A Distributed Splitting Algorithm for Exploiting Multiuser Diversity

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I. Summary

Multiuser diversity [1] refers to the inherent diversity present across the user population in a wireless network. For example, in a fading multiaccess channel, this diversity can be exploited by allowing only the user with the best channel conditions to transmit at any time. However, this requires a centralized scheduler with knowledge of each user's channel gain. Such an approach may not scale well for large networks, and the delays involved in gathering the required knowledge may also limit the performance. In this paper, we focus on *decentralized* approaches for exploiting multiuser diversity, where each user only has knowledge of its own fading level, but no knowledge of the fading levels of the other users in the cell. This is similar to decentralized power control problems, as in [2].

In [4], we have shown that multi-user diversity can still be exploited in a distributed setting by using a simple variation of a slotted ALOHA protocol, where each user randomly transmits based on their local channel knowledge. By appropriate choice of transmission probability, it can be shown that, asymptotically, the only penalty incurred from distributed channel knowledge is the contention inherent in the ALOHA protocol. Also, with a moderate number of backlogged users this approach achieves a higher throughput than a deterministic TDMA protocol. In this paper, we consider a type of splitting algorithm [3] to reduce the contention when the time-scale over which the channel varies is larger than the round-trip time between each transmitter and the receiver. Unlike traditional splitting algorithms, the goal is not to simply allow all backlogged users to transmit, but to enable the user with the best channel conditions to transmit.

We consider the time-slotted block-fading model where the channel gain is fixed during each slot and changes independently between slots. At the beginning of each time-slot, several mini-slots of length β are used to execute the splitting algorithm. We assume that each time-slot contains K mini-slots. The splitting algorithm will determine two thresholds, H_l and H_h for each mini-slot, such that only users whose channel gains, h satisfy $H_l < h < H_h$ are allowed to transmit. After a mini-slot, each user receives $(0, 1, e)$ feedback, indicating if the transmissions in a mini-slot resulted in an idle, success or collision. We denote the received feedback by m. If $m = 1$, only the user with best channel gain transmitted in the mini-slot; the user will then continue to transmit through the remainder of the time slot. If $m = 0$ or $m = e$, the users will adjust their thresholds and repeat the algorithm until either a success occurs or the time-slot ends. The exact manner in which this is done is given by the following pseudo-code. Here H_{ll} is largest value of H_l used in prior mini-slots such that there are some users above H_{ll}.

initialize: $H_l = h_0 \log(n)$, $H_h = \infty$ and $H_{ll} = 0$
while $m \neq 1$ and $k \leq K$ **do**
  m = the number of users within $h > H_l$.
  if $m = e$ **then**
    $H_{ll} = H_l$; $H_l = \text{split}(H_l, H_h)$;
  else if $m = 0$ **then**
    $H_h = H_l$;
    if $H_{ll} \neq 0$ **then**
      $H_l = \text{split}(H_{ll}, H_h)$;
    else
      $H_l = \text{lower}(H_l)$
    end if
  end if
  k = k+1
end while

Here, the functions "split" and "lower" are given by:

$$\text{split}(H_l, H_h) = F_H^{-1}\left(\frac{F_H(H_l) + F_H(H_h)}{2}\right).$$

$$\text{lower}(H_l) = \begin{cases} F_H^{-1}\left(F_H(H_l) + 1/n\right) & H_l > 0 \\ 0 & \text{otherwise.} \end{cases}$$

We denote the throughput of a system with n backlogged users using the splitting algorithm by $s_s(n)$. Let $s_{ct}(n)$ denote the throughput that can be achieved by the optimal centralized scheduler. If each time-slot has a length of t seconds, then $\frac{s_s(n)}{s_{ct}(n)} = 1 - \frac{\bar{m}\beta}{t}$, where $\bar{m}$ is the average number of mini-slots used per time-slot to find the user who has the best channel gain. Clearly, as n increases, $\bar{m}$ should increase. However, it can be shown to be bounded, as stated next.

Proposition 1 *The throughput ratio of the splitting algorithm to the optimal centralized scheme is asymptotically bounded as*

$$1 - \frac{2.5070\beta}{t} < \lim_{n\to\infty} \frac{s_s(n)}{s_{ct}(n)} < 1 - \frac{2.4414\beta}{t}.,$$

It can also be shown that knowing the number of users involved in each collision does not significantly improve the performance.

References

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