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Channel equalization and beamforming for quaternion-valued wireless communication systems

Wei Liu[1]

Communications Research Group, Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield S1 4ET, United Kingdom

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Abstract

Quaternion-valued wireless communication systems have been studied in the past. Although progress has been made in this promising area, a crucial missing link is lack of effective and efficient quaternion-valued signal processing algorithms for channel equalization and beamforming. With most recent developments in quaternion-valued signal processing, in this work, the author fills the gap to solve the problem by studying two quaternion-valued adaptive algorithms: one is the reference signal based quaternion-valued least mean square (QLMS) algorithm and the other one is the quaternion-valued constant modulus algorithm (QCMA). The quaternion-valued Wiener solution for possible block-based calculation is also derived. Simulation results are provided to show the working of the system.

1. Introduction

Increasing the capacity of a wireless communication system has always been a focus of the wireless communications research community. It is well-known that polarisation diversity can be exploited to mitigate the multipath effect to maintain a reliable communication link with an acceptable quality of service (QoS), where a pair of antennas with orthogonal polarisation directions is employed at both the transmitter and the receiver sides. However, the traditional diversity scheme aims to achieve a single reliable channel link between the transmitter and the

E-mail address: w.liu@sheffield.ac.uk
[1]Fax: +441142225834.

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receiver, while the same information is transmitted at the same frequency but with different polarisations, i.e. two channels. This is not an effective use of the precious spectrum resources as the two channels could be used to transmit different data streams simultaneously. For example, we can design a four-dimensional (4-D) modulation scheme across the two polarisation diversity channels using a quaternion-valued representation, as proposed in [1]. An earlier version of quaternion-valued 4-D modulation scheme based on two different frequencies was proposed in [2]. However, due to the change of polarisation of the transmitted radio frequency signals during the complicated propagation process including multipath, reflection, refraction, etc., interference will be caused to each other at the two differently polarised receiving antennas. To solve the problem, efficient signal processing methods and algorithms for channel equalization and interference suppression/beamforming are needed for practical implementation of the proposed 4-D modulation scheme.

Recently, quaternion-valued signal processing has been introduced and studied in detail to solve problems related to three or four-dimensional signals [3], such as vector-sensor array signal processing [4–9], and wind profile prediction [10]. With most recent developments in this area, especially the derivation of quaternion-valued gradient operators and the quaternion-valued least mean square (QLMS) algorithm [10,11,12], we are now ready to effectively solve the 4-D equalisation and interference suppression/beamforming problem associated with the proposed 4-D modulation scheme. Now the dual-channel effect on the transmitted signal can be modeled by a quaternion-valued infinite impulse response (IIR) or finite impulse response (FIR) filter. At the receiver side, for channel equalisation, we can employ a quaternion-valued adaptive algorithm to recover the original 4-D signal, which inherently also performs an interference suppression operation to separate the original two 2-D signals. Moreover, multiple antenna pairs can be employed at the receiver side to perform the traditional beamforming task to suppress other interfering signals.

In particular, two representative quaternion-valued equalisation/beamforming algorithms will be derived: the first one is the quaternion-valued Wiener filter as a follow-up to the previously derived QLMS algorithm for reference signal based equalisation/beamforming, and the second one is the quaternion-valued constant modulus algorithm (QCMA) for blind equalisation/beamforming. Compared to the summary contribution in [13], in addition to the detailed analytical modeling steps, the main difference is the GCMA algorithm and the related simulations. Although quaternion-valued wireless communication employing multiple antennas has been studied before, such as the design of orthogonal space–time-polarization block code in [14], to my best knowledge, it is the first time to study the quaternion-valued equalization and interference suppression/beamforming problem in this context. Moreover, the dual-polarised antenna pair or an array of them has a similar structure to the well-studied vector sensors or sensor arrays [15–18], where they are used mainly for traditional array signal processing applications. Although the recently developed quaternion-valued array signal processing algorithms based on such traditional array applications employed a quaternion-valued array model [4–6], the desired signals are still traditional complex-valued signals, instead of quaternion-valued communication signals.

In the following, the 4-D modulation scheme based on two orthogonally polarised antennas will be introduced in Section 2 and the required quaternion-valued equalisation and inter-channel interference suppression solution and their extension to multiple dual-polarised antennas are presented in Section 3. Simulation results are provided in Section 4, followed by conclusions in Section 5.

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