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A JOINT TIME-INVARIANT FILTERING APPROACH TO WIRELESS RELAY NETWORK FOR TRANSMISSION RATE MAXIMIZATION

[1] **Prof. A. S. Mali**, [2] **Mr. Nitin Madhukar Tambe**

[1] Professor, Dept. of E&TC Engg. Tatyasaheb Kore Institute Of Engg. & Technology Warananagar, Affiliated to Shivaji University Kolhapur, India,

[2] M.E. Student, Dept. of E&TC Engg. Tatyasaheb Kore Institute Of Engg. & Technology Warananagar, Affiliated to Shivaji University Kolhapur, India.

Abstract : Relay networks have drawn extensive interest from the research community because they play an important role in enlarging the network coverage in wireless communications. In this proposed work the linear Gaussian relay problem is considered. In the context of the linear time-invariant (LTI) model, the issue of maximizing the rate in the linear Gaussian relay channel is expressed in the frequency domain, utilizing the Toeplitz distribution theorem. Given the additional assumption of feasible input spectra, the rate maximization challenge is transformed into a joint design problem for the source and relay filters, subject to two power Constraints are present, one at the source and another at the relay, and a viable solution to this problem is proposed based on the (adaptive) projected (sub)gradient approach. Numerical findings indicate that the suggested approach provides a significant advantage compared to the instantaneous amplify-and-forward (AF) scheme in inter-symbol interference (ISI) channels. Furthermore, the effectiveness of the AF scheme among one-tap relay filters is confirmed in flat-fading channels.

I. INTRODUCTION

Relay networks have garnered significant attention due to their crucial role in enhancing network coverage within wireless communications. This proposed study addresses the linear Gaussian relay issue. Utilizing the linear time-invariant model, the rate maximization challenge in the linear Gaussian relay channel is articulated in the frequency domain, drawing on the Toeplitz distribution theorem. The rate maximization challenge is transformed into a joint design problem for the source and relay filters, subject to two power constraints—one at the source and another at the relay. A practical solution to this challenge is introduced, leveraging the (adaptive) projected (sub)gradient method. Numerical findings indicate that our approach demonstrates strong performance and provides a significant advantage compared to the AF scheme in ISI relay channels.

II. RELEVANCE

Two fundamental features distinguish wireless communication from wire-line communication: first, the broadcast nature of wireless communication; wireless users communicate over the air and a signal from any one transmitter is heard by multiple nodes with possibly different signal strengths .Second, the superposition nature; a wireless node receives signals from multiple simultaneously transmitting nodes, with the received signals all superimposed on top of each other. Due to these two effects, links within a wireless network are never isolated; rather, they interact in ways that may appear complex. Recently, relay network has received increasing attention as it provides flexible extension, proven capacity increase to the traditional wireless systems.

In recent years, broadband wireless systems have emerged as one of the fastest-growing and most rapidly developing sectors within the telecommunications industry. The prevailing trends and requirements necessitate the provision of multimedia services, including voice, video, high definition television (HDTV), and interactive games, all with assured Quality of Service (QoS). In order to facilitate high-quality multimedia services, a substantial data transmission capacity is essential. The serious problem is that most of the wireless systems operate in high frequency bands above 2 GHz. The transmission signal on such frequencies is highly attenuated in comparison with low bands. This leads to smaller cell size and thus more Base Stations (BSs) is needed. Another drawback in using of high frequencies is high power transmission requirement. An efficient way to reduce power consumption and extend the range is offered by Relay Networks.

The main distinguished characteristic of relay networks is possibility of multi-hop communication. Multi-hop communication occurs when data travel from the source to the destination node via more than two hops. Thanks to this feature, range of the network can be significantly extended. This could be achieved without need of other costly base stations. The maximum permissible number of hops should be thoughtfully evaluated (an increased number of hops leads to a longer transmission time). Multi-hop based network may also improve system performance thanks to cooperative relay technique. This is accomplished by sending information simultaneously via multiple different paths and combining the received information at the side of receiver.

Although the precise capacity of relay networks is not known, various advanced coding strategies, including decode-and-forward and compress-and-forward have been developed with the fundamental Amplify-and-Forward approach. Recently proposed an advanced linear scheme for relay networks based on causal linear processing at the relay to compromise the complexity and performance between the complicated coding strategies and the simple AF scheme. In this dissertation, the AF scheme means the instantaneous AF scheme which can easily be implemented by simple analog processing is used.

While information theorists examined the issue from the standpoint of capacity and capacity-achieving strategies, researchers within the signal-processing community also addressed this challenge using metrics such as the received signal-to-noise ratio or minimum mean-square error. While these studies offer significant strategies for the relay issue, they fail to tackle the core challenge of maximizing data rates directly. To optimize the data rate in the relay channel, it is essential to integrate the processing at the source, including the design of the input covariance function, with the processing performed at the relay. However, the joint design of source and relay processing for rate maximization is a hard problem. While there exist some results on the rate-maximizing beam former design in the case of multiple-input and multiple-output (MIMO) relay networks, not many results are available for the general linear Gaussian relay channel. In general time-varying linear processing at the relay in the Gaussian relay channel is considered for improvement. Despite the potential for frequency-division linear relaying, the overall case of linear relays has not been thoroughly examined. In the general linear relay case, the problem is a sequence of non-convex optimization problems, and it is seemingly intractable. To avoid such difficulty, in this dissertation, we consider tractable and practical LTI filtering at the source and the relay, and provide a practical solution to design the source and relay filters jointly to maximize the transmission rate for general ISI Gaussian relay networks.

III. Literature Review

Relay networks have drawn extensive interest from the research community because they play an important role in enlarging the network coverage in wireless communications. Although the capacity of relay networks is not exactly known yet, many ingenious coding strategies including decode-and-forward (DF) and compress-and-forward (CF) beyond the simple AF scheme have been developed [1]. Recently, Zahedi*et al.* proposed an advanced linear scheme for relay networks based on causal linear processing at the relay to compromise the complexity and performance between the complicated coding strategies and the simple AF scheme [2]. (In this paper, the AF scheme means the instantaneous AF scheme which can easily be implemented by simple analog processing.) While information theorists approached the problem from the perspective of capacity and capacity-achieving schemes [3], researchers in the signal-processing community also tackled this problem based on measures like the received signal-to-noise ratio (SNR) or minimum mean-square error (MMSE) . Although [4], these works provide meaningful approaches to the relay problem, they do not address the fundamental problem of data rate maximization directly.

To maximize the data rate in the relay channel the processing at the source such as the input covariance function design should be incorporated together with the processing at the relay. However, the joint design of source and relay processing for rate maximization is a hard problem, as shown in [2].While there exist some results on the rate-maximizing beam former designing the case of multiple-input and multiple-output (MIMO) relay networks, not much results are available for the general linear Gaussian relay channel. In reference [2], The authors investigated the notion of general time-varying linear processing at the relay in relation to the Gaussian relay channel. While they successfully derived the capacity for frequency-division linear relaying, the broader case of general linear relaying was not thoroughly investigated [2]. In the general linear relay case, the problem is a sequence of non-convex optimization problems, and it is seemingly intractable. To circumvent such difficulty, in this paper, we consider tractable and practical LTI filtering at the source and the relay, and provide a practical solution to design the source and communicate filters collaboratively to enhance the transmission rate for general ISI Gaussian relay networks [5].

Under the LTI framework, the linear Gaussian relay problem can be formulated in the frequency domain using the Toeplitz distribution theorem [6]. When the relay filter is given and there is no power constraint on the relay, the problem reduces to the classical ISI channel problem for which the optimal strategy is known as water-filling in the frequency domain. However [7], the freedom to design the relay filter and the power constraint at the relay make the problem far more difficult than the classical ISI channel problem, especially When constraints of stability and causality are applied to the source and relay filters. Our approach to this problem is that we first convert the problem to a constrained optimization problem in a finite dimensional space by restricting the source and relay filters to the category of finite impulse response (FIR) filters, as is common in many practical filtering applications, and subsequently implement the (adaptive) projected (sub) gradient method, which was first introduced by Goldstein [8] and fully developed by Yamada et al[9], to this problem. The advantage of this approach is that the adaptive filtering principle can be applied to the filter design for rate maximization in the linear Gaussian relay channel and a very efficient adaptive implementation is possible in the case of realistic time-varying channels beyond static channels. Numerical findings indicate that our approach demonstrates strong performance and provides a significant advantage compared to the AF scheme in ISI relay channels.

IV. Proposed work

In the LTI framework, the linear Gaussian relay problem can be formulated in the frequency domain using the Toeplitz distribution theorem. When the relay filter is given and there is no power constraint on the relay, the problem reduces to the classical ISI channel problem for which the optimal strategy is known as water-filling in the frequency domain. Nevertheless, the ability to design the relay filter combined with the power limitations at the relay complicates the issue significantly more than the traditional ISI channel problem, particularly when stability and causality constraints are imposed on the source and relay filters. Our approach to this problem is that we first convert the problem to a constrained optimization problem in a finite dimensional space by restricting the source and relay filters to the category of finite impulse response (FIR) filters, as is common in many practical filtering applications, and subsequently employ the (adaptive) projected (sub)gradient method. The advantage of this approach is that the adaptive filtering principle can be applied to the filter design for rate maximization in the linear Gaussian relay channel and a very efficient adaptive implementation is possible in the case of realistic time-varying channels beyond static channels. Numerical results will be calculated to demonstrate that our approach is effective and provides a significant improvement compared to the AF scheme in ISI relay channels.

The block diagram of the proposed work is illustrated in Figure 1 below.

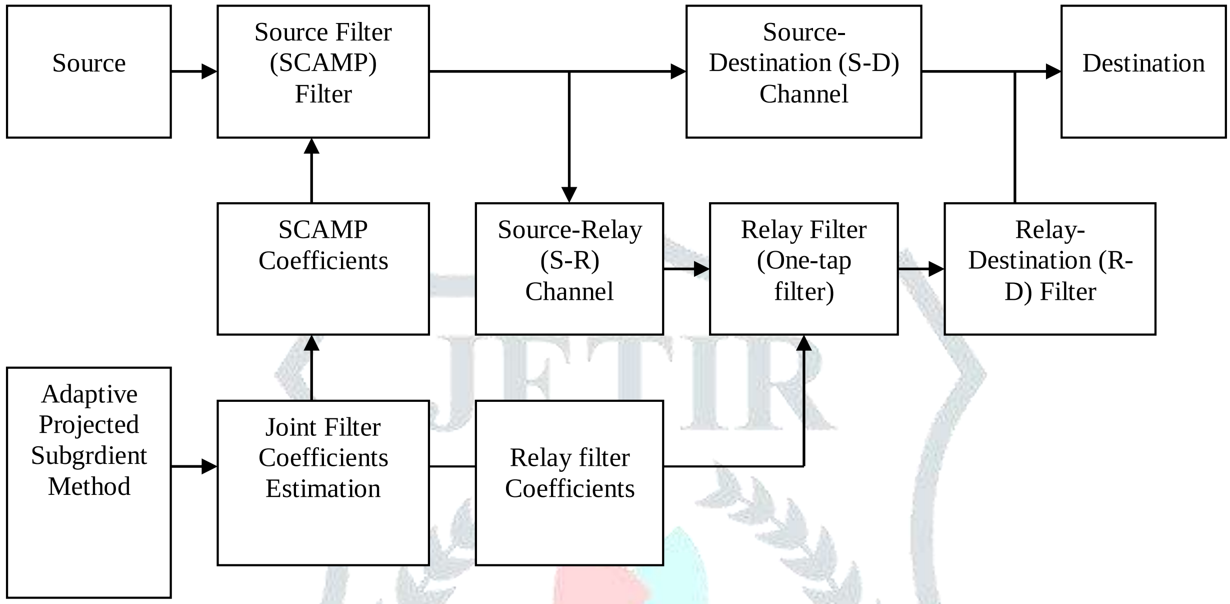

Figure 1: Block diagram of proposed work.

V. CONCLUSION

In this proposed study, the linear Gaussian relay issue is addressed and resolved. Utilizing the linear time-invariant model, the challenges of maximizing the rate in the linear Gaussian relay channel are articulated in the frequency domain, citing the Toeplitz distribution theorem. This rate maximization challenge is transformed into a joint design problem for the source and relay filters, subject to two power constraints: one at the source and another at the relay. A practical solution to this challenge is introduced, leveraging the adaptive projected subgradient method. Numerical findings indicate that the proposed approach offers a significant advantage over the instantaneous amplify-and-forward scheme in inter-symbol interference channels. Furthermore, the optimality of the AF scheme within the category of one-tap relay filters is confirmed in flat-fading channels.

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