# Distributed Double Differential Space-Time Coding with Amplify-and-Forward Relaying

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***Abstract*—This paper provides the double differentially modulated distributed space-time coding for amplify-and-forward (AF) relaying cooperative communications system under time-varying fading channels. In many wireless systems, the communication terminals are mobile. In such case, frequency offsets arise subjected to Doppler's effect and frequency mismatch amongst the terminals' local oscillators. The double differential coding is proposed to overcome the problem of frequency offsets that present in the channel due to the rapidly fast moving nodes. The advantage of the double differential is that the scheme requires neither channel nor frequency offset knowledge for decoding process at the desired destination. However, the conventional two-codeword approach fails to perform and leads to error floor, a region where the error probability performance curve flattens for high signal-to-noise ratio (SNR) regime in fast fading environment. Hence, a low complexity multiple-codeword double differential sphere decoding (MCDDSD) is proposed. The simulation results show that the proposed MCDDSD significantly improve the system performance in time-varying environment.**

***Index Terms*—Distributed Space-Time Coding; Double Differential Detection; Frequency Offsets; Sphere Decoding; Time-Varying Relaying Channel**

## I. INTRODUCTION

Recently, cooperative diversity has stimulated much attention in the wireless communication system due to its ability to achieve diversity gain and improve the system performance. Previous studies have primarily assumed that either perfect channel knowledge is known at relay and destination or the channel is over slow fading condition. Generally, channel knowledge estimation acquired the use of pilot symbols or blind detection at the cost of spectral efficiency loss and excessive computational complexity, especially for fast fading channels. Thus, it is particularly important to explore differential schemes that obviate the need for channel estimation at the destination. The differential space-time block code relaying system is widely studied in [1–3]. The differential system works for channels that remain fixed over at least two symbol interval time. However, the system fails to perform in rapidly fading mobile environments due to the presence of frequency offsets. Frequency offsets happen because of the relative motion amongst the nodes and are proportional to the Doppler shift. Another cause of frequency offsets is the mismatch carrier frequency between the terminals' oscillators. To address the problem of frequency offsets, double differential coding regardless of channel estimation is studied.

Several space-time block coded modulation based on double differential and their performance analyses can be found in [4–8]. Liu et al. in [4] and Bhatnagar et al. in [5] implemented double differential coding under time-selective fading channel and flat block-fading correlated Rayleigh channel, respectively in multiple-input multiple-output (MIMO) system. The low complexity scheme enables diversity gain foregoes the knowledge of channel and frequency offsets. However, the proposed scheme in [5] requires partially known channel fading statistics at the source. The double differential for cooperative communication system was further proposed in [6] and [7]. However, the studies only consider relayed communication with no direct link between the source and destination. Furthermore, the model in [7] assumed that oscillators' synchronization is achieved between the source and relay.

Although the above researchers showed many interesting results indicating the potential of the differential based space-time coding to overcome the complex computational channel knowledge and frequency offsets estimation, the network performance employing codeword based detection, however, experiences degradation (i.e. error floor) at high signal-to-noise ratio (SNR) in a relatively fast fading environment. This is the motivation behind the present study. Multiple codeword differential detections (MCDD) has been investigated in [9–11] for unitary space-time codes in multiple-input multiple-output (MIMO) systems and dual-hop cooperative communication network, accordingly to overcome the performance degradation of the two-codeword based detection at the cost of an increased complexity. In general, MCDD processes blocks of received codeword and improve the power efficiency as the block size increases. However, the search space increases exponentially with the block size and the complexity of MCDD becomes highly prohibited when maximum likelihood (ML) decoding is applied. ML decoder is based on full search over the codeword that is continuously transmitted from the source and relays. In order to reduce the exhaustive search of the MCDD detection, Lampe et. al. in [12] developed a sphere decoding algorithm so as to reduce the search area during the decoding process. The sphere decoding algorithm has near ML performance with reasonably low complexity. In the context of relay networks, the optimum decision metric does not yield a closed-form solution due to the complexity of the distributed received signals at the desired destination. Thus, a low-complexity alternative decision rule is proposed to replace the optimum decision rule. This research outperforms the previously suggested schemes and is able to additionally integrate the direct link between the source and destination terminals.