PROJECTED MAJORIZED-CORRELATION TECHNIQUE FOR NOISE FILTERING AND ACCURACY IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

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By

ALAA ABDULLAH MOHAMMED ALSAADI

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PROJECTED MAJORIZED-CORRELATION TECHNIQUE FOR NOISE FILTERING AND ACCURACY IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

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Phase noise is a random unwanted variation interfered with Orthogonal Frequency Division Multiplexing (OFDM) signal according to many factors. One of the important factor is related to oscillator itself which generates the carrier signals and causes Inter Channel Interference Noise (ICI). The second main factor is a multipath fading channel which causes a delay in OFDM signal and results for Inter Symbol Interference Noise (ISI).Basically, phase noise is considered as main problem that causes significant degradation in detecting packet-based OFDM signals. Therefore, its estimation is essential to reduce the interference among other subcarrier signals.

The main objective of this thesis is to develop a new technique for phase noise, accuracy and complexity in OFDM signal. This technique is called Projected Quadratic Majorized Covariance Correlation (PQMCC) technique. PQMCC technique is proposed to reduce the power of noise in OFDM signal, arise the accuracy of received signal and decrease the complexity. Precisely, by proposing the projected signal ($py^{\rightarrow}$) in PQMCC technique has solved the three main issues: power of noise, accuracy in received random signal ($y^{\rightarrow}$) and complexity in Tight Quadratic Majorization algorithm (TQM) for Phase Noise Estimation Technique.

PQMCC Technique is simulated in MATLAB. The simulation results shows that the Wiener Process Phase Noise (PHN) has no effect over the proposed signal ($py^{\rightarrow}$) since it utilizes the properties of orthogonal projection matrix which leads to preserve data [theta (θ) and vectors (h)] from destruction of noise. Literally, the power of noise is reduced from 69dB (7.8458e+06Hz) to 67.2dB (5.2069e+06Hz) when signal to noise ratio (snr) is 15dB. Moreover, the accuracy of the proposed projected signal ($py^{\rightarrow}$) is proven when the sinusoidal signal shows right angle (θ=90°) and the area of recovered projected signal ($py^{\rightarrow}$) is reduced by around 46.2891% in cm^2 comparing with random signal ($y^{\rightarrow}$) in TQM algorithm. In addition to that, by proposing the projected signal ($py^{\rightarrow}$) in PQMCC technique, complexity of TQM algorithm is reduced from second order of big notation $\mathrm{O}(\mathrm{Nc}^2)$ to first order $\mathrm{O}(\mathrm{Nc})$.In summary, the outcome of PQMCC technique based on noise attenuation, accuracy, and complexity reduction has achieved and proven in this thesis.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

TEKNIK KORELASI UTAMA JANGKAAN UNTUK MENYARING KEBISINGAN DAN KETEPATAN DALAM MULTIPLEKS DIVISYEN FREKUENSI ORTOGANAL (OFDM)

Oleh

ALAA ABDULLAH MOHAMMED ALSAADI

Februari 2020

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Fasa kebisingan adalah rawak variasi tidak diingini yang mengganggu isyarat Multipleks Divisyen Frekuensi Ortoganal **(**OFDM) berdasarkan dari banyak factor. Salah satu factor yang penting adalah berkaitan dengan pengayun sendiri yang menjana isyarat pembawa dan menyebabkan Kebisingan Gangguan Inter-saluran (ICI). Faktor utama yang kedua adalah pemudaran saluran pelbagai laluan yang menyebabkan kelewatan isyarat OFDM dan menghasilkan Gangguan Kebisingan Inter-simbol (ISI). Secara asasnya, kebisingan fasa merupakan isu utama yang menyebabkan kemerosotan signifikan dalam mengesan isyarat Multipleks Divisyen Frekuensi Ortoganal **(**OFDM) berasaskan paket. Justeru itu, anggarannya adalah penting untuk mengurangkan gangguan antara isyarat *subcarrier* yang lain.

Objektif utama tesis ini adalah untuk membangunkan model baru untuk fasa kebisingan, ketepatan dan kompleksiti dalam isyarat OFDM. Teknik ini dipanggil teknik Korelasi Kovarians Terutama Kuadratik Jangkaan (PQMCC). Teknik PQMCC ini dicadangkan bagi mengurangkan kuasa kebisingan dalam isyarat OFDM, meningkatkan ketepatan bagi isyarat diterima dan mengurangkan kompleksiti. Secara tepatnya, isyarat jangkaan yang dicadangkan ($py^{\rightarrow}$) dalam teknik PQMCC teleh menyelesaikan tiga isu utama: kuasa bagi kebisingan, ketepatan dan kompleksiti dalam algoritma Keutamaan Kuadratik Ketat (TQM) untuk Teknik Penganggaran Fasa Kebisingan.

Teknik PQMCC disimulasikan dalam MATLAB. Hasil simulasi menunjukkan bahawa Fasa Kebisingan Proses Wiener (PHN) tidak memberi kesan ke atas isyarat yang dicadangkan ($py^{\rightarrow}$) kerana ia menggunakan sifat-sifat matriks unjuran ortogonal yang mengekalkan data [theta (θ) dan vektor (h)] dari

pemusnahan kebisingan. Selain itu, kuasa bunyi dikurangkan dari 69dB (7.8458e+06Hz) kepada 67.2dB (5.2069e+06Hz) bila isyarat kepada ratio kebisingan (snr) ialah 15dB. Selain itu, ketepatan isyarat unjuran ($py^{\rightarrow}$) terbukti bila isyarat sinusoidal menunjukkan sudut tegak (θ=90°) dan kawasan bagi pemulihan isyarat unjuran ($py^{\rightarrow}$) telah dikurangkan kepada sekitar 46.2891% dalam cm^2 dibandingkan dengan isyarat rawak ($y^{\rightarrow}$) di dalam algoritma TQM. Tambahan dari itu, dengan mencadangkan isyarat unjuran ($py^{\rightarrow}$) dalam teknik PQMCC, kompleksiti bagi algoritma TQM dikurangkan dari susunan kedua notasi besar $\mathrm{O}\,(\mathrm{Nc}^2)$ ke susunan pertama $\mathrm{O}(\mathrm{Nc})$. Secara ringkasnya, hasil bagi teknik PQMCC berasaskan pelemahan kebisingan, ketepatan, dan pengurangan kompleksiti telah tercapai dan terbukti di dalam tesis ini.

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LIST OF ABBREVIATIONS

VLSI	Very Large Scale Integration
CDMA	Code Division Multiple Access
AMPS	Advanced Mobile Phone Service
GSM	Global System for Mobile
CDMA	Code Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
SINR	Signal to Interference Noise Ratio
CPE	Common Phase Error
ICI	Inter-Channel Interference
SDPs	Semi Definite Programming
MM	Majorization and Minimization
TQM	Tight Quadratic Majorization
SVD	Singular Value Decomposition
LMMSE	Linear Minimum Mean Square Error
MMSE	Minimum Mean Squared Error Estimation
MSE	Mean Square Error
PHN	Phase Noise
MTSO	Mobile Telephone Switching Office
MSC	Mobile Switching Center
TDMA	time-division multiple access
ISI	Inter-Symbol Interference
CP	Cyclic Prefix
DAB	Digital Audio Broadcasting
ADSL	Asymmetric Digital Subscriber Lines

HDSL	High-Bit-Rate Digital Subscriber Lines
WLAN	Wireless Local Area Network
WIMAX	Worldwide Interoperability for Microwave Access
LTE	Long Term Evolution
ECG	Electro Cardio Gram
Nc	Number of Subcarriers
BW	Bandwidth
QoS	Quality of Service
FDM	Frequency Division Multiplexing
IDFT	Inverse Discrete Fourier Transform
DFT	Discrete Fourier Transform
Sc BW	Single Carrier Bandwidth
BER	Bit Error Rate
FEC	Forward Error Control
BPSK	Binary Phase Shift Keying
QAM	Quadrature Amplitude Modulation
FFT	Fast Fourier Transform
IFFT	Inverse Fast Fourier Transform
DAC	Digital-to-Analog Converter
RF	Radio Frequency
ADC	Analog-to-Digital Converter
PARP	Peak to Average Power Ratio
CFO	Carrier Frequency Offset
SRO	Sample Rate Offset
dB	Decibel

LSE	Least Square Error
FIR	Finite Impulse Filter
CIR	Channel Impulse Response
ML	Maximum Likelihood
GC	Gradient Conjugate
EM	Expectation Maximization
PDF	Probability Density Function
i.i.d	identical independent distribution
E	Expectation
PSAM	Pilot-Symbol Assisted Modulation
SDP	Semi Definite Programming
BIC	Bayesian Information Criterion
RLS	Regularized Least Squares
DSLs	Digital Subscriber Lines
AWGN	Additive White Gaussian Noise
SNR	Signal to Noise Ratio
TQM	Tight Quadratic Majorization
LQM	Loose Quadratic Majorization
PQMCC	Projected Quadratic Majorized Covariance Correlation
DES	Discrete Event Simulation
CLI	Command Line Interface

CHAPTER 1

INTRODUCTION

This chapter offers a broad picture for wireless communications area, which reflects the research background, problem statement and the interest behind the current work. It also analyzes the intention of the research, the scope of the research and research importance. In addition, it highlights the research contributions, which justify the benefits. Ultimately, this chapter summarizes the organization of this thesis.

1.1 Background

Wireless is the one of the most vibrant topic in the communication field nowadays. The past two decades has seen a surge of activities in this area, despite it has been a topic since the 1960’s. The reason for this belongs to several factors. First is the explosive increase in demand for wireless connectivity. Second, the dramatic progress in Very Large Scale Integration (*VLSI*) technology has enabled small-area and low-power implementation of sophisticated signal processing algorithms and coding techniques. Third, the success of second-generation (2G) digital wireless standards, in particular, the IS-95 Code Division Multiple Access (*CDMA*) standard, provides a concrete demonstration. The research thrust in the past two decades has led to a much richer set of perspectives and tools on how to communicate over wireless channels, and the picture is still very much evolving(David Tse and Pramod Viswanath,2005; Lal Chand Godara , 2018).

To be very specific, there are two fundamental aspects of wireless communication that create the problem challenging and interesting. First aspect is the phenomenon of fading: the time-variation of the channel strengths due to the small scale of multipath fading, as well as larger scale effects such as path loss via distance attenuation and shadowing by the obstacles. Second aspect is significant interference between users.

Literally, the interference could be between transmitters communicating with a common receiver (e.g. uplink of a cellular system), between signals from a single transmitter to multiple receivers (e.g. downlink of a cellular system), or between different transmitter-receiver pairs (e.g. interference between users in different cells) (David Tse and Pramod Viswanath, 2005; Lal Chand Godara, 2018).

The question now is how to deal with fading and interference which is a core of the design of wireless communication systems. In spite of, signal processing is belong to physical layer but the truth is the management of fading and interference has ramification across multiple layers. From this point the importance to give a remedy for fading and interference is appeared.

Generally, the design of wireless systems has been focused on increasing the reliability of the air interface; in this context, fading and interference are viewed as nuisances that are to be countered. While recent focus has been shifted more towards increasing the spectral efficiency, e.g., Orthogonal Frequency Division Multiplexing (OFDM).Precisely, association with this shift, a new point of view has been emerged that fading problem could be viewed as an opportunity to be exploited.

Therefore, the aim for providing a unified treatment is started. In order to do so, a cellular network example is taken. This example can give enormous help to get to the point of a tradeoff solution for wireless signal especially in OFDM.

Literally, the origination of wireless system is designed to serve cellular system, e.g., Advanced Mobile Phone Service (*AMPS*) which is developed in U.S. in 80's, for a voice waveform purposes. In this scenario, the interference problem of cellular systems is uncommon since different users in the same cell are assigned different frequencies, adjacent cells use different sets of frequencies and cells sufficiently far away from each other can reuse the same set of frequencies.

While, the second generation (2G) of cellular system is developed for digital purposes e.g., Global System for Mobile (*GSM*). This generation is known as narrowband system since user transmission within a cell are restricted to separate narrowband channels. Further, neighboring cells use different narrowband channels for transmission purposes. Basically, this requires to split the total bandwidth and reduce the frequency reuse in the network.

Literally, the interference problem is emerged very clearly in third generation (3G), e.g., Code Division Multiple Access (*CDMA*) and *OFDM* wireless system which is also known wideband system. Wideband systems are developed to handle data and/or voice. Therefore, it is necessary to provide a large bandwidth to serve this purpose. Precisely, *CDMA* and *OFDM* are utilized the same spectrum in every cell since it costs a lot to provide a large spectrum of different frequencies.

OFDM is considered a special case from wideband since it combines the advantage of *CDMA* (frequency reuse) and narrowband system *GSM* (no intra-cell interference). Indeed, in *OFDM* system user's information is spread by hopping in the time-frequency grid. Basically, where the transmissions inside a cell is orthogonal (bandwidth is divided into multiple subcarriers which is orthogonal to each other).While, adjacent cells utilize the same bandwidth (frequency reuse).Therefore, the inter-cell interference problem in *OFDM* still exists. In other words, *OFDM* is inheritance the interference issue from *CDMA* modulation (David Tse and Pramod Viswanath, 2005; Nicola Marchetti et al., 2009; Zhongju Wang et al., 2017).

Since our research is particularly on *OFDM* estimation signal (channel and phase noise estimation) therefore, the priority is to concentrate on the reasons stand behind *OFDM* limitations, second thing is to provide a compromise method to mitigate the detrimental effects for these limitations.

1.2 Problem Statement

OFDM accommodates many users each with very low average data rate, the fixed overhead need to perform tight power control for each user (David Tse and Pramod Viswanath, 2005; Nicola Marchetti et al., 2009; Zhongju Wang et al., 2017). Precisely, this is considered the central issue for *OFDM* system since the probability to increase the interference between the subcarriers (neighbor cells) is very high which leads to sensitivity to frequency synchronization errors between the transmitter side and receiver side (Pramod Mathecken et al., 2016; Zhongju Wang et al., 2017). Therefore, estimation process is necessary to mitigate the huge effects of synchronization issues in time-domain as well as in frequency-domain.

Several researches have been going through different optimization methods to eliminate sensitive synchronization error of *OFDM* signal (stringent requirement on frequency and timing synchronization) which happens according to several factors (e.g., difference between the incoming waveform and the local references applied for signal demodulation).As corresponding, the imperfect synchronization between sender and receiver side is represented by the term of phase noise which is mainly generated by local oscillator at transmitter side and accumulated when signal passes through different obstacles (multiple path fading channel) till reaches to receiver side whose oscillator is already executed in different way than the sender side in terms of synchronization. This imperfection (synchronization error) causes system performance degradation even in noiseless environment especially in the presence of fading channel. In addition to that, the Doppler spread due to the relative motion between the transmitter and the receiver.Literally, both timing and frequency synchronization introduce extra interference to OFDM systems and become a very challenging task in *OFDM* signal.Thereby, it is of much significance to propose a method to improve the existing synchronization methods.In order to do so, the investigation is done in this research based on a very sophisticated technique which is called Majorization and Minimization (*MM*).This technique provides an approximation-based iterative approach to solving an optimization problem of a generic form. Since the original problem is difficult to address directly, the MM technique follows an iterative procedure:-a simpler surrogate objective function is minimized in each iteration to find a local optimum. According to the conditions of MM technique, Tight Quadrature Method (*TQM*) algorithm for phase noise estimation in *OFDM* signal is proposed (Zhongju Wang et al., 2017).

However, in practice, *TQM* Algorithm comes at price: it is failure to converge with low rate of *OFDM* data symbols block or with low number of sub-carriers, e.g., diagonal matrix. Precisely, it works fine only with high rate of *OFDM* data symbols block or with high level of sub-carriers, e.g.; square matrix. In other word, it does not have the flexibility to deal with all types of signals (rigid). In terms of noise, high level of subcarriers leads to increase the chances of *ICI* because carriers in this type of scenario are very close to each other which results on reducing the synchronization between sender and receiver side and increasing the chances of phase noise (David Tse et al., 2005) .In terms of accuracy, received signal is recovered as a random signal which is basically a noisy signal. Finally, the complexity of *TQM* algorithm is still high since it is associated with high number of subcarriers.

In this research, *TQM* algorithm is investigated as benchmark experiment in MATLAB. Add to that, by considering the previous issues of *TQM*, Projected Quadratic Majorized Covariance Correlation (*PQMCC*) Technique is proposed. The clue of this technique is constructed from the investigation of *OFDM* transmission signal during time-domain (analog signal) and frequency-domain (digital signal). Literally, the result of this investigation leads to the main research question which is how to formulate a technique to generate an adaptive *OFDM* signal that can preserve data during transmission period and perform simply and accurately with less computational burden (low complexity) when it is estimated at receiver side.

In order to achieve this aim, *PQMCC* Technique is formulated by taking into consideration low-complexity and signal recovery when the properties (e.g., covariance and correlation) of probability density function and randomness variables is combined .Literally, this combination is represented the distribution of *OFDM* signal which is associated with the properties of spectral geometry for *OFDM* signal transmission (e.g., singular value decomposition). In other words, it is like a linking between statistical concepts which represented by probability and random distribution with zero-mean and variance (σ^2) and mathematical concepts which represented by the transformation process between two different systems (the path has been taken by signal which represents the distance between sender and receiver side), e.g., eigenvalue and eigenvector.

1.3 Research Objective

The main objective from this research is to propose Projected Quadratic Majorized Covariance Correlation (*PQMCC*) Technique for noise attenuation, accuracy and complexity reduction.

1.By formulating an orthogonal projection matrix ($py^{\rightarrow}$) received *OFDM* signal, to protect signal from noise which is basically come from local oscillators, obstacles and fading channels. Add to that, by developing covariance and correlation matrix when the characteristic of Linear Minimum Mean Square Error Estimation (LMMSE) is utilized. This idea leads to verify the accuracy of projected signal ($py^{\rightarrow}$).Besides that, by proposing the *OFDM* transformation data block (*p*) based on Singular Value Decomposition (*SVD*) to obtain a diagonal matrix that leads to reduce the complexity of *PQMCC* Technique.

1.4 Motivation and Contribution

In line with the aforesaid problems, our motivation is dedicated to establish adaptive *OFDM* signal which considered the stability between time-domain and frequency-domain is number one. In keeping with adaptive signal, linking the properties of transformation process for signal between two different systems, e.g., (sender side and receiver side) which is termed as spectral geometry of phase noise with eigenvalue and eigenvector by adopting the theory of Singular Value Decomposition (*SVD*), is resulted to reduce the computation burden. In other words, implementation happens in low-complexity. Thereby, signal adaptation and signal transformation is taken into consideration. Then, correlation steps of estimation technique are coming consecutively either during transmitted signal (time-domain or Inverse Discrete Fourier Transform *IDFT* process) or when it is captured by receiver in frequency-domain after Discrete Fourier Transform *DFT* process is applied or both of them. Based on aforementioned motivation procedure according to our perspective, the contribution is summarized as follows:

1. In this research, adaptive projected *OFDM* signal is proposed which is based on the idea of projection matrix$P = A(A^H A)^{-1} A^H$. This signal is formulated in terms of convoluted diagonal matrix which contains data symbols in its diagonal with semi unitary matrix which is formulated with slow fading channel impulse response as its columns.

2. Projected Quadratic Majorized Covariance Correlation (*PQMCC*) Technique is proposed. This technique is constructed based on adaptive projected *OFDM* signal that has been proposed earlier. Add to that, it is enhanced the work of Tight Quadratic Majorization (*TQM*) algorithm by eliminating phase noise , recovering *OFDM* signal and reducing the complexity with Projection Matrix,

Linear Minimum Mean Square Error (*LMMSE*) and Singular Value Decomposition (*SVD*) respectively, as the experiment in Chapter 5 is proved that. Basically, *TQM* algorithm is derived from Majorization and Minimization technique (*MM*) and implemented in time-domain. On the other hand *LMMSE* is derived from Minimum Mean Squared Error Estimation (*MMSE*) and executed in frequency domain.

1.5 Research Scope

This research is focusing on linking and normalizing the properties of wireless transmission signal specifically in *OFDM* modulation system according to spectral geometry transformation and providing a comprehensive knowledge for all operations inside OFDM transceiver. Mainly, by proposing and formulating an adaptive *OFDM* signal as a projection matrix introduces the idea to construct *PQMCC* Technique. Indeed, that leads to facilitate the task of phase noise estimation and signal recovery.

1.6 Thesis Organization

The thesis are organized as follows:

Chapter1 offers abroad picture for wireless communication area which reflects the research background, problem statement and the interest behind the current work. It also analyzes the intention of the research the scope of the research and research importance. In addition, it highlights the research contributions, which justify the benefits. Ultimately, this chapter summarizes the organization of this thesis.

Chapter2 presents an overview for phase noise and the previous research works that addressed issues related to Signal to Noise Ratio (*SNR*) and optimization technique for channel estimation, phase noise estimation and joint estimation for both of them. Optimization technique is classified into two type: conventional and advanced optimization.

Chapter3 explores the research framework and explain the stages in details. The experimental setup as well as the performance metrics and validation of the technique are also presented in this chapter.

Chapter4 presents the design of the proposed *PQMCC* Technique. It describes the behavior of projected signal and the formulation of *OFDM* block transformation based on Singular Value Decomposition (*SVD*) whose parameters are eigenvalue, eigenvector and unitary matrix. Moreover, it explains in details *TQM* algorithm for phase noise estimation which is an iterative algorithm based on *MM* technique and *LMMSE* function which is a non-iterative function based on the statistical probability theory to distribute the random variables according to compute their correlation and covariance.

Chapter5 clarifies and evaluates the measurements by considering Mean Square Error (*MSE*) and Signal to Noise Ratio (*SNR*) associating with accuracy.

Chapter6 concludes the work and recommends some promising directions for further research.

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