Energy Efficient Opportunistic Uplink Packet Forwarding in Hybrid Wireless Networks

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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

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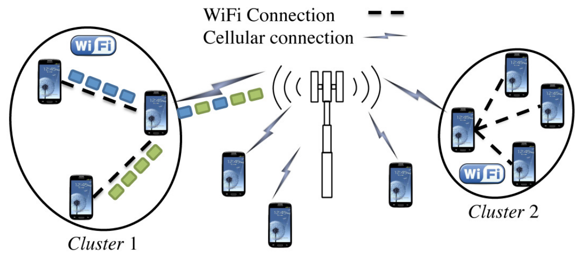


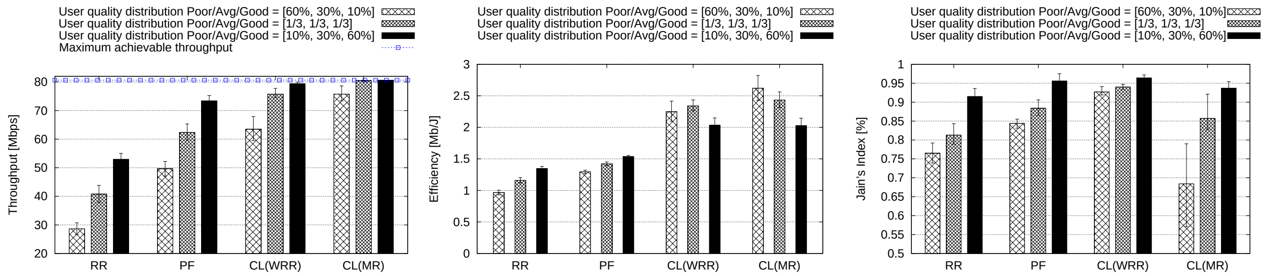
Figure 1: Our proposed clustered architecture.

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) a baseline power consumption of each of the two wireless interfaces; (ii) the power spent for LTE transmission by *cluster heads*; (iii) the power spent for WiFi reception by *cluster heads*; and (iv) the power spent for WiFi transmission by cluster members.



(a) Aggregate cell throughput. (b) Per-user energy efficiency. (c) Jain's fairness indexes.

Figure 2: aggregate throughput, energy efficiency and user fairness for single cell scenario.

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).

Figure 2(a) confirms the superiority of cluster-based schedulers over RR and PF which is due to exploiting cooperative diversity and user channel diversity. Although PF also uses user channel diversity, it is still outperformed by cluster-based schedulers due to the cooperative architecture we propose. RR has the lowest throughput because it does not take advantage of cooperation and user channel diversities. Regarding the effect of user quality distributions, we can see that cluster-based schedulers almost achieve the maximum throughput with 33% *good* users in the network. Also the throughput differences among different schedulers shrink as the number of *good* users increases. This is expected because opportunistic gain relies on the channel diversity of users and increasing number of *good* users reduces this diversity.

In Figure 2(b) we see that cluster-based schedulers are more energy efficient than user-based schedulers. Since with cluster-based scheduling, the likelihood of transmitting under good channel quality is higher than PF and RR, mobiles can use high data rate with low packet loss, leading to higher energy efficiency. The evaluation results confirm that cluster-based schedulers provide a minimum 30% gain in energy efficiency with respect to PF, and the gain can reach up to 100% in presence of more *poor* users. The energy efficiency gain with respect to RR is even higher.

Figure 2(c) shows that fairness is lowest when there are more *poor* users in the system because of opportunistic schedulers bias toward serving *good* users. This also explains the reason why CL(MR) is outperformed by RR and PF. It is interesting to observe that CL(WRR) achieves the highest per-user fairness level in the system (even higher than PF). 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.

4. ACKNOWLEDGEMENTS

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