CHAPTER 1: INTRODUCTION

2.6.1 Background

These days the broadband connectivity appears almost everywhere to reach the capital of regencies and cities in Indonesia. Telkom Indonesia recently has been deploying a fiber optics network to connect cellular broadband BTS also called Node-B across the country. Unfortunately, it does not yet cover low-populated region beyond the area because of low business feasibility and technical consideration.

In term of technical consideration, there is Cognitive Radio (CR) technology that offering an approach in serving the digital gap in this area. It introduces a technique to access UHF frequency spectrum dynamically across the vacant channel temporarily. The vacant communication channel in white spaces application is not available in a wideband (6 – 8 MHz) and spread from 54 MHz to 862 MHz. It is possible to utilize several channels in an application to get more bandwidth with one condition that no interference to low power broadcasting signal. The **dynamically spectrum detection and allocation capabilities** are among the most important characteristics in the next generation communication system.

On the other hand, the Wireless Regional Area Network (WRAN IEEE 802.22) in white spaces application also requires a good spectrum efficient modulation system to guarantee the safety of primary user in using the existing channel from interference. This modulation technique is offered by GFDM that not only has a very high data rate (broadband) and low power but also **low out of band emission** to produce less interference signal than other modulation technique.

Today, the standard technology for multiplexing and modulating signals in modern digital communication (especially the 4^{th} generation of mobile communication) is Orthogonal Frequency Division Multiplexing (OFDM). Basically, this is a multicarrier system that utilizing very small bandwidth for each subcarrier to get the benefit of flat fading channel. The term orthogonal means each carrier will not interfere their neighbor at the point of sampling period. This characteristic inherited from the *sinc* function that is frequency domain of rectangular pulse used to shape the subcarriers.

The orthogonal characteristic and multicarrier system of OFDM technology gives an excellent performance both in the signal error ratio (SER) and the higher data rate compared to a non-multicarrier system. Unfortunately, it brings with them two downsides that degrade the effectiveness of OFDM. Firstly, the emission of the out of band (OOB) power or the power of transmission signal outside the desired spectrum is very high and so will give significant

interference to the next occupied bandwidth. To mitigate the impact of ISI, OFDM uses a cyclic prefix placed between its symbols, but in return it will decrease the spectrum effectivity. Secondly, the peak to average power ratio (PAPR) is very high. Therefore, the RF power amplifiers has to be operated in a very wide linear region. Otherwise, the power amplifier will cause a distortion because the signal peaks get into the non-linear region and creating intermodulation among the subcarriers.

There is a generalization of OFDM technology that introduced by Fetweiss et all. in [3] called Generalized Frequency Division Multiplexing (GFDM). It does not take the benefit of the orthogonality, but on the other hand it utilizing better time – frequency localization characteristic of pulse to shape the subcarriers. There are a lot of research in progress to increase the performance of the GFDM system to level the OFDM performance but with lower OOB emission and PAPR.

2.6.2 Problems

The OFDM is a robust multiplexing and modulation system and capable mitigate the effect of frequency-selective fading. It uses a method of dividing wideband signal into multiple small subcarriers to get the benefit of flat fading for each subcarrier. Unfortunately, the high link performance of OFDM system is hold back by two significant flaws of high out of band (OOB) emission and peak to average power ratio (PAPR).

The high OOB is an impact of the implementation of rectangular pulse to shape the subcarrier. It creates a shape of *sinc* function in frequency domain and has ripple in the side lobe that decay very slowly. Eventually, it produces high power spectral density outside its spectrum.

The PAPR of OFDM system is high, theoretically can be explained by the fact that OFDM symbol is simply a superposition of a number of complex tones. While the OFDM signal is composed of K number of tones that will contribute $10 \log_{10} K$ dB peak power.

2.6.3 Previous Works

The past and recent works in the development of GFDM system ca be summarized as follows:

No.	Authors	Title	Publication	Contributions
1	Jinfeng Du	Pulse Shape Adaptation and Channel Estimation in Generalized Frequency Division Multiplexing Systems	Licentiate Thesis in Electronics and Computer Systems, Stockholm, Sweden 2008	The study of pulse shaping filters in GFDM system to combat the impact of both time and frequency dispersion. The functions studied in this paper include Rect, Cosine, Gaussian, Isotropic Orthogonal Transform Algorithm (IOTA), Extended Gaussian Function (EGF) and TFL1 function. The Heisenberg parameter ξ and the direction parameter κ is used to determine the localisation property of pulse. The Gauss pulse achieves the maximum of ξ=1 and therefore has the best TFL property.
2	Gerhard Fettweis, Marco Krondorf, Steffen Bittner	GFDM – Generalized Frequency Division Multiplexing	Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th, June 2009	Performance analysis of GFDM with RC filter (roll off 0.1) over OFDM system in white spaces UHF Band application. The PAPR performance of GFDM is about 1 dB lower than that in OFDM at a probability of 10^{-3} and the GFDM BER performance is slightly worse due to the orthogonality loss, which can be controlled by appropriate filter designs.
3	Nicola MICHAILOW, Michael LENTMAIER, Peter ROST, Gerhard FETTWEIS	Integration of a GFDM Secondary System in an OFDM Primary System	Future Network & Mobile Summit (FutureNetw), June 2011	Spectrum overlay analysis found that GFDM as secondary system is better than OFDM as secondary system in cognitive radio with OFDM as primary system, but in higher error rate; reasearch sow: - Pulse shaping filter RC and RRC - BER in AWGN Channel
4	A. S Kang, Vishal Sharma	Pulse Shape Filtering in Wireless Communication-A Critical Analysis	International Journal of Advanced Computer Science and Applications (IJACSA), Vol. 2, No.3, March 2011	The study of pulse shaping filtering to reduce channel banwidth and intersymbol interference in WCDMA system. Different pulse shapes was studied include Rect, RC, RRC, Gaussian, Flipped Exponential, Flipped Hyperbolic Secant and Flipped Inverse Hyperbolic Secant Pulse.
5	Rohit Datta, Nicola Michailow, Stefan Krone, Michael Lentmaier, Gerhard Fettweis	Generalized Frequency Division Multiplexing in Cognitive Radio	20th European Signal Processing Conference (EUSIPCO 2012)	Performance analysis of GFDM with RRC Filter (roll-off 0.1) and MF reciver based sensing characteristics and OFDM sensing receiver operating charateristic in cognitive radio. The sensing receiver operating characteristic (ROC) of a GFDM transmission is sensed by a GFDM receiver is better than an OFDM sensing by a traditional OFDM based sensor.
6	Nicola Michailow, Ivan Gaspar, Stefan Krone, Michael Lentmaier, Gerhard Fettweis	Generalized Frequency Division Multiplexing: Analysis of an Alternative Multi-Carrier Technique for Next Generation Cellular Systems	www.researchgate.net /publication/261231239, August 2012	The implementation complexity analysis of GFDM with RRC filter (roll off 0.25) over OFDM system related to LTE standard.
7	Nicola Michailow, Gerhard Fettweis	Low Peak-to-Average Power Ratio for Next Generation Cellular Systems with Generalized Frequency Division Multiplexing	International Symposium on Intelligent Signal Processing and Communication Systems, November 2013	The PAPR comparison in an uplink multiple access scenario using OFDM, SC-FDM and GFDM (RC Filter, roll-off 0.1, 0.5 and 0.9) resulted about 2 dB lower PAPR in SC-FDMand GFDM than in OFDM at a probability of 10^{-3}.
8	Bruno M. Alves, Luciano Leonel Mendes, Dayan Adionel Guimaraes, Ivan Simoes Gaspar	Performance of GFDM over Frequency – Selective Channels	Revista Telecom. Vol. 15, October 2013	SER analysis of GFDM over OFDM using system parameters RRC Filter (rolloff 0.5), MFR, ZFR, MFR+DSIC Receiver in AWGN and Frequency-selective channels. The GFDM with MFR-DSIC receiver can match the performance of OFDM system.
9	Nicola Michailow, Maximilian Matthe, Ivan Simoes Gaspar, Ainoa Navarro Caldevilla, Luciano Leonel Mendes, Andreas Festag, Gerhard Fettweis	Generalized Frequency Division Multiplexing for 5th Generation Cellular Networks	IEEE Transactions on Communications, Vol. 62, No. 9, September 2014	1) The GFDM waveform's spectral properties 2) Analytical analysis of symbol error performance over different channel models - Filters: RC, RRC, 1st order and 4th order Xia - Channels: AWGN, FSC and TVC 3) Concepts for MIMO-GFDM to achieve diversity; 4) Preamble-based synchronization that preserves the excellent spectral properties of the waveform; 5) Bit error rate performance for Space-Time coded GFDM transmission using iterative receivers; 6) Relevant application scenarios and suitable GFDM parameterizations 7) GFDM proof-of-concept and implementation aspects of the prototype using hardware platforms available today.
10	Maximilian Matthe, Nicola Michailow, Ivan Gaspar, Gerhard Fettweis	Influence of Pulse Shaping on Bit Error Rate Performance and Out of Band Radiation of Generalized Frequency	IEEE International Conference on Communications Workshops (ICC), June 2014	Performance analysis of GFDM resulted the RC pulse shaping filter have an acceptable interference and reduced OOB radiation 58 dB below OFDM; research sow: - BER over AWGN Channel - OOB: RC, RRC, Gaussian, Xia 1st order, Xia 4st order, Dirichlet pulse
11	Behrouz Farhang-Boroujeny, Hussein Moradi	Derivation of GFDM Based on OFDM Principles	IEEE International Conference on Communications (ICC) 2015	A point of view of GFDM that builds based on the same principles as OFDM and resulting an implementation of less complex GFDM transmitter.
12	Shwetal K. Antapurkar, Avinash Pandey, K. K. Gupta	GFDM performance in terms of BER, PAPR and OOB and comparison to OFDM system	2nd International Conference on Communication Systems, At BKBIET, Pilani, October 2015	Performance of GFDM with RRC filter (roll off 0.1) over OFDM in terms of OOB, PAPR and Bit Error Rate (BER) in AWGN and Rayleigh Channels. The OOB perfomance is about 15-20 dB below that of OFDM signal, the PAPR is lower than that in OFDM and BER slightly degraded as compared
13	Ali Bulut Ucuncu, Ali Ozgur Yilmaz	Out-of-Band Radiation Comparison of GFDM, WCP-COQAM and OFDM at Equal Spectral Efficiency	IEEE SIGNAL PROCESSING LETTERS, SUBMITTED DRA 2015	To compare OFDM, GFDM and WCP- COQAM in terms of OOB emissions and carrier frequency offset immunities for dynamic spectrum access application in CR. The OOB of GFDM over OFDM is about 9 dB, W-GFDM and WCP-COQAM over W-OFDM is about 7 dB and GW-OFDM, GW-GFDM & GWCP-COQAM is about the same. (RC pulse is used for GFDM and WCP- COQAM, roll off 0.1).
14	Nicola Michailow, Luciano Mendes, Maximilian Matthe, Ivan Gaspar, Andreas Festag, Gerhard	Robust WHT-GFDM for the Next Generation of Wireless Networks	IEEE COMMUNICATIONS LETTERS, VOL. 19, NO. 1, JANUARY 2015	The scheme that combined GFDM with Walsh-Hadamard Transform to improve BER by 9 dB over severe FSC condition.

2.6.4 Scope of Work & Contribution

The simulation and analysis of OOB, PAPR and Link Performance of the GFDM system in this thesis are referred to the system as defined by Alves et. all. especially the transmitter and receiver configuration of GFDM system [2]. There are *M* different timeslots with *K* subcarriers for each timeslot that will be fed into a pulse-shaping filter. It will be utilized the same mapper for each subcarrier in the timeslots. In the receiver side, the match filter (MF) detector will be used to get the information back to the user. In addition, the link performance will be calculated under AWGN channel.

The Scope of work is summarized as follows:

- Modelling of GFDM and OFDM system
- Simulation using Matlab ver. 2015b
- Performances analysis in term of OOB, PAPR and SER
- Pulse shaping filter RC, RRC and Gaussian for GFDM and Rect for OFDM
- Communication channel AWGN

The contribution of this work is the comprehensive study on OOB, PAPR and SER performance analysis of GFDM with RC, RRC and Gaussian filters over OFDM system.

2.6.5 Objective

The main objective of this thesis is to calculate the performance of a GFDM system in term of out of band (OOB) emission, peak to average power ratio (PAPR) and link performance (SER/BER). Of course, the results will be compared to the value in a OFDM system as the reference system. In other word, we will build a GFDM system with link performance that catch the OFDM quality but lower OOB and PAPR than in OFDM.

2.6.6 Hypothesis

The performance of OFDM system in term of OOB and PAPR can be enhance by utilizing a proper type of pulse to shape the subcarriers to replace the usage of rectangular pulse. The pulse to be chosen in this application is characterized with a high time-frequency localization (TFL) represented by the parameter Heisenberg ξ and direction κ. Various pulses exercised in this thesis have an excellent TFL grade as described in [5] i.e. raised cosine/root raised cosine (ξ=0.886, κ=0.738) and Gaussian (ξ=1.0, κ=1.0) compared to rectangular pulse (ξ=0.346, κ=0.245).

2.6.7 Research Methodology

A study on a generalized frequency division multiplexing (GFDM) mainly on IEEE journal or conference to explore the building block of the transmitter and receiver of the system. A publication by Alves et all. [2] has expanded the result of the research of the founder of GFDM system [3] in term of the chance to implement different mapper on each leg of GFDM transmitter. In general, the GFDM system will be built on the flexibility of pulse implementation to shape the subcarriers.

For analysis of the GFDM system, the transmitter and receiver has to be simulated using a Matlab code based on the configuration publish by Alves et all [3]. Based on the code, simulation will be conducted by interchange the filter from rectangular, root raised cosine, raised cosine, and Gaussian pulse to shape the subcarriers. The link performance is calculated to meet the quality in OFDM system, and the parameters of out of band emission and peak to average power have to compete for better performance than in OFDM system.