Performance Analysis of Wireless Scheduling with ARQ in Fast Fading Channels

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Abstract. We develop a Markov model to study the performance of opportunistic scheduling for downlink data transmissions with type-II packet-combining hybrid ARQ in a multirate cellular network for a fast fading environment. For a two-user scenario with two feasible transmission rates, there exists an operating region within which opportunistic scheduling maintains its scheduling gain over round-robin scheduling. In ongoing work, we seek to extend the analysis of the model as well as generalize the model to a multi-user scenario.

1 Introduction

Emerging multirate cellular networks are envisaged to provide high-rate data services to mobile users. Various opportunistic scheduling approaches (e.g., [1]) were proposed recently that transmits to the user with the best or relatively-best according to the predicted feasible transmission rate so as to maximize channel efficiency. However, transmission errors may occur due to the inaccuracy of feasible rate prediction. For the seamless operation of higher layer protocols (e.g., TCP) over such a network, link-layer protocols such as ARQ (automatic repeat request) are used to improve the transmission reliability through packet retransmissions. Assuming perfect prediction, while the same probability of packet success is maintained at every transmission attempt with pure ARQ, hybrid type-II packet-combining ARQ (e.g., [2]) combines the soft decision values of previous noisy copies to improve the probability of packet success.

While opportunistic scheduling and ARQ have mostly been studied separately, few works have emerged recently that considered the problems collectively. While pure ARQ is considered in [3], packet-combining ARQ is considered in [4]. The assumption of a slow fading channel is crucial in both works, where the assumptions of perfect feasible rate prediction in [3] and constant user channel over the analysis interval in [4] are justified.

In this paper, we develop an analysis model for opportunistic scheduling with packet-combining ARQ in a fast fading environment. In such an environment, the analysis becomes more complex since the probability of decoding failure also depends on the feasible rate. Numerical results show that under certain conditions, opportunistic scheduling actually loses its scheduling gain over round robin scheduling, which is channel-unaware.

2 System Model and Assumptions

We consider the downlink slotted transmission from a single base station to M mobile users, where each fixed-size time slot is allocated to one user and the data flow corresponding to each mobile user is continuously backlogged. We characterize the channel condition of user j in terms of (a) its *feasible* transmission rate (bits/slot), t_j^f, where $t_{min} \leq t_j^f \leq t_{max}$, and (b) the resulting probability of decoding failure, p_j^e, if it transmits. We consider a fast fading channel, where t_j^f is uniformly distributed over $[t_{min}, t_{max}]$ and independent in each slot.

To characterize the mechanism of packet-combining ARQ, let $t_{r_j,j}^a$ denote the *actual* transmission rate of user j at the $(r_j+1)^{th}$ transmission attempt. For the first attempt (r_j=0), user j transmits at $t_{0,j}^a$ corresponding to the predicted feasible rate. For a fast fading channel, $t_{0,j}^a$ and t_j^f are identically distributed.

However, if the first attempt fails, subsequent transmissions ($r^j >0$) occur at the same rate as the previous attempt, i.e., $t_{r_j,j}^a = t_{r_j-1,j}^a$, and we expect the probability of decoding failure to be reduced with r_j, i.e., if p_j^e=α for r_j=a, then:

$$p_j^e < \alpha \quad \text{if } r_j > a \tag{1}$$

In addition to Eq. (1), it is reasonable to assume that if $p_j^e = \beta$ for $t_{r_j,j}^a = t_j^f$, then the following properties should hold:

$$p_j^e \begin{cases} > \beta,\ t_{r_j,j}^a > t_j^f; \\ \leq \beta,\ t_{r_j,j}^a < t_j^f. \end{cases} \tag{2}$$

Hence, we propose the following model for p_j^e that satisfies both Eq. (1) and (2):

$$p_j^e = \begin{cases} (1 + \frac{t_{\max(r_j-1,0),j}^a - t_j^f}{t_{max} - t_{min}})\delta \cdot 0.5^{r_j},\ r_j < r_{max}; \\ 0, \qquad\qquad\qquad\qquad\qquad r_j = r_{max}. \end{cases} \tag{3}$$

where r_{max} is the retransmission threshold such that if r=r_{max}, the transmission is always successful, and δ is a constant that indicates channel quality, 0$\leq \delta \leq \frac{1}{2}$, so that 0$\leq p_j^e < 1$. We note that Eq. (3) is also applicable to pure ARQ.

We consider an opportunistic scheduling mechanism which selects the mobile user m^* with the lowest probability of decoding failure for transmission so as to maximize the overall system throughput, i.e.,

$$m^* = \arg \min_{1 \leq j \leq M} p_j^e \tag{4}$$

A round-robin scheduler is also considered as a comparison benchmark.

3 Performance Evaluation

According to Eq. (4), to determine m^* in each slot i, it is necessary to compute $p_j^e\ \forall\, j$, which in turn depends on the values of r_j and $t_{\max(r_j-1,0),j}^a$. By defining x_j

$= (r_j, t^a_{\max(r_j-1,0),j})$ as the state variable for user j in any slot, we can model the scheduling and ARQ mechanism as a Markov chain. By analyzing the Markov model, we can derive the throughput distribution for each user.

We evaluate the mean throughput (μ_t) as well as throughput fluctuation (σ_t) of opportunistic scheduling (**OS**) and round-robin scheduling (**RR**) with pure and packet-combining ARQ for a two-user scenario with two feasible transmission rates. The results are shown in Fig. 1 for t_{min}=100 and t_{max}=2t_{min}.

We note that for sufficiently large δ, $\mu_t^{OS} > \mu_t^{RR}$, i.e., **OS** maintains its scheduling gain over **RR** as expected. However, as δ is reduced below some threshold δ^{μ_t}, this scheduling gain is lost. Similarly, there exists a corresponding threshold for throughput fluctuation (denoted by δ^{σ_t}) such that when $\delta < \delta^{\sigma_t}$, the throughput of **OS** is less jittery than that of **RR** and vice versa. Since $\delta^{\mu_t} < \delta^{\sigma_t}$, we can define the region $\delta^{\mu_t} \leq \delta \leq \delta^{\sigma_t}$ where **OS** is the preferred scheduling scheme with higher and less jittery throughput; beyond this region, there is a trade-off between **OS** and **RR** in terms of μ_t and σ_t.

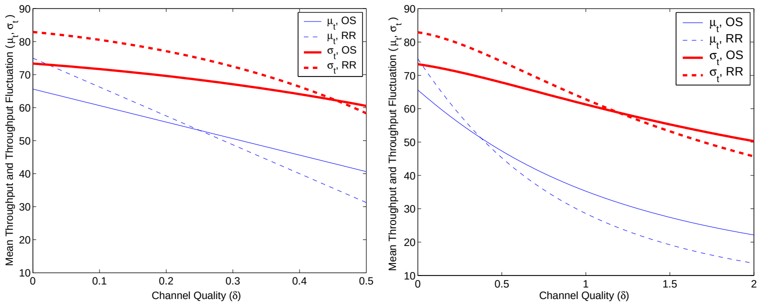

Fig. 1. Performance comparison of Opportunistic and Round-Robin Scheduling for two-user scenario in a fast fading channel with t_{min}=100 and t_{max}=2t_{min} for various δ with (left) pure and (right) packet-combining (r_{max}=2) ARQ.

References

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