Chapter 16
Applications of Majorization Theory in Space-Time Cooperative Communications

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ABSTRACT

This chapter discusses important aspects in cooperative communications such as power allocation and node distributions using majorization theory, spanning both theoretical foundations and practical issues. Majorization theory provides a large amount of tools and techniques which can be used in order to accelerate the pace of developments in this fascinating research area of cooperative communications. The aim of the chapter is to build good intuition and insight into this important field of cooperative communications and how majorization theory can be used in order to solve quite complex problems in a very efficient and elegant way. Although we focus on some specific applications, the tools can be also applied to other setups and processing techniques.

INTRODUCTION

In recent years, the goal of providing high speed wireless data services has generated a huge amount of interest among the research community. Recent information theoretic results have demonstrated that the ability of a system to support a high link quality and higher data rates in the presence of Rayleigh fading improves significantly with the use of multiple transmit and receive antennas (Telatar 1999; Foschini & Gans 1998; Tarokh, Seshadri, & Calderbank 1998), so called MIMO (multiple input multiple output) systems. However, due to the size and power requirements the number of antennas at the mobile units is limited. Furthermore, shadowing and the impact of scatterers distribution limits the available degrees of freedom. With this restriction in addition to a disturbed link between mobile and destination, reliable communication can not be guaranteed by using a conventional point-to-point connection.

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Therefore, (Sendoris, Erkip, & Aazhang 1998; Sendoris, Erkip, & Aazhang 2003) proposed to allow cooperation between users and relays. For example, they can create a virtual MIMO system in order to achieve transmit diversity and to reduce the detrimental effect of pass-loss and shadowing in wireless environments. From an information theoretic point of view the cooperative scheme is founded in the relay channel. Recent studies on relay channels can be found in, e.g., (Kramer, Gastpar, & Gupta 2003) and references therein.

Among others, the capacity was investigated by T. M. Cover and A. El Gamal in their fundamental work (Cover and El Gamal 1979) based on work of E.C. van der Meulen (van der Meulen 1971), who introduced this channel model. Note that cooperative communication is a generalization of relay channels, since cooperative users act both as sources as well as relays. From a different perspective, cooperative transmission schemes can be seen as a network code for a special scenario (Fragouli and Soljanin 2007; Yeung, Li, Cai, & Zhang 2005).

The use of cooperation diversity has been shown to result in a reduction of transmit power and increase of spectral efficiency. Several methods are available in order to realize cooperative cooperation, including decode-and-forwarding and amplify-and-forwarding. Depending on the method used and on the quality of the link between the cooperating nodes significant gains can be achieved. This was shown e.g. in (Oechtering & Sezgin 2004). In (Nosratinia and Hunter 2007), it was shown that network-wide diversity gains can be achieved even with distributed grouping and partner selection procedures in such networks.

Relaying, so far only for the extension of coverage, has already been introduced in the 802.16j (WiMAX) standard. However, this is promising that cooperative methods will be adopted in more commercial products in the future, perhaps in a much more sophisticated way.

As discussed in the introduction of (Kramer, Berry, El Gamal, El Gamal, Franceschetti, Gastpar, & Laneman 2007), analyzing the performance of such networks appears be much more difficult than single point-to-point links. Thus, although several important results in cooperative communications have been obtained, many open questions remain in both the theory as well as the practice. Majorization theory (Marshall & Olkin 1979, Palomar & Jiang 2006; Jorswieck & Boche 2006) is a useful tool in order to derive the optimal transmit strategy and to characterize the impact of different systems parameters on the performance of a wireless network. It provides some interesting insights into the behavior of the system, even when the performance function is rather difficult to analyze, as e.g. for non-convex functions. Majorization itself has been used in a vast field of applications. It was already applied successfully in point-to-point MIMO communication links (Palomar & Jiang 2006; Jorswieck & Boche 2006). For example, Majorization theory was used in (Palomar & Jiang 2006) to optimize classes of objective functions in multiple antenna and cellular systems and in (Jorswieck & Boche 2007) in order to investigate the impact of spatial correlation and user distribution on the capacity of such systems.

This chapter discusses important aspects in cooperative communications using Majorization theory, spanning both theoretical foundations and practical issues. Majorization theory provides a large amount of tools and techniques which can be used in order to accelerate the pace of developments in this fascinating research area of cooperative communications. We first discuss different ways how cooperation among users and relays might take place, both for bidirectional communication as well as for unidirectional communication. We focus on Decode-and Forward and Amplify-and-Forward Relay Processing, however, the tools can be also applied to other relay processing techniques. We then introduce the theory of Majorization with some definitions, properties and examples. We also show how functions can be characterized with respect to Schur-convexity and discuss some proof techniques. Furthermore, the

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