

with performance degradation due to rate-diversity/fairness and TCP behaviour. On our testbed we have demonstrated that it improves downlink goodput by 400-700 % and enhances user experience by reducing average response time for a request by 30-40 %. We have tested *WiFox* for robustness and have demonstrated that under various test conditions it outperforms the existing WiFi implementations. *WiFox* requires modifications to AP's software only and is adaptive to various traffic loads, making it a suitable candidate for wide scale deployments.

There are few open problems related to design of *WiFox*: exploring relationship between different traffic patterns and appropriate APC variants, characterizing performance of *WiFox* for MIMO based 802.11n APs and developing a priority aware scheduler enabling QoS support. *WiFox* improves the overall network goodput achieved thus we expect it to improve the performance for real time applications also for LAEs. We believe that it should be possible to ensure QoS and support real time applications with appropriate tuning of prioritization parameters and we intend to pursue this direction in future. Our testbed currently supports evaluation for 802.11g only and we plan to further extend our analysis for 802.11n also.

8. ACKNOWLEDGEMENTS

We would like to thank the following people. Our shepherd, Bhaskar Raman, for his helpful feedback, as well as Suman Banerjee, Venkata N. Padmanabhan, Kyunghan Lee for their valuable comments. We would also like to thank Marhn Fullmer for his help in setting up the testbed. This work is supported in part by NSF awards CNS-1016216 and IIS-0910868. Any opinions, findings and conclusions expressed in this work are those of the authors and do not necessarily reflect the views of NSF.

9. REFERENCES

- [1] DummyNet: <http://info.iet.unipi.it/luigi/dummyNet/>.
- [2] MADWIFI Project: <http://madwifi-project.org/>.
- [3] E. Aguilera, J. Casademont, J. Cotrina, and A. Rojas. Perf. enhancement of wlan IEEE 802.11 for asymmetric traffic. In *IEEE PIMRC*, 2005.
- [4] A. Aziz, J. Herzen, R. Merz, S. Shneer, and P. Thiran. Enhance & explore: an adaptive algorithm to maximize the utility of wireless networks. In *International Conference on Mobile computing and networking*, MobiCom '11. ACM, 2011.
- [5] A. Babu, L. Jacob, and V. Brijith. A novel scheme for achieving time based in IEEE 802.11 multirate wireless LANs. In *IEEE ICON*, 2005.
- [6] A. Banchs, P. Serrano, and H. Oliver. Proportional fair throughput allocation in multirate IEEE 802.11 e wireless LANs. *Wireless Networks*, 2007.
- [7] P. Barford and M. Crovella. Generating representative Web workloads for network and server performance evaluation. In *ACM SIGMETRICS Perform. Eval. Rev.*, 1998.
- [8] M. Belshe. More bandwidth doesn't matter (much).
- [9] R. Bruno, M. Conti, and E. Gregori. Design of an enhanced AP to optimize TCP perf. in Wi-Fi hotspot networks. *Wirel. Netw.*, 2007.
- [10] M. Crovella and A. Bestavros. Self-Similarity in www Traffic: Evidence and Possible Causes. *IEEE/ACM ToN*, 5, 1997.
- [11] M. H. Franck, F. Rousseau, G. Berger-sabbatel, and A. Duda. Performance Anomaly of 802.11b. In *IEEE INFOCOM*, 2003.
- [12] S. Ha, L. Le, I. Rhee, and L. Xu. Impact of background traffic on performance of high-speed TCP variant protocols. *Computer Networks*, 2007.
- [13] N. Hegde, A. Proutiere, and J. Roberts. Evaluating the voice capacity of 802.11 wlan under distributed control. In *Local and Metropolitan Area Networks, 2005. LANMAN 2005. The 14th IEEE Workshop on*, pages 6–pp. IEEE, 2005.
- [14] J. Jeong, S. Choi, and C. Kim. Achieving weighted fairness bw uplink and downlink in IEEE 802.11 DCF-based WLANs. In *QShine*, 2005.
- [15] L. B. Jiang and S. C. Liew. Proportional fairness in wireless LANs and ad hoc networks. In *IEEE WCNC*, 2005.
- [16] B. T. Kandula S., Lin K. and K. D. FatVAP: Aggregating AP Backhaul Capacity to Maximize Throughput. In *USENIX NSDI*, 2008.
- [17] F. Keceli, I. Inan, and E. Ayanoglu. Weighted Fair Uplink/Downlink Access Provisioning in IEEE 802.11 e WLANs. In *IEEE ICC*, 2008.
- [18] S. W. Kim, B. Kim, and Y. Fang. Downlink and uplink resource alloc. in IEEE 802.11 wlangs. *IEEE TVT*, 2005.
- [19] S. Kopparty, S. Krishnamurthy, M. Faloutsos, and S. Tripathi. Split tcp for mobile ad hoc networks. In *GLOBECOM*, 2002.
- [20] G. Maier, A. Feldmann, V. Paxson, and M. Allman. On dominant characteristics of residential broadband internet traffic. In *Internet Measurement Conference*. ACM, 2009.
- [21] R. Murty, J. Padhye, R. Chandra, A. Wolman, and B. Zill. Designing high perf. enterprise wi-fi networks. In *NSDI*, 2008.
- [22] N. Nandiraju, H. Gossain, D. Cavalcanti, K. Chowdhury, and D. Agrawal. Achieving Fairness in Wireless LANs by Enhanced IEEE 802.11 DCF. In *IEEE WiMob*, 2006.
- [23] R. Raghavendra, E. Belding, K. Papagiannaki, and K. Almeroth. Unwanted link layer traffic in large ieee 802.11 wireless networks. *Mobile Computing, IEEE Transactions on*, 9(9):1212–1225, sept. 2010.
- [24] C. Raiciu, D. Niculescu, M. Bagnulo, and M. Handley. Opp. mobility with mptcp. In *MobiArch*, 2011.
- [25] K. K. Ramakrishnan, S. Floyd, and D. Black. The Addition of Explicit Congestion Notification (ECN) to IP, 2001.
- [26] S. Rayanchu, V. Shrivastava, S. Banerjee, and R. Chandra. Fluid: improving throughputs in enterprise wlangs through flexible channelization. *MobiCom '11*, 2011.
- [27] M. Rodrig, C. Reis, R. Mahajan, D. Wetherall, and J. Zahorjan. Measr. based char. of 802.11 in a hotspot setting. In *ACM E-WIND*, 2005.
- [28] A. Schulman, D. Levin, and N. Spring. On the fidelity of 802.11 packet traces. In *PAM*, 2008.
- [29] S. Shah and B. Noble. A study of e-mail patterns. *Software, Practice & Practice*, May 2007.
- [30] J. Shin, H. Roh, D. Lee, and S. Kim. Generalized proportional fair rate allocation schemes for IEEE 802.11e wireless LANs. In *APCC*, 2008.
- [31] S. Shin and H. Schulzrinne. Balancing uplink and downlink delay of VoIP traffic in WLANs using Adaptive Priority Control (APC). In *ACM QShine*, 2006.
- [32] H. Soroush, P. Gilbert, N. Banerjee, B. Levine, M. Corner, and L. Cox. Concurrent wi-fi for mobile users: analysis and measurements. In *ACM CoNEXT 2011*.
- [33] G. Tan and J. Gutttag. Time-based fairness improves performance in multi-rate WLANs. In *USENIX ATC*, 2004.
- [34] I. Tinnirello and S. Choi. Temporal Fairness Provisioning in Multi-Rate Contention-Based 802.11e WLANs. In *IEEE WoWMoM*, 2005.
- [35] H. Velayos, I. Mas, and G. Karlsson. Overload protection for ieee 802.11 cells. In *Quality of Service, 2006. IWQoS 2006. 14th IEEE International Workshop on*, 2006.
- [36] X. Wang and S. A. Mujtaba. Perf. enhancement of 802.11 wlan for asymm. traffic using an adaptive MAC layer protocol. In *IEEE VTC*, 2002.