Aalto University
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Practical Power Modeling of Data Transmission over 802.11g for Wireless Applications

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E-Energy 2010

Outline

- Introduction
- Related Work
- Power Model
- Model Validation
- Discussion
- Conclusion

Introduction

Power consumption of data transmission in WLAN

- 802.11 Wireless network interface (WNI)
  - Different power consumption in different operating modes

  Energy = Power(operating mode) Duration(operating mode)*

  - The duration information is not easily accessible

- Estimate the operating modes & durations
  - 802.11 power saving mode (PSM)
  - Traffic burstiness

Related Work

Power analysis of network protocols

- Power analysis of different TCP versions such as Reno, Newreno and SACK[9]
- Impact on power consumption from different TCP header options such as window scale option[10]
- Power consumption of MAC/PHY layer overhead[14]

Power models that use low-level information

- Power model based on WNI operating modes [3]

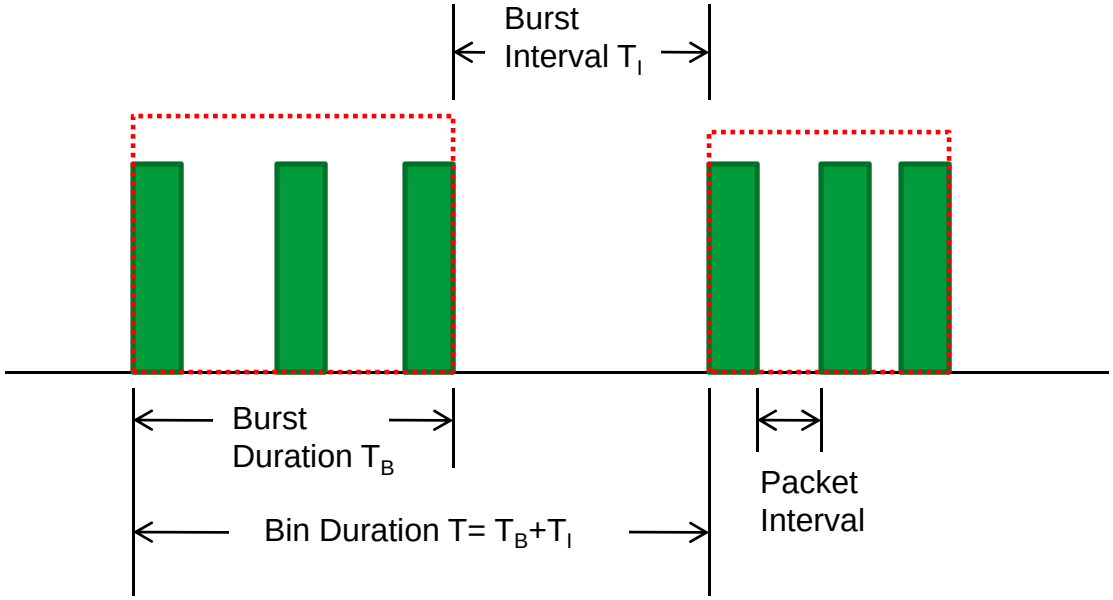
Power Model

- Traffic Burstiness

Burst size S_B

Bin rate r

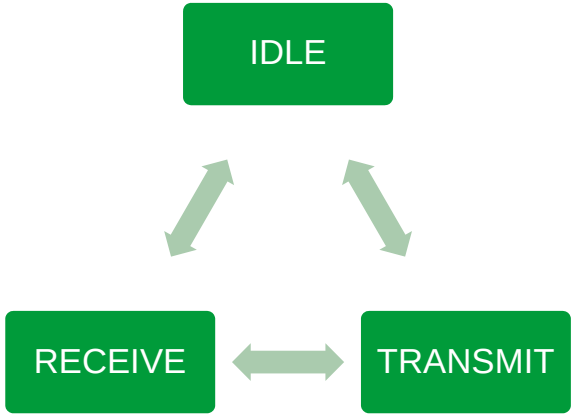
$r = S_B/T = S_B/(T_B+T_I)$



In a Burst: {Packet interval < Threshold}

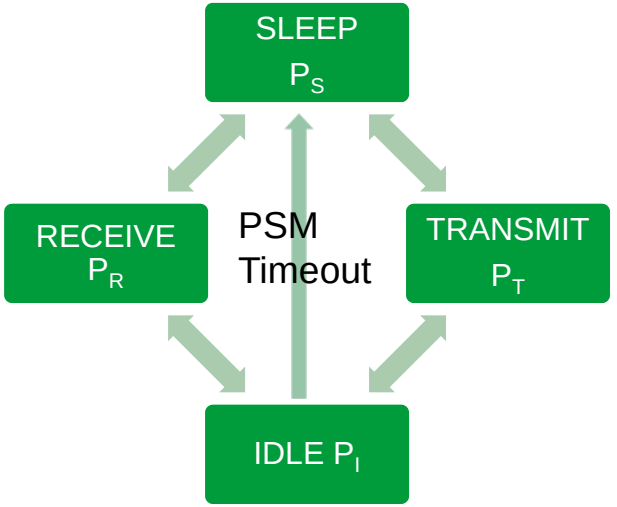
WNI Operating Modes: CAM vs. PSM

- Continuously Active Mode (CAM)



- Power Saving Mode(PSM)

$$T_{sleep} = T_I - T_{timeout}$$



Two Scenarios

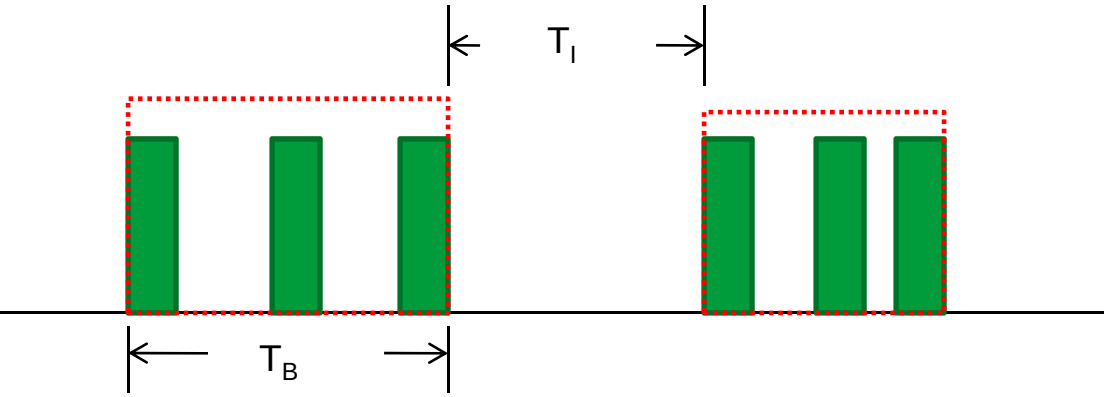
Threshold of bin rate r_c

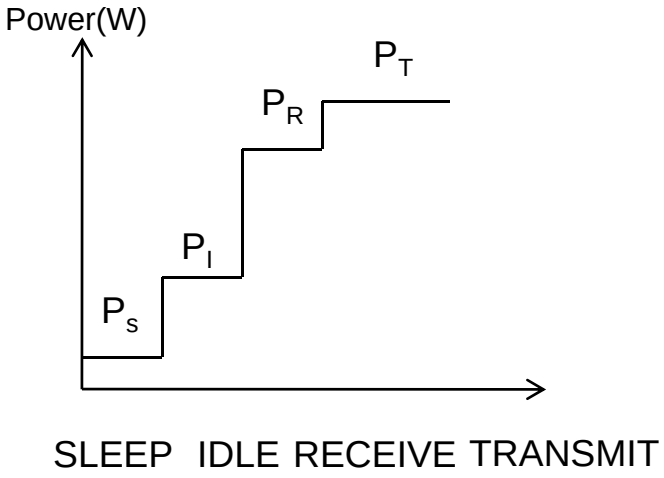
When $T_{sleep} = 0$,

$$r_c = S_B / (T_B + T_{timeout}).$$

- Scenario 1: {{$r >= r_c$ } and {PSM is enabled}} or {CAM is enabled} .
- Scenario 2: { $r < r_c$ } and {PSM is enabled}.

Downlink Power Consumption





Energy(J): $E = P_R T_B + P_I T_I$

Power(W): $P_d(r) = E/T$

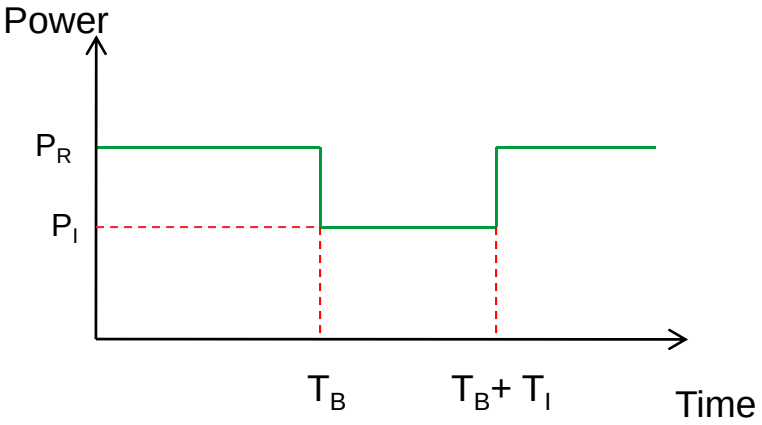
Energy Utility (b/J): $E_0(r) = r/P_d(r)$

Downlink Power Consumption

- Scenario 1

$E = P_R T_B + P_I T_I$

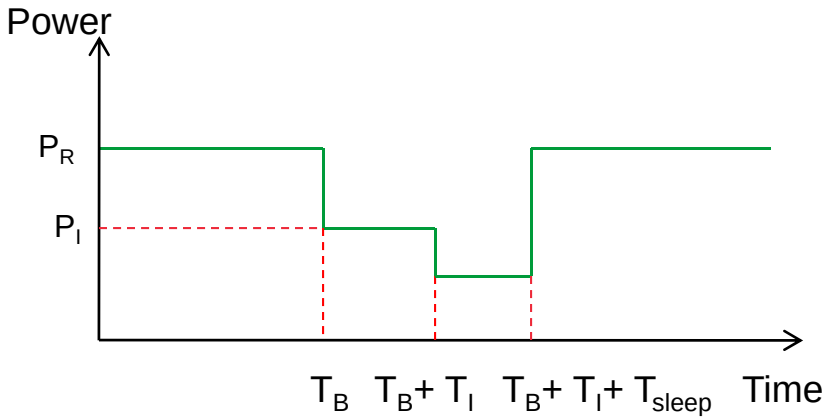
$P_d(r) = E/T = P_I + r(P_R - P_I)\, T_B/S_B$



- Scenario 2

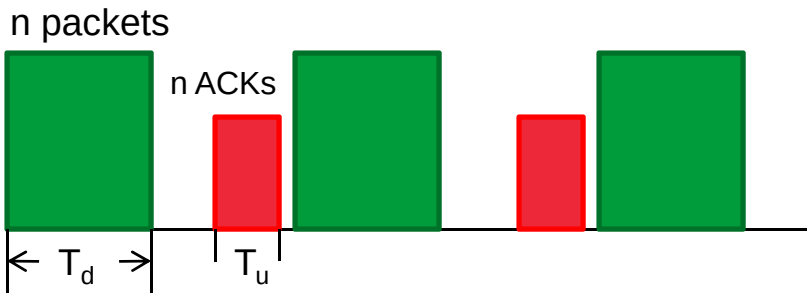
$E = P_R T_B + P_I T_{timeout} + P_S T_{sleep}$

$P_d(r) = E/T = P_S + r[(P_R - P_S)\, T_B/S_B + (P_I - P_S)\, T_{timeout}/S_B]$



TCP Power Consumption

Downlink data rate r_d
Downlink burst size S_B
Uplink data rate $r_u = nS_{ACK}r_d/S_B$



Data rate threshold $r_c = S_B/(T_d+T_u+T_{timeout})$

Scenario 1:

$P(r_d)=P_d(r_d)+P_u(r_u)-P_I= P_I+[T_d(P_R-P_I)+T_u(P_T-P_I)]r_d/S_B$

Secenario 2:

$P(r_d)=P_d(r_d)+P_u(r_u)-P_S$

$=P_S+[T_d(P_R-P_S)+T_u(P_T-P_S)+T_{timeout}(P_I-P_S)]r_d/S_B$

Simplified TCP Power Model

- Drop the power consumption caused by ACKs
- Scenario 1:

$P(r_d) = P_I + (P_R - P_I) r_d / r_{max}$

Total energy consumption of receiving m bins:

$$E_{sum} = \sum_{i=1}^{m} P(r_i) T_i = P_I \sum_{i=0}^{m} T_i + \frac{P_R - P_I}{r_{max}} \sum_{i=0}^{m} r_i T_i = P(r) T_{sum} = [P_I + \frac{r}{r_{max}} (P_R - P_I)] T_{sum} \qquad r = \frac{\sum_{i=0}^{m} r_i T_i}{\sum_{i=0}^{m} T_i}, T_{sum} = \sum_{i=0}^{m} T_i$$

- Scenario 2:

$P(r_d) = P_I + (P_R - P_S) r_d / r_{max} + (P_I - P_S) r_d T_{timeout} / S_B$

$$E_{sum} = \sum_{i=1}^{m} P(r_i) T_i = P_S T + \frac{P_R - P_S}{r_{max}} rT + (P_I - P_S) \sum_{i=1}^{m} \frac{r_i}{r_i T_i} T_i' T_i = P_S T + \frac{P_R - P_S}{r_{max}} rT + (P_I - P_S) \sum_{i=1}^{m} T_i' \qquad \sum_{i=1}^{m} T_i' = m T_{timeout} (1 - F(T_{timeout}))$$

Multiple TCP Flows

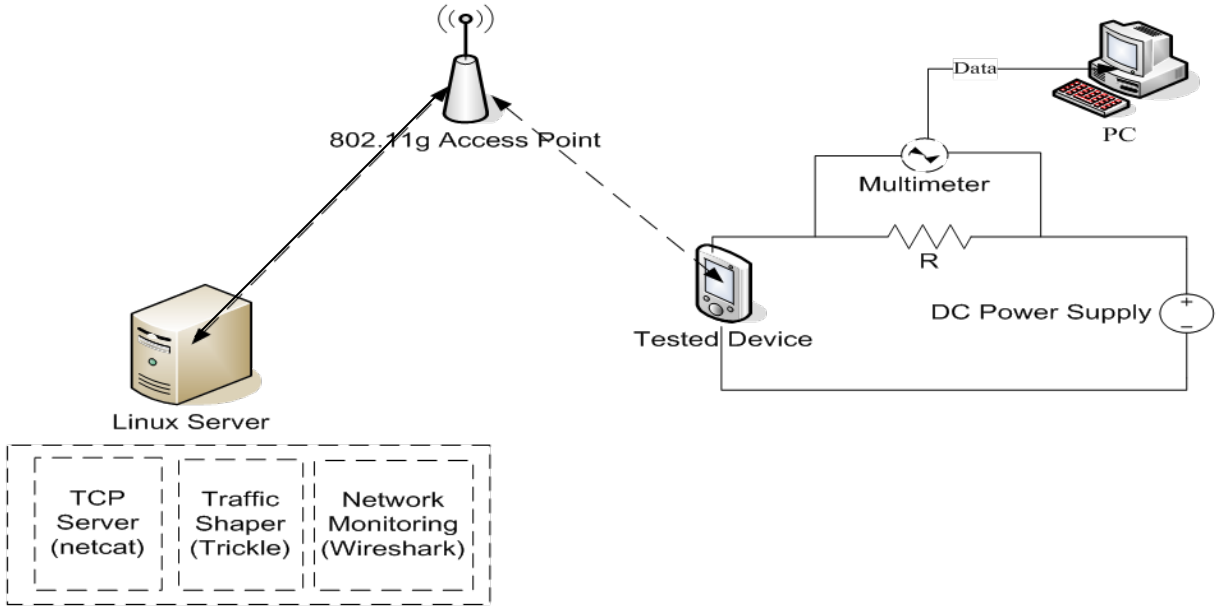
- The number of TCP flows: n
- The aggregate TCP throughput : $\sum_{i}^{n} r_i$
- The throughput of the i^{th} flow: r_i

TCP download Power consumption:

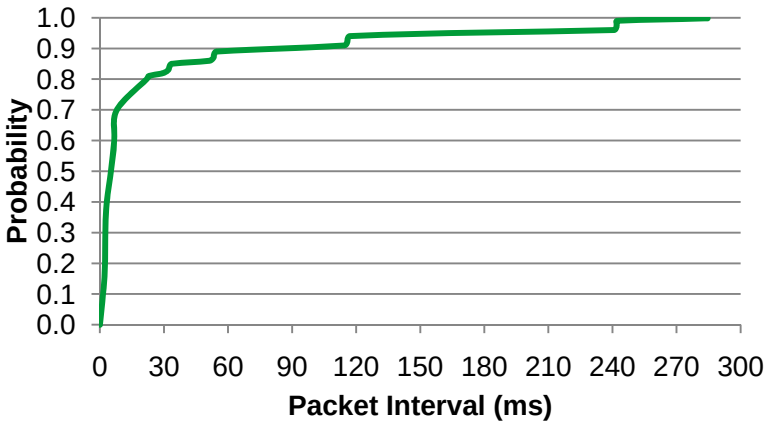
- Replace the r_d with $\sum_{i}^{n} r_i$

Validation

- Experimental Setup



Internet flow characteristics



	Nokia N810	HTC G1	Nokia N95
Downlink burst size (KB)	4	4	4
Downlink burst duration (ms)	8	10	10
Uplink burst duration (ms)	0.5	0.5	0.35

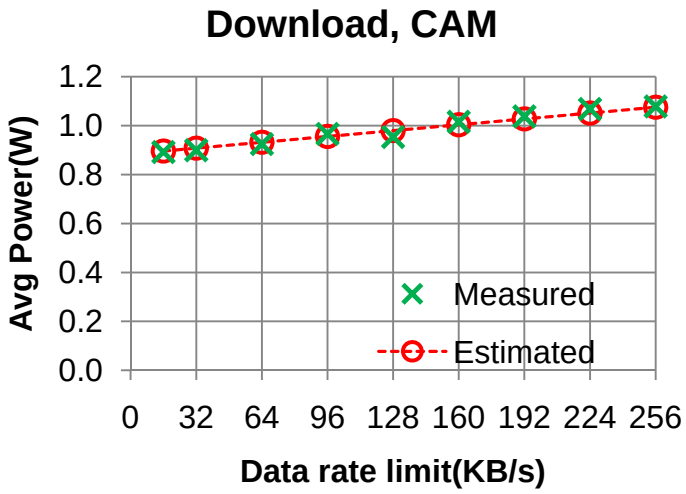
	Nokia N810	HTC G1	Nokia N95
Uplink burst size (KB)	4	4	4
Uplink burst duration (ms)	6	8	12
Downlink burst duration (ms)	0.1	0.1	0.2

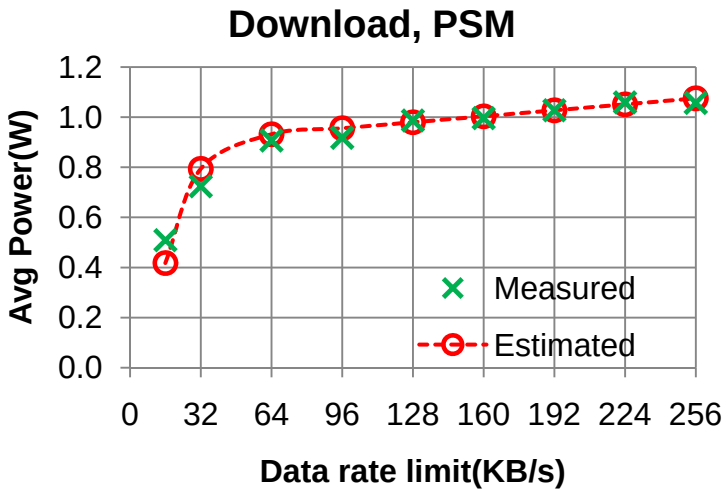
WNI operating mode

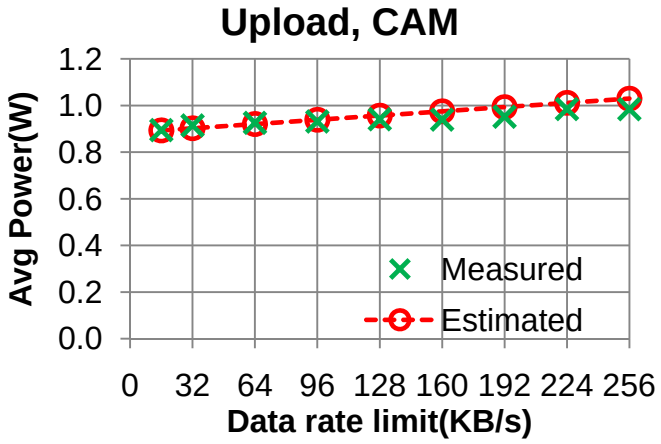
- Power consumption in different operating mode

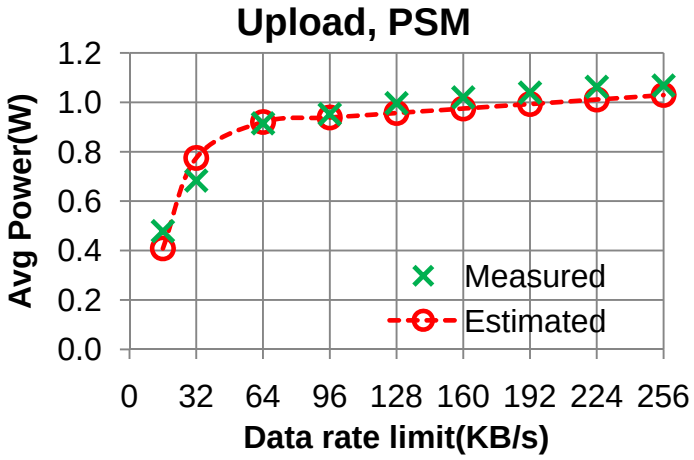
WNI operating mode	Average Power (W)		
	Nokia N810	HTC G1	Nokia N95
IDLE	0.884	0.650	1.038
SLEEP	0.042	0.068	0.088
TRANSMIT	1.258	1.097	1.687
RECEIVE	1.181	0.900	1.585

Nokia N810

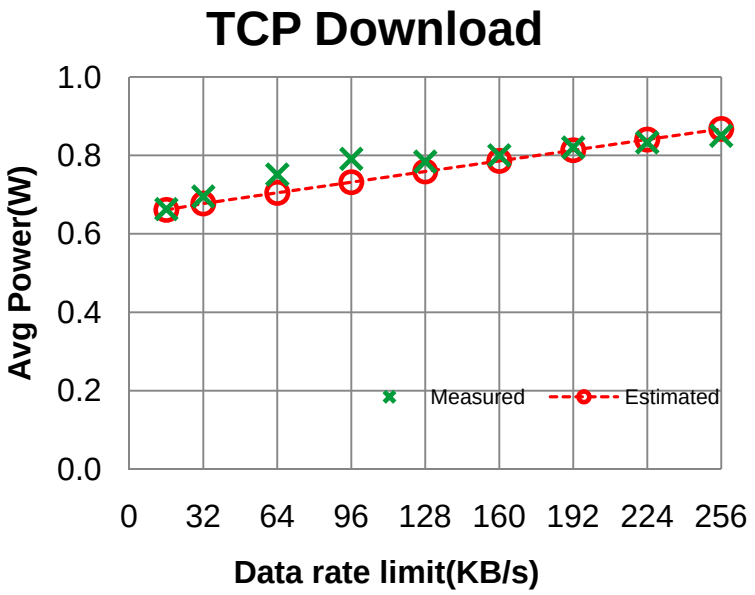

Download, CAM
Avg Power(W)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)
Measured
Estimated

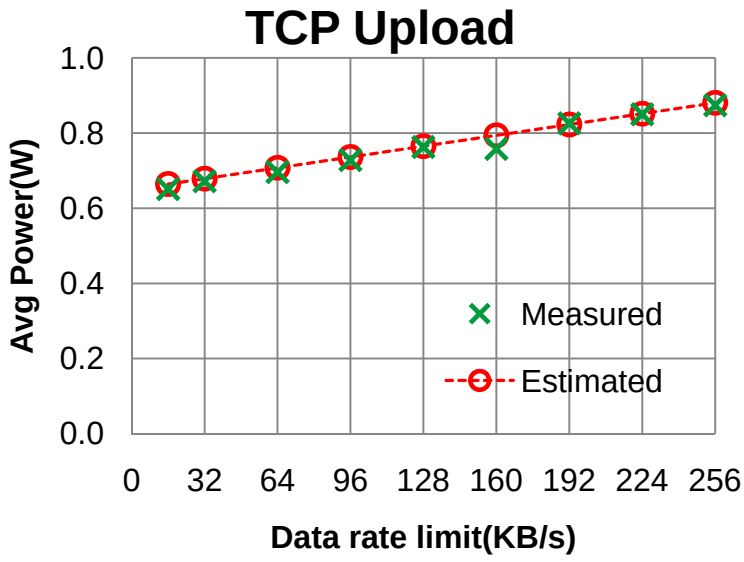

Download, PSM
Avg Power(W)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)
Measured
Estimated


Upload, CAM
Avg Power(W)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)
Measured
Estimated

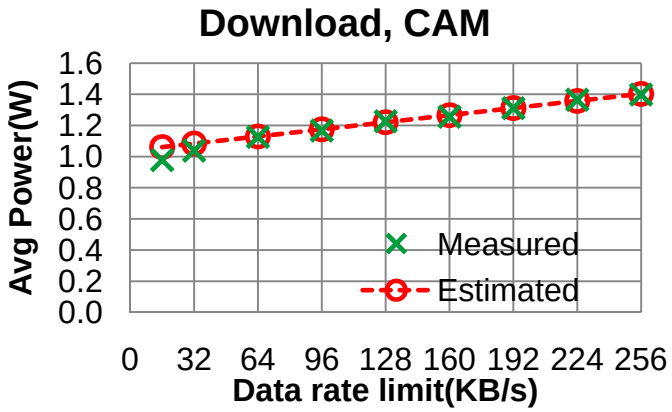

Upload, PSM
Avg Power(W)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)
Measured
Estimated

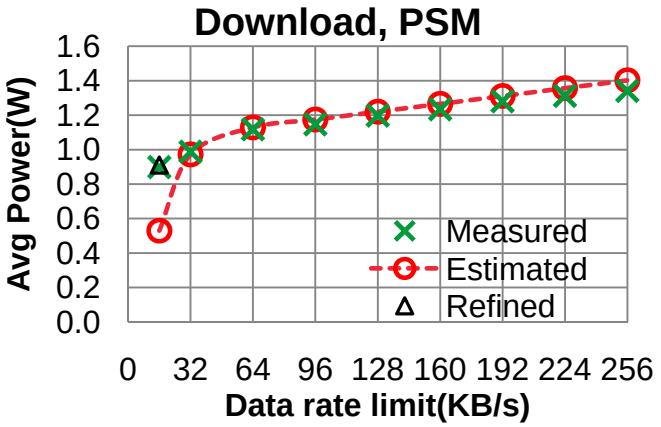
HTC G1

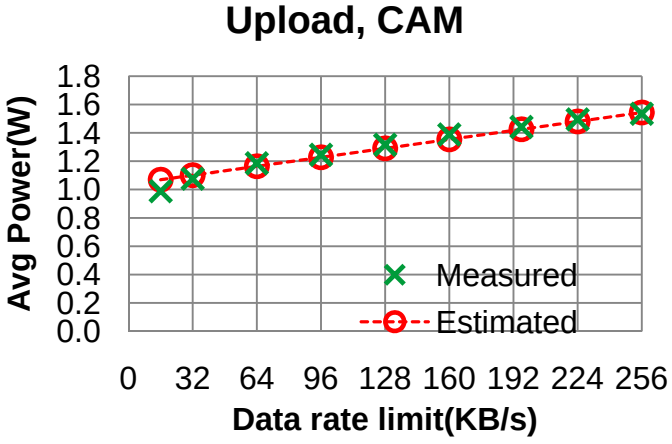

TCP Download
Avg Power(W)
1.0
0.8
0.6
0.4
0.2
0.0
0
32
64
96
128
160
192
224
256
Data rate limit(KB/s)
Measured
Estimated

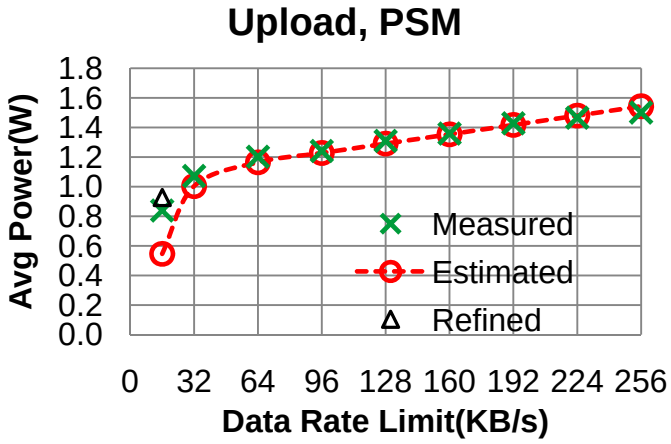

TCP Upload
Avg Power(W)
1.0
0.8
0.6
0.4
0.2
0.0
0
32
64
96
128
160
192
224
256
Data rate limit(KB/s)
Measured
Estimated

Nokia N95


Download, CAM
Avg Power(W)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Estimated
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)

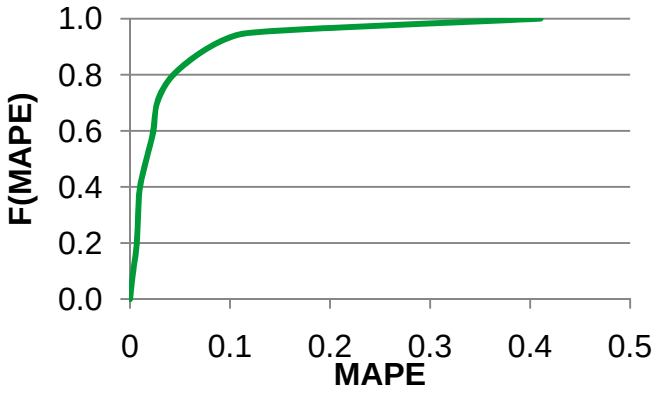

Download, PSM
Avg Power(W)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Estimated
Refined
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)


Upload, CAM
Avg Power(W)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Estimated
0 32 64 96 128 160 192 224 256
Data rate limit(KB/s)


Upload, PSM
Avg Power(W)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Estimated
Refined
0 32 64 96 128 160 192 224 256
Data Rate Limit(KB/s)

Accuracy

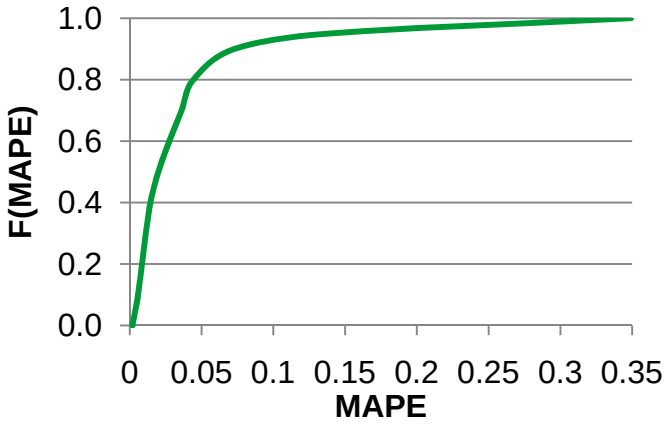
- Download cases



MAE: less than 0.068394W

MAPE: less than 6.7724%.

- Upload cases



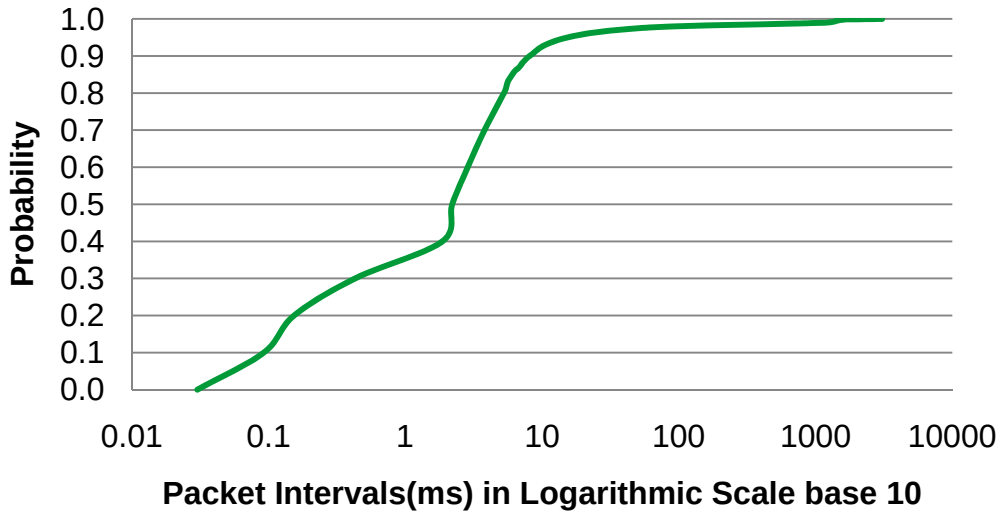
MAE: less than 0.055923W

MAPE: less than 5.7599%

Runtime Power Estimation

- YouTube

File size: 8.9MB
Average data rate: 33.5KB/s
Measured: 276.433 J
Estimated: 245.888
MAPE: 11%



Discussion and Future Work

- Runtime Power Estimation
- Network simulation
- Energy-efficient network transmission

Conclusion

Usage of WNI → Internet flow characteristics (e.g. network throughput)

Traffic pattern (e.g. Burstiness)

WNI operating mode → 802.11 Power Saving Mode

Thank you! Questions?

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