Design Group D11-050

作品名稱

適用於多輸入多輸出正交分頻多工之內插式QR分解處理器

Interpolation-based QR Decomposition Processor for MIMO-OFDM

隊伍名稱

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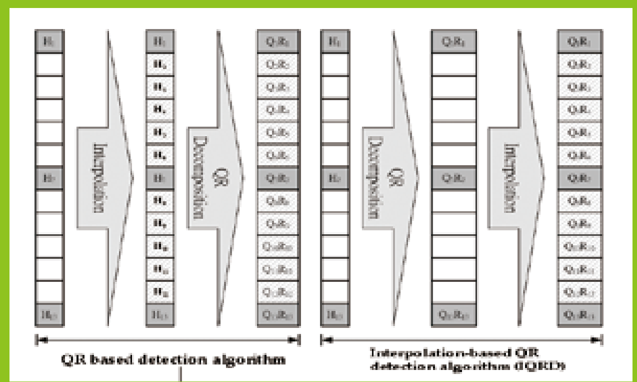
作品摘要

在先進的MIMO-OFDM 系統中速度需求巨幅攀升，以往tone-by-tone 的QR分解處理方式，如Figure 1左圖所示，在QR分解部分耗費相當多的計算，此高運算複雜度特性造成了實作上的瓶頸。為了解決上述傳統作法之高運算量問題，提出內插式QR分解演算法，如Figure 1右圖所示，此演算法已證實能改良傳統作法，降低大量複雜度。根據我們所知，提出的內插式QR 分解演算法是截至目前為止複雜度最低的QR 分解演算法。因此本次研究修正內插式QR分解演算法，提出單步運算(one-step process)，展示於Figure 2中，用以降低內插式QR分解演算法的複雜度，並且加入可規模性讓演算法適用於不同大小的通道矩陣，最後將改良後方法命名為修正型內插式之QR分解演算法(Modified Interpolation-based QR Decomposition)。

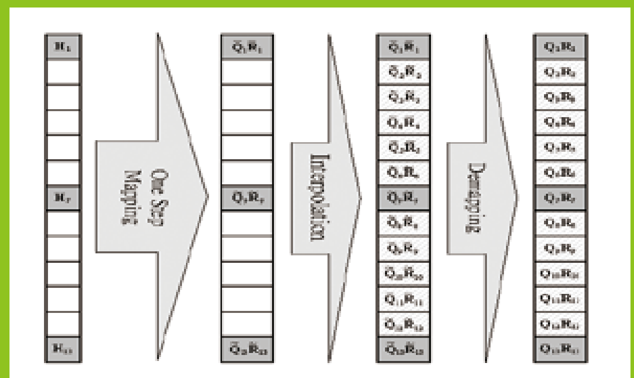
本研究之目的在於設計出高吞吐量之內插式QR分解處理器。而本研究所提出的演算法具有可重組化之特性，所以當多輸入多輸出系統中的天線維度改變時，根據天線數量控制電路運作，達到節省功率的目的；此外，在多輸入多輸出正交分頻多工系統中，本團隊整合了頻率域上的通道估測以及QR分解的特性，因此，相較於原有的技術而言，本演算法具有較低的運算複雜度。

實現度而言，本次研究使用UMC 90奈米的技術實現硬體，並將結果分享於成果中，本團隊設計之晶片可支援4x4. 4x2 和2x2 通道矩陣，以及QPSK, 16-QAM 和 64-QAM 的調變方式，可支援3GPP-LTE規格中，所規範之多輸入多輸出系統的天線維度，並在不影響晶片功能運作的環境下，可達到最快140.65MHz時脈速度，相當於35.16MQRD/s的運算吞吐量，為現有的文獻中速度最快之QR分解晶片。



圖一 傳統QR分解處理器與內插式QR分解處理器之比較

Fig.1 Comparison with QR-based detection algorithm and Interpolation-based QR detection Algorithm



圖二 所提出之修正型內插式QR分解處理器

Fig.2 Proposed modified interpolation QR decomposition

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- 2001年至2005年，曾於視傳科技股份有限公司擔任研發部門經理，從事開發類比及數位電視廣播系統之電視解調電路設計；於2005年於清華大學電機工程學系及通訊工程研究所擔任助理教授迄今。
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ABSTRACT

More and more ubiquitous applications of wireless communication in our daily lives have increased demand for high data rate and high-quality wireless access. The adoption of orthogonal frequency division multiplexing with multiple-input multiple-output technology (MIMO-OFDM) promises a significant increase in data rate and spectral efficiency without bandwidth expansion.

The iterative detection schemes, like successive interference cancellation (SIC), and the tree-search-based detection schemes, like sphere decoding and K-best algorithm, are two kinds of the most popular algorithms. Both kinds of detection algorithms need the QR decomposition preprocessing to avoid the complicated pseudo inverse computation of channel matrix. Then, the subsequent detection processes become more simple.

The throughput and complexity are two implementation issues of the QR decomposition. The complexity of QR decomposition is $O(n^3)$ for an $n \times n$ matrix, and grows proportionally with the FFT size in the OFDM system. Because the FFT size is usually very large and the MIMO detection must be performed on every subcarrier, the complexity of QR decomposition becomes tremendous in the MIMO-OFDM systems.

Accordingly, the interpolation-based QR decomposition (IQRD) algorithms in Fig. 1 were proposed to mitigate the complexity issue of QR decomposition in the MIMO-OFDM system. The interpolation-based QR decomposition algorithm efficiently combines the calculations of channel estimation in the OFDM system and the QR decomposition in the MIMO detection so as to greatly reduce the overall complexity. The algorithm performs QR decomposition only on the pilot subcarriers and obtains the mapped QR matrices of the data subcarriers by interpolation. Based on the generic idea, we propose a scalable interpolation-based QR decomposition algorithm for the high-dimension MIMO-OFDM system.

We propose a modified interpolation-based QR decomposition (MIQRD) algorithm which computes the Hermitian matrix of the channel matrix before performing the QR decomposition. Then, the $\tilde{Q}$ and $\tilde{R}$ matrices are computed directly from the entries of channel matrix and its corresponding Hermitian matrix with only multiplication and addition. After the $\tilde{Q}$ and $\tilde{R}$ matrices are calculated by this one-step processing, the subsequent processes are the same as the traditional interpolation based QR decomposition algorithm such as interpolation and inverse mapping. The proposed algorithm can be illustrated in Fig. 2. The proposed algorithm has better stability than the Gram-Schmidt-based interpolation-based QR decomposition algorithm because the proposed algorithm does not need square root and division operations before the inverse mapping process. Moreover, we establish a configurable hardware architecture to support various MIMO configurations according to the MIMO channel rank. The proposed algorithm features a scalability property for different MIMO schemes. In the practical MIMO-OFDM system, the equivalent channel matrix may be not square because of non-full-rank channel or system deployment. In the reduced-rank MIMO channel, the proposed hardware architecture can save computation power by the scalability property of the proposed algorithm. Moreover, we also develop a timing-schedule analysis algorithm based on the proposed hardware architecture so that the hardware architecture and timing schedule can be easily extended to the higher-dimension MIMO scheme.

The architecture is suitable for designing a high-throughput QR decomposition processor for MIMO-OFDM receiver. To our best knowledge, the proposed QR decomposition has the lowest complexity among QR decomposition algorithms. The processor is designed and implemented as a single chip. The well-verified chip using 90nm UMC CMOS technology supports 2x2, 4x2, 4x4 QR-based MIMO detection for the 3GPP-LTE MIMO OFDM system and achieves the throughput of 35.16MQRD/s at its maximum clock rate 140.65MHz. This chip outperforms other chips for QR decomposition in the literature.