Energy-efficient and Cross-layer Networking in Mobile MIMO-OFDM Systems

Yongsen Ma
Shanghai Jiao Tong University
Email: mayongsen@gmail.com

I. STATEMENT OF PURPOSE

The wireless networks such as LTE, WiMAX, WLAN have experienced rapid development in recent years, which leads to the increase of traffic loads and users requirements. The wide expansion of wireless services has brought serious challenges to the issues of spectrum efficiency.

As demand for more powerful hardware, more advanced software, and constant data connections grows larger, the need for a more efficient and longer lasting mobile battery is becoming increasingly vital to the future of the industry.

A. Traffic Requirements

B. Spectrum Efficiency

C. Energy Efficiency

II. RESEARCH QUESTIONS

These should be framed as questions, or hypotheses. They should not be statements or descriptions. Here are some examples for phrasing questions:
- What are the major determinants of women's success in the job market?
- Why are there variations in women's earnings across three provinces?
- What does the changing role of gender play in early 20th century Chinese fictions?
1) System level
2) Protocol level

III. LITERATURE REVIEW

Say how other scholars have tried to answer the questions that you mention above. The literature review must be relevant to the questions you are asking. For example, if you want to know how women's lives have changed as a result of starting a business in China, you do not need to review all the literature on China's political and economic reforms. Instead, you want to locate the literature on how women's lives are affected by the development of market economies.

IV. STATEMENT OF SIGNIFICANCE

Think about the overall implications of your work. Look beyond how undertaking the degree will help you personally. PhD or MPhil theses may have several implications. Consider the following:
1) They may contribute to a body of academic literature. They may, for instance, advance a neglected theoretical position.
2) They may have practical or policy implications. For example, they may change the way that a certain group of people practice their occupation, handle their clients or deal with their work.
3) They may make a political statement or a cultural critic. They may point to an injustice, an inequality, or a contradiction.

But be realistic. It is not realistic to claim that your work will, say, transform the educational system in Hong Kong. It may be realistic, however, to say that your thesis will help explain why students often fail to live up to teachers' expectations.
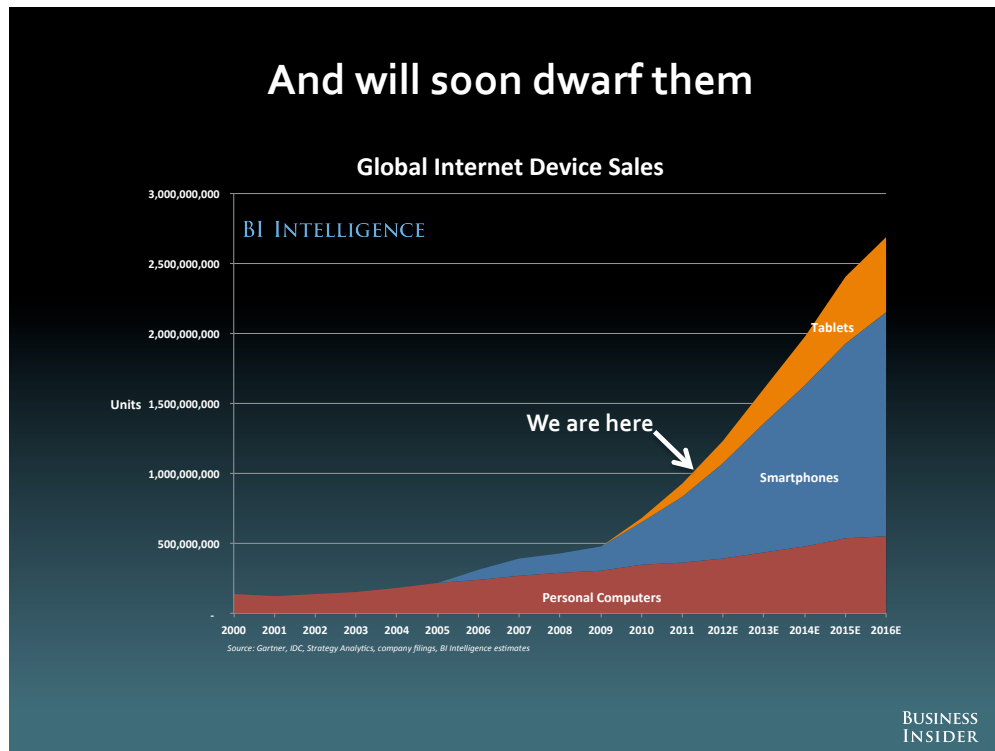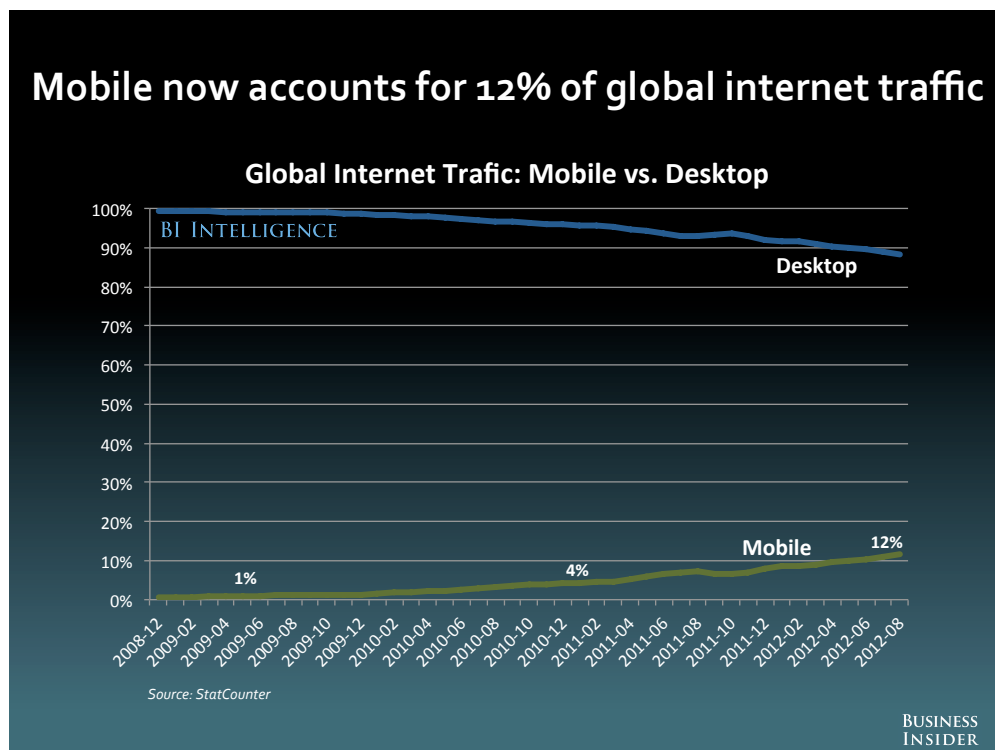
Fig. 1.   Global Internet Device Sales.

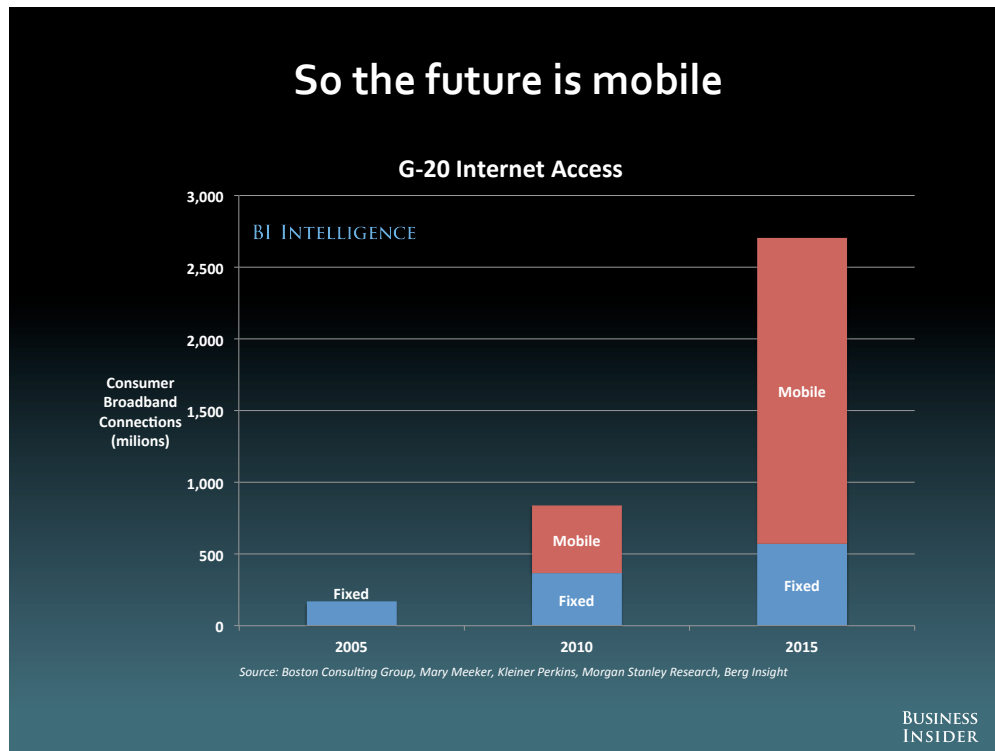Fig. 2.   Global Internet Traffic: Mobile vs. Desktop.

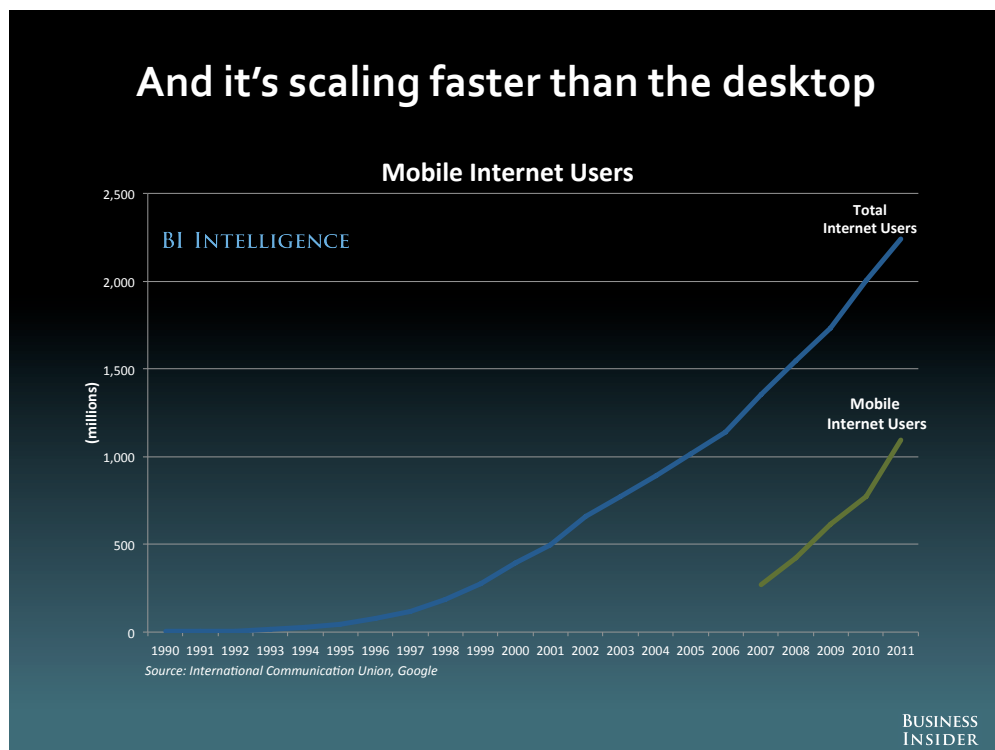Fig. 3.   Internet Access: Mobile vs. Fixed.

Fig. 4.   Mobile Internet Users.

V. RESEARCH METHODOLOGY

Research methodology concerns the manner by which data are collected. Documentation, observation, in-depth interview, survey, and statistical data are the main methods of data collection in the social sciences.

Your methodology must be appropriate to the questions you are asking. That is, you must show how the methods you use will answer the questions you are asking. If you want to study recreational drug use in Hong Kong, for example, it would not be appropriate to study only youth in your housing estate who do not take drugs.

Further, your methodology must be feasible. A proposal to interview workers from 500 factories in Shenzhen is not feasible–in the time that you have to complete the degree. It may, however, be feasible to interview workers from ten factories, or obtain production statistics from 500 enterprises.

Finally, your methodology must be detailed. For example, if you plan to do a survey, how many people do you plan to include in your sample? And how will you decide which people to sample?

REFERENCES

[1] E. Aryafar, N. Anand, T. Salonidis, and E. W. Knightly. Design and experimental evaluation of multi-user beamforming in wireless lans. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 197–208, New York, NY, USA, 2010. ACM.

[2] E. Aryafar, M. A. Khojastepour, K. Sundaresan, S. Rangarajan, and M. Chiang. Midu: enabling mimo full duplex. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 257–268, New York, NY, USA, 2012. ACM.

[3] H. V. Balan, R. Rogalin, A. Michaloliakos, K. Psounis, and G. Caire. Achieving high data rates in a distributed mimo system. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 41–52, New York, NY, USA, 2012. ACM.

[4] 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, New York, NY, USA, 2010. ACM.

[5] A. Bhartia, Y.-C. Chen, S. Rallapalli, and L. Qiu. Harnessing frequency diversity in wi-fi networks. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 253–264, New York, NY, USA, 2011. ACM.

[6] E. Chai, J. Lee, S.-J. Lee, R. Etkin, and K. G. Shin. Building efficient spectrum-agile devices for dummies. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 149–160, New York, NY, USA, 2012. ACM.

[7] J. I. Choi, M. Jain, K. Srinivasan, P. Levis, and S. Katti. Achieving single channel, full duplex wireless communication. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 1–12, New York, NY, USA, 2010. ACM.

[8] F. R. Dogar, P. Steenkiste, and K. Papagiannaki. Catnap: exploiting high bandwidth wireless interfaces to save energy for mobile devices. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 107–122, New York, NY, USA, 2010. ACM.

[9] 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, New York, NY, USA, 2011. ACM.

[10] H. Falaki, R. Mahajan, S. Kandula, D. Lymberopoulos, R. Govindan, and D. Estrin. Diversity in smartphone usage. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 179–194, New York, NY, USA, 2010. ACM.

[11] P. X. Gao, A. R. Curtis, B. Wong, and S. Keshav. It's not easy being green. In *Proceedings of the ACM SIGCOMM 2012 conference on Applications, technologies, architectures, and protocols for computer communication*, SIGCOMM '12, pages 211–222, New York, NY, USA, 2012. ACM.

[12] S. Gollakota, F. Adib, D. Katabi, and S. Seshan. Clearing the rf smog: making 802.11n robust to cross-technology interference. In *Proceedings of the ACM SIGCOMM 2011 conference*, SIGCOMM '11, pages 170–181, New York, NY, USA, 2011. ACM.

[13] E. Goma, M. Canini, A. Lopez Toledo, N. Laoutaris, D. Kostić, P. Rodriguez, R. Stanojević, and P. Yagüe Valentin. Insomnia in the access: or how to curb access network related energy consumption. In *Proceedings of the ACM SIGCOMM 2011 conference*, SIGCOMM '11, pages 338–349, New York, NY, USA, 2011. ACM.

[14] A. Gudipati and S. Katti. Strider: automatic rate adaptation and collision handling. In *Proceedings of the ACM SIGCOMM 2011 conference*, SIGCOMM '11, pages 158–169, New York, NY, USA, 2011. ACM.

[15] D. Halperin, W. Hu, A. Sheth, and D. Wetherall. Predictable 802.11 packet delivery from wireless channel measurements. In *Proceedings of the ACM SIGCOMM 2010 conference*, SIGCOMM '10, pages 159–170, New York, NY, USA, 2010. ACM.

[16] H. Han, Y. Liu, G. Shen, Y. Zhang, and Q. Li. Dozyap: power-efficient wi-fi tethering. In *Proceedings of the 10th international conference on Mobile systems, applications, and services*, MobiSys '12, pages 421–434, New York, NY, USA, 2012. ACM.

[17] S. S. Hong, J. Mehlman, and S. Katti. Picasso: flexible rf and spectrum slicing. In *Proceedings of the ACM SIGCOMM 2012 conference on Applications, technologies, architectures, and protocols for computer communication*, SIGCOMM '12, pages 37–48, New York, NY, USA, 2012. ACM.

[18] J. Huang, F. Qian, A. Gerber, Z. M. Mao, S. Sen, and O. Spatscheck. A close examination of performance and power characteristics of 4g lte networks. In *Proceedings of the 10th international conference on Mobile systems, applications, and services*, MobiSys '12, pages 225–238, New York, NY, USA, 2012. ACM.

[19] 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, New York, NY, USA, 2010. ACM.

[20] M. Jain, J. I. Choi, T. Kim, D. Bharadia, S. Seth, K. Srinivasan, P. Levis, S. Katti, and P. Sinha. Practical, real-time, full duplex wireless. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 301–312, New York, NY, USA, 2011. ACM.

[21] R. Keralapura, A. Nucci, Z.-L. Zhang, and L. Gao. Profiling users in a 3g network using hourglass co-clustering. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 341–352, New York, NY, USA, 2010. ACM.

[22] K.-H. Kim, A. W. Min, and K. G. Shin. Sybot: an adaptive and mobile spectrum survey system for wifi networks. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 293–304, New York, NY, USA, 2010. ACM.

[23] M. B. Kjæ rgaard, S. Bhattacharya, H. Blunck, and P. Nurmi. Energy-efficient trajectory tracking for mobile devices. In *Proceedings of the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 307–320, New York, NY, USA, 2011. ACM.

[24] C.-Y. Li, C. Peng, S. Lu, and X. Wang. Energy-based rate adaptation for 802.11n. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 341–352, New York, NY, USA, 2012. ACM.

[25] K. Lin, A. Kansal, D. Lymberopoulos, and F. Zhao. Energy-accuracy trade-off for continuous mobile device location. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 285–298, New York, NY, USA, 2010. ACM.

[26] K. C.-J. Lin, S. Gollakota, and D. Katabi. Random access heterogeneous mimo networks. In *Proceedings of the ACM SIGCOMM 2011 conference*, SIGCOMM '11, pages 146–157, New York, NY, USA, 2011. ACM.

[27] Y. Ma and S. Banerjee. A smart pre-classifier to reduce power consumption of tcams for multi-dimensional packet classification. In *Proceedings of the ACM SIGCOMM 2012 conference on Applications, technologies, architectures, and protocols for computer communication*, SIGCOMM '12, pages 335–346, New York, NY, USA, 2012. ACM.

[28] E. Magistretti, K. K. Chintalapudi, B. Radunovic, and R. Ramjee. Wifi-nano: reclaiming wifi efficiency through 800 ns slots. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 37–48, New York, NY, USA, 2011. ACM.

[29] E. Magistretti, O. Gurewitz, and E. Knightly. Inferring and mitigating a link's hindering transmissions in managed 802.11 wireless networks. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 305–316, New York, NY, USA, 2010. ACM.

[30] 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, New York, NY, USA, 2011. ACM.

[31] R. Mittal, A. Kansal, and R. Chandra. Empowering developers to estimate app energy consumption. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 317–328, New York, NY, USA, 2012. ACM.

[32] S. Nath. Ace: exploiting correlation for energy-efficient and continuous context sensing. In *Proceedings of the 10th international conference on Mobile systems, applications, and services*, MobiSys '12, pages 29–42, New York, NY, USA, 2012. ACM.

[33] N. P. Nguyen, T. N. Dinh, S. Tokala, and M. T. Thai. Overlapping communities in dynamic networks: their detection and mobile applications. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 85–96, New York, NY, USA, 2011. ACM.

[34] J. Paek, J. Kim, and R. Govindan. Energy-efficient rate-adaptive gps-based positioning for smartphones. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 299–314, New York, NY, USA, 2010. ACM.

[35] J. Paek, K.-H. Kim, J. P. Singh, and R. Govindan. Energy-efficient positioning for smartphones using cell-id sequence matching. In *Proceedings of the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 293–306, New York, NY, USA, 2011. ACM.

[36] A. Pathak, A. Jindal, Y. C. Hu, and S. P. Midkiff. What is keeping my phone awake?: characterizing and detecting no-sleep energy bugs in smartphone apps. In *Proceedings of the 10th international conference on Mobile systems, applications, and services*, MobiSys '12, pages 267–280, New York, NY, USA, 2012. ACM.

[37] I. Pefkianakis, Y. Hu, S. H. Wong, H. Yang, and S. Lu. Mimo rate adaptation in 802.11n wireless networks. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, MobiCom '10, pages 257–268, New York, NY, USA, 2010. ACM.

[38] C. Peng, S.-B. Lee, S. Lu, H. Luo, and H. Li. Traffic-driven power saving in operational 3g cellular networks. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 121–132, New York, NY, USA, 2011. ACM.

[39] L. Popa, G. Kumar, M. Chowdhury, A. Krishnamurthy, S. Ratnasamy, and I. Stoica. Faircloud: sharing the network in cloud computing. In *Proceedings of the ACM SIGCOMM 2012 conference on Applications, technologies, architectures, and protocols for computer communication*, SIGCOMM '12, pages 187–198, New York, NY, USA, 2012. ACM.

[40] 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 the 9th international conference on Mobile systems, applications, and services*, MobiSys '11, pages 321–334, New York, NY, USA, 2011. ACM.

[41] 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, New York, NY, USA, 2010. ACM.

[42] H. S. Rahul, S. Kumar, and D. Katabi. Jmb: scaling wireless capacity with user demands. In *Proceedings of the ACM SIGCOMM 2012 conference on Applications, technologies, architectures, and protocols for computer communication*, SIGCOMM '12, pages 235–246, New York, NY, USA, 2012. ACM.

[43] S. Rayanchu, V. Shrivastava, S. Banerjee, and R. Chandra. Fluid: improving throughputs in enterprise wireless lans through flexible channelization. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 1–12, New York, NY, USA, 2011. ACM.

[44] E. Rozner, V. Navda, R. Ramjee, and S. Rayanchu. Napman: network-assisted power management for wifi devices. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 91–106, New York, NY, USA, 2010. ACM.

[45] S. Sanadhya, R. Sivakumar, K.-H. Kim, P. Congdon, S. Lakshmanan, and J. P. Singh. Asymmetric caching: improved network deduplication for mobile devices. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 161–172, New York, NY, USA, 2012. ACM.

[46] 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, New York, NY, USA, 2010. ACM.

[47] W.-L. Shen, Y.-C. Tung, K.-C. Lee, K. C.-J. Lin, S. Gollakota, D. Katabi, and M.-S. Chen. Rate adaptation for 802.11 multiuser mimo networks. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 29–40, New York, NY, USA, 2012. ACM.

[48] C. Shepard, H. Yu, N. Anand, E. Li, T. Marzetta, R. Yang, and L. Zhong. Argos: practical many-antenna base stations. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 53–64, New York, NY, USA, 2012. ACM.

[49] B. Vamanan, G. Voskuilen, and T. N. Vijaykumar. Efficuts: optimizing packet classification for memory and throughput. In *Proceedings of the ACM SIGCOMM 2010 conference*, SIGCOMM '10, pages 207–218, New York, NY, USA, 2010. ACM.

[50] J. Wang, H. Hassanieh, D. Katabi, and P. Indyk. Efficient and reliable low-power backscatter networks. In *Proceedings of the ACM SIGCOMM 2012 conference on Applications, technologies, architectures, and protocols for computer communication*, SIGCOMM '12, pages 61–72, New York, NY, USA, 2012. ACM.

[51] X. Wei, L. Gomez, I. Neamtiu, and M. Faloutsos. Profiledroid: multi-layer profiling of android applications. In *Proceedings of the 18th annual international conference on Mobile computing and networking*, Mobicom '12, pages 137–148, New York, NY, USA, 2012. ACM.

[52] X. Zhang and K. G. Shin. E-mili: energy-minimizing idle listening in wireless networks. In *Proceedings of the 17th annual international conference on Mobile computing and networking*, MobiCom '11, pages 205–216, New York, NY, USA, 2011. ACM.

[53] Z. Zhuang, K.-H. Kim, and J. P. Singh. Improving energy efficiency of location sensing on smartphones. In *Proceedings of the 8th international conference on Mobile systems, applications, and services*, MobiSys '10, pages 315–330, New York, NY, USA, 2010. ACM.

[54] E. Zohar, I. Cidon, and O. O. Mokryn. The power of prediction: cloud bandwidth and cost reduction. In *Proceedings of the ACM SIGCOMM 2011 conference*, SIGCOMM '11, pages 86–97, New York, NY, USA, 2011. ACM.