Review on Different Methods for Achieving Power Efficient Rake Receiver

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Abstract: ***The multipath fading is one of the major problems in wireless communications especially in the mobile communication systems. The effect of multipath fading leads to significant impairment in the received signal by the mobile units. The effect is more severe when the path delays of multipath structures are less than the chip delays. The rake receiver has been used to reduce multipath fading in wideband code division multiple access (WCDMA) systems to achieve better performance in bit error rate and system throughput. The rake receiver consists of sub components which make the system to be computationally complex and power consuming. The paper proposed a simplified and power efficient system based on sorted QR decomposition (SQRD) which is applicable in WCDMA systems to reduce multipath fading and co-channel interference. The proposed scheme is compared with the conventional approach and compare the efficiency of different schemes***

Keywords: Fading, Interference, Wideband, Throughput, Received signal

1. Introduction

The next generation of mobile communication systems aim at seamless integration of wide variety of communication services such as high speed data, video, multimedia traffic and voice signals. Walsh-Hadamard codes or orthogonal variable spreading factor (OVSF) codes are used but in a typical wireless environment, the orthogonality is destroyed by multipath fading and intracell interference between users. The received signal in mobile radio communication environment is subjected to the statistical nature of the channel and is the sum of various transmitted signals which have been delayed, phase shifted and scaled according to the strengths of the multipath channel[1,2]. The multipath transmission introduced by the wireless channels that hinders signal propagation. Multipath fading degrades the quality of the received signal. The advanced technique such as multiuser detection (MUD) can significantly improve the overall performance of a mobile system.

The RAKE receiver is still the receiver structure of choice for 3G and 4G systems. Multi Access Interference (MAI), Inter Symbol Interference (ISI), Spreading Factor (S.F) are the issues which limits the BER performance of Rake Receiver. A RAKE receiver consists of matched filter and channel estimator which make the system to be computationally complex and power consuming. Consequently, there is need for less complex and power efficient system. This paper focuses on mitigating multipath effect in WCDMA and OFDM with the aid of RAKE receiver to improve the bit errors rate caused by signal interference and proposes a simplified and power efficient RAKE receiver which is based on Sorted QR decomposition (SQRD) scheme.Sorted QR Decomposition (SQRD) is a preprocessing technique for detecting symbols in multiple-input and multiple output (MIMO) system. The computational attempt involved in searching the optimum detection sequence can be decrease by adopting Sorted QR decomposition (SQRD). The SQRD is based on the modified Gram Schmidt algorithm. Sorted QR decomposition technique also increases the quality of the received signal to a great extent which is destroyed by several severe effects.

2. Rake Receiver

2.1 Overview of Rake Receiver

Due to reflections from obstacles a radio channel can consist of many copies of originally transmitted signals having different amplitudes, phases, and delays. If the signal components arrive more than duration of one chip apart from each other, a RAKE receiver can be used to resolve and combine them. The RAKE receiver uses a multipath diversity principle. It is like a rake that rakes the energy from the multipath propagated signal components.

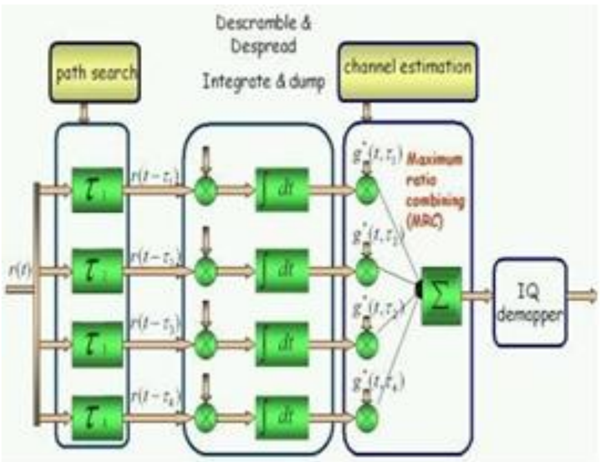

Figure 1: Block diagram of rake receiver is shown

RAKE receiver is a radio receiver designed to counter the effects of multipath fading. RAKE receiver consists of matched filter and channel estimator which make the system to be computationally complex and power consuming. Consequently, there is need for less complex and power efficient system. It does this by using several "sub-receivers each delayed slightly in order to tune in to the multipath components [3, 4]. Each component is decoded independently, but at a later stage it is combined.

2.2 Multipath Fading In Rake Receiver

Multipath fading affects most of radio communications links in one form or another. Multipath fading can be detected on many signals across frequency spectrum from the HF bands right up to microwaves and beyond. It is experienced not only by short wave radio communications where signals fade in and out over a period of time, but it is also experienced by many other forms of radio communications systems including cellular communications and many other users of the VHF and UHF spectrum. Multipath fading may also cause distortion to the radio signal. As the various paths that can be taken by the signals vary in length, the signal transmitted at a particular instance will arrive at a receiver over a spread of times. This can cause problems with phase distortion and inter symbol interference when data transmissions are made. As a result, it may be necessary to incorporate features within the radio communications system that enables the effect of these problems to be minimized. At times there will be changes in the relative path lengths[7,8]. This could result from either the radio transmitter or receiver moving, or any of the phase of the signals arriving at the receiver changing, and in turn this will result in the signal strength varying as a result of the different way in which the signals will sum together.

As discussed rake receiver is so designed to mitigate the effects of multipath fading .This can be shown by an instant. Consider diagram below .It is shown in figure in three path delays are considered which are due to different instants as shown in figure 2.

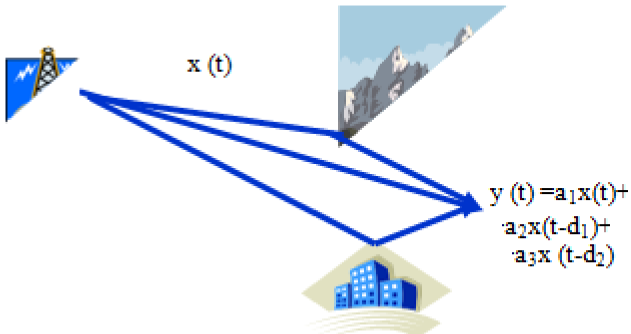

Figure 2: Multipath Fading

In Figure 3 below shows the approach of rake receiver on this delays .As already discussed RAKE receiver comprises of a matched filter and a correlator. The received signals are fed on to the sub receivers or fingers as per the delays occurred. These signals proceeded into a descrambler in which the received signals are spreader by mitigating the scrambling codes . The same symbols obtained via different paths are then combined together using combining scheme like maximum ratio combining (MRC) .The combined outputs are then send to a simple decision device to decide on the transmitted bits. MRC corrects channel phase rotation and weighs components with channel amplitude estimate. MRC can be represented simply as shown in Fig 3 MRC. The correlator outputs are weighted so that the correlators responding to strong paths in the multipath environment have their contributions added, while the correlators not synchronizing with any significant path are suppressed.

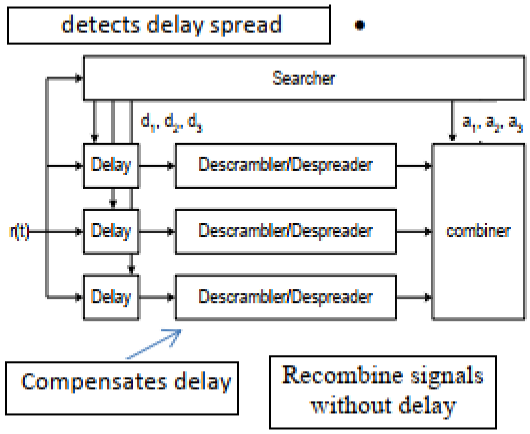

Figure 3: RAKE receiver working model

3. System Overview

One of the applications of the RAKE receiver is in wideband code division multiple access systems (WCDMA). In a WCDMA system all the users transmit in the same band concurrently and each transmitted bit is spread by the transmitter by orthogonal variable spreading factor (OVSF) and scrambling code [5,6]. The length of the scrambling code is known as the spreading factor and larger spreading factors give a better resistance against interference. Furthermore, at the receiver, the RAKE receiver de-spreads the received multipath signal by multiplying it by the same spreading sequence. The code generator gives the spreading sequence which is employed by the RAKE receiver in de-spreading and correlation operations. The RAKE receiver has multiple fingers to correlate different delayed signals that are received from different paths and combines the results to produce one output signal.

Impulse responses of the multipath channel are obtained by a matched filter for signal de-spreading. The filter tracks and monitors multipath channel peaks with respect to the speeds of mobile station and also on the propagation environment. The number of RAKE fingers is determined by the chip rate and the channel profile. Higher chip rate gives more resolvable paths with wider bandwidth. In order to exploit all energy from the channel, more RAKE fingers are required but large number of fingers results in implementation problems and combination losses. There are two primary methods that can be employed to combine the receiver finger outputs. One method weighs each output equally and it is known as equal-gain combining. The second method uses the data to evaluate weights, which maximize the Signal-to-Noise Ratio (SNR) of the combined output.

3.1 System Model

The wireless mobile communication systems transmitted and received signals in a realistic mobile units of WCDMA systems can be model in stages. The signal emanates from the transmitter and passes over the multipath channel to the receiver. The models for each of these communication elements are presented [9, 10].

Transmitter Model

The CDMA transmitter sends the complex valued data sequence x_n which are spread by the spreading factor Nc using the effective spreading sequence. The complex valued spread sequence is transmitted using a pulse shaping filter. The Third-Generation Partnership Program (3GPP) specification for the pulse shaping filter is the root-raised-cosine (RRC) function also known as the square-root-raised-cosine (SRRC) filter with a roll-off factor of 0.22. The resultant baseband transmit signal is given in equation 1.

$$s(t)=\sum_{n} x_n \sum_{v=0}^{N_c-1} q_v p\left(t-nT-vT_c\right) \quad (1)$$

Where T and T_c are the symbol and chip duration respectively. According to [3] the spreading sequence can be replaced by in order to incorporate effective spreading sequences with a periodicity longer than one symbol in order to incorporate effective spreading sequences with a periodicity longer than one symbol.

With reference to the wide-sense stationary uncorrelated scattering (WSSUS) model, the transmitted signals propagate through multipath channel with independent paths characterized by different delay and the time-variant complex multipath fading coefficient C_1[3]. Since a WSSUS channel is assumed, the fading coefficients of different paths are independent [1, 2, 3]. Therefore, the impulse response of the multipath channel between the mobile station and the base station is modeled by

$$h(\tau)=\sum_{l=0}^{L-1} c_l(t)\delta\left(\tau-\tau_l\right) \quad (2)$$

where δ is the impulse function. Depending on the specific propagation environment, C_1 is a positive random variable with density function that can be represented by Rayleigh, Racian or more generally a Nakagami distribution.

Receiver Model

The received signal is the sum of signal transmitted through the multipath fading channel and the additive white Gaussian noise (AWGN) z(t) with power spectrum-density of N_0. Therefore, the received signal signal at time, t is expressed as,

$$r(t)=\sum_{l=0}^{L-1} c_l(t)\sum_{n} x_n \sum_{v=0}^{N_c-1} q_n N_c + v p_r\left(t-nT-vT_c-\tau_l\right)+z(t) \quad (3)$$

For simplicity, a generalized MIMO scheme with transmit antennas and receive antennas is assumed and the received signal can be modeled in matrix notation as,

$$r = Hs + z \quad (4)$$

Where *s* is the transmitted data symbol vector, r is the received signal vector, *H* is the channel matrix which contains the channel information of all users and *z* is the complex additive white, Gaussian noise (AWGN) vector.

Interference Cancellation Techniques

To detect the transmitted symbol vector s from vector r, interference cancellation techniques are required. Most linear interference cancellation techniques work on the principle that the desired layer is detected while considering other layers as interference. The nulling of each layer can be performed with a ZF(zero forcing) or an MMSE(minimum mean square error) equalizer. Subsequently, when the transmitted symbol vector has been detected, a decision on the vector is made either by quantization or by calculating the log-likelihood ratios (LLR) of the transmitted bits. The linear detectors are optimal if the channel matrix is orthogonal. However, this is not usually the case in practice. Method such as lattice reduction (LR) can be used to transform the channel matrix into a more orthogonal one. Furthermore, in fading channels, linear detectors suffer significant performance degradation especially when there is spatial correlation between the antenna elements.

The linear interference cancellation techniques have the disadvantage that some of the diversity potential of the receiver antenna array is lost in the decoding process. Therefore, their performances are not up to that of maximum likelihood (ML) decoder. There are some nonlinear techniques such as ordered successive interference cancellation (OSIC), parallel interference cancellation (PIC) and sorted QR decomposition (SQRD) that have significant performance improvements by the diversity potential for receiver antennas.

In the parallel interference cancellation (PIC), all the layers are detected simultaneously and then cancelled from each other followed by another stage of detection. PIC was proposed to reduce the latency from SIC but has a higher computational complexity. The SQRD algorithm performance is extremely close to that of OSIC but the SQRD algorithm always requires less computation effort to decode multiple antennas symbols compared to the OSIC decoder. Furthermore, performance of the SQRD scheme can be enhanced with the linear detector. The implementation is illustrated in the following section.

3.2 Sorted QR Decomposition

The most valuable factor about SQRD is it can be adapted according to different channels and systems .Here some of the techniques are discussed in the following sections [4, 5, 6].

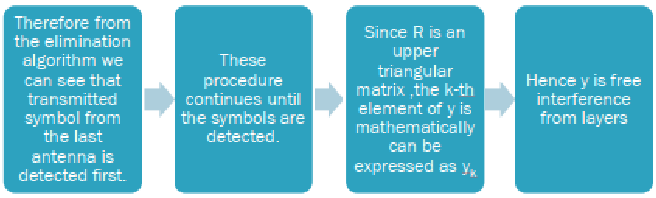

Figure 4: SQRD Algorithm

MIMO Systems Based on Pair Wise Column Symmetrization

Multiple-Input and Multiple-Output (MIMO) is a key technology for realizing high performance wireless communication [1]. In the MIMO technology, a single data stream is demultiplexed into multiple spatial streams called layers, and transmitted through multiple antennas. Such multi-dimensional data transmission associated with multiple antennas can improve the data rate and/or the error rate without increasing the bandwidth or the transmission power. However, it entails huge computational complexity without efficient algorithms.

This section proposes a low-complexity algorithm for SQRD. The proposed algorithm performs SQRD through the orthogonalization steps based on the MGS (Modified Gram-Schmidth) process. As in the conventional SQRD, the column vectors are rearranged before each step, so that the layers are sorted to improve the symbol detection performance. The proposed algorithm, however, rearranges the column vectors in pairs by treating two adjacent vectors as a pair. This pairwise rearrangement of column vectors maintain the symmetry in each pair, which is known as symmetrization in this paper. By the symmetry in each pair, the computations required for the orthogonalization of one of the two vectors in a pair can be eliminated effectively [5, 6].

The MGS process in the proposed algorithm is described from the 6th through the 23rd lines of the algorithm. The *i*-th step of the process, $1 \leq i \leq N$, orthogonalizes two adjacent column vectors in a pair: $\mathbf{Q}_{2i}-1$ and $\mathbf{Q}_{2i}$ are normalized to be bases, and the remaining column vectors are updated to be orthogonal to the bases. Since two column vectors are orthogonalized for each step of the MGS process in the proposed algorithm, the total number of steps is reduced to N, as described in the 6thine of the algorithm. $\mathbf{Q}_{2i}$ and $\mathbf{Q}_{2i-1}$ are orthogonalized for the *i*-th step of the MGS process in the proposed algorithm. Note that the orthogonalization is computed only for $\mathbf{Q}_{2i-1}$. The orthogonalization of $\mathbf{Q}_{2i}$ is not computed but derived based on that of $\mathbf{Q}_{2i-1}$; thus, no computations are required to orthogonalize $\mathbf{Q}_{2i}$. This is enabled by exploiting the pairwise symmetry in $\mathbf{Q}$.

Let us illustrate a simple example to present how to compute SQRD by using the proposed algorithm. The example performs SQRD for a channel realization in 2 × 3 MIMO systems, where

$$\mathbf{G} = \begin{bmatrix} 1-j & -j \\ 1-j & 1+j \\ -1 & -j \end{bmatrix}$$

Computational Complexity

The computational complexity is analyzed by counting the number of numerical operations required for an algorithm. Both algorithms perform SQRD based MGS process; however, the number of steps for the MGS process is halved in the proposed algorithm because two column vectors are orthogonalized for each step. Furthermore, the computations required to orthogonalize one of the two column vectors can be eliminated completely by utilizing the symmetry between them. Therefore, the computational complexity involved for each step is not increased at all. As a result, the overall computational complexity of the proposed algorithm is reduced by almost 50%, when compared to the conventional algorithm.

Memory Requirement in a MIMO System

Several practical MIMO systems such as IEEE 802.11 assume a quasi-static environment in which a channel is static or a frame [2], [3]. SQRD is a per-frame preprocessing technique; it is performed once in a frame header, and the results are stored in the memory to be used repetitively to detect symbol vectors in a payload. Since the resultant matrices in the proposed algorithm, **Q** and **R**, also have the symmetry, we can exploit the symmetry in order to reduce the memory requirement for sorting them. More specifically, we have to store only every other column of **Q**, and the remaining columns can be retrieved based on the symmetry. For $N \times M$ systems, the number of words required to store **Q** per channel is reduced from $4MN$ to $2MN$ by the proposed algorithm, where each element of **Q** is stored as a single word. Similarly, we have to store only distinctive elements of **R**; other redundant elements need not be stored because they can also be retrieved by the stored elements. For N ×M systems, the number of words required to store **R** per channel is reduced from $2N2 + N$ to $N2$ by the proposed algorithm, where each element of **R** is stored as a single word. The reduction of the memory requirement is considerable in practical systems. For instance, in IEEE 802.11ac that supports up to 8 × 8 MIMO configuration with 468 sub-channels in a single band, the conventional memory requirements to store **Q** and **R** are as large as 1916.9 Kbits and 1018.4 Kbits, respectively, if each element in **Q** and **R** is represented in 16 bits [15]. Employing the proposed algorithm, we can reduce them to 958.5 Kbits and 479.2 Kbits, respectively

Effect on the Symbol Detection Performance

As in the conventional SQRD, the proposed algorithm sorts the layers to improve the symbol detection performance while performing QRD. The proposed algorithm rearranges column vectors so as to maintain the symmetry, whereas in the conventional algorithm, the rearrangement is performed without such symmetrization. Therefore, the detection order of layers determined by the proposed algorithm may be different from that by the conventional SQRD, which affects the symbol detection performance. To investigate the effect on the symbol detection performance, numerical simulations are conducted for the symbol detection with the proposed algorithm as well as the conventional algorithm. The simulations adopt Gray symbol mapping with two famous symbol detection algorithms: the successive interference cancellation (SIC) [4], [5] and the K-best detection [8], where the parameters of the K-best detection are configured to achieve a near-optimal error-rate performance. Fig. 1–3 show the BER performance for three MIMO configurations. As shown in the figures, the BER performance is improved with the appropriate detection order of layers determined by SQRD, which is observed clearly in particular for the results of the SIC detection. The performance gap between the proposed and conventional algorithms is negligibly small for the SNR range of practical interest. The effect of the proposed algorithm is also investigated for the soft-output symbol detection.

4. QR decomposition in OFDM

Orthogonal frequency division multiplexing (OFDM) technology has been used widely in many wireless (ADSL), and future 4G systems. OFDM systems can provide higher bandwidth efficiency and communication systems, such as digital audio broadcasting (DAB), digital video broadcasting

(DVB), wireless local area network (WLAN), asymmetric digital subscriber loop achieve higher data throughput. In order to enhance the data rate, multi-antenna technique is applied to existing systems [3, 5]. Multiple-input multiple-output (MIMO) communication refers to wireless communication systems using an array of antennas (i.e.multiple antennas) at either the transmitter or the receiver. Multiplexing would cause interference, but MIMO systems use smart selection and/or combining techniques at the receiving end to transmit more information and to improve signal quality. Block diagram of an OFDM system is also shown below

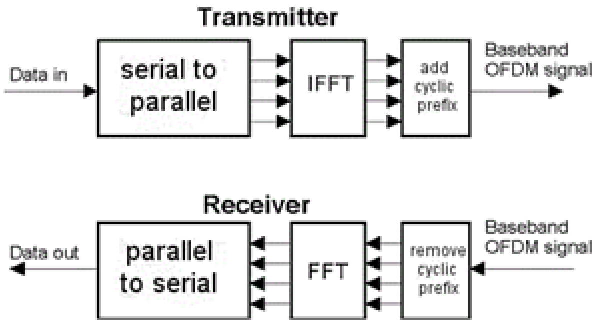

Figure 5: Block diagram of OFDM

Wireless communication is having the fastest growth phase in history because of unprecedented evolution in the field. The kind of wireless communication is experiencing golden days due to various wireless standards such as Wi-Fi, GSM, Wimax and LTE. These standards operate within lower microwave range (2-4GHz). Due to intrinsic propagation losses at these frequencies and problem of multipath fading, it was necessary to provide a solution which can offer robustness in multipath environments and against narrowband interference and is efficient. OFDM, in all this aspects, proves to be an apt candidate by not only providing high-capacity, high-speed wireless broadband multimedia networks but also coexists with current and future systems. Orthogonal frequency-division multiplexing (OFDM) is a method of digital modulation in which a signal is split into several narrowband channels at different frequencies. OFDM has been adopted by several technologies such as Asymmetric Digital Subscriber Line (ADSL) services, IEEE 802.11a/g, IEEE 802.16a, Digital Audio Broadcast (DAB), and digital terrestrial television broadcast: DVD in Europe, ISDB in Japan 4G, IEEE 802.11n, IEEE 802.16, and IEEE 802.20. OFDM converts a frequency-selective channel into a parallel collection of frequency flat sub channels [2].Though it is derived from frequency division multiplexing (FDM), OFDM provides many advantages over this conventional technique. In OFDM the subcarrier frequencies are chosen so that the signals are mathematically orthogonal over one OFDM symbol period. Both modulation and multiplexing are attained digitally using an inverse fast Fourier transform (IFFT) and thus, the required orthogonal signals can be generated accurately [3]. This paper is organized as follows: it describes the architecture of OFDM and Section 3 focuses on application of OFDM in various systems. Section 4 enlightens future work in this area. Finally, conclusions are presented. In order to support cell sizes of macro, micro, and pico IEEE 802.20 should operate in a traditional cellular environment. To increase the availability of coverage area, increase throughput available to the users, and enable a higher overall spectral efficiency, advanced antenna technologies such as multi antenna at the base station should be employed. MIMO OFDM systems are regarded as attractive systems for high speed transmission. Hence, the integration of these two technologies has the potential to meet the ever growing demands of future communication systems [1]. If space-time coding is used at the transmitter, the channel knowledge is required at the receiver to decode the transmitted symbols. Therefore, accurate channel estimation plays a key role in data detection especially in MIMO-OFDM system where the number of channel coefficients is M×N time more than SISO system. (M and N are the number of transmitted and received antenna respectively). Technically, there are four types of channel estimation; training-based, blind, semi blind and data–aided channel estimation. In wireless communications, signals are always distorted by channel. The wireless channel is time or location variant the channel state information to compensate the channel distortion. Pilot signals can be spaced separated in the transmitted symbols. In the receiver, the channel impulse response can be estimated at the positions of pilot signals. The other channel information at the data signals can be obtained by interpolating the estimated channel impulse response. However, error caused by channel interpolation cannot be avoided. A good channel estimation method can provide higher reliable data detection.

Iterative channel estimation based on QR Decomposition for MIMO OFDM systems. The aim of this section is to investigate the effectiveness of QRD (QR decomposition) to reduce the computational complexity of channel estimation algorithms in MIMO-OFDM system, and design high performance channel estimation for this system by using iterative technique. It require less complexity for equalization at the receiver. This is an added advantage especially in the MIMO environments since the spatial multiplexing transmission of MIMO systems inherently requires high complexity equalization at the receiver .In addition to improvements in these multiplexing systems, improved modulation techniques are being used.

Iterative QRD Channel Estimation

In order to complete data-aided channel estimation, pilot signals can be spaced separated in the transmitted symbols. In the receiver, the channel impulse response can be estimated at the positions of pilot signals by several algorithms, such as least square method. The other channel information at the data signals can be obtained by interpolating the estimated channel impulse response.

$$\hat{H}^{j}_{QRD} = \Gamma \tilde{h}^{j}$$

$\tilde{h}$ can be obtained from $\begin{bmatrix} R \\ 0 \end{bmatrix}_{M\times N} \cdot \tilde{h} = Q_{M\times M}{}^{H} \cdot Y$

Where $\Gamma = \begin{bmatrix} F & F & \cdots & F \\ 0 & F & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & F \end{bmatrix}$ $\quad F = e^{-j2\pi mn/N}, \quad 0 \le m \le N-1, 0 \le n \le L-1$

And then the channel estimate is set as initial

$$\hat{H}^{j}_{QRD}{}^{(k)}, k = 0$$

QRD. Secondly, the receiver uses the estimated channel to help the detection/decision of data signals. The detection data can done using zero forcing method.

Where $\hat{H}^{(k)\,\Phi}_{QRD}$ is pseudo inverse of $\hat{H}^{j}_{QRD}$

$$\hat{H}^{(k)}_{QRD} = \begin{bmatrix} \hat{H}^{1,1(k)}_{QRD,diag} & \hat{H}^{2,1(k)}_{QRD,diag} & \cdots & \hat{H}^{N_t,1(k)}_{QRD,diag} \\ \hat{H}^{1,2(k)}_{QRD,diag} & \hat{H}^{2,2(k)}_{QRD,diag} & \cdots & \hat{H}^{N_t,2(k)}_{QRD,diag} \\ \vdots & \vdots & \vdots & \vdots \\ \hat{H}^{1,N_r(k)}_{QRD,diag} & \hat{H}^{2,N_r(k)}_{QRD,diag} & \cdots & \hat{H}^{N_t,N_r(k)}_{QRD,diag} \end{bmatrix}$$

And then the channel estimation treats the detected signals as known data to perform a next stage channel estimation iteratively and the index k adds 1. Go to the first step and repeat the process till the mean-square-error of channel estimate is converged or the expected iterations reach. By utilizing the iterative channel estimation and signal detection process we can reduce the estimation error caused by channel interpolation between pilots. The accuracy of the channel estimation can be improved by increasing the number of iteration process. Iterative QRD channel estimation algorithm has good performance efficiency it can provide better mean square error and bit error rate performance than conventional methods. However the computational complexity of the QRD channel estimation is much lower than LS algorithm. In addition, computational complexity for QRD channel estimation is approximately linearly.

5. Conclusion

A simplified and power efficient system for reducing multipath fading useful in a realistic scenario is considered that is based on Sorted QR decomposition (SQRD).

a) Reduces multipath fading in WCDMA
b) Increase in quality of received signal
c) Reduce BER & Power Dissipation

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