

How Green is Multipath TCP for Mobile Devices?

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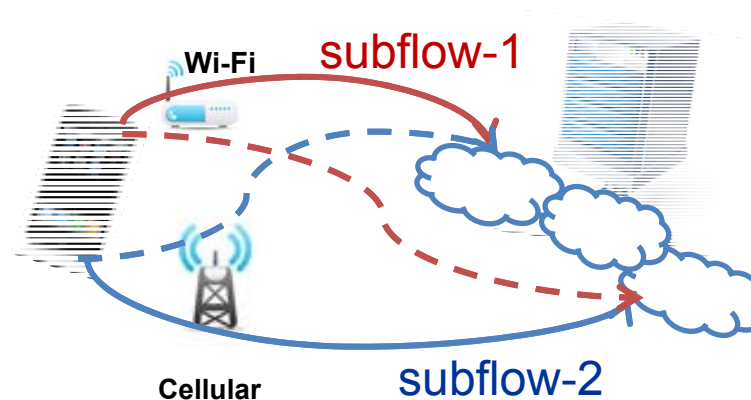


Outline

- Introduction
- Motivation
- Experimental Setup
- MPTCP Energy Model
- Approach: eMPTCP
- Evaluation
- Conclusion

Introduction

- Mobile devices have **at least two** wireless interfaces
- State of art: switch between available interfaces
 - WiFi vs. 3G/4G
 - Not used **simultaneously**
- Multi-Path TCP: leverages **multiple interfaces** simultaneously
 - Robust data transport
 - Dynamic traffic balancing
 - Application Transparency



Motivation

- Mobile devices are constrained by available energy in batteries
- MPTCP consumes additional energy for operating multiple network interfaces

How much additional energy does MPTCP consume compared with TCP over single interface?

Is there any opportunity for MPTCP to be **more energy efficient**?

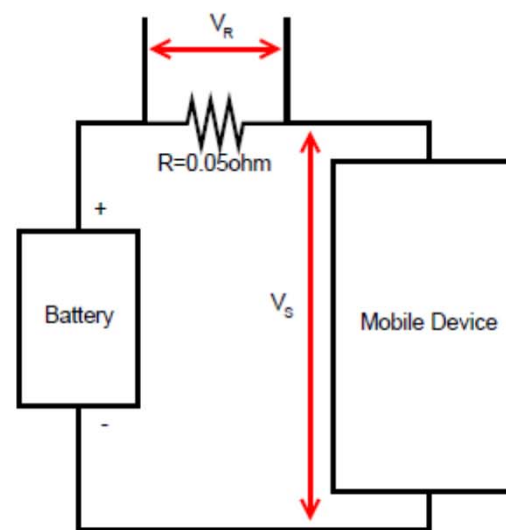
If so, how should we change MPTCP?

Experimental Setup

- MPTCP is ported into Samsung Galaxy S3
- To measure current and voltage supplied to device
 - DAQ measures voltage supplied to mobile device and voltage drop across resistor



(a) Setup



(b) Circuit

Profiling TCP over single interface

- Fixed Energy Overhead

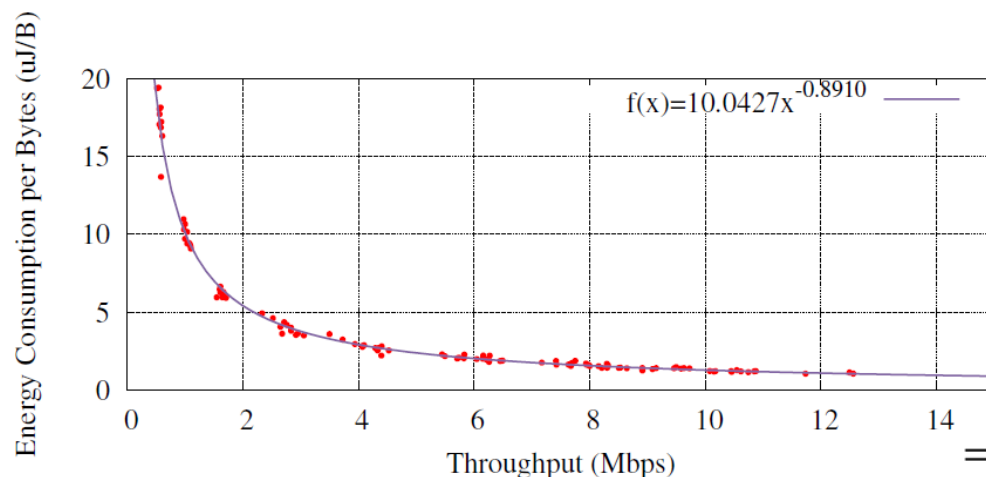
- Energy consumption during promotion and tail

State		Average Duration (sec)	Average Energy Consumption (J)	Fixed Energy Overhead (J)
HSDPA	Promotion	2.098 (±0.455)	1.463 (± 0.306)	11.337
	Tail	16.123 (±1.137)	9.873 (±1.057)	
LTE	Promotion	0.405 (±0.047)	0.311 (±0.041)	2.908
	Tail	11.490 (±0.492)	2.597 (±0.275)	
WiFi	Promotion	0.095 (±0.029)	0.040 (± 0.017)	0.149
	Tail	0.295 (±0.152)	0.109 (± 0.080)	

Profiling TCP over single interface

- During Packet Transfer

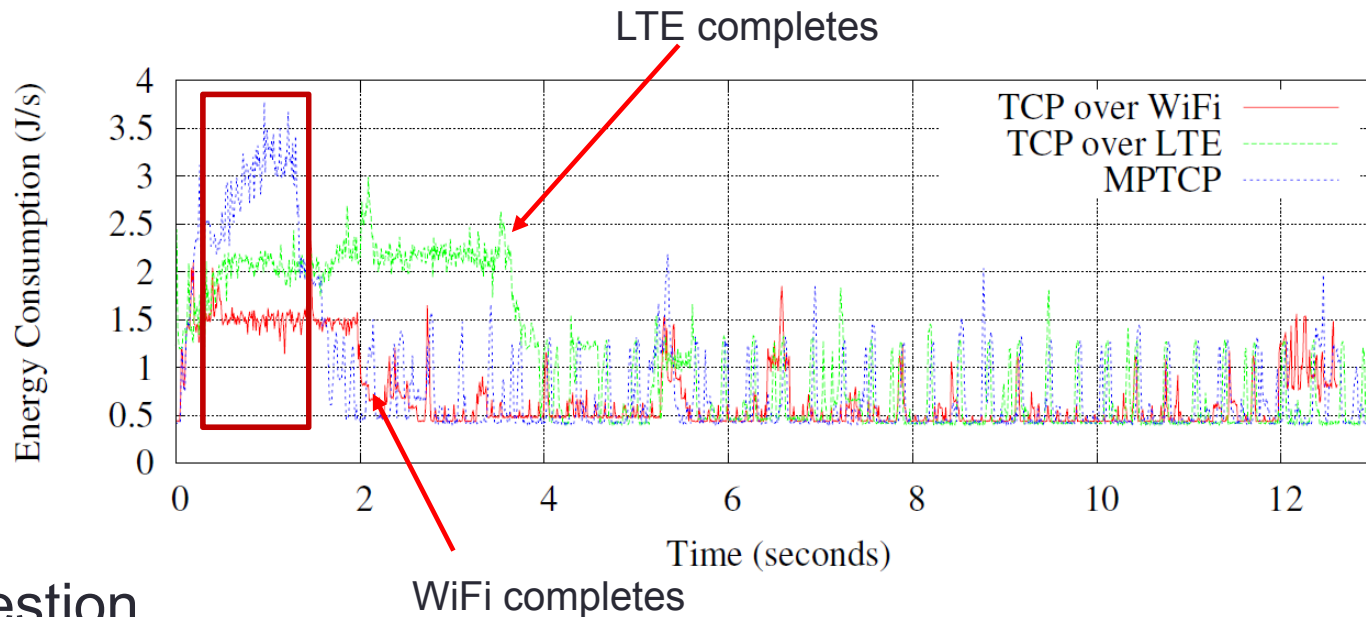
- Energy consumption per transferred byte, $P(B)$ ($\mu\text{J}/\text{Byte}$)
 - As function of available throughput, B
 - $P(B) = \alpha \times B^\beta$
 - e.g. LTE for Downloading when throughput is B_L^D
 - $P_L^D(B_L^D) = 10.0427 \times B_L^D^{-0.8910}$



LTE energy consumption per downloaded byte according to throughput

State		Interface		
		HSDPA	LTE	WiFi
Download	α^d	9.3440	10.0427	4.6750
	β^d	-0.9286	-0.8910	-0.8179
Upload	α^u	12.5294	13.3438	3.6135
	β^u	-0.8524	-0.8358	-0.6617

MPTCP Energy Model



- Question
 - Does MPTCP just consumes sum of energy for operating each interface?
- Assumptions
 - Each interface **separately** consumes fixed energy overhead to switch interface state
 - BUT, while simultaneously transferring packets, some amount of consumed energy is **shared**

MPTCP Energy Model

- using WiFi and LTE

- In MPTCP, while transferring $S = S_W + S_L$ bytes

- $t_W = S_W/B_W, t_L = S_L/B_L$

- Estimated overlapped ratio $\theta = \frac{\min(t_W, t_L)}{\max(t_W, t_L)}$

S : Transferred bytes

- $E_M = \underbrace{C_W + C_L}_{\text{Fixed Overhead}} + \underbrace{(P_W(B_W) \times S_W + P_L(B_L) \times S_L)}_{\text{Energy Consumption during Packet Transfer}} \times \underbrace{(1 - \theta + \gamma\theta)}_{\text{Multiply } \gamma \text{ during overlapped period}}$

Fixed Overhead

Energy Consumption during Packet Transfer

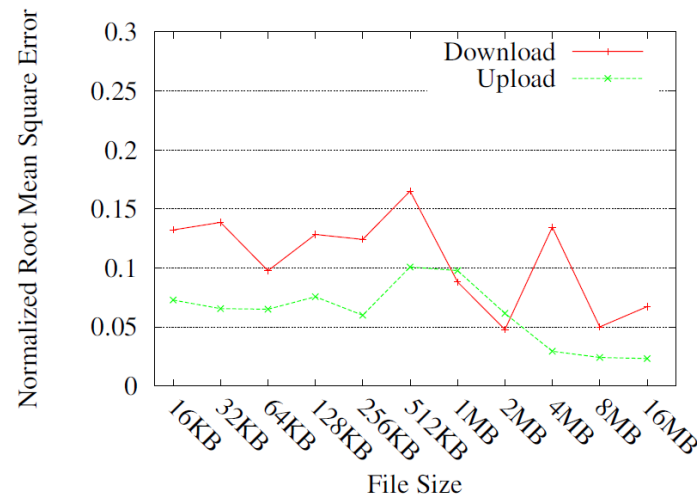
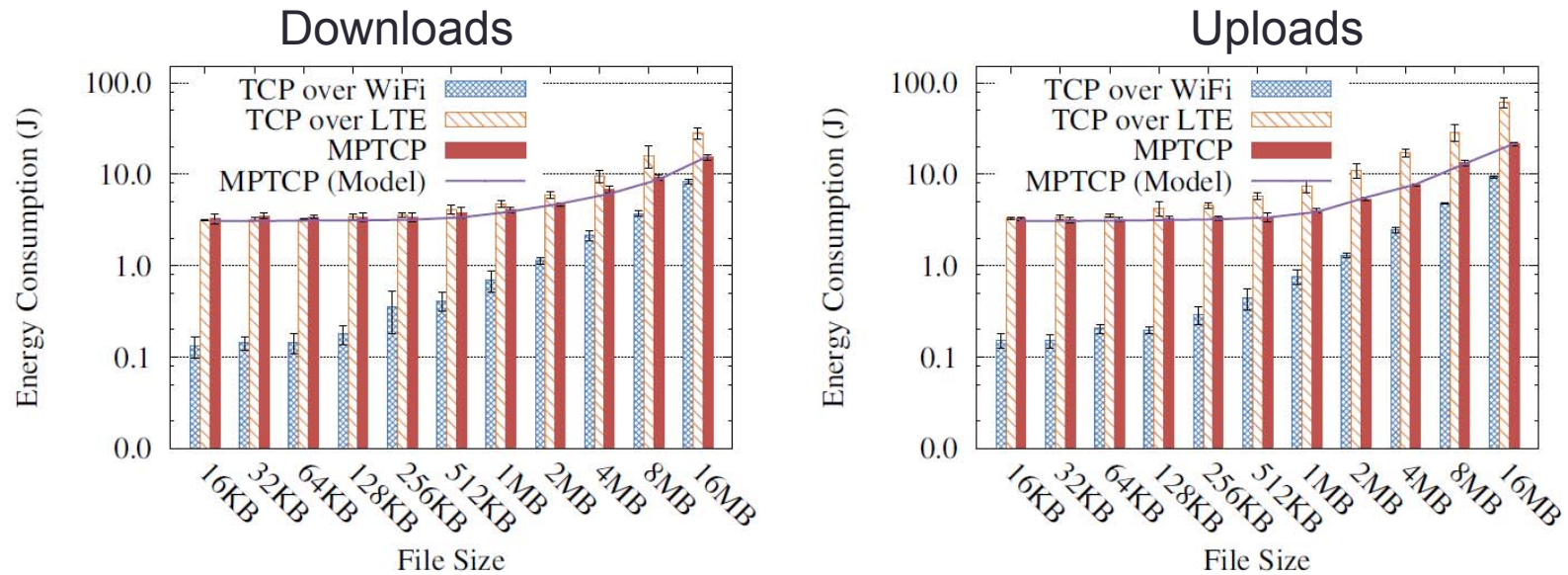
Multiply γ during overlapped period

We choose γ to minimize mean square error between measured and estimated values

- Downloading $\gamma = 0.8485$. Uploading $\gamma = 0.8687$
- Around 15% of consumed energy is shared during packet transfer

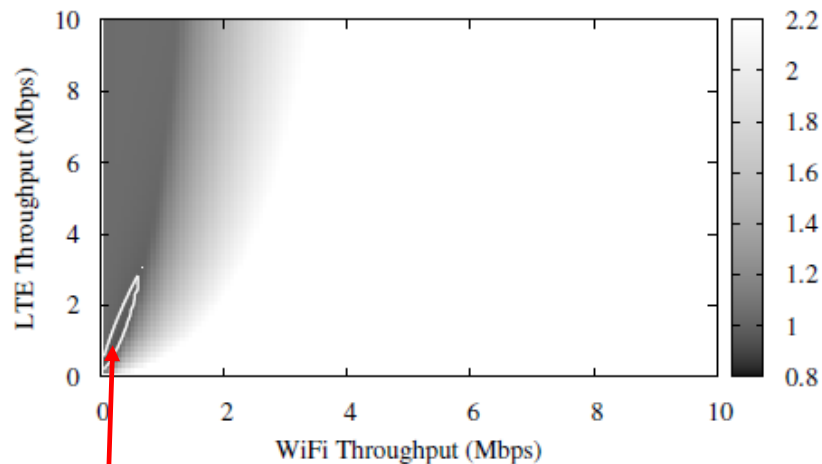
MPTCP Energy Model

- Validation (using WiFi and LTE)

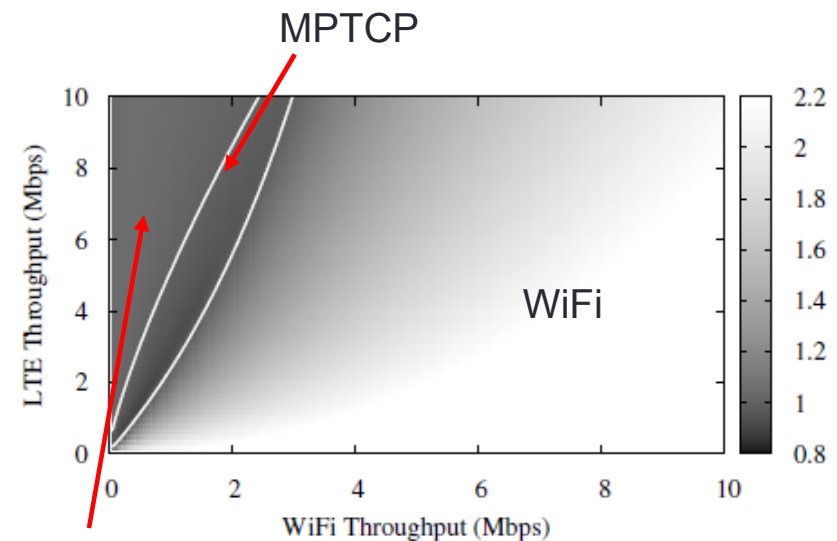


Can MPTCP be more energy efficient than TCP over single interface?

- Based on our model
 - MPTCP Total Energy Consumption Normalized by Most Energy Efficient TCP



(a) 1MB Download



LTE

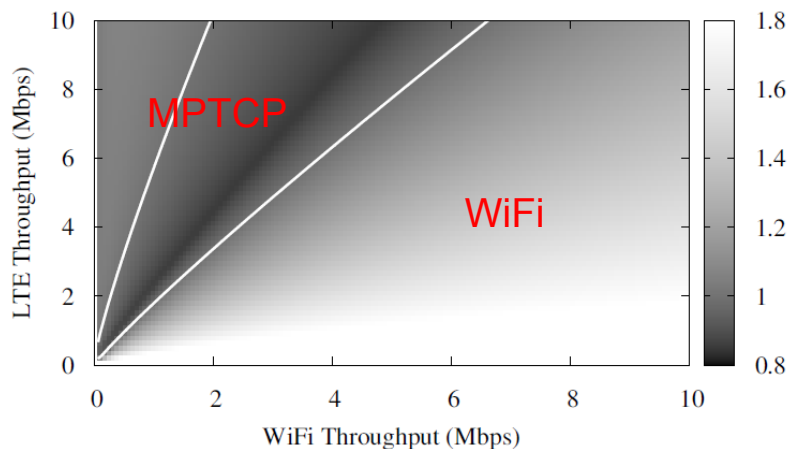
(b) 4MB Download

Hard for MPTCP to be more energy efficient

Approach: eMPTCP

- Delayed LTE subflow establishment
 - Start only with WiFi
 - Until transferring κ bytes
 - Or if transferring κ bytes is not done in τ sec
- After establishing both
 - No knowledge about future traffic length
 - Greedy path usage selection according to energy consumption per transferred byte
 - Throughput prediction using Holt-Winters Forecasting

Normalized MPTCP energy consumption per downloaded byte

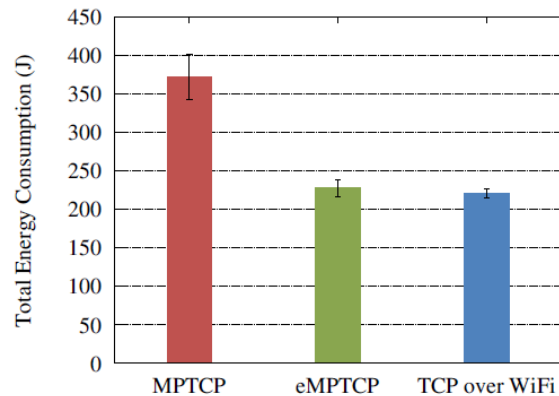


- Given WiFi and LTE throughput, choose most energy efficient one in terms of per-byte energy consumption

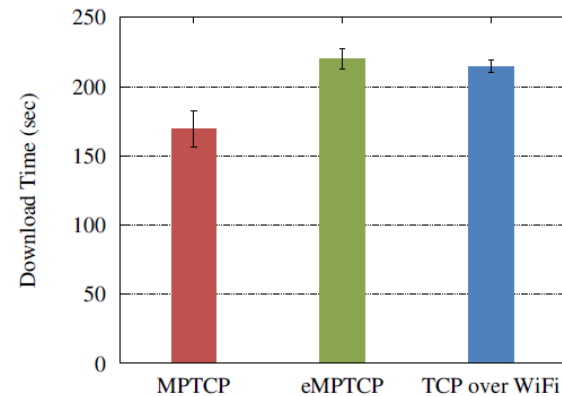
Evaluation

- eMPTCP is implemented on Samsung Galaxy S3
 - For downloading which are more common in mobile devices
- Threshold Parameters: $\kappa = 1MB$, $\tau = 3sec$
- Scenarios (256MB download while controlling WiFi bandwidth)
 1. Persistent High WiFi Bandwidth (>10Mbps)
 - eMPTCP behaves as TCP over WiFi
 2. Persistent Low WiFi Bandwidth (<1Mbps)
 - eMPTCP behaves like MPTCP, except for delayed LTE establishment
 3. WiFi Bandwidth randomly changes between 1Mbps and 10Mbps with mean interval time of 40 seconds
 - eMPTCP switches between TCP over WiFi and MPTCP according to available bandwidth

Evaluation - Persistent WiFi bandwidth

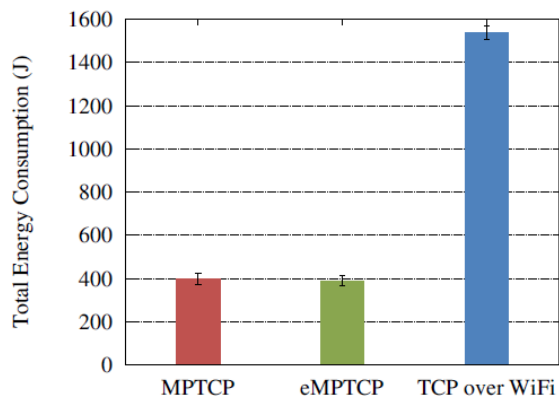


(a) Energy Consumption

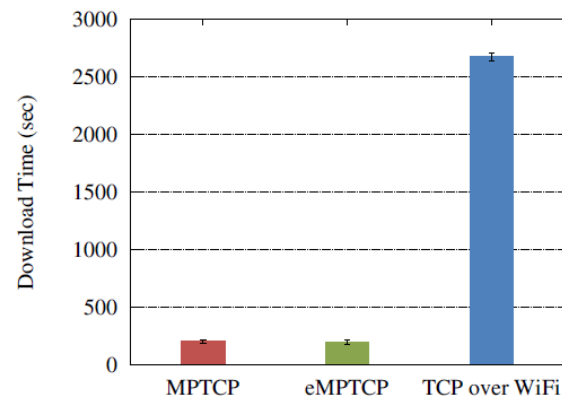


(b) Download Time

- Persistent High WiFi
 - eMPTCP behaves as TCP over WiFi
 - Similar energy consumption and download time to TCP over WiFi
 - Slower than MPTCP



(a) Energy Consumption

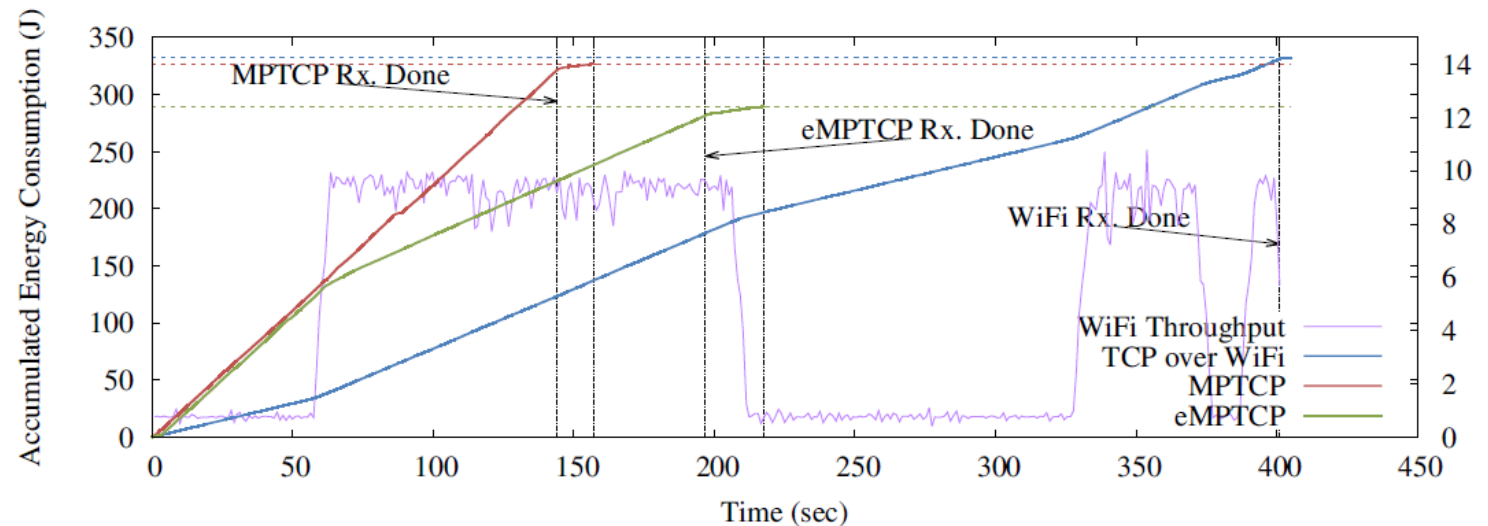


(b) Download Time

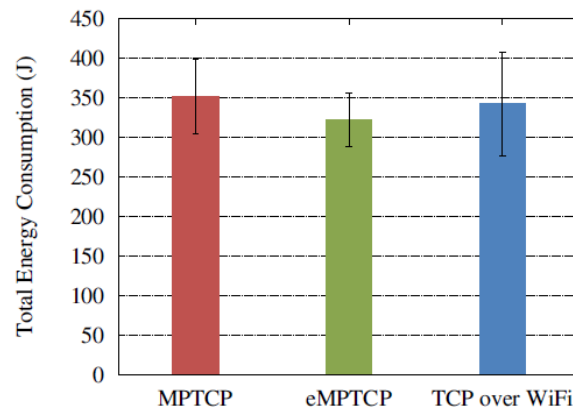
- Persistent Low WiFi
 - eMPTCP behaves like MPTCP
 - Faster and more energy efficient than TCP over WiFi

Evaluation - Random WiFi Bandwidth Changes

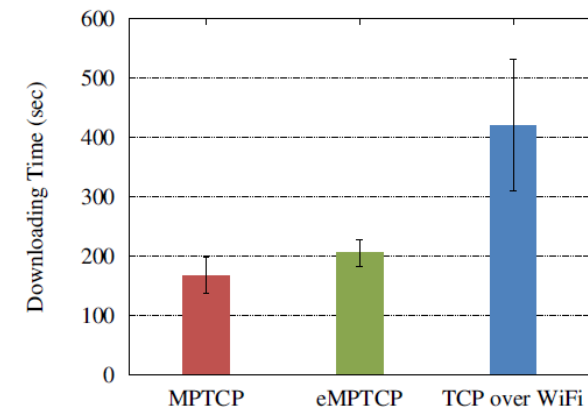
Example Accumulated Energy Consumption Trace



- eMPTCP consumes 8% & 6% less energy than MPTCP and TCP over WiFi, respectively
- eMPTCP completes downloads twice as fast as TCP over WiFi (close to MPTCP)



(a) Energy Consumption



(b) Download Time

Summary

- Ported MPTCP to an off the shelf mobile handset
- Detailed model of MPTCP energy consumption behavior
- Determined operating region where MPTCP is more energy efficient than TCP over single interface
- Developed eMPTCP to provide better energy efficiency without losing the benefits of MPTCP



Thank you!

Questions?