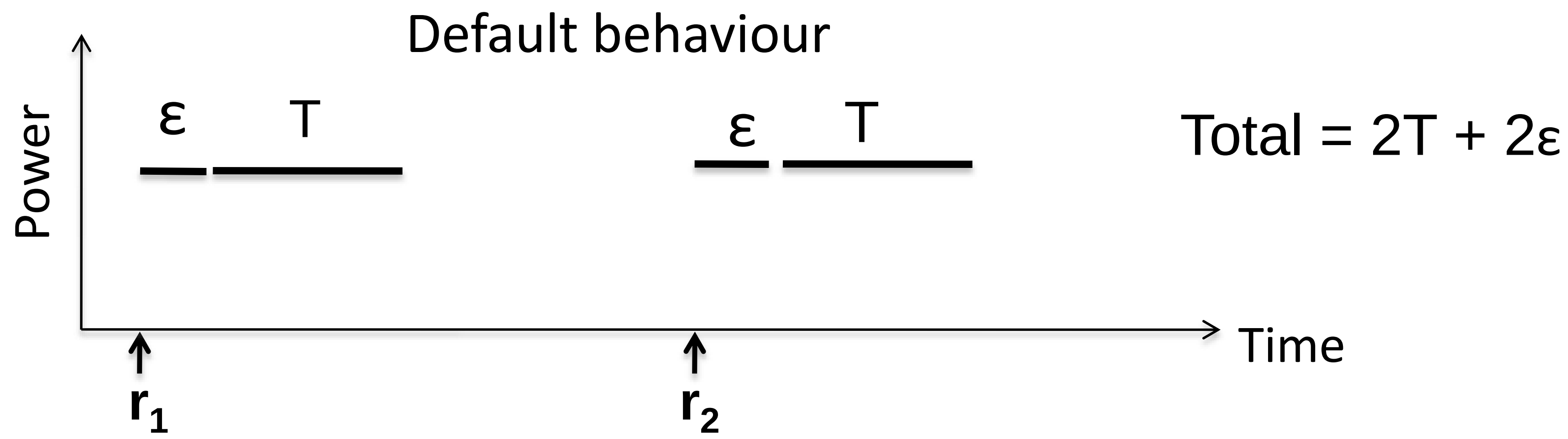
TailEnder

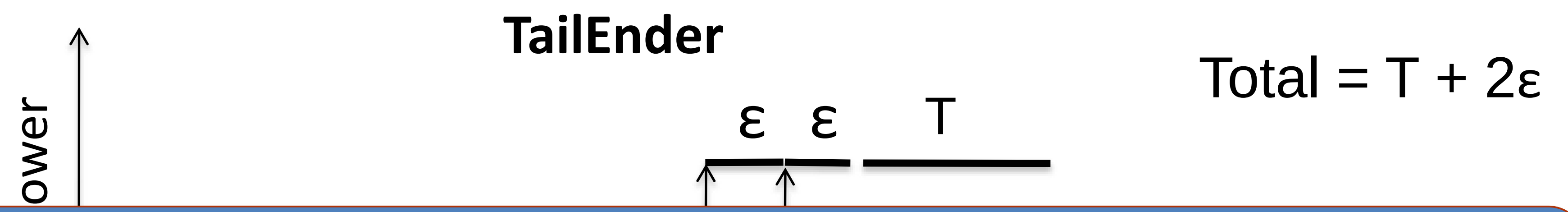
- **Observation**: Several applications can
  - Tolerate delays: Email, Newsfeeds
  - Prefetch: Web search

- **Implication**: Exploiting prefetching and delay tolerance can decrease time between transfers



Exploiting delay tolerance

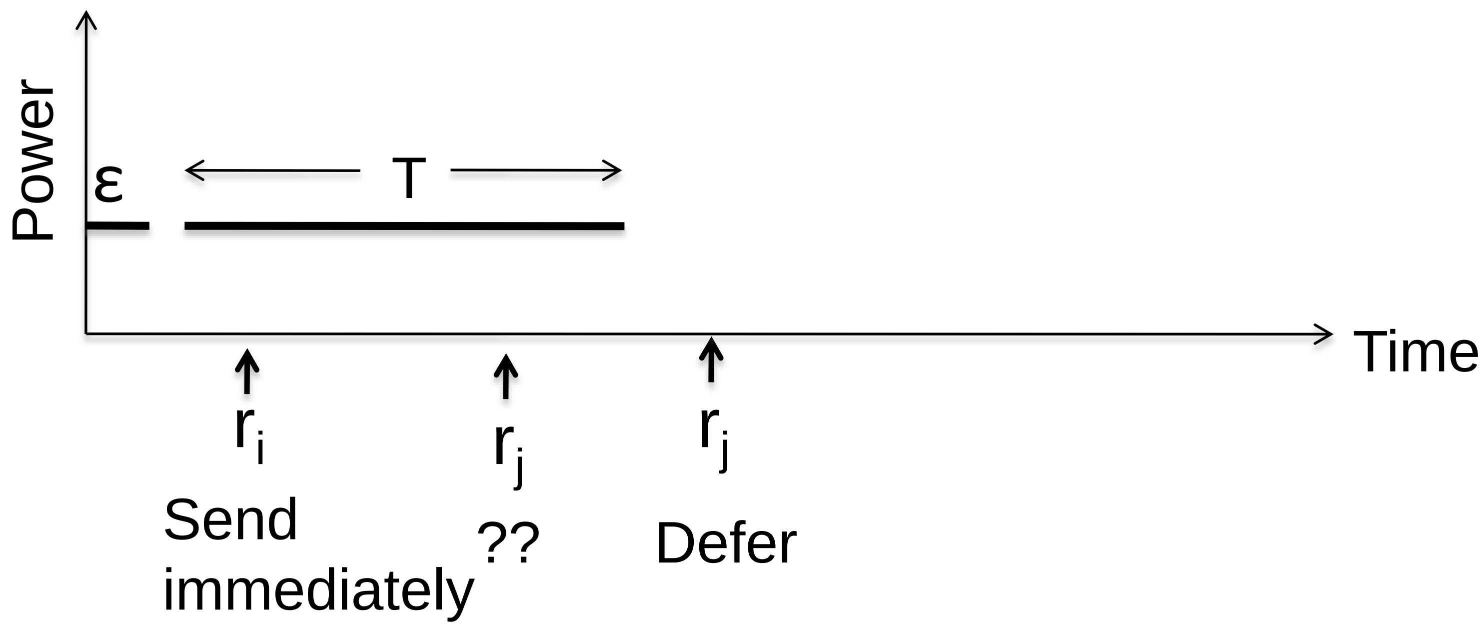




How can we schedule requests such that the time in the high power state is minimized?

TailEnder scheduling

- Online problem: No knowledge of future requests



TailEnder algorithm

– If the request arrives within ρ.T from the previous deadline, *send immediately*

0<=ρ<=1 **Tail time**

- Else, *defer until earliest deadline*

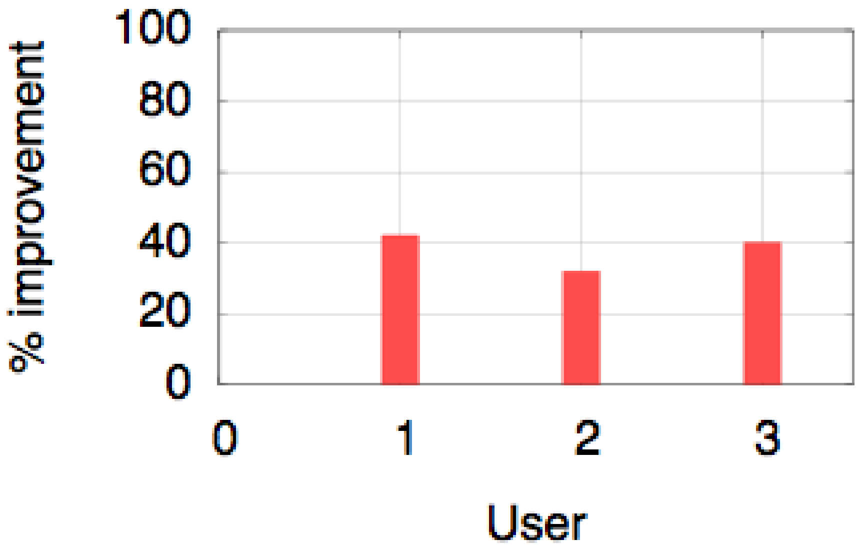
1. TailEnder is within 2x of the optimal offline algorithm
2. No online algorithm can do better than 1.62x

Applications

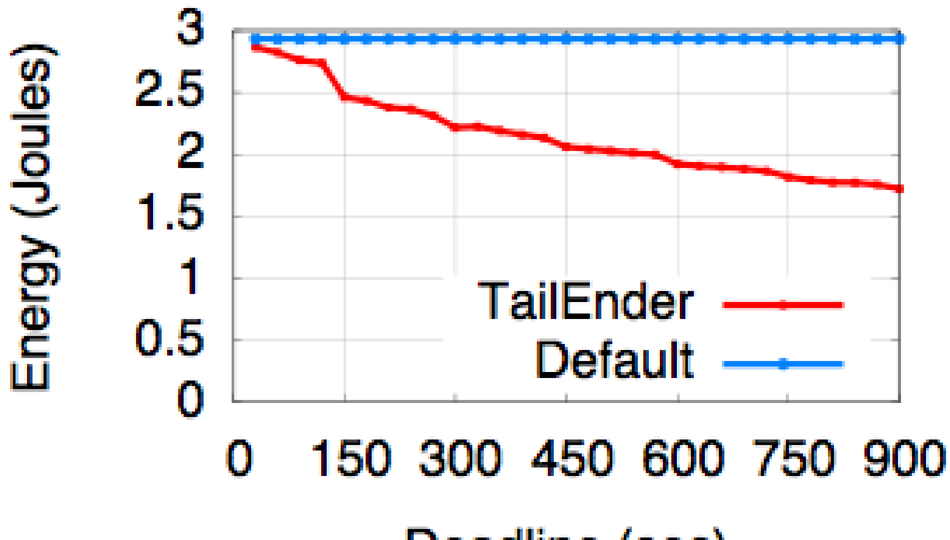
- Email:
  - Data from 3 users over a 1 week period
  - Extract email time stamp and size
- Web search:
  - Click logs from a sample of 1000 queries
  - Extract web page request time and size

Model-driven evaluation: Email

With delay tolerance = 10 minutes



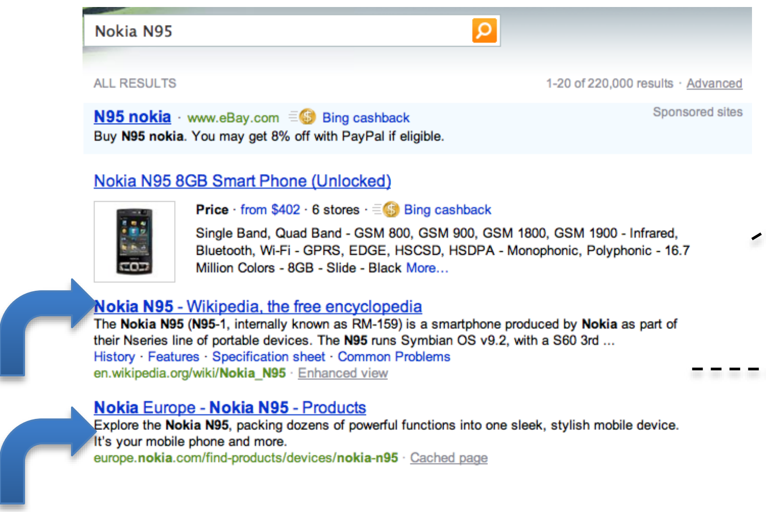
For increasing delay tolerance

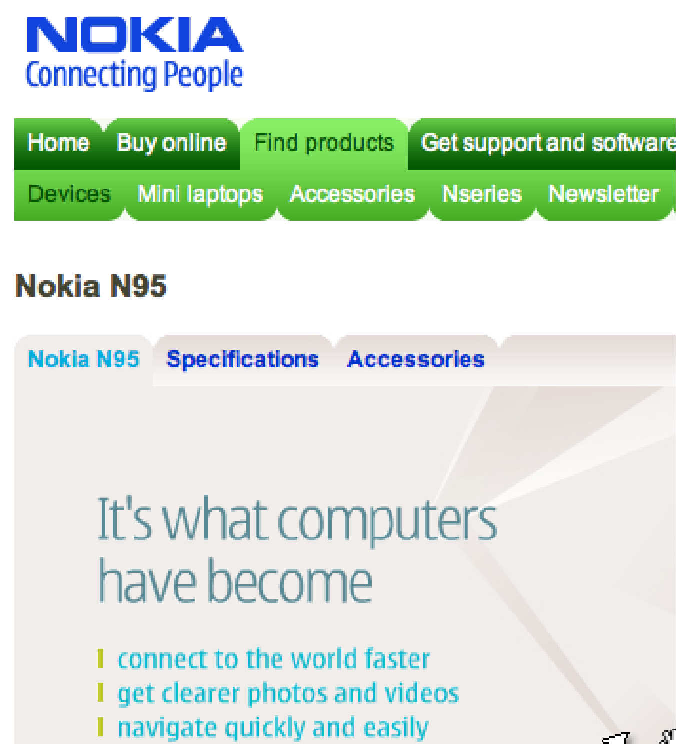


TailEnder nearly halves the energy consumption for a 15 minute delay tolerance. (Over GSM, improvement is only 25%)

TailEnder for web search

Current web search model





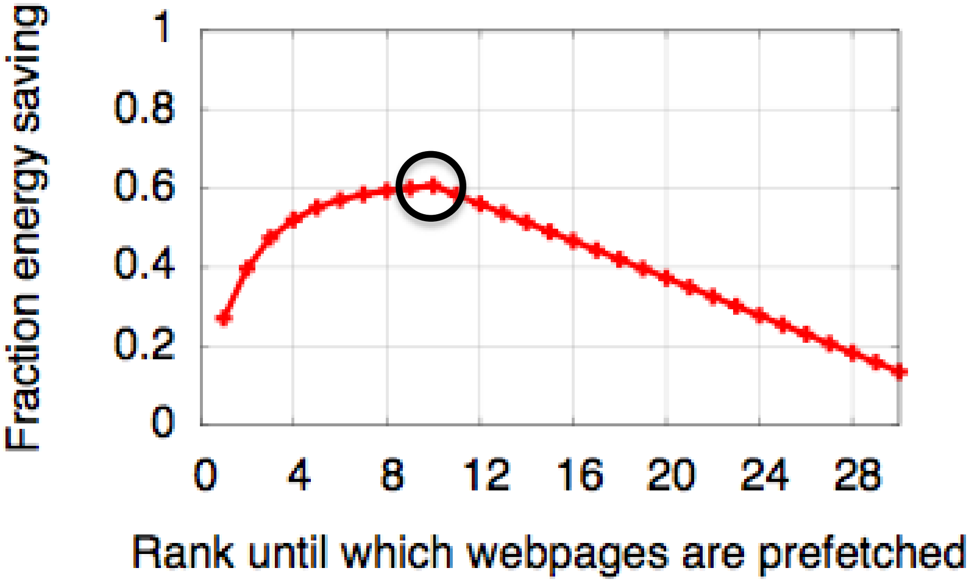
Idea: Prefetch web pages.

Challenge: Prefetching is not free!

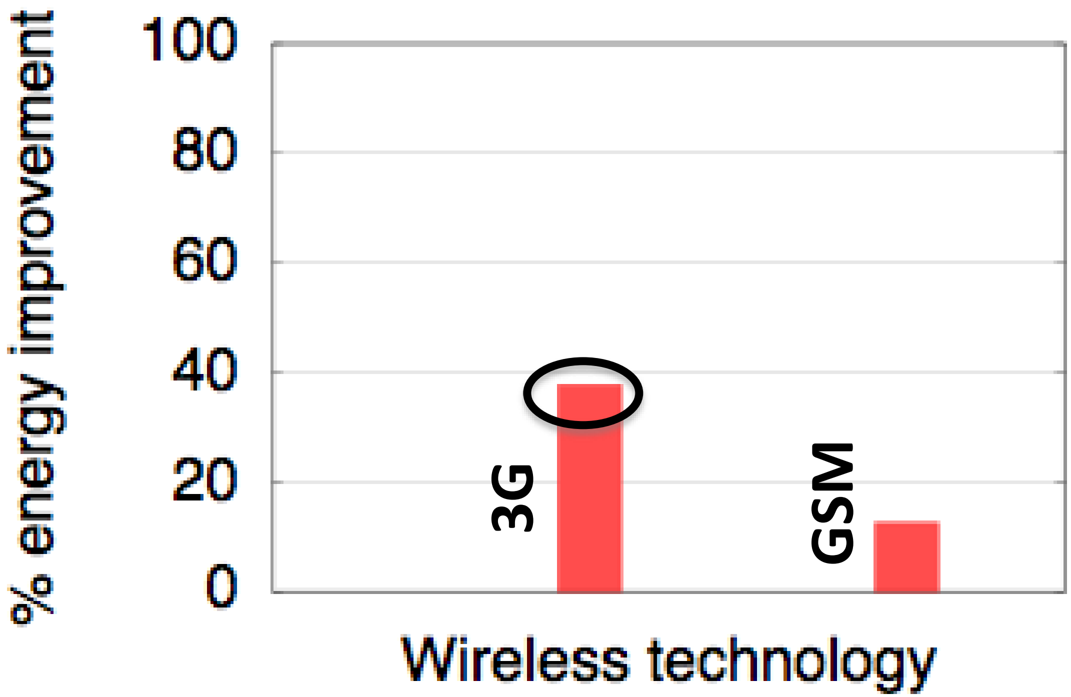
How many web pages to prefetch?

- Analyzed web logs of 8 million queries
  - Computed the probability of click at each web page rank

TailEnder prefetches the top 10 web pages per query



Model-driven evaluation: Web search



Web search emulation on phone

Metrics: Number of queries processed before the phone runs out of battery

	Default	TailEnder

In the paper:

1. Quantify the energy savings of switching to the WiFi network when available.
2. Evaluate the performance of RSS feeds application

TailEnder retrieves more data, consumes less energy and lowers latency!

TailEnder Summary

– Measurement study over 3G, 2.5G and WiFi
  - Energy depends on traffic pattern, not just data size
– 3G incurs a disproportionately large overhead

=> non-intuitive implications for application design

– Designed TailEnder protocol to amortize 3G overhead
  - Energy reduced by 40% for common applications including email and web search

Bartendr: A Practical Approach to Energy-aware Cellular Data Scheduling

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University of Maryland

Pralhad Deshpande
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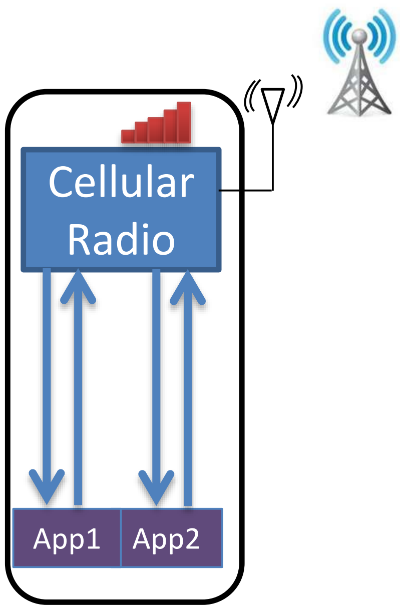
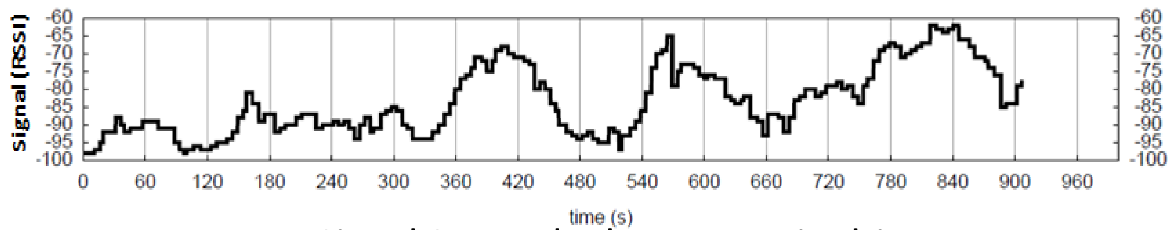
Vishnu Navda
Ramachandran Ramjee
Venkata N. Padmanabhan
Microsoft Research India

Kamal Jain
Microsoft Research Redmond

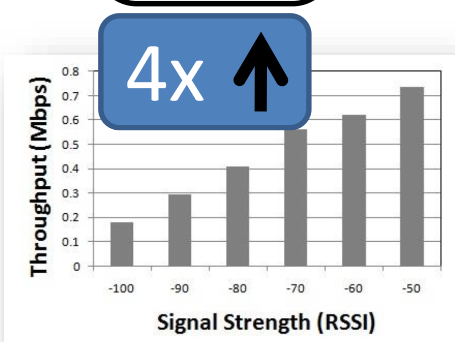
Impact of signal quality



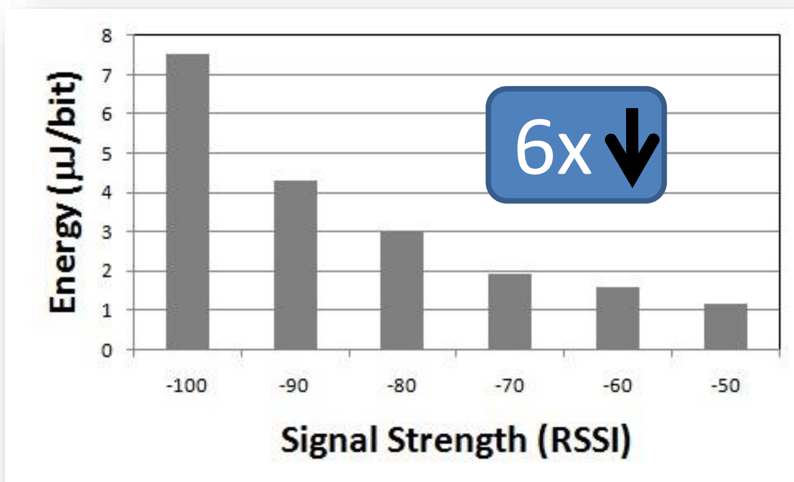
Wireless coverage is non-uniform

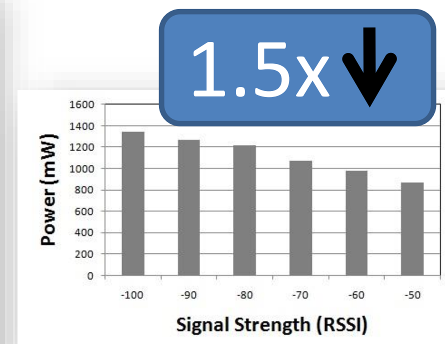


Signal Strength along a 15min drive



Bits per sec



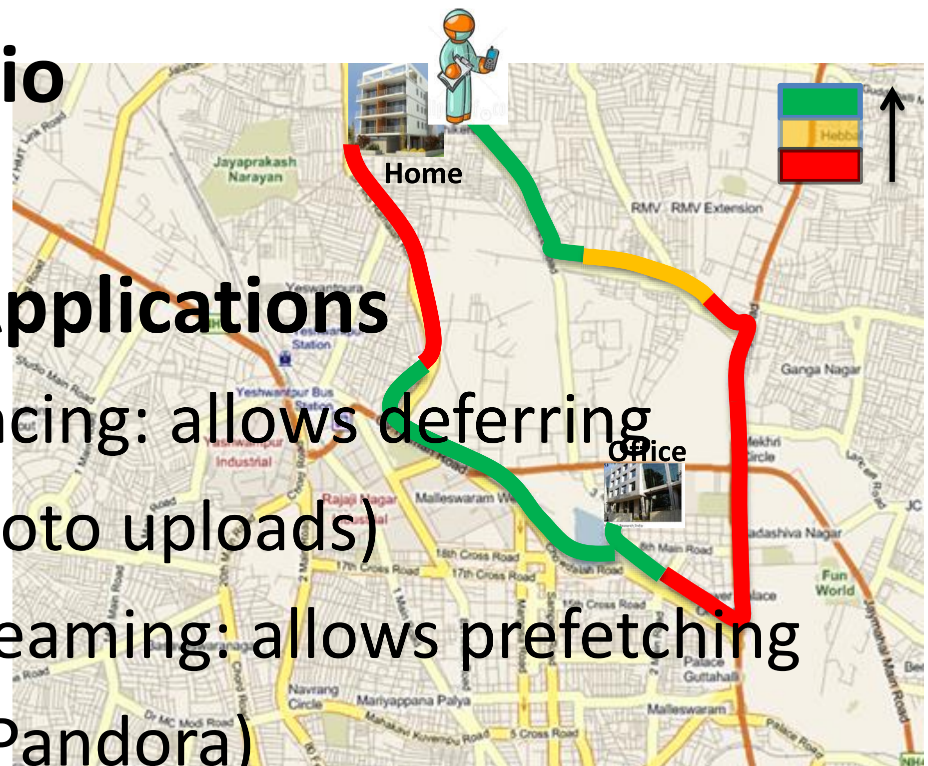


Joules per sec

Communicating at poor signals can increase energy cost by 6X

Signal-based Scheduling

- **Idea: Signal-based scheduling**
  - preferentially communicate when signal is good
- **Example scenario**
  - Daily commute
- **Delay-flexible Applications**
  - Background syncing: allows deferring (e.g. emails, photo uploads)
  - On-demand streaming: allows prefetching (e.g. YouTube, Pandora)



Obstacles to energy efficient scheduling

energy consumer	consumption	Bartendr
locating the phone on a path (1D not 2 or 3D)	GPS is 400 mW and slow to fix, WiFi must be in receive mode	phone already maintains signal strength, cell id, and neighbor cells - find closest match on path
wakeup and sleep	1 J to wake up 0.5 J to sleep	schedule syncs minutes into the future
radio energy tail	3 - 10 s of radio power after communication (at least 400 mW)	consider the radio's power state when scheduling a stream

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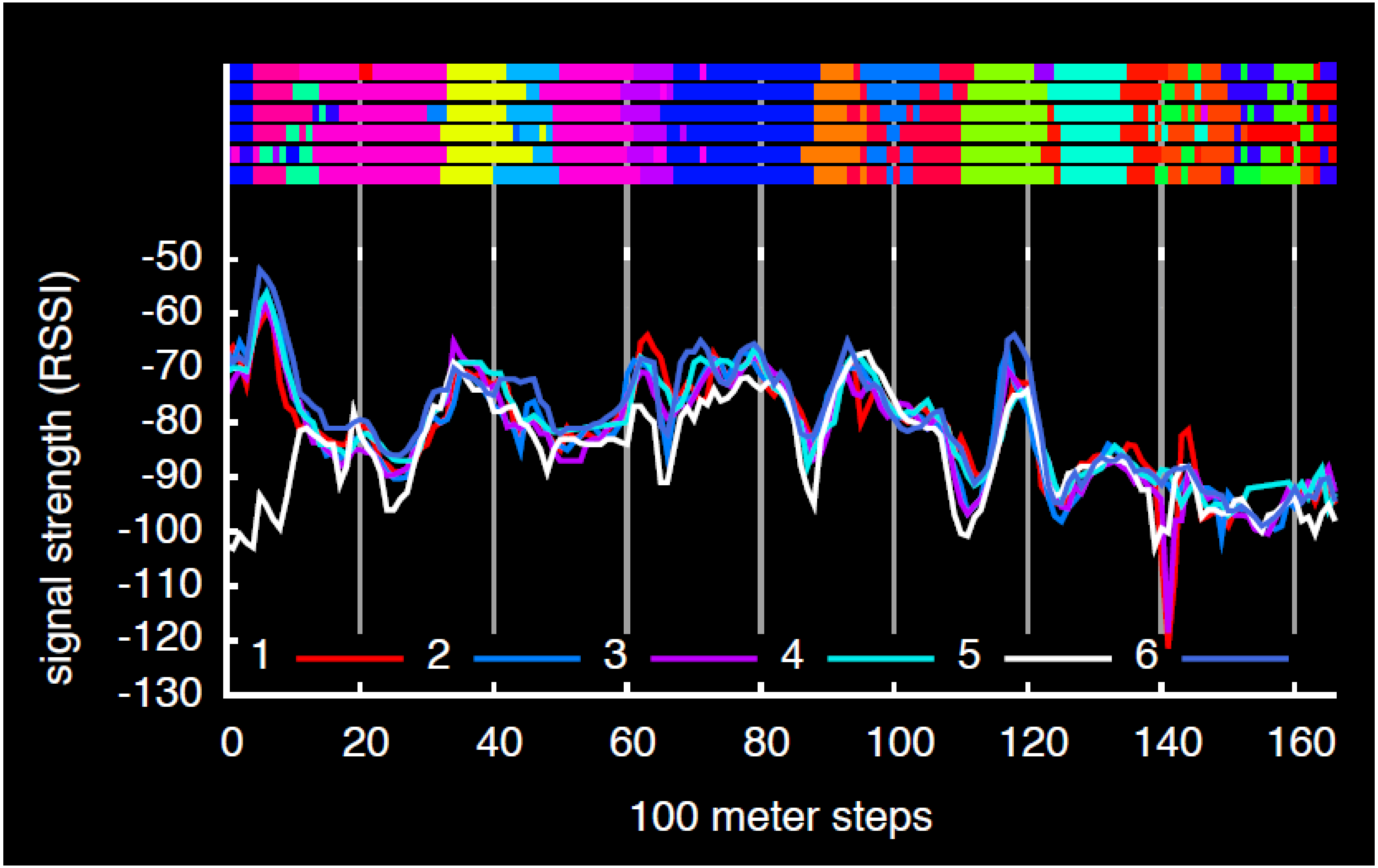
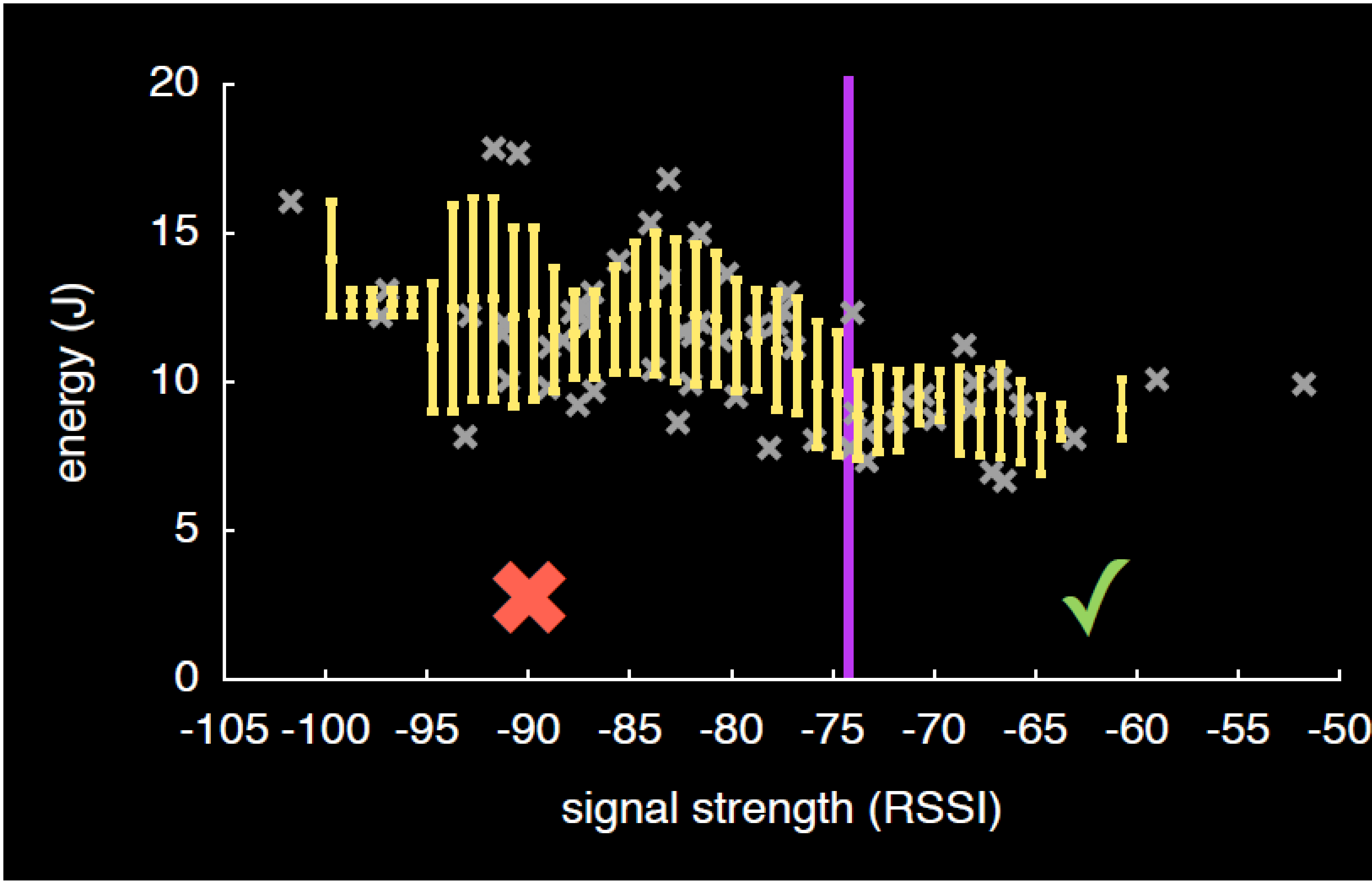
Signal Strength Variation on a Path



Email Sync



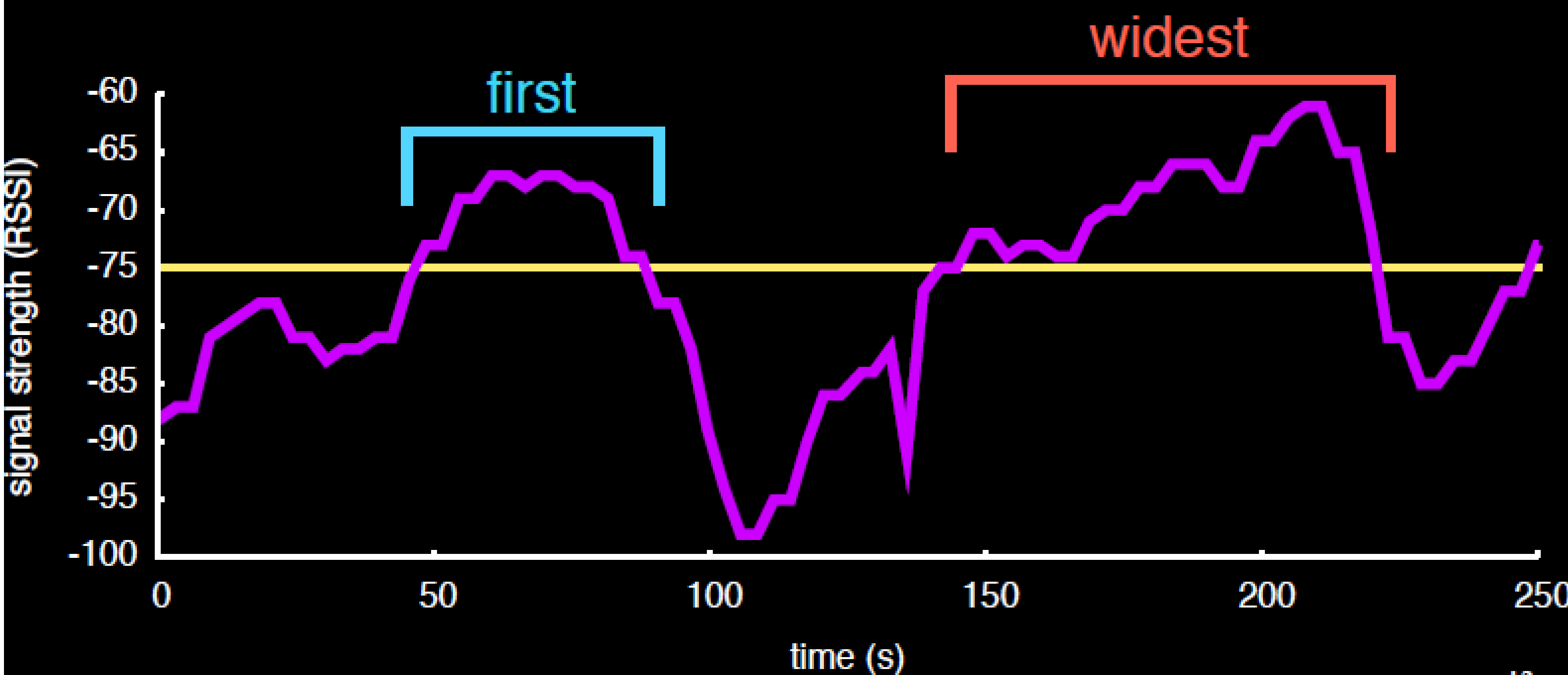
20
15
10
5
0
energy (J)
-105
-100
-95
-90
-85
-80
-75
-70
-65
-60
-55
-50
signal strength (RSSI)

Scheduler for sync

Wake-up, sync, schedule, sleep

Uses threshold for efficient sync

Schedules for either first or widest signal



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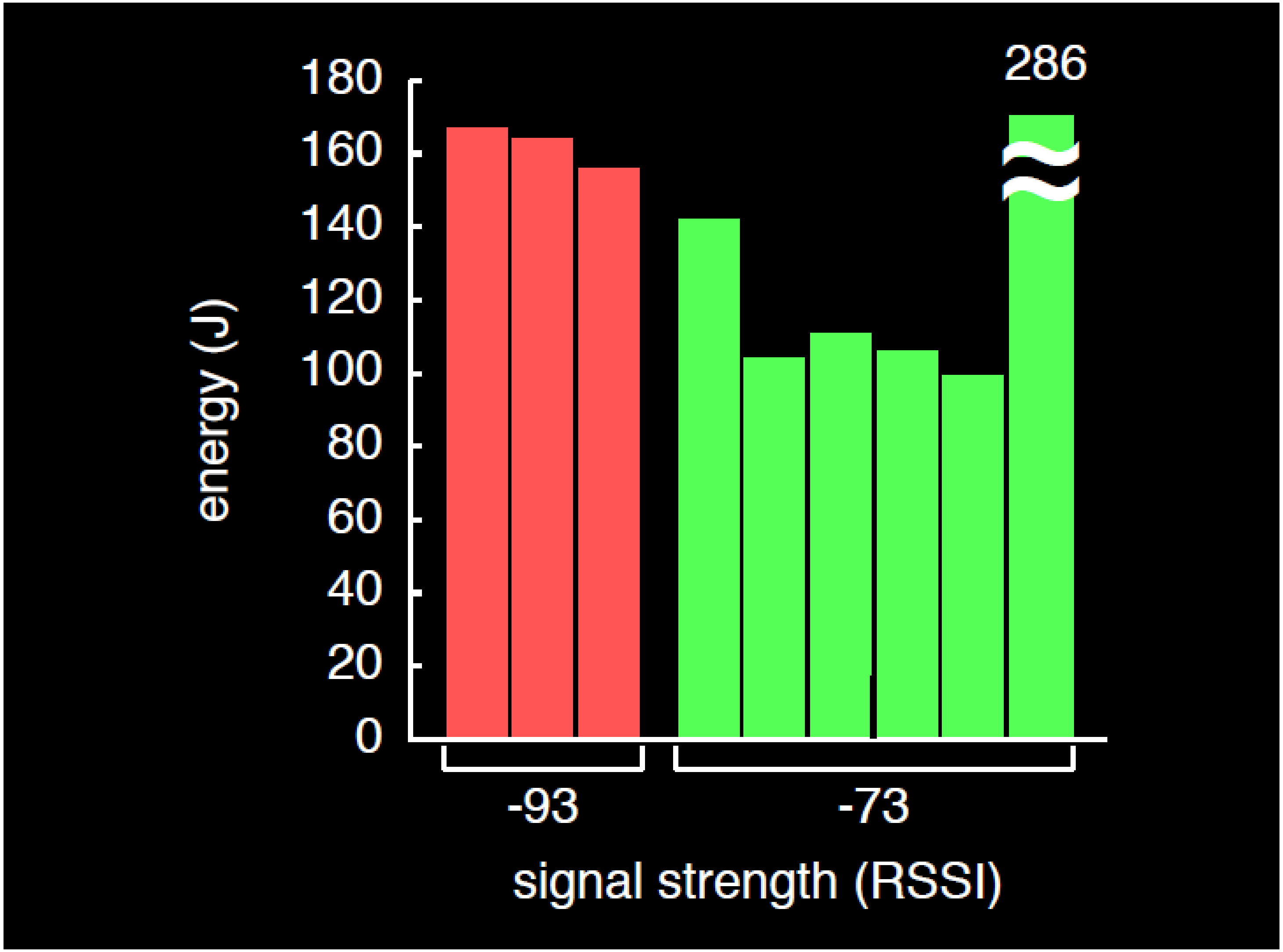
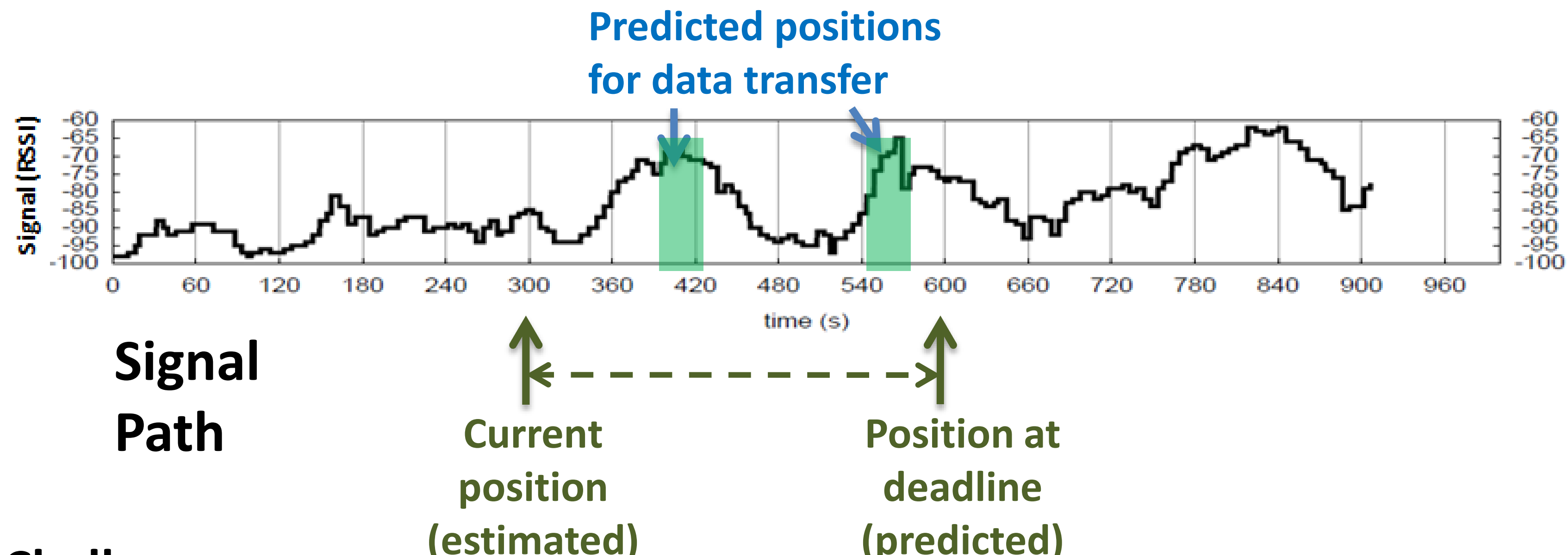
YouTube Video Clip



Scheduling



- **Challenges**
  - Efficient positioning: GPS-based positioning is expensive
  - Tail energy: tradeoff between communication spurts and signal quality
  - Variability: possibility of error
- **Approach**
  - Relative positioning in signal domain
  - Threshold-based vs. dynamic programming solver to minimize energy
  - On-the-fly recomputation of schedule for robustness

Evaluation methodology

Several 17 km drives of throughput and signal for signal prediction and energy simulation

Simulated energy consumption of syncs and streaming from many starting points

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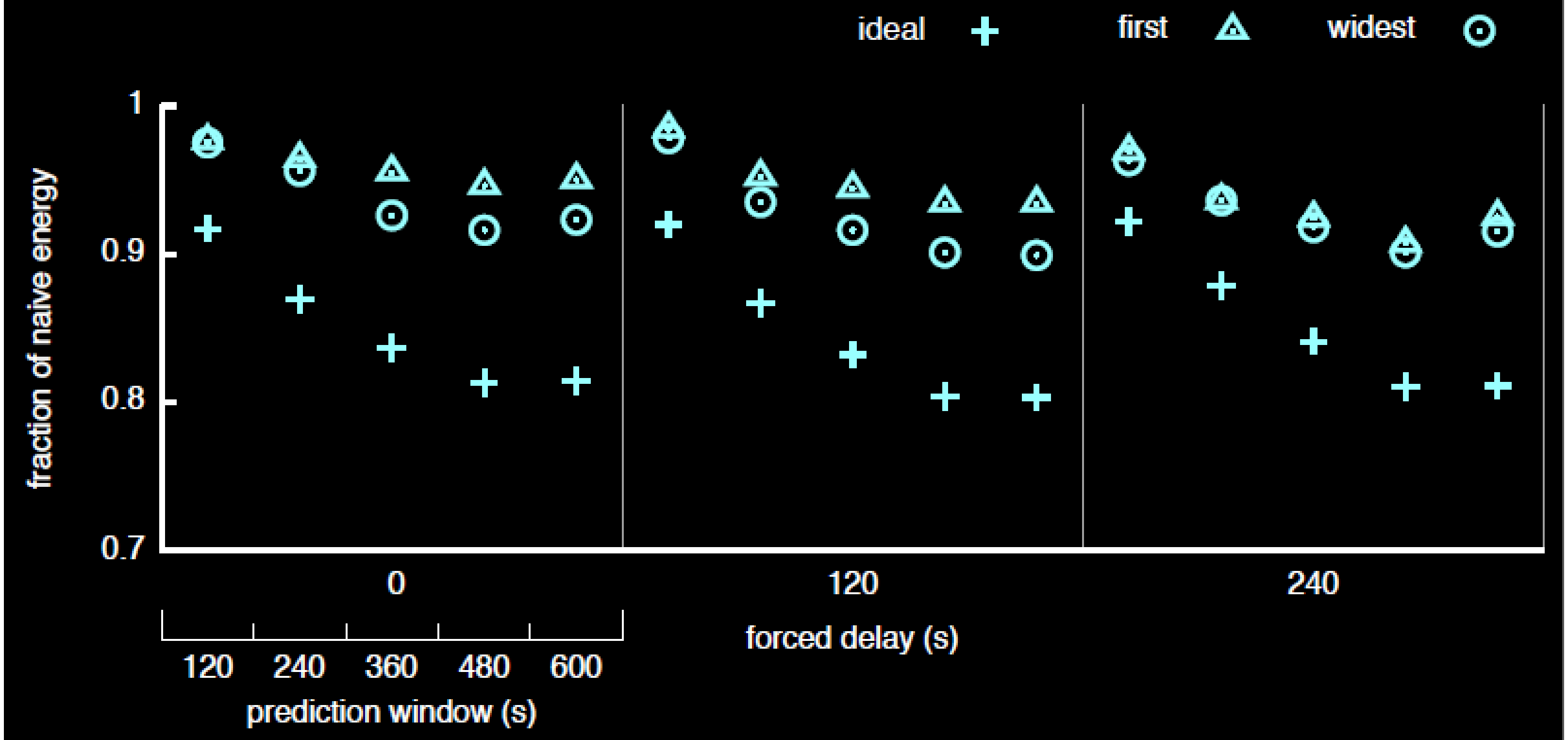
Syncing simulation



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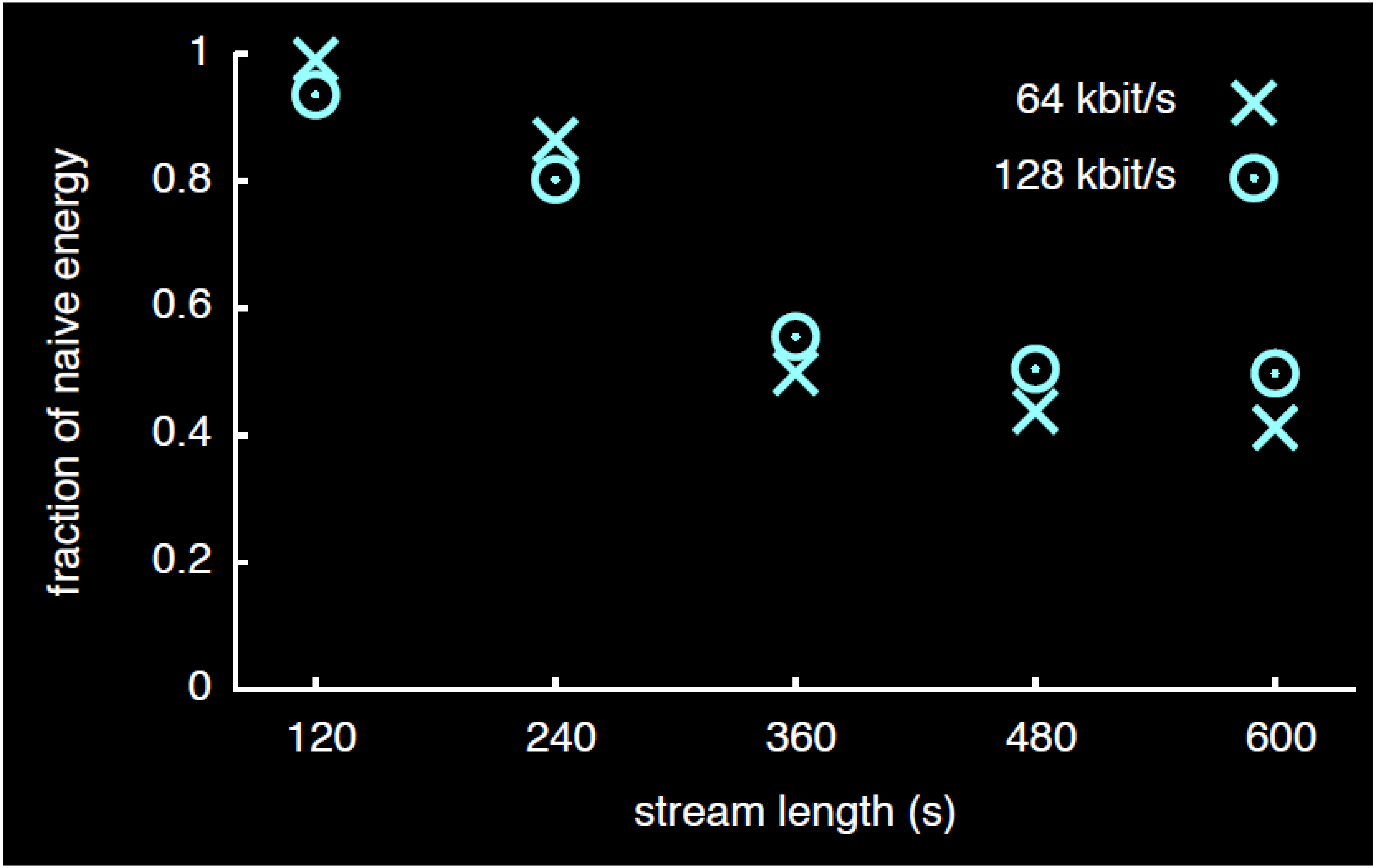
Streaming Simulation



Demo Video: Streaming

Bartendr Summary

Signal strength affects energy consumption

Applications like sync and streaming can be more efficient by deferring and prefetching

Previous drives can predict signal strength without breaking the energy bank

Scheduling can reduce energy consumption by up to 50% for large workloads and 10% for small

MobiSys2012

A Close Examination of Performance and Power Characteristics of 4G LTE Networks

Junxian Huang[1] Feng Qian[1] Alexandre Gerber[2]
Z. Morley Mao[1] Subhabrata Sen[2] Oliver Spatscheck[2]

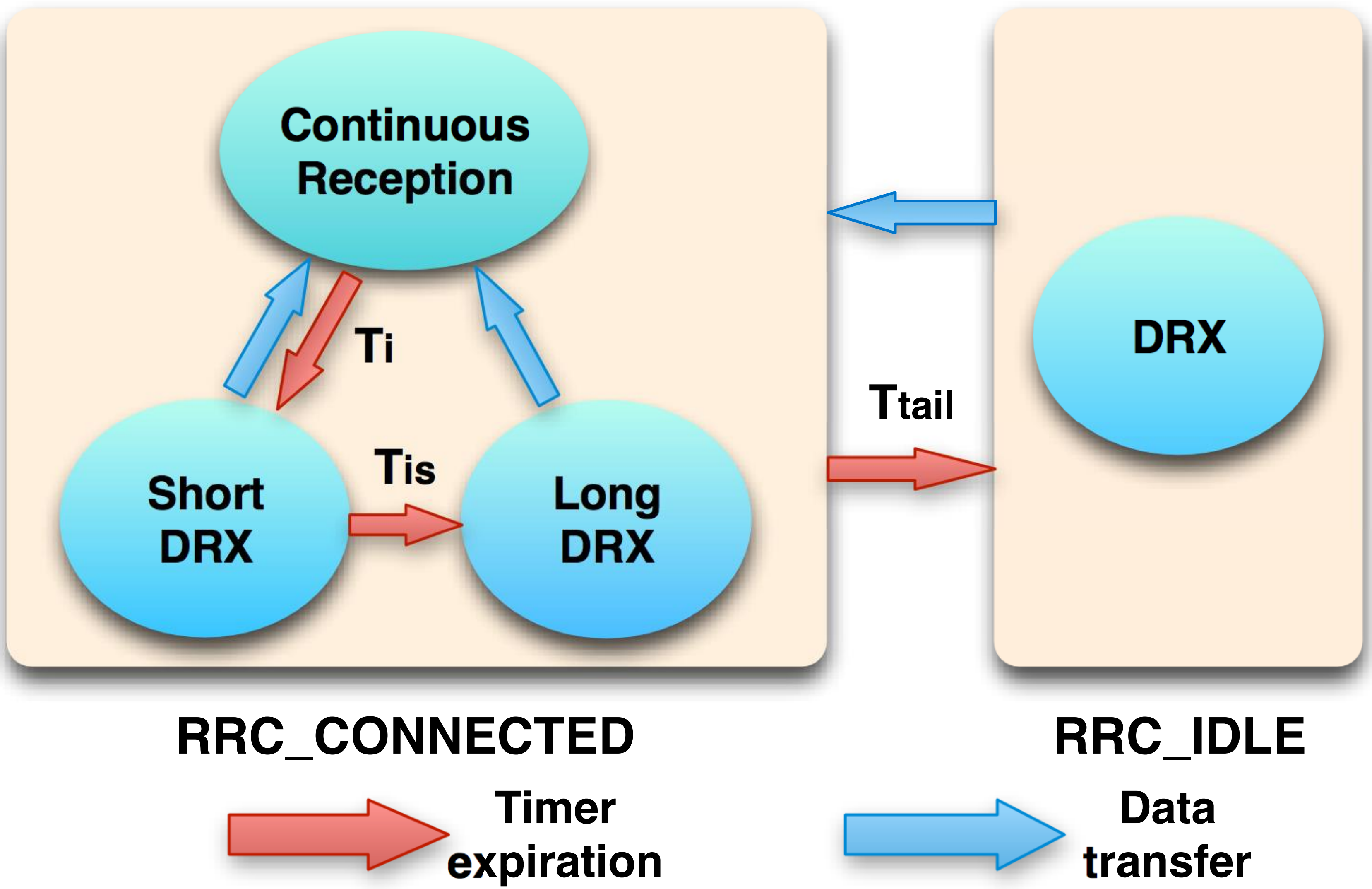
[1]University of Michigan [2]AT&T Labs - Research

June 27 2012

LTE is new, requires exploration

- 4G **LTE (Long Term Evolution)** is future trend
  - Initiated by 3GPP in 2004
    - **100**Mbps DL, **50**Mbps UL, **<5**ms latency
  - Entered commercial markets in 2009
- Lessons from 3G UMTS networks
  - Radio Resource Control (RRC) state machine is important
  - App traffic patterns trigger state transitions, different states determine UE power usage and user experience
  - State transitions incur energy, delay, signaling overhead

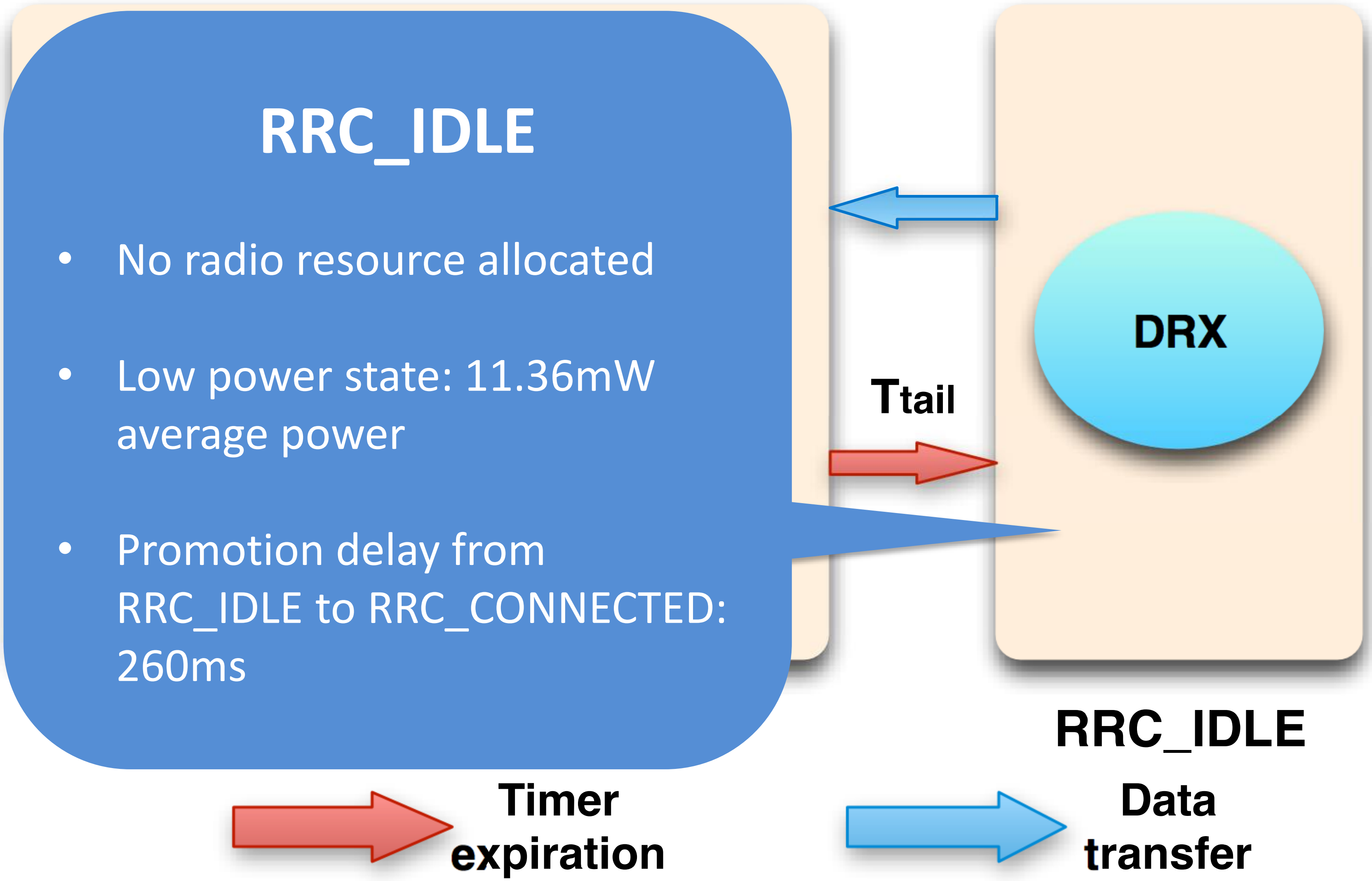
RRC state transitions in LTE



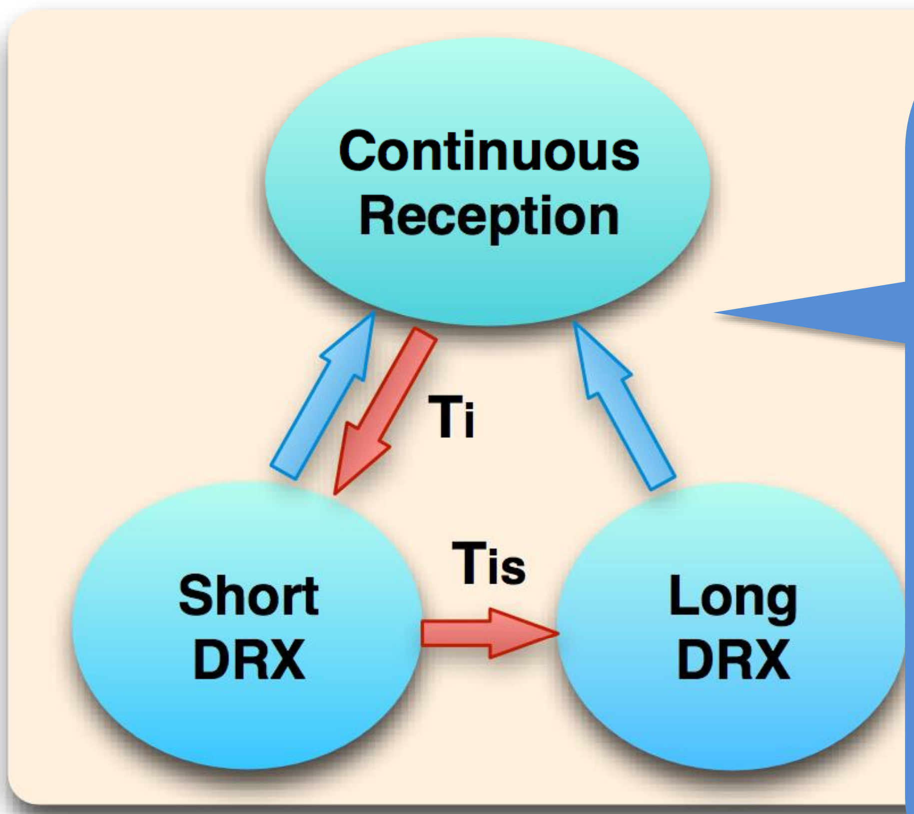
RRC state transitions in LTE

RRC_IDLE

- No radio resource allocated
- Low power state: 11.36mW average power
- Promotion delay from RRC_IDLE to RRC_CONNECTED: 260ms



RRC state transitions in LTE

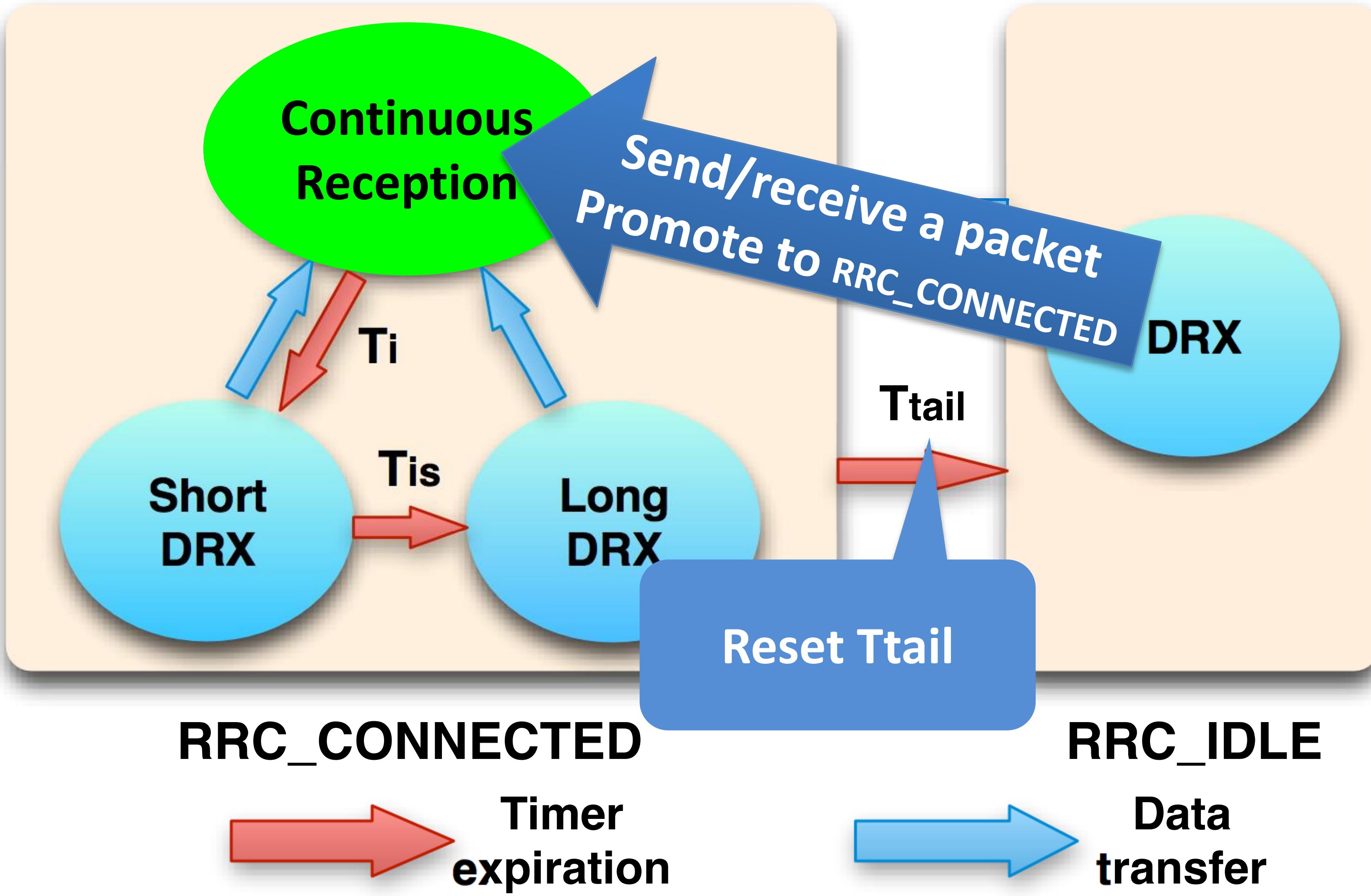


RRC_CONNECTED

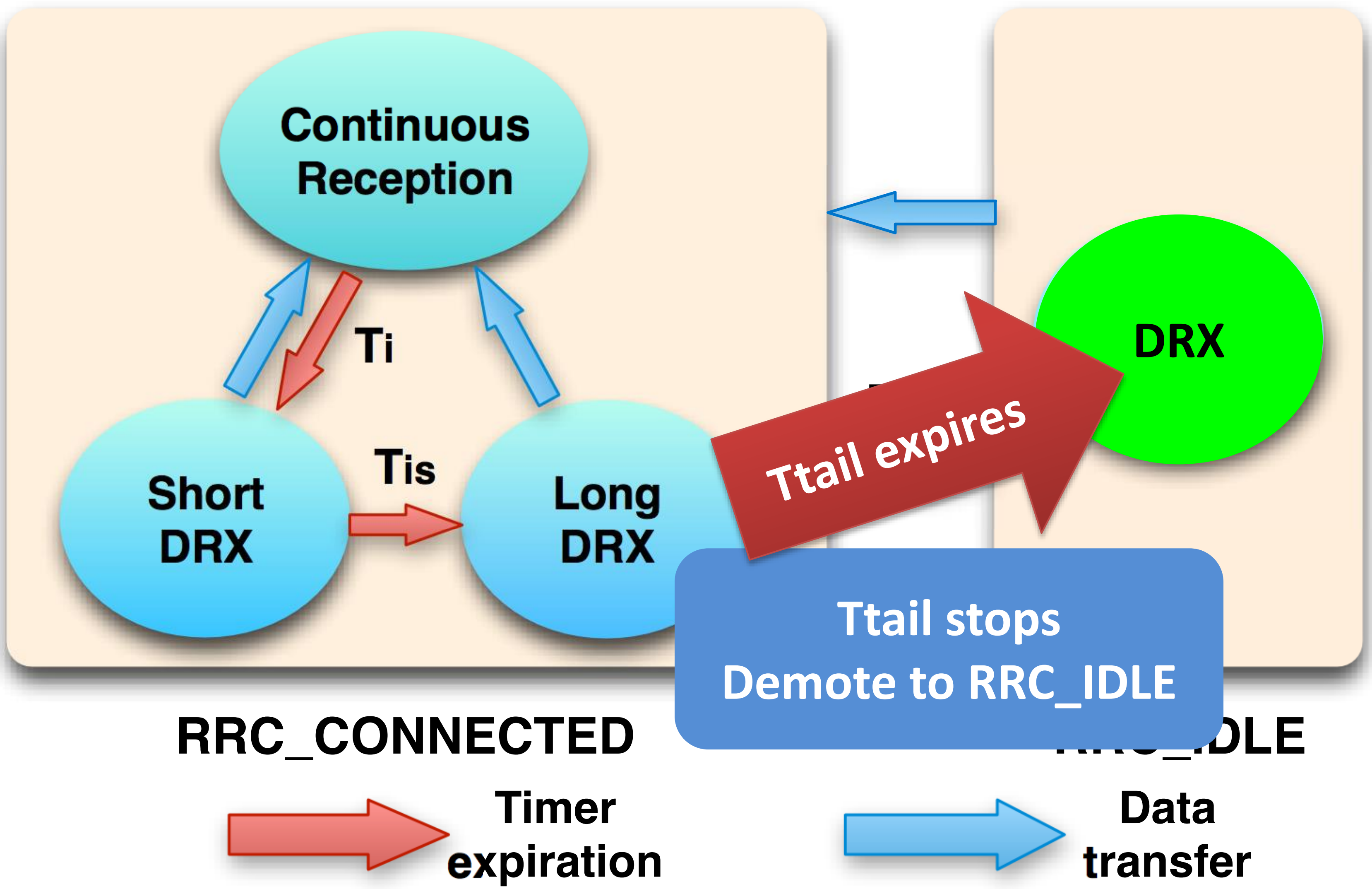
RRC_CONNECTED

- Radio resource allocated
- Power state is a function of data rate:
  - 1060mW is the base power consumption
  - Up to 3300mW transmitting at full speed

RRC state transitions in LTE



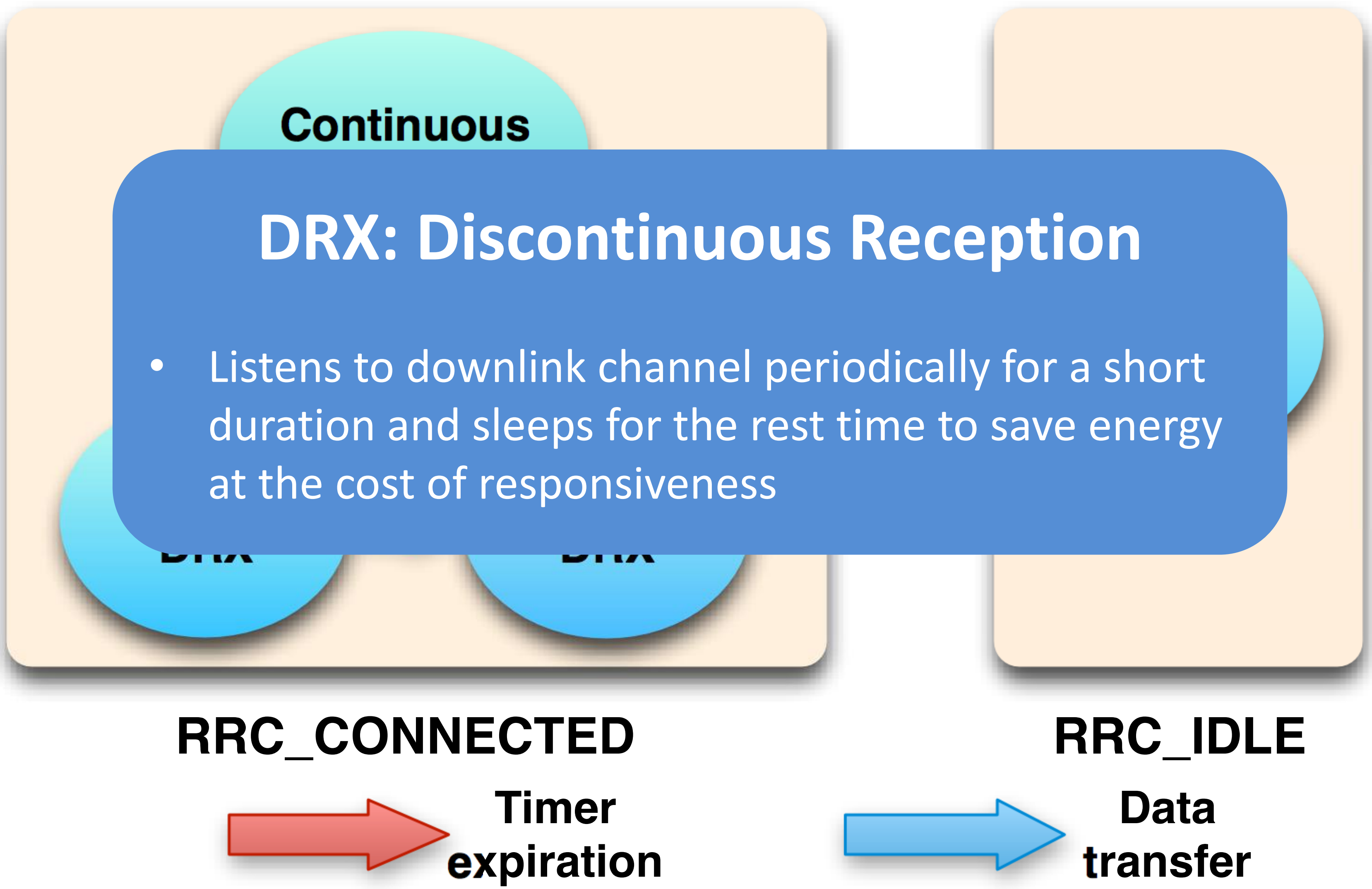
RRC state transitions in LTE



Tradeoffs of *Ttail* settings

Ttail setting	Energy Consumption	# of state transitions	Responsiveness
Long	**High**	**Small**	**Fast**
Short	**Low**	**Large**	**Slow**

RRC state transitions in LTE



DRX: Discontinuous Reception

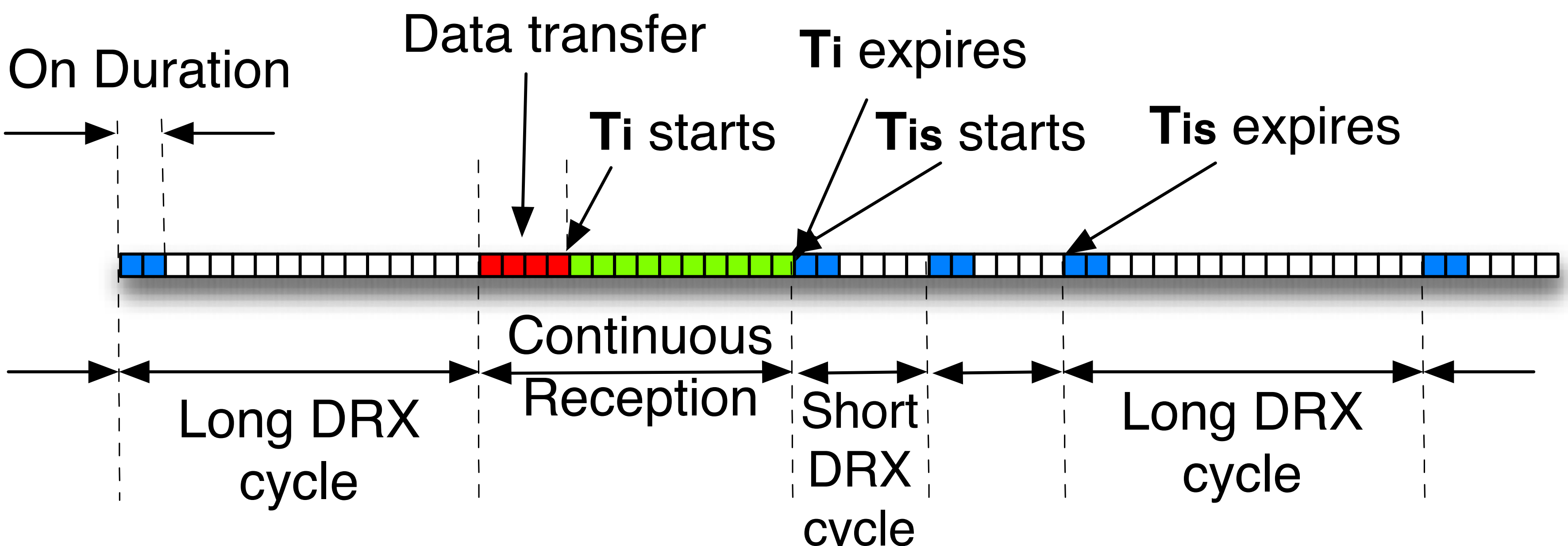
- Listens to downlink channel periodically for a short duration and sleeps for the rest time to save energy at the cost of responsiveness

Discontinuous Reception (DRX): micro-sleeps for energy saving

- In LTE 4G, DRX makes UE ***micro-sleep periodically*** in the RRC_CONNECTED state
  - Short DRX
  - Long DRX
- DRX incurs tradeoffs between energy usage and latency
  - Short DRX – *sleep less and respond faster*
  - Long DRX – *sleep more and respond slower*
- In contrast, in UMTS 3G, UE is always listening to the downlink control channel in the data transmission states

DRX in LTE

- A DRX cycle consists of
  - 'On Duration' - UE monitors the downlink control channel (PDCCH)
  - 'Off Duration' - skip reception of downlink channel
- T_i: Continuous reception inactivity timer
  - When to start Short DRX
- T_{is}: Short DRX inactivity timer
  - When to start Long DRX



LTE power model

- Measured with a LTE phone and Monsoon power meter, averaged with repeated samples

	Power* (mW)	Duration (ms)	Periodicity (ms)
Screen off (base)	11.4±0.4	N/A	N/A
Screen 100% on	847.2±2.7	N/A	N/A
LTE promotion	1210.7±85.6	T_{pro}: 260.1±15.8	N/A
LTE Short DRX On in **RRC_CONNECTED**	1680.2±15.7	T_{on}: 1.0±0.1	T_{ps}: 20.0±0.1
LTE Long DRX On in **RRC_CONNECTED**	1680.1±14.3	T_{on}: 1.0±0.1	T_{pl}: 40.1±0.1
LTE Off Duration in **RRC_CONNECTED**	1060.0±3.3	T_{tail}: 11576.0±26.1	N/A
LTE DRX On in **RRC_IDLE**	594.3±8.7	T_{oni}: 43.2±1.5	T_{pi}: 1280.2±7.1

LTE consumes more instant power than 3G/WiFi in the high-power tail

- Average power for WiFi tail
  - **120** mW
- Average power for 3G tail
  - **800** mW
- Average power for LTE tail
  - **1080** mW

Power model for data transfer

- A linear model is used to quantify instant power level:
  - Downlink throughput t_d Mbps
  - Uplink throughput t_u Mbps

$$P = \alpha_u t_u + \alpha_d t_d + \beta$$

Data transfer power model

< 6% error rate in evaluations with real applications

Energy per bit comparison

- LTE's high throughput compensates for the promotion energy and tail energy

Transfer Size	LTE μ J / bit	WiFi μ J / bit	3G μ J / bit
10KB	**170**	6	100
10MB	**0.3**	0.1	4

Total energy per bit for downlink bulk data transfer

Energy per bit comparison

- LTE's high throughput compensates for the promotion energy and tail energy

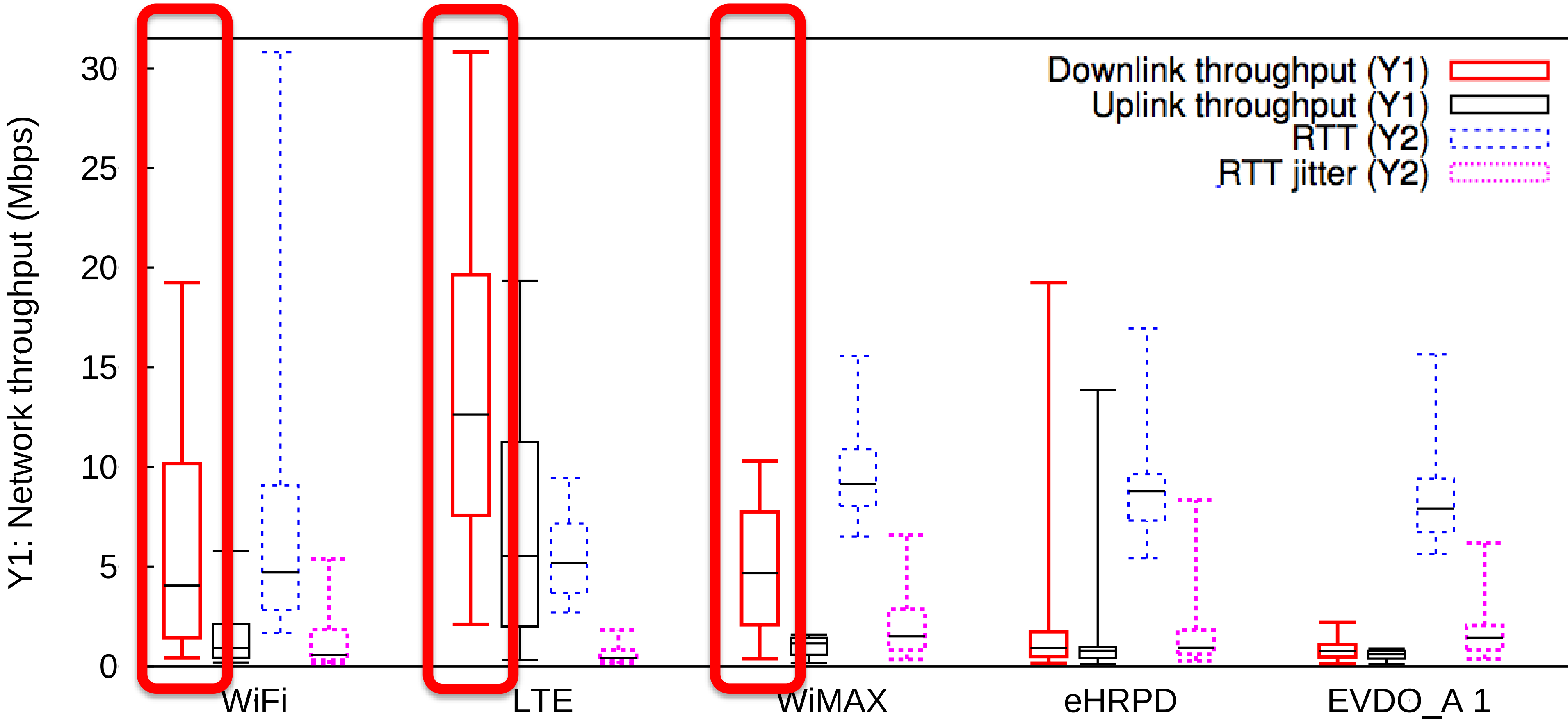
Small data transfer, LTE wastes energy
Large data transfer, LTE is energy efficient

10MB	**0.3**	0.1	4

Total energy per bit for downlink bulk data transfer

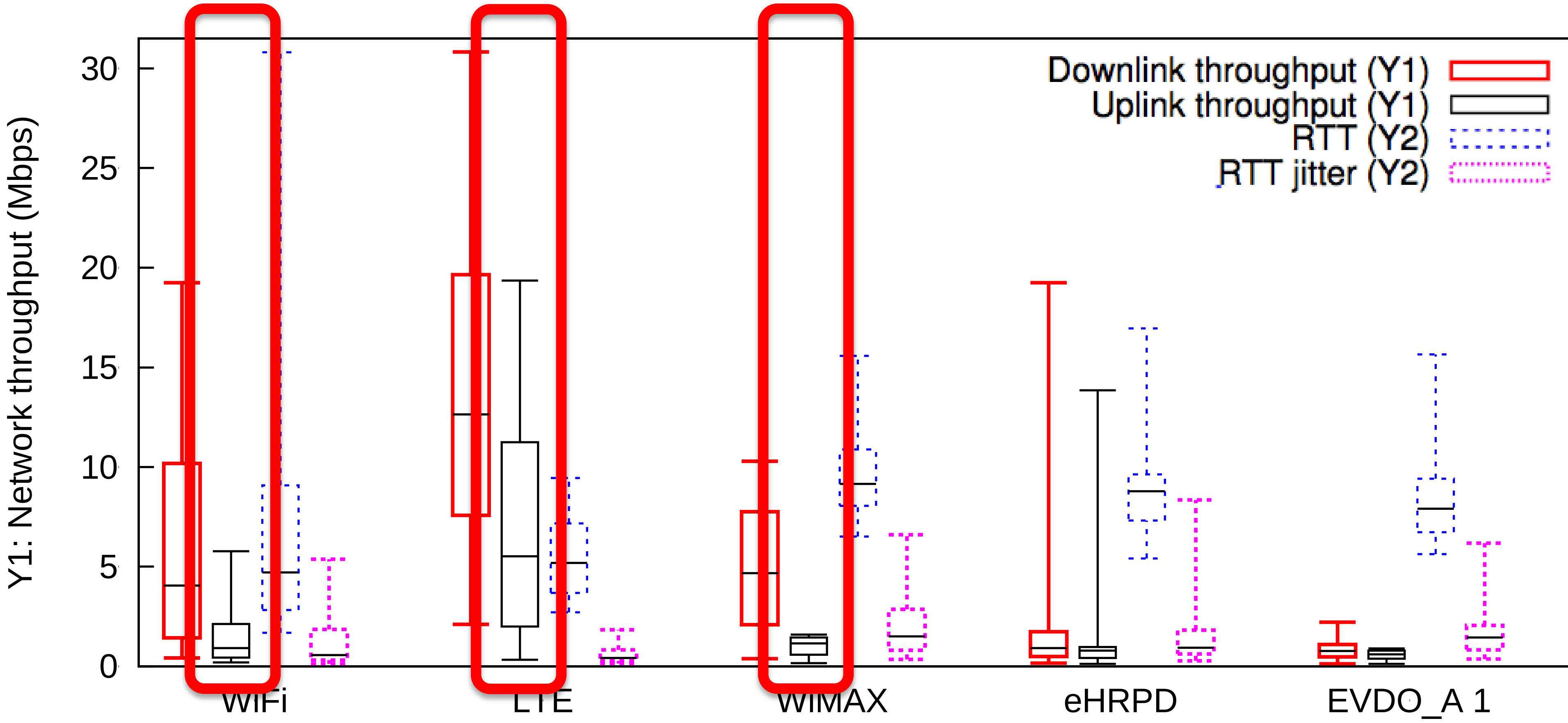
Downlink throughput

- LTE median is **13**Mbps, up to **30**Mbps
  - The LTE network is relatively unloaded
- WiFi, WiMAX **< 5**Mbps median



Uplink throughput

- LTE median is **5.6**Mbps, up to **20**Mbps
- WiFi, WiMAX **< 2**Mbps median



Summary

- LTE has significantly higher speed, compared to 3G and WiFi
- LTE is much less power efficient than WiFi due to its tail energy for small data transfers
- Derived a power model of a commercial LTE network, with less than 6% error rate
- UE processing is the bottleneck for web-based applications in LTE networks
- Mobile app design should be LTE friendly

Next Lecture: Sight & Touch