# Ubiquitous and Mobile Computing CS 528: Empowering Developers to Estimate App Energy Consumption


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# Introduction of Background

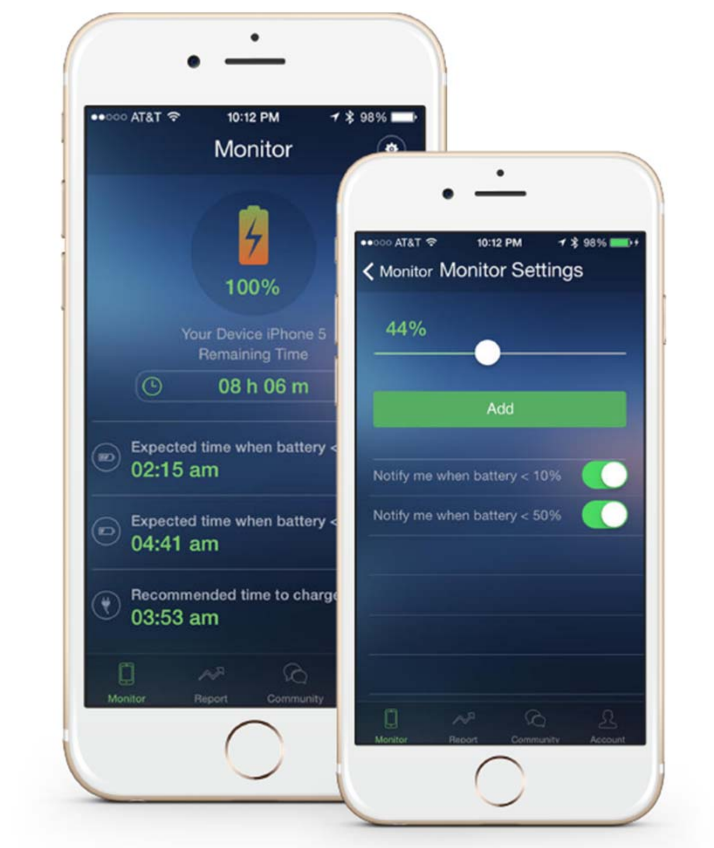
- Why it is important to estimate App energy consumption?

Pooly written app: consume 30%-40% phone's battery

Critical performance  and user experience
 metric

- What factors affect the battery life?

network congestion
choice of mobile operator
user settings for screen brightness



# Method to Improve Battery Life

- Higher battery density
- Dedicated low power processors

→ Platform layer improvements

- Optimizing the battery impact of background OS service
  ------->OS designers' task
- **Optimizing the battery impact of interactive foreground apps (significant portion of battery is used here)**
  -------> app developpers' task
  power meter to measure the energy
  "battery use"tool : nokia energy profiler(NEP) / eProf

# Related Work

- Power Scope:tracks the application with the active context on the processor and measure the power
- eProf:traces system calls made by applications and uses power state models for various components to infer energy used.
- TOSSIM
- OLED/LCD Model

# Introduction of WattsOn

- identify engergy hungry segments during the app run.
- determine which component(display, network or CPU) consumes the most energy.

Emulates the display, network, CPU only

Dominant energy consumers, consuming 800-1500mW

Others like GPU(250-350mW)and A-GPS(160-350mW)

--small fraction

# WattsOn System

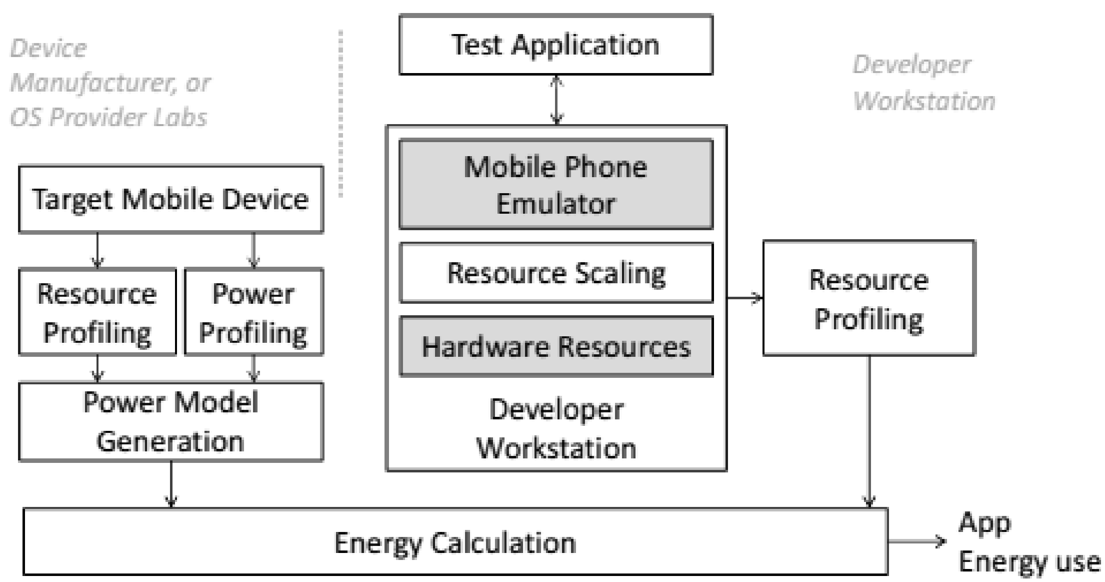
- It is the first system that can estimate app engergy consumption in different operating options.
- Enable to be profiled within the  development environment without requiring  a specific mobile device.
- Expand the catelogue of power models available for mobile devices.
- Validate WattsOn  with multiple applications, devices, network, carrier. 4%-9% error.

# WattsOn System Design

- Two major techniques

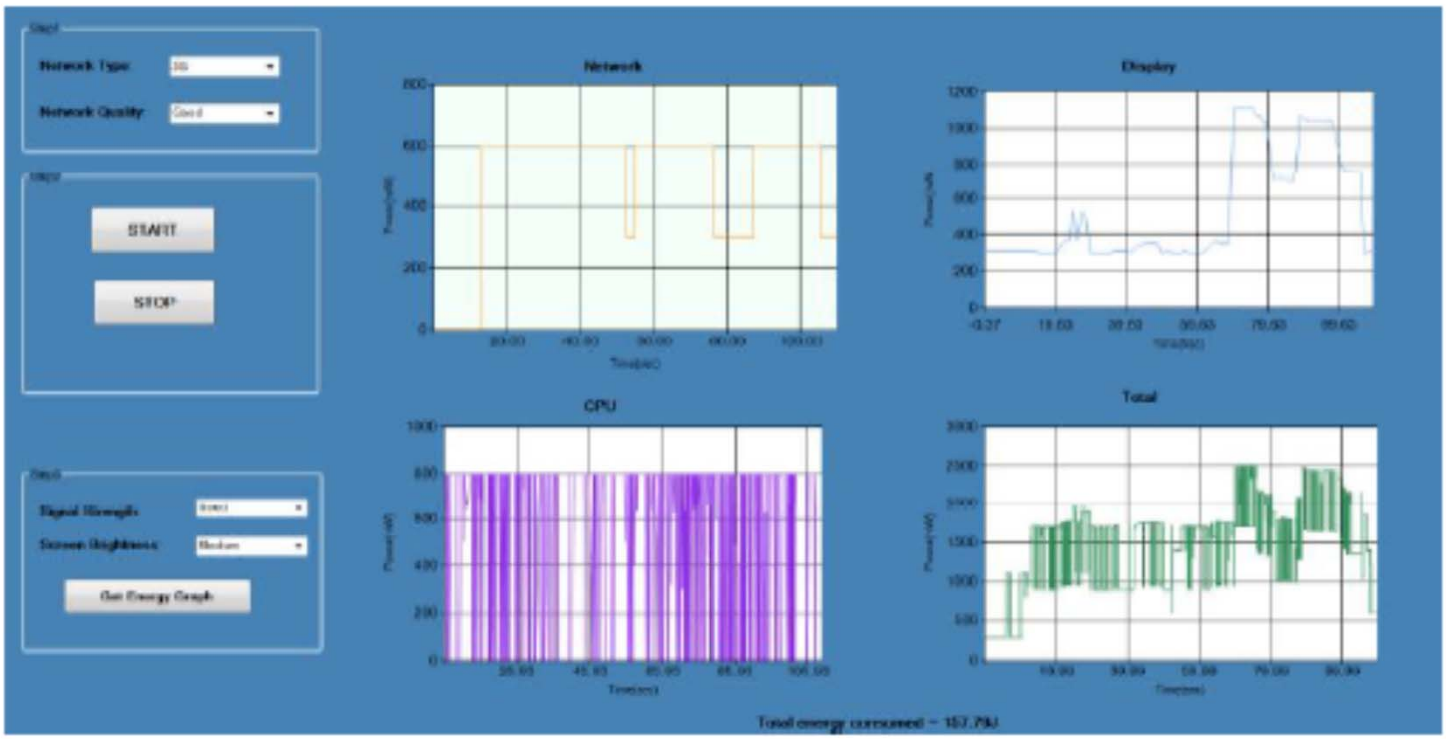
1) power modeling

2)resource scaling



# WattsOn System Implementation

- The input encapsulated into XML file, energy use across multiple devices emulation.
- 1) A time series of power consumed for every component.
- 2)The total energy consumed.
- http://www.logicpd.com/products/software/wattson/



# Cellular Network(3G)

- Resource scaling

1)Virtual Clock: simply record time in ticks

2)Trace Stretching: capture the packet activity over the high speed network and stretch the timing characteristic to match those on the lower speed link.

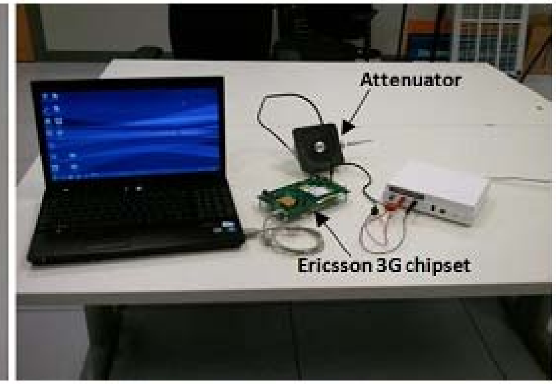
**3)Link Shaping**: shape the network link bandwidth,latency and loss.

layer 2.3(between IP and MAC layer)

distribution based model

# Cellular Network(3G)

- Power Modeling


ARO model

tail time: active state(DCH) intermediate state (FACH) powered intermediate state (PCH)

| Signal Strength | DCH (mW) | FACH (mW) |
|---|---|---|
| High | 600 | 300 |
| Medium | 800 | 300 |
| Low | 1500 | 400 |

**Table 2: Cellular interface power variation with signal strength for the AT&T network.**

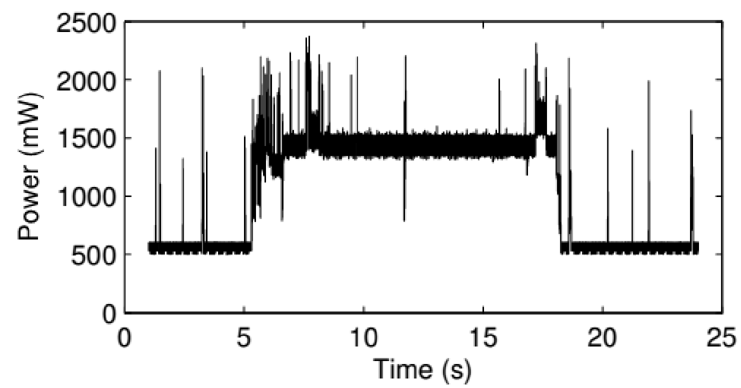



**Figure 3: Network tail energy measurement for Sprint. The data communication ends near time = 7s along the x-axis but the radio stays in a higher power state for an additional 10 seconds after that.**

# WIFI Network

- Resource scaling

Not needed or the same with cellular network

- Power model

Use PSM model(contains 4 states)

Deep sleep(10 mW)

Light sleep(120 mW)

Idle(400 mW)

High(600 mW)

# Display

- Emulators alreday provide resource scaling
- Power Model

Prior work has provided power models for LCD and OLED.

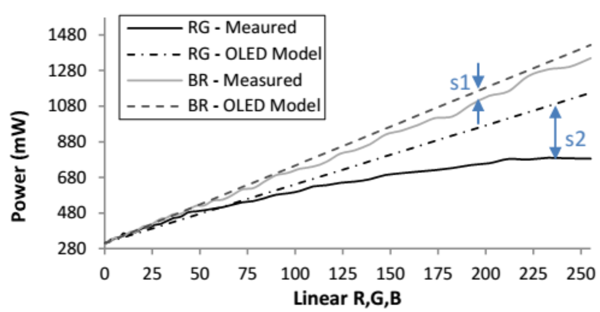
AMOLED : not fit existing model

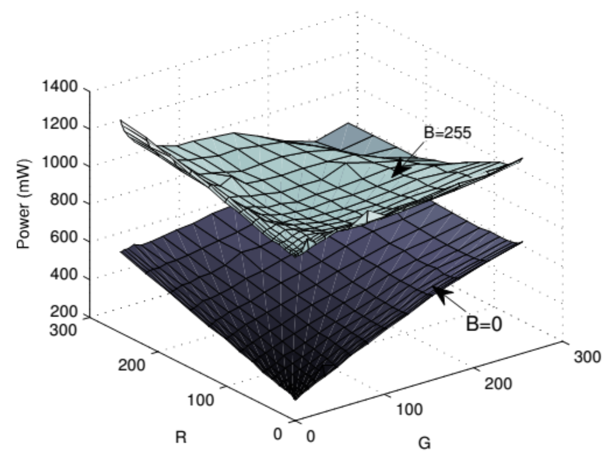
OLED: sum of the energy consumption of R, G, B, linear

AMOLED: both additive and lineariry properties break down

not only depends on the area

but also varies by color



# Display

- Power model

Use a look up table

16 color magnitudes per component

16*16*16 entries contain power value

$$P_{display} = \beta(\mathbf{s}) * L(\mathbf{s}) + (1 - \beta(\mathbf{s})) * O(\mathbf{s})$$

# CPU

- Resource Scaling

detailed cycle-accurate simulation--->impratical

Scale down the performance by restricting the processor cycles available for the movile device emulator.

Mobile device processor:(SAMSUNG) 1GHz Scorping CPU 100%

Development machine: 2.7GHz Intel core-2 Quad core processor. 13.8%/core

Slow down:7.2

- Power model

$$P_{cpu} = \alpha * u_{cpu}$$

# Performance Evaluation

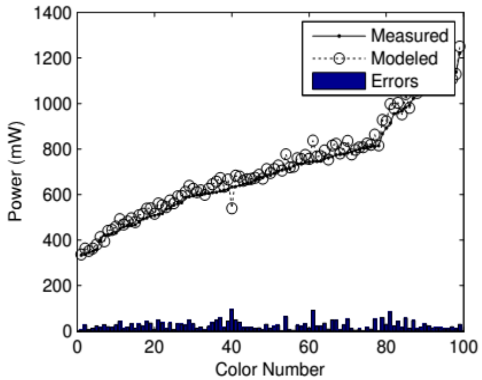



**Figure 8: Testing the AMOLED display power model with 100 random colors.**

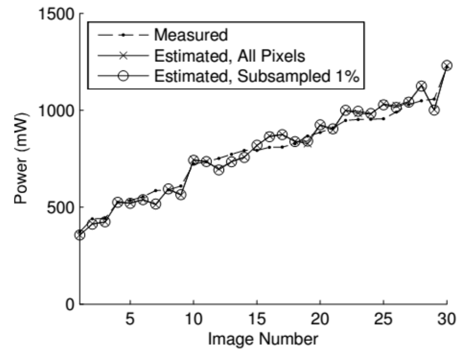



**Figure 9: Measured and emulated energy for Application 1, with 30 different images. Images are sorted by the measured energy used.**

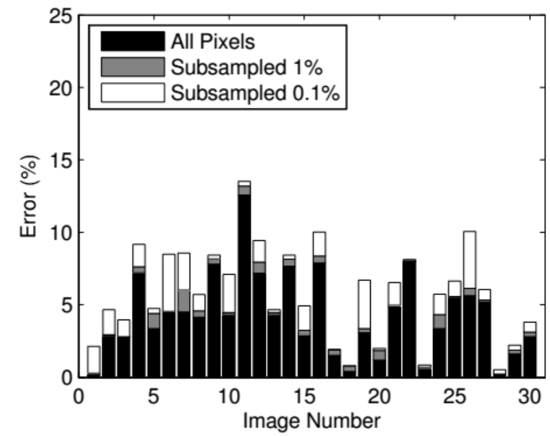



**Figure 10: Display model error when all pixels are considered, or only 1% or 0.1% of the pixels are considered.**

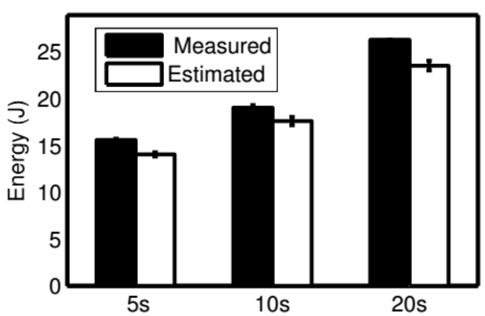



**Figure 12: Experimental evaluation of emulation accuracy for Application 2.**

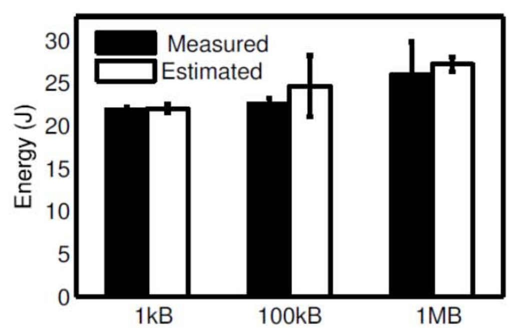



**Figure 14: Estimated and measured energy for Application 3 with varying download sizes.**

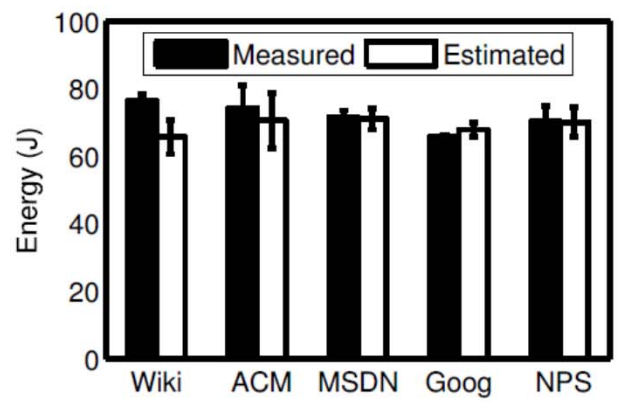



**Figure 15: Accuracy evaluation for Application 4.**

# Case study

- Image dose not help save energy
- The displaying is consuming the largest
- CPU energy consumption of the third is the highest


Figure 16: Sample images considered for an app.

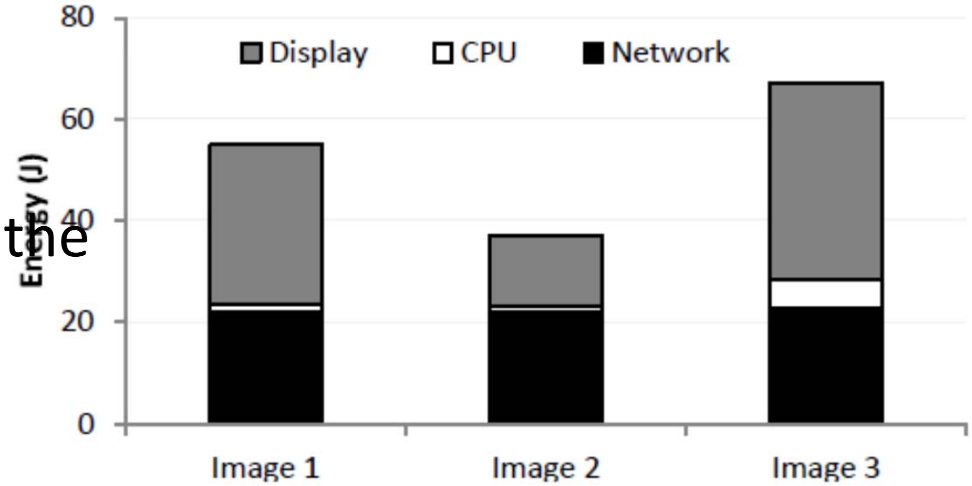



Figure 17: Energy breakdown into multiple components.

# Conclusion and Future Work

- Present a system to estimate energy consumption.
- Use feedback to write more energy efficient app.
- Test the app's energy consumption under various scenarios and operating conditions.
- Obtain the measurements from the wild.
- Augment power models with real measurements data.

# References


[1] A. Balasubramanian, R. Mahajan, and A. Venkataramani. Augmenting mobile 3g using wifi. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 209–222, 2010.

[2] D. Brooks, V. Tiwari, and M. Martonosi. Wattch: a framework for architectural-level power analysis and optimizations. In *ISCA*, pages 83–94, 2000.

[3] T. L. Cignetti, K. Komarov, and C. S. Ellis. Energy estimation tools for the palm. In *Proceedings of the 3rd ACM international workshop on Modeling, analysis and simulation of wireless and mobile systems*, MSWIM '00, pages 96–103, 2000.

[4] M. Dong, Y.-S. K. Choi, and L. Zhong. Power modeling of graphical user interfaces on oled displays. In *Proceedings of the 46th Annual Design Automation Conference*, DAC '09, pages 652–657, 2009.

[5] M. Dong and L. Zhong. Chameleon: a color-adaptive web browser for mobile oled displays. In *Proceedings of the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 85–98, 2011.

[6] M. Dong and L. Zhong. Self-constructive high-rate system energy modeling for battery-powered mobile systems. In *Proceedings of the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 335–348, 2011.

[7] J. Flinn and M. Satyanarayanan. Powerscope: A tool for profiling the energy usage of mobile applications. In *Proceedings of the Second IEEE Workshop on Mobile Computer Systems and Applications*, WMCSA '99, pages 2–, 1999.

[8] R. Fonseca, P. Dutta, P. Levis, and I. Stoica. Quanto: tracking energy in networked embedded systems. In *Proceedings of the 8th USENIX conference on Operating systems design and implementation*, OSDI'08, pages 323–338, Berkeley, CA, USA, 2008. USENIX Association.

[9] J. Huang, Q. Xu, B. Tiwana, Z. M. Mao, M. Zhang, and P. Bahl. Anatomizing application performance differences on smartphones. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 165–178, 2010.

[10] S. Jha. Poorly written apps can sap 30 to 40% of a phone's juice., June 2011. CEO, Motorola Mobility, Bank of America Merrill Lynch 2011 Technology Conference.

[11] H. V. Madhyastha, T. Anderson, A. Krishnamurthy, N. Spring, and A. Venkataramani. A structural approach to latency prediction. In *Proceedings of the 6th ACM SIGCOMM Conference on Internet Measurement*, IMC '06, 2006.

[12] J. Manweiler, S. Agarwal, M. Zhang, R. Roy Choudhury, and P. Bahl. Switchboard: a matchmaking system for multiplayer mobile games. In *Proceedings of the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 71–84, 2011.

[13] J. Manweiler and R. Roy Choudhury. Avoiding the rush hours: Wifi energy management via traffic isolation. In *Proceedings of the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 253–266, 2011.

[14] J. C. McCullough, Y. Agarwal, J. Chandrashekar, S. Kuppuswamy, A. C. Snoeren, and R. K. Gupta. Evaluating the effectiveness of model-based power characterization. In *Proceedings of the 2011 USENIX annual technical conference*, USENIXATC'11, pages 12–12, 2011.

[15] A. Pathak, Y. C. Hu, M. Zhang, P. Bahl, and Y.-M. Wang. Fine-grained power modeling for smartphones using system call tracing. In *Proceedings of the sixth conference on Computer systems*, EuroSys '11, pages 153–168, 2011.

[16] Qemu: open source processor emulator. http://wiki.qemu.org/Main_Page.

[17] F. Qian, Z. Wang, A. Gerber, Z. Mao, S. Sen, and O. Spatscheck. Profiling resource usage for mobile applications: a cross-layer approach. In *Proceedings of International Conference on Mobile Systems, Applications, and Services*, MobiSys '11, pages 321–334, 2011.

[18] F. Qian, Z. Wang, A. Gerber, Z. M. Mao, S. Sen, and O. Spatscheck. Characterizing radio resource allocation for 3g networks. In *Proceedings of the 10th annual conference on Internet measurement*, IMC '10, pages 137–150, 2010.

[19] M.-R. Ra, J. Paek, A. B. Sharma, R. Govindan, M. H. Krieger, and M. J. Neely. Energy-delay tradeoffs in smartphone applications. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 255–270, 2010.

[20] S. Rivoire, P. Ranganathan, and C. Kozyrakis. A comparison of high-level full-system power models. In *Proceedings of the 2008 conference on Power aware computing and systems*, HotPower'08, pages 3–3, 2008.

[21] A. Schulman, V. Navda, R. Ramjee, N. Spring, P. Deshpande, C. Grunewald, K. Jain, and V. N. Padmanabhan. Bartendr: a practical approach to energy-aware cellular data scheduling. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 85–96, 2010.

[22] V. Shnayder, M. Hempstead, B.-r. Chen, G. W. Allen, and M. Welsh. Simulating the power consumption of large-scale sensor network applications. In *Proceedings of the 2nd international conference on Embedded networked sensor systems*, SenSys '04, pages 188–200, 2004.

[23] W. L. Tan, F. Lam, and W. C. Lau. An empirical study on the capacity and performance of 3g networks. *IEEE Transactions on Mobile Computing*, 7:737–750, June 2008.

[24] H. Zeng, C. S. Ellis, A. R. Lebeck, and A. Vahdat. Ecosystem: managing energy as a first class operating system resource. In *Proceedings of the 10th international conference on Architectural support for programming languages and operating systems*, ASPLOS-X, pages 123–132, 2002.

[25] L. Zhang, B. Tiwana, Z. Qian, Z. Wang, R. P. Dick, Z. M. Mao, and L. Yang. Accurate online power estimation and automatic battery behavior based power model generation for smartphones. In *Proceedings of the eighth IEEE/ACM/IFIP international conference on Hardware/software codesign and system synthesis*, CODES/ISSS '10, pages 105–114, 2010.

[26] X. Zhao, Y. Dong, H. tao Zhao, Z. Hui, J. Li, and C. Sheng. A real-time congestion control mechanism for multimedia transmission over 3g wireless networks. In *Communication Technology (ICCT), 2010 12th IEEE International Conference on*, pages 1236 –1239, nov. 2010.

# Thank you for your attention.

- Any questions?