Chapter 3
Power Allocation for Cooperative Communications

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ABSTRACT

In this chapter, we review the optimal power allocation policies for fading channels in single user and multiple access scenarios. We provide some background on cooperative communications, starting with the relay channel, and moving onto mutually cooperative systems. Then, we consider power control and user cooperation jointly, and for a fading Gaussian multiple access channel (MAC) with user cooperation, we present a channel adaptive encoding policy, which relies on block Markov superposition coding. We obtain the power allocation policies that maximize the average rates achievable by block Markov coding, subject to average power constraints. The optimal policies result in a coding scheme that is simpler than the one for a general multiple access channel with generalized feedback. This simpler coding scheme also leads to the possibility of formulating an otherwise non-concave optimization problem as a concave one. Using the perfect channel state information (CSI) available at the transmitters to adapt the powers, we demonstrate significant gains over the achievable rates for existing cooperative systems. We consider both backwards and window decoding, and show that, window decoding, which incurs less decoding delay, achieves the same sum rate as backwards decoding, when the powers are optimized.

INTRODUCTION

The wireless medium brings along its unique challenges such as fading and multiuser interference, which complicate the design and analysis of the communication systems. On the other hand, these very same challenges are what give rise to the concept of diversity, which can be carefully exploited to the advantage of the network capacity.

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Fading may become a major limiting factor on the performance of wireless networks, unless appropriate measures are taken against it. Perhaps the most prominent measure to combat fading is power control, which relies on some sort of channel state information to adapt the transmit strategies to the evolving channel conditions. When adaptive transmission is an option, the presence of fading creates diversity across time, which is called temporal diversity, and across users, which is called multiuser diversity. Power control can be cleverly used to maximize the system performance, by making use of these forms of diversity to adjust the signals transmitted by the users.

Another distinguishing feature arising from the physical nature of the wireless channel is what is traditionally thought of as interference in networks: overheard information. The fact that signals from all sources in the network are superposed in the transmit medium can be taken advantage of in the design of wireless networks, by allowing cooperation between the nodes in the network, yielding cooperative diversity.

Although user cooperation and power control are often seen as two separate ways to combat fading, they are inherently coupled approaches. Specifically, in cooperative communication, a user has to decide on how much of its available power should be allocated for cooperation, and how much for only its own transmission. Going a step further, it may come down to deciding whether to cooperate or not in the first place, during a given channel condition.

How power control needs to be performed for a specific wireless network strongly depends on the underlying application. The initial wireless networks that have been deployed in practice were invariably intended to carry voice traffic, and therefore had to make sure that a desired quality of service is attained, so that the delay sensitive voice application is not disrupted. Such networks need to find ways to combat the possible deep attenuations caused by the fading at given time instants, and the associated power control policies therefore have to compensate for worse channel states by boosting the transmit power.

Recently, the growing volume of data traffic (email, files, etc.) and the emergence of wireless networks as a medium for communicating higher rate but less delay sensitive traffic have made it essential to investigate resource allocation policies that are more efficient and opportunistic. In this case, it is possible to exploit the time diversity within a long block of transmission: if the transmitter faces a deep fade level, knowing that the better channel states are to be realized in the future, it can save its available resources, for example transmit power, to the upcoming favorable states. This type of approach leads to worse instantaneous performance at some channel states, but is expected to improve the average performance metrics, such as the long term average Shannon capacity.

In this chapter, we provide an information theoretic approach to power control in cooperative wireless networks. We will focus on a two user fading multiple access channel, where both users mutually cooperate using a decode and forward type of strategy, which relies on block Markov superposition coding, and backwards or window decoding. The fading will be modeled as a stationary and ergodic random process, whose statistics, as well as the instantaneous realization are known to the communicating parties. The main goals of this chapter are:

- to provide a general background on ways to approach user cooperation and power control,
- to present a channel adaptive encoding mechanism which integrates power control to block Markov superposition coding,
- to obtain the optimal power control policies which maximize the long term average rates achievable by user cooperation, and the associated improved rate regions,

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