ABSTRACT
Opportunistic schedulers have been primarily proposed to enhance capacity of cellular networks. However, little is known about opportunistic scheduling with fairness and energy efficiency constraints. In this work, we show that adapting opportunistic scheduling can dramatically ameliorate energy efficiency for uplink transmissions, while achieving near-optimal throughput and high fairness. To achieve this goal, we propose a novel two-tier uplink forwarding scheme in which users cooperate, in particular by forming clusters of dual-radio mobiles in hybrid wireless networks.

Keywords
LTE, opportunistic scheduling, clustering.

Categories and Subject Descriptors
C.2.1 [Computer-communication networks]: Network Architecture and Design—Wireless communication

1. INTRODUCTION
Designing a scheduler that maintains fairness, high spectral efficiency and low power costs in cellular networks is challenging. Although opportunistic schedulers exist and remedy bandwidth limitations [1,2], achieving joint fairness and low power consumption of smartphones is an open issue. For instance, the majority of smartphones are now equipped with at least two radio interfaces (i.e., LTE and WiFi) and use powerful processing hardware, which comes at the expense of potentially elevated power consumptions. Thereby, improving energy efficiency is of utmost importance.

In this paper, we propose an architecture which leverages cooperative communications and opportunistic scheduling to boost the energy efficiency of uplink communications (see Figure 1). Specifically, we exploit the secondary radio interface (e.g., WiFi) to form clusters among mobile devices. Cluster members use this secondary interface to forward their traffic to the cluster head, i.e., the cluster member with the best channel quality to the base station at that instant. Energy efficiency is substantially increased since only cluster heads talk to the base station, while using the secondary interface among cluster members requires low power.

Our proposed architecture benefits from opportunistic scheduling and cooperative communication techniques. Opportunistic schedulers have been extensively studied within past two decades (for a comprehensive survey see [3]). Clustering and relaying are common cooperative techniques used in wireless community, especially in sensor networks. An energy saving clustering approach for sensor networks is proposed in [4] where sensors volunteer to be the cluster head. Our approach is different in the sense that communications occur on distinct and heterogeneous radio interfaces and cluster head selection is opportunistic. The authors of [5,6] propose to use dual-radio mobiles/relay stations to improve the network performance. However, unlike our proposal there is no cluster formation among mobiles/relay stations. Moreover, the relay selection is not opportunistic that significantly impacts capacity. In [7], single antenna mobiles form cluster to create a virtual MIMO transmission. Unlike our proposal, in virtual MIMO all cluster members have to communicate with the base station.

2. CLUSTER-BASED SCHEDULERS
In this section, we illustrate the performance of our proposal by providing preliminary results obtained from numerical simulations run on Mathematica.

System model. We consider an LTE-like uplink communication scheme, using 20 MHz bandwidth and operating in FDD mode. Uplink channel is assumed to follow a stationary Rayleigh fading model. For simplicity, we categorize the users into three predefined user channel quality classes (referred to as user qualities), namely, poor, average, and good. The mean achievable rates for poor, average, and good users are 20%, 50%, and 80% of the maximum transmission rate achievable in the system, respectively. In our evaluation scenario mobiles form three clusters with 6, 8, and 10 users, see Figure 1. Each mobile is equipped with LTE and WiFi interface and all queues are fully-backlogged. A cluster is simply a group of mobile users that communicate with each other over a WiFi network. We derive the power consumption of mobiles from the empirical power models proposed for LTE and WiFi in [8] and [9], respectively. The resulting power consumption of a device consists of: (i) the power spent for LTE transmission by cluster head; (ii) the power spent for WiFi reception by cluster heads; and (iv) the power spent for WiFi transmission by cluster members.
Wireless interfaces are assumed to be in idle mode when no packet has to be transmitted or received.

**Cluster scheduling.** Our scheduling architecture benefits from a two-tier system. The first-tier scheduler performs resource allocation among clusters by utilizing weighted round robin, namely CL(WRR), or MaxRate [1], namely CL(MR). CL(WRR) allocates resources to the clusters in a WRR manner with the weight being the cluster size. CL(MR) schedules the cluster whose cluster head is experiencing the best channel quality among all cluster heads in that instant. The second-tier scheduler is responsible for intra-cluster scheduling, and uses MaxRate to select the cluster head. We benchmark the proposal against Round Robin (RR) and Proportional Fair (PF) algorithms.

**Evaluation.** In addition to investigating different schedulers, we also explore the impact of user quality distribution on system performance. Hence, our evaluation includes the results for scenarios with: (i) equiprobable user quality distribution, (ii) statistically more poor users (i.e., the percentage of poor, average, and good users is {10%, 30%, 60%}, respectively), (iii) statistically more good users (i.e., 60% of poor, 30% of average, and 10% of good users).

In our clustering approach, the bandwidth is equally distributed among cluster members that smoothen the throughput differences among users. This improvement is the reason why CL(WRR) performs better than PF.

**3. CONCLUSION**

In this paper, we have shown that cluster-based schedulers can exploit the coexistence of LTE and WiFi interfaces in smartphones to enhance both system performance and device’s battery life. Specifically, the impact of cluster-based schedulers is threefold: (i) they significantly improve the throughput of a cellular network, (ii) boost energy efficiency, and (iii) achieve fairness levels higher than PF.

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**5. REFERENCES**