How Green is Multipath TCP for Mobile Devices?

Yeon-sup Lim[1], Yung-Chih Chen[1], Erich M. Nahum[2], Don Towsley[1] and Richard J. Gibbens[3]

[1] University of Massachusetts Amherst
[2] IBM T.J. Watson Research Center
[3] University of Cambridge

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Outline

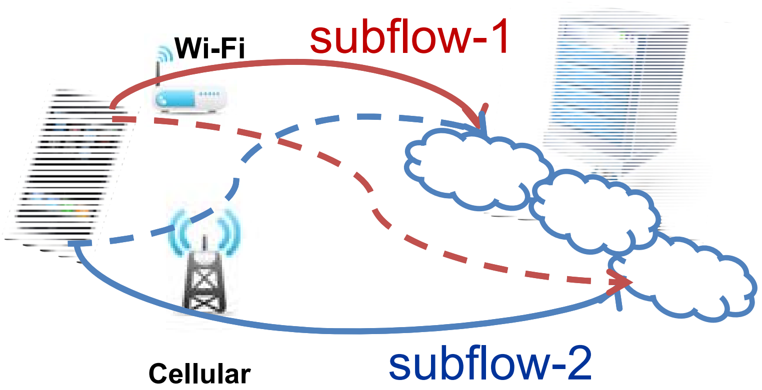
- Introduction
- Motivation
- Experimental Setup
- MPTCP Energy Model
- Approach: eMPTCP
- Evaluation
- Conclusion

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

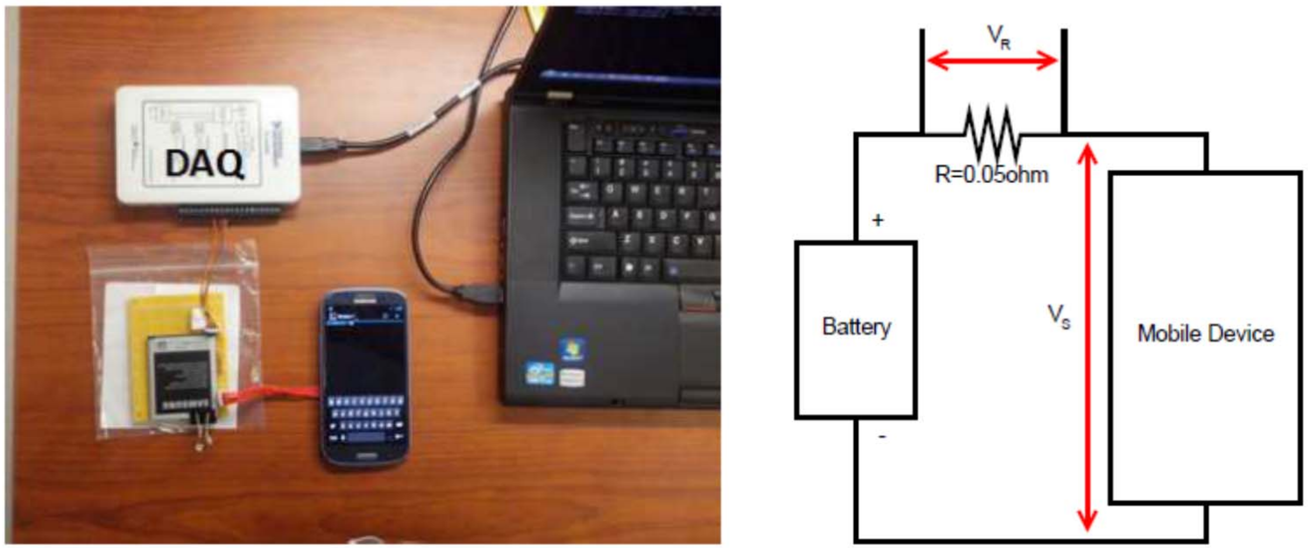
How much additional energy does MPTCP consume compared with TCP over single interface?

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

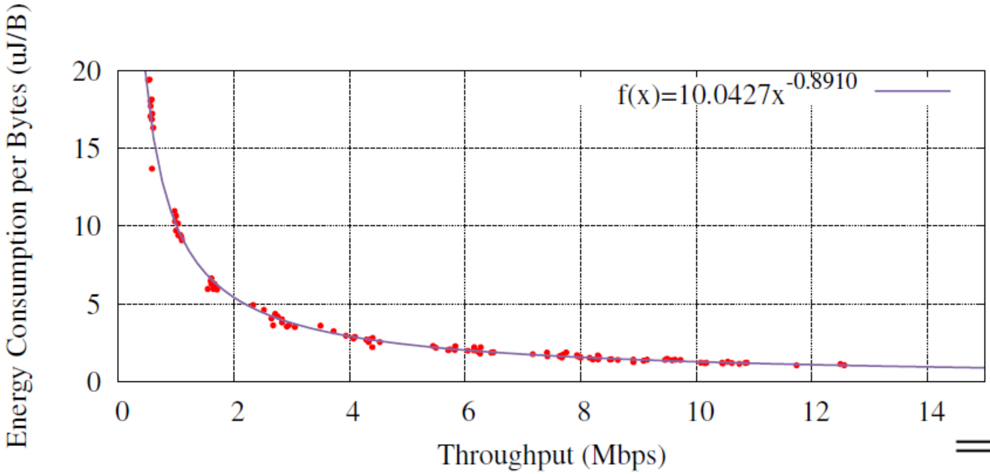
- Fixed Energy Overhead

- 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

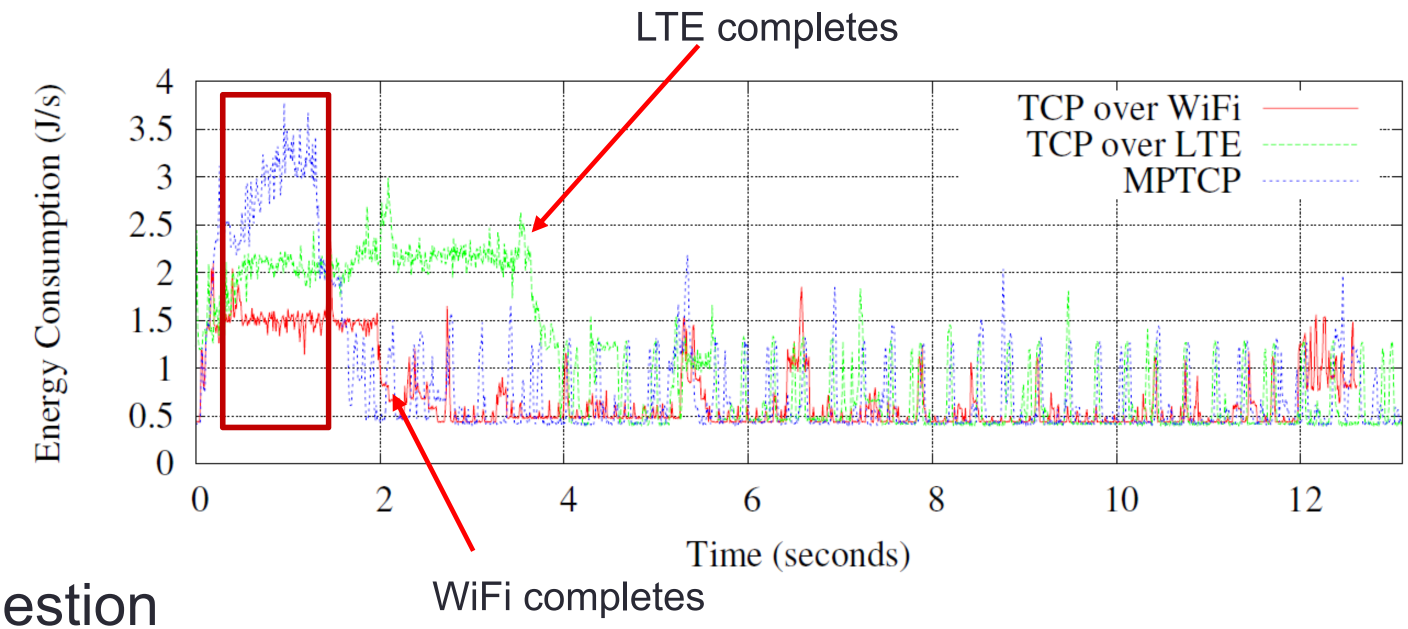
- Energy consumption per transferred byte, $P(B)$ $(\mu J/Byte)$
  - As function of available throughput, *B*
    - $P(B) = \alpha \times B^{\beta}$
  - e.g. LTE for Downloading when throughput is B_L^D
    - $P_L^D(B_L^D) = 10.0427 \times {B_L^D}^{-0.8910}$



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

S : Transferred bytes

Fixed Overhead

Energy Consumption during Packet Transfer

Multiply γ during overlapped period

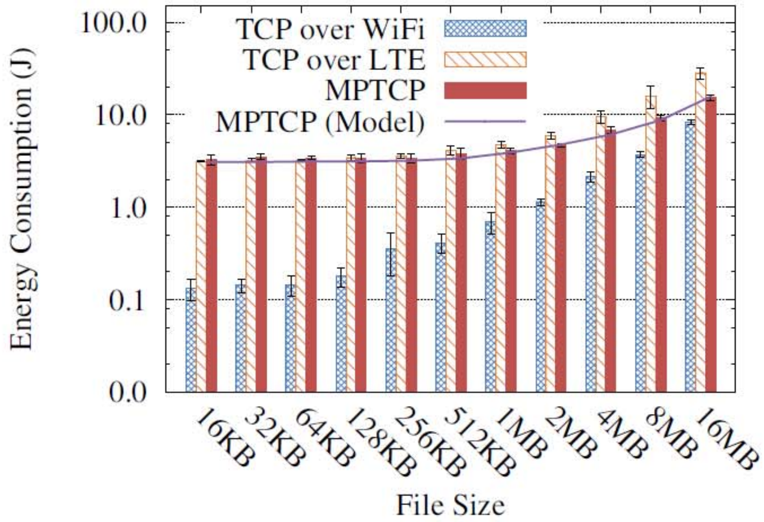
We choose γ to minimize mean square error between measured and estimated values

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

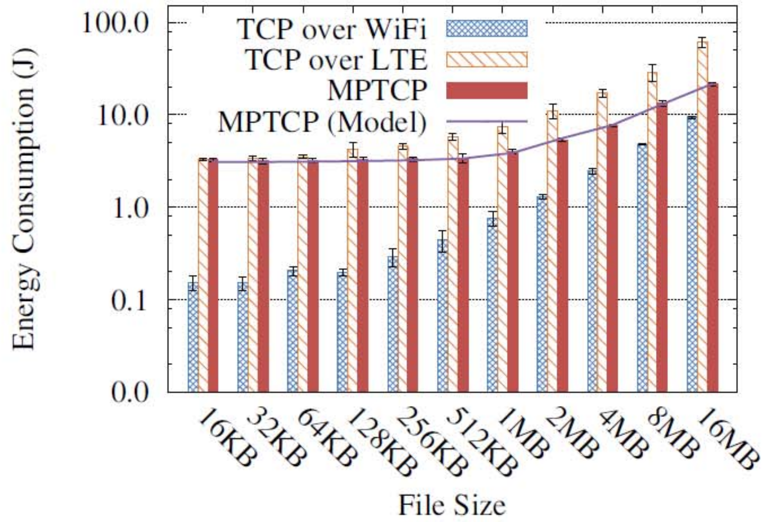
MPTCP Energy Model

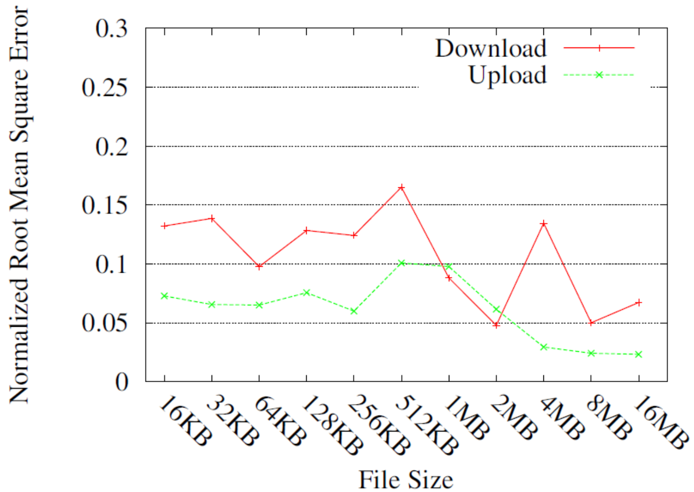
- Validation (using WiFi and LTE)

Downloads



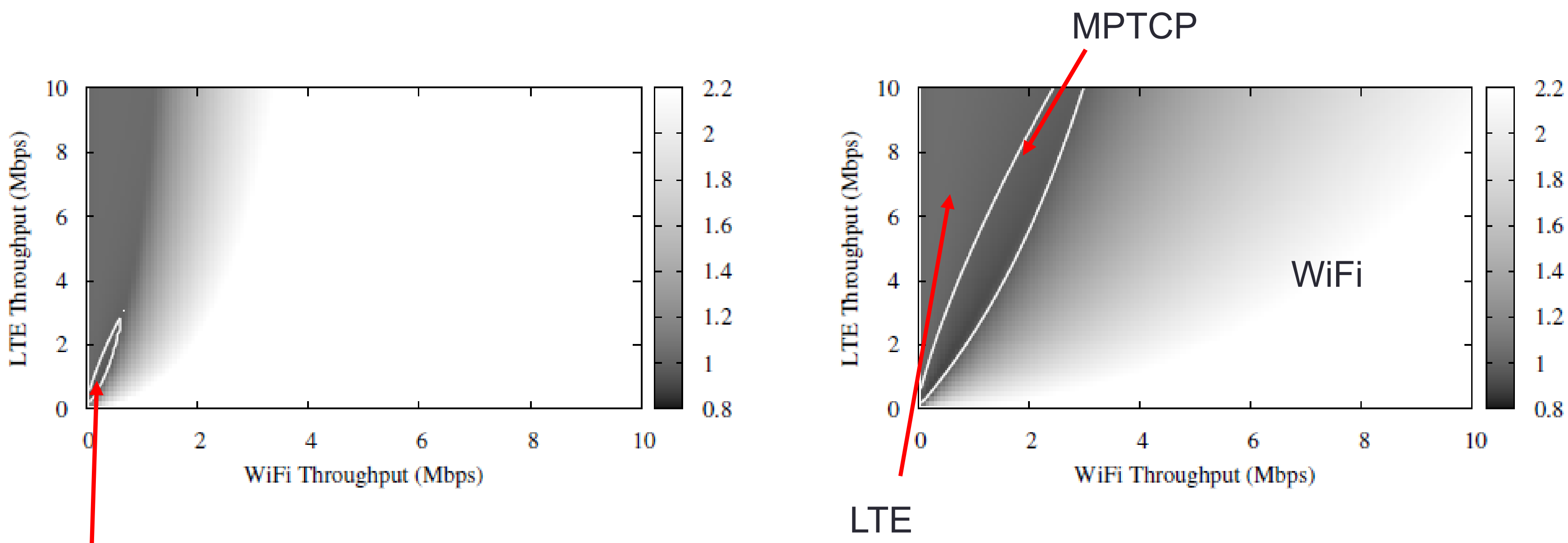
Uploads





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

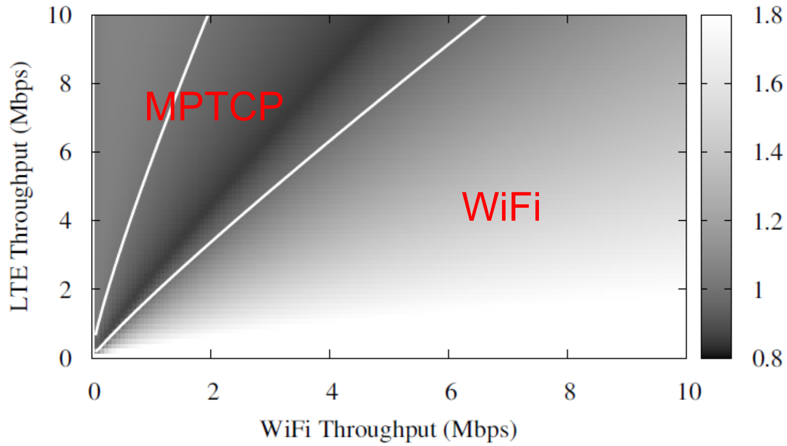
(b) 4MB Download

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

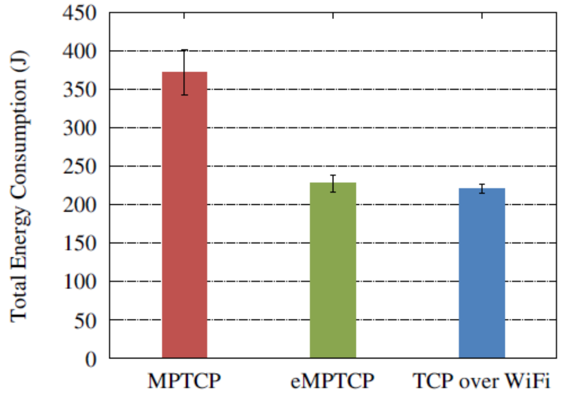
- Threshold Parameters: $\kappa = 1MB,\ \tau = 3sec$

- Scenarios (256MB download while controlling WiFi bandwidth)
  1. Persistent High WiFi Bandwidth (>10Mbps)
     - eMPTCP behaves as TCP over WiFi

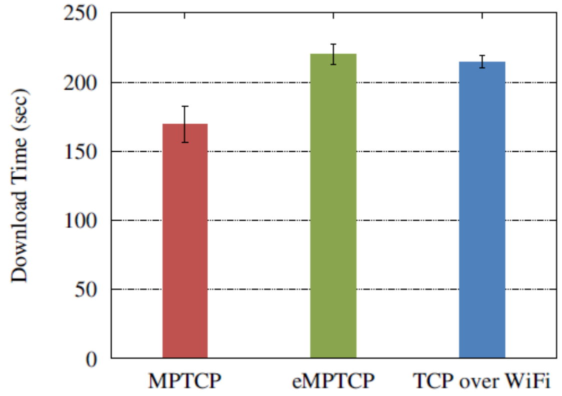
  2. Persistent Low WiFi Bandwidth (<1Mbps)
     - eMPTCP behaves like MPTCP, except for delayed LTE establishment

  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

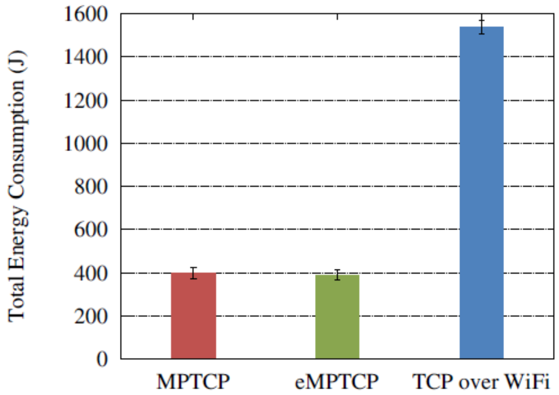


(a) Energy Consumption

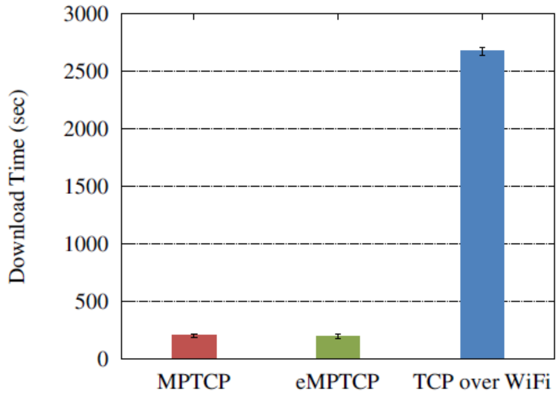


(b) Download Time

- 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

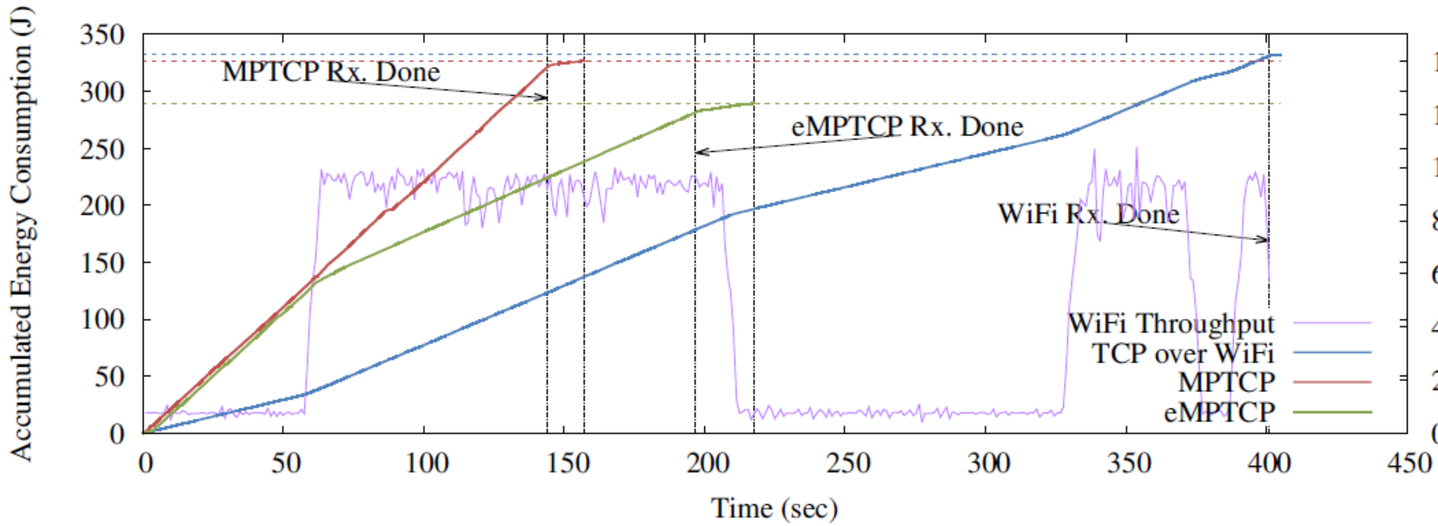


(b) Download Time

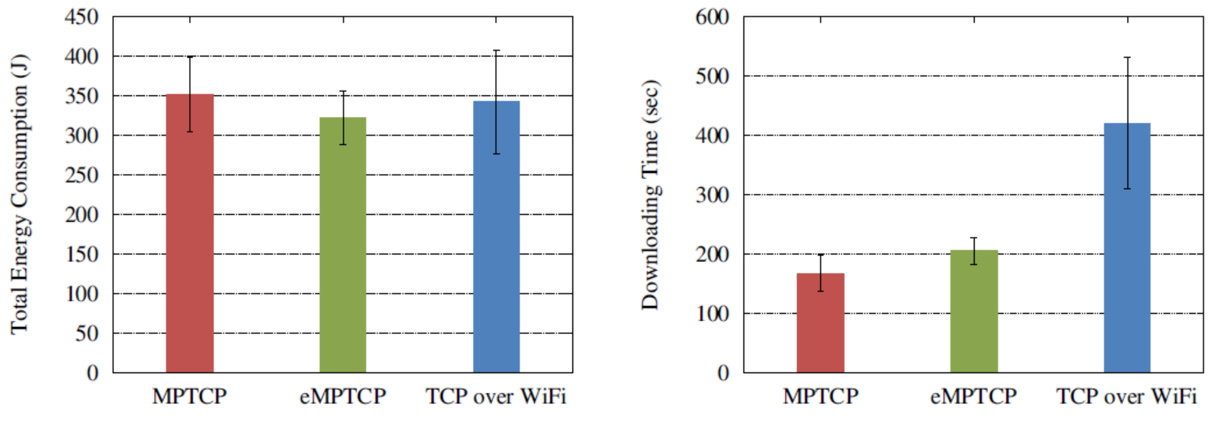
- Persistent Low WiFi
  - eMPTCP behaves like MPTCP
    - Faster and more energy efficient than TCP over WiFi

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?