Master's Thesis

Investigation of Cross Modulation for SC-FDMA Signals in Radio over Fiber Mobile Fronthaul

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Abstract

Analog-type RoF link is promising solution for broad bandwidth, simple configuration of remote antenna site and low latency transmission. However, nonlinearity property in E/O device causes distortion due to cross modulation. In general, performance deterioration due to the cross modulation is serious in case if multi-carrier transmission rather than single carrier. Although many articles have reported the cross modulation and its countermeasure, cross modulation effect has not evaluated when the SC-FDMA signals are transmitted through RoF link using an external modulator. This thesis investigates transmission performance of RoF mobile fronthaul for transmitting the SC-FDMA signals in terms of its error vector magnitude (EVM) and bit error rate (BER).

Keywords:

Radio over Fiber, Cross Modulation, SC-FDMA, Mobile Fronthaul, Uplink

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Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Radio over Fiber (RoF) technology is seen as a potential solution to provide heterogeneous radio access, low-latency signal transmission and reduce energy consumption in mobile fronthaul (MFH) especially at remote node. MFH with large data capacity attracted attention in recent years, especially on the next generation wireless network. A number of distinct base station as remote node are grouped at a central office pool, that are connected to support Centralized Radio Access Network (C-RAN). There are two types of transportation, digital RoF (D-RoF) that the former transmits digitized radio signal over fiber link using Common Public Radio Interface(CPRI) protocol and analog RoF (A-RoF), the transfers radio signal by keeping its signal format. A-RoF link enables us to build simple configuration of remote node and applicable as an option on MFH in cellular system. It has simplicity in applying signal transmission between Remote Radio Unit (RRU) or Remote Radio Head (RRH) to Central Office (CO) or Baseband Unit (BBU) in long term evolution (LTE) system. However, analog signal has vulnerability to both nonlinearity of the microwave and optical components used and additive noise. Industrial consensus seems currently to agree that short-term solutions can come within digital MFH, but the required is maximization of bandwidth utilization, offered by A-RoF transmission, renders the transition towards concepts based on an analog longer term 5G solution [1]. In long-haul fiber transmission, the A-RoF system may decrease in information signal power caused by attenuation in optical power, signal dispersion, and Inter-Modulation Distortion (IMD), which is mainly caused by nonlinearity of microwaves and optical components.

The single carrier frequency division multiple access (SC-FDMA) technique has been employed by the 3rd Generation Partnership Project (3GPP) for the uplink air interface in next generation wireless communication system because of low peak to average power ratio property. It helps in avoiding high signal distortion, simplifying transceiver design and reducing power consumption and thus increases battery life of mobile terminals [2]- [3]. A-RoF link suffers not only from the IMD but also from cross-modulation (XM) distortion effect. Out-of-band signals can degrade system dynamic range especially when the various channels differing power levels. In related work, researchers analyzed nonlinearity, IMD and XM in RoF link, such a investigation intra band XM in multi band RoF and monitoring channel to detect and compensate the nonlinearity in the RoF system. In this thesis, the XM effect when the SC-FDMA signals are transferred in A-RoF link using external modulator is investigated for the first time. Computer simulation is used as a mean for performance evaluation.

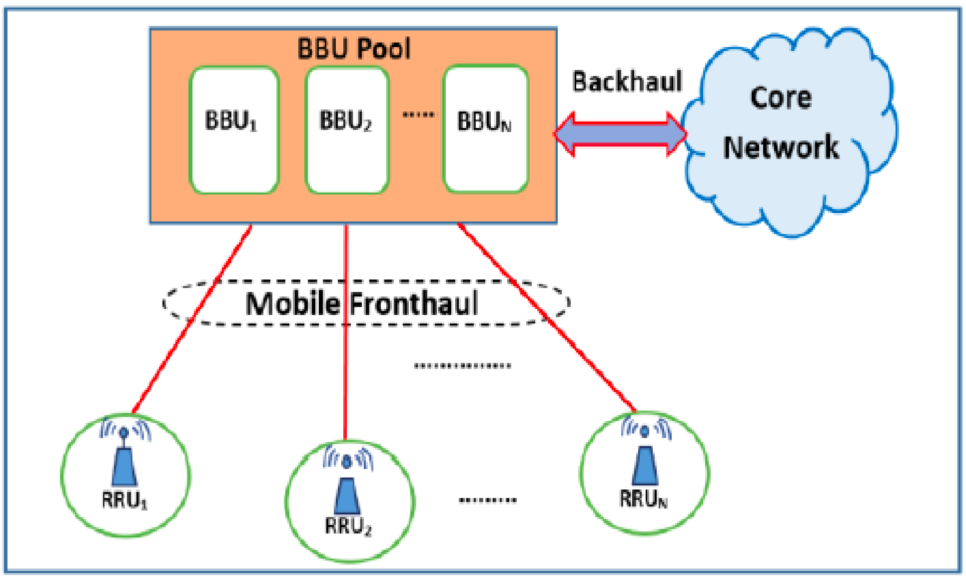

Figure 1. Radio over Fiber Basic Transmission [4]

1.2 Motivation and Purpose

The A-RoF is the candidates option to achieve the requirements in several standards, without changing much of the system that has been implemented at this time. A-RoF also has efficiency on the RRH because it doesn't add many parts so the energy consumption is low. The Mach - Zehnder Modulator as external modulator, is the intermodulation is the dependent on Normalize Optical Modulation Index (NOMI), in this thesis the approach by tuning NOMI that the investigation can be carried out using existing parameter.

Our motivations for this work are : 1) It is an interesting research topic in wireless communication systems, when the low latency, efficient bandwidth and low energy consumption, that are important point in wireless telecommunication system. 2) It is also to analyze the IMD effect in an uplink system that uses SC-FDMA as recommended by The 3GPP.
Our purposes for this work are : 1) to investigate performance in the uplink system mobile fronthaul when using SC-FDMA system according to the 3GPP standards in multiple access systems 2) to investigate the effect of cross modulation that is the system combined from radio frequency signal and optical wave during fiber optic cable. 3) to estimate the NOMI value while this technology is implemented to the uplink transmission signal on the mobile fronthaul system.

1.3 Contributions of this thesis

The main contribution of this thesis is to evaluate of the SC-FDMA performance signal in the A-RoF mobile fronthaul. Since the limited dynamic range, nonlinear distortions, and cumulating noise are major concerns with A-RoF, in related work researchers analyzed IMD and XM in downlink A-RoF have high PAPR but for the uplink A-RoF system needs more details, especially because it has Low PAPR. Meanwhile the limited power of user equipment (UE) cause we can only process power signals without being able to manage and suppress distortion in UE, this problems can be done to improve by maximizing the RRH and BBU functions, after the signal going through the RoF channel using an external modulator, we need to investigate the IMD effect for transmitting SC-FDMA signal in RoF channel that has Low PAPR. The results of our investigation, it is expected to be used as a reference for the amount of power [dB] on the optical modulation index until the quality of the performance signal network uplink system can be managed appropriately.

1.4 Structure of this thesis

The rest of the thesis is organized as follows. Chapter 2 presents the overview of the uplink system using A-RoF. In Chapter 3, an approach for investigate the performance will be brief information about our block diagram and SC-FDMA scheme. The results will be presented to show the performance uplink system configuration in mobile link using spectrum baseband signal, EVM and BER in Chapter 4. Finally, Chapter 5 summarizes this work, with the conclusion and suggestion in the future work.

2. Definition

2.1 C-RAN

The advanced Centralized Radio Access Network (C-RAN) architecture is adopted for the LTE and New Generation wireless communication systems. This architecture consist of a Baseband Unit (BBU) that performs digital processing and Radio Remote Head (RRH) which has function of transmitting and receiving radio waves. Some RRHs are configurations that carry out centralized control with a BBU. The link between BBU and RRH using Common Public Radio Interface (CPRI) Protocol by optical fiber, additionally the waveform is reproduced analog to digital conversion of the waveform of wireless signal [5]. Fig.2 illustrates the fiber-wireless transmission system in C-RAN.

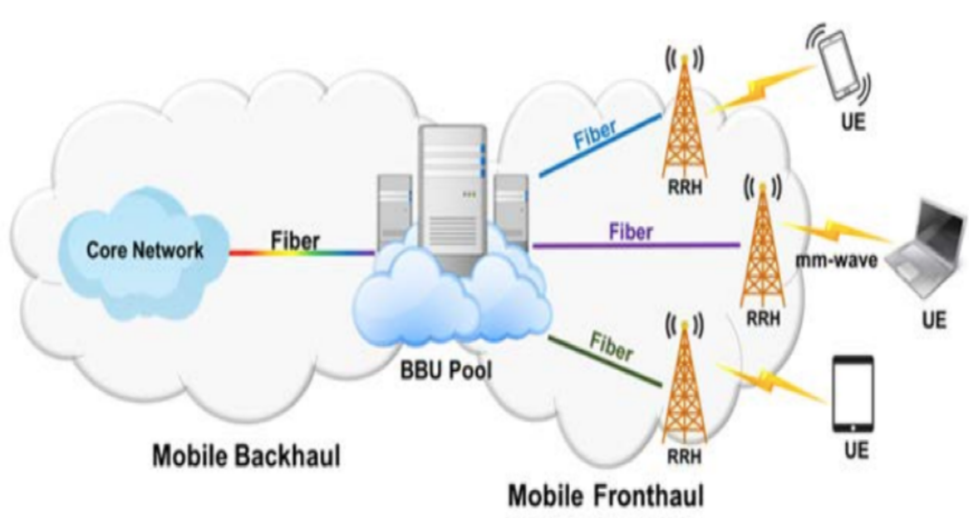

Figure 2. Fiber-wireless transmission system [6]

In the C-RAN architecture right now designed for the LTE Advanced mobile networks using digitized RoF, where the interface is based on CPRI protocol seems to be a significant challenge for 5G topologies. The current exploitation of digital optical transmission, a technique that produces 10x bandwidth demand of each wireless bit-rate [7]. This digital approach cannot be improved with increasing radio bit rate and number of antennas needed by the 5G network approach, which has one of the requirements is maximum bandwidth utilization.

2.2 Radio over Fiber

In this section we mainly focus on the general concept of wireless access cellular communication using Radio over Fiber (RoF) on a centralized radio access network communication. RoF is a technology that is seen as one of the candidate solutions in cellular communication networks that provides a high level of centralization and minimizes the complexity of data distribution systems that are seen as promising next-generation integrated optical and wireless access network platforms due to large bandwidth, low-loss of optical fiber transmission while maintaining wireless service mobility [8] - [9]. In cellular communication network C-RAN divide 2 part, the first is core network to BBU called mobile backhaul and the other part is the transmission links between the BBUs and the RRHs are called the mobile fronthaul (MFH).
RoF is proposed to transmit signals in MFH. Some researchers are optimistic that RoF can reach the target to make the network low latency and efficient bandwidth. In RoF system, radio frequency signals are transmitted using light waves through fiber optic cables, where is the previous signal and after the optical fiber will be the same without any interference from outside fiber as shown in Fig.3.

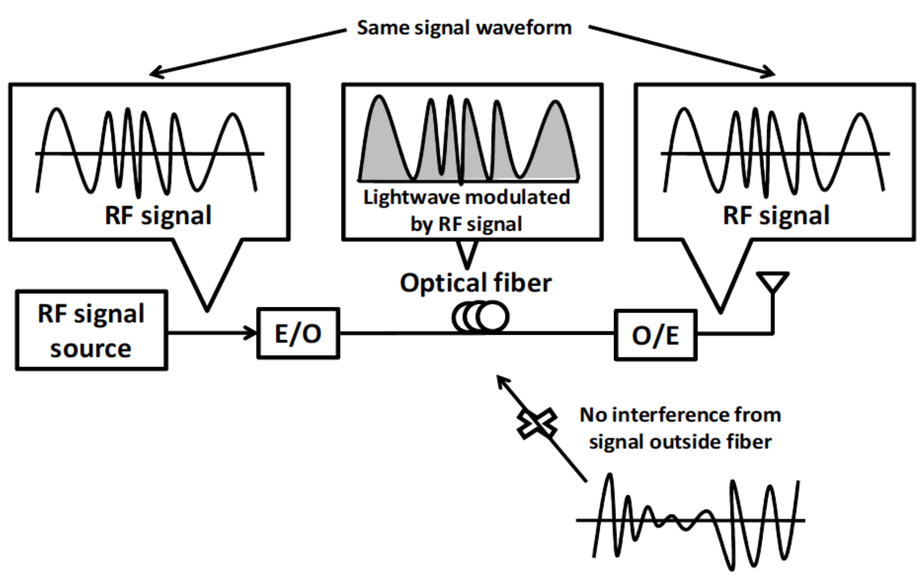

Figure 3. Radio over Fiber Basic Transmission [10]

After performing all baseband signal processing in the BBU, the RF signal is converted to an optical signal by an Electric / Optical (E/O) converter. Optical transmission going through by fiber optic cable to RRH, and optical signal will be re-convert into electric signal in Optical / Electric (O/E) modulators. This signal is converted to a channel signal and transmitted by RF (Radio Frequency) transceiver.

2.3 Mobile Fronthaul Transmission

In RoF system a central office is connected to remote base station by optical fiber, which carries the microwave subcarrier. On the base station the photodetector recover the microwave signals. For RoF, the function of the use of lasers that can be used in various applications, because of it has high efficiency and low noise. E/O uses a light source from a laser diode to modulate the RF signal. The atoms vibrate to perform a beam radiation by using the capability of the p-n junction [11]. The length of a single wave with the same phase applies to all waves.

2.3.1 RoF Classification

There are any 2 types of RoF classification, the digitized and the analog RoF. Analog transmission systems are the basis of transmission because radio waves can be directly distributed from the BBU as the central office to RRH. Moreover, instead of CPRI protocol to transmit radio carrier frequency while using digitized RoF. The digitized radio is determined to transmit waveform but the the speed is higher than the radio bandwidth is required. The analog optical fiber radio is the direct modulating the light source intensity by using the radio signal waveform and detecting the original signal by Photo Diode (PD) as shown in Fig.4. Furthermore, Fig.5 and Fig.6 illustrate the configuration digitized RoF and analog RoF, thus we can comparison of the pros and cons each other. Table 1 describe that the analog RoF have low complexity, simple base station, and high bandwidth utilization, but the nonlinearity is high.

The CPRI protocol in digitized RoF is a standard for digitizing line signals and optically transmitting to the RRH [12], where Analog to Digital (A/D) conver-

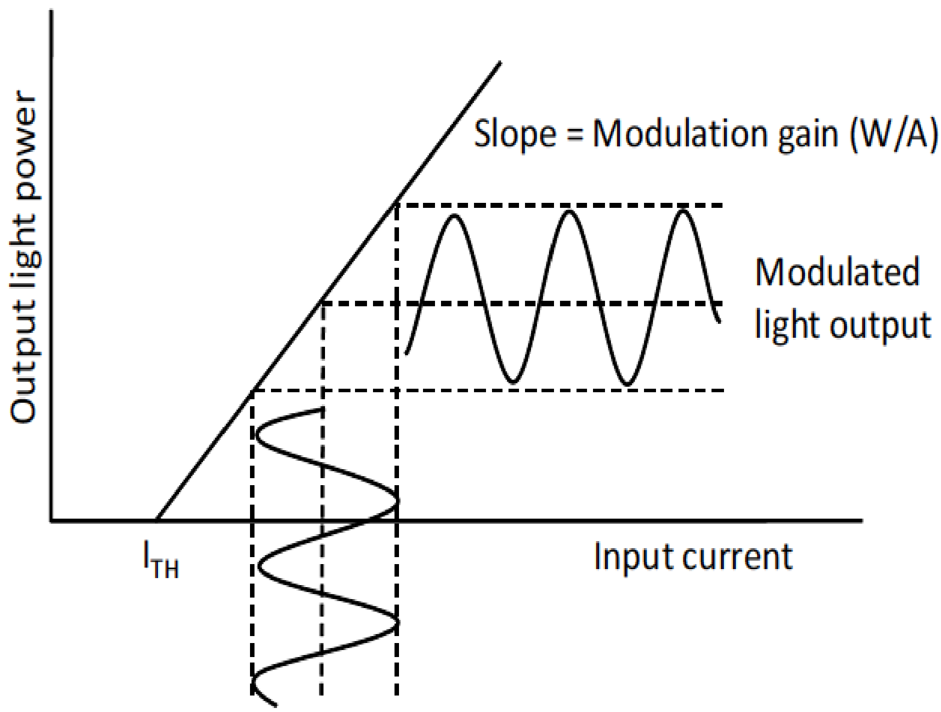

Figure 4. Photodiode Linear Responsivity Curve

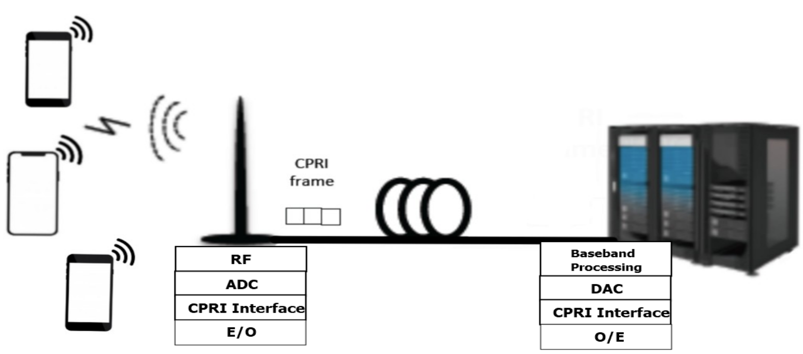

Figure 5. Digitized RoF

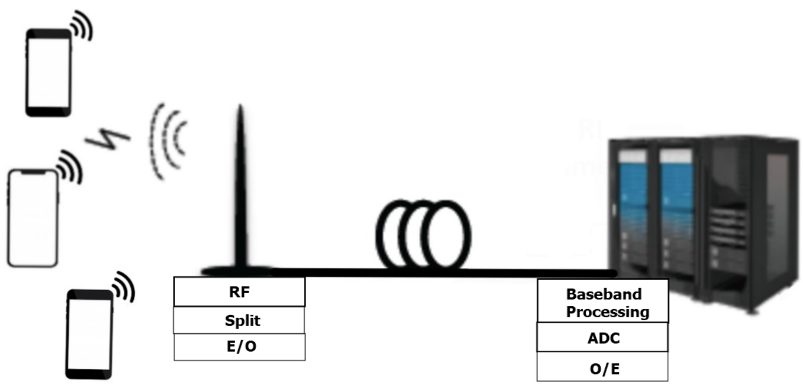

Figure 6. Analog RoF

sions are needed to convert the radio signal in the BBU. At this time, the sampling rate as number of quantization bits and the number of Multiple In Multiple Out (MIMO) antenna transmission rate is required in this system. To provide services, an antenna configuration with a bandwidth of 20 MHz and 2x2 MIMO [13]. The optical transmission rate of the MFH is calculated by the following equation, 20 [MHz] x 15 (sample width) x 1.536 (oversampling) x 2(I/Q) x 16/5 (control OH) x 10/8 (8B10B) x 2(2x2 MIMO) = 2.47576[Gbps]. Since the bandwidth usage and the number of MIMO are increased, recently the CPRI has transmission rate up to 24.3 Gbps has been specified [14].

It is assumed that MIMO will be used with CPRI standard in next generation is too heavy, optical transponder for 10 GbE (Gigabit Ethernet) is necessary to use a transmission device, and there is a concern that construction cost will be increase to manage the bandwidth configuration. To overcome the problem such as the lackness bandwidth to accomodate MIMO 4x4 or 8x8, the A-RoF scheme has been proposed to accomodate more mobile channel, over a single wavelength leading to higher optical bandwidth efficiency and hence increases the capacity of MFH. Moreover, the A-RoF does not even need A/D to convert the digital signal [15].

Table 1. Comparison of digitized RoF and analog RoF

	Digitized RoF	**Analog RoF**
Base Station	complex	simple
Complexity	high	low
Bandwidth Utilization	low	high
Non-Linearity	low	high

2.3.2 Transmission Uplink System

In the context of 3GPP LTE (Third Generation Partnership Project Long Term Evolution), the target data rates are 100 Mbps in downlink and 50 Mbps in uplink, and other system features include flexible bandwidths, and moderate power consumption of mobile terminals. In downlink system, the base stations transmits simultaneous signals to multiple UE in its coverage area. It has very high transmission power capability because will share to multiple UE, the opposite of that uplink transmission has low power from UE, therefore SC-FDMA was choosen by the 3GPP to accommodate the low power and avoid high signal distortion. Table 2. is shown The 3GPP LTE requirement [16],

Table 2. 3GPP LTE Requirement

Specification	**Detail**
Modulation Type	QPSK, 16QAM, 64QAM
Peak uplink speed (Mbps)	50(QPSK), 57(16QAM), 86(64QAM)
Channel bandwidth (MHz)	1.4, 3, 5, 10, 15, 20
Access schemes	OFDMA (downlink), SC-FDMA(uplink)
Duplex schemes	FDD,TDD

2.4 SC-FDMA

Orthogonal frequency division multiple access (OFDMA) system in the last several years has received a lot of attention due to their abilities to overcome the frequency selective fading impairment by transmitting data over narrower sub bands in parallel, but have disadvantage such as the high Peak to average power ratio (PAPR). The 3GPP LTE has adopted the single carrier frequency division multiple access for uplink system to solve this problem. Single-carrier frequency-division multiple access (SC-FDMA) is widely used in the uplink of long- term evolution (LTE) and LTE-advanced systems [17]- [18]. It is similar to orthogonal frequency-division multiplexing (OFDM) used in the downlink of LTE systems , but with an extra discrete Fourier transform (DFT) block prior to subcarrier mapping, SC-FDMA shows its strength robust to high peak-to-average-power ratio (PAPR) which produces benefits of both terminal expense and power efficiency. Simulation results show that the subcarrier mapping has a significantly lower PAPR compared to OFDMA. SC-FDMA significantly reduces the envelope fluctuations in the transmitted waveform, which means less sensitivity to carrier frequency offset [19]. That is improves the radio frequency (RF) power amplifier efficiency and also the mean power output from a battery driven mobile terminal or UE. The scheduler can assign one or multiple resource block (RB) to UE. In practical applications, the subcarriers assigned to a UE are relatively small [20].

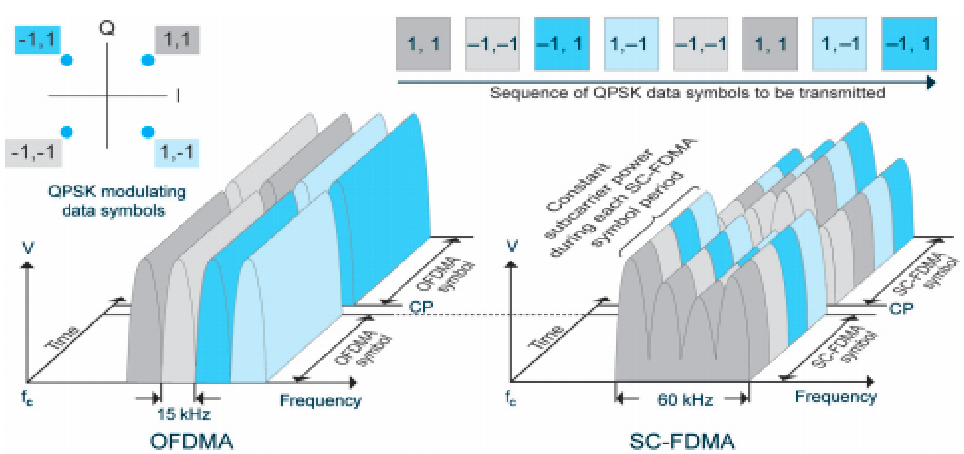

Figure 7. SC-FDMA transmission

The SC-FDMA signals are allocated in units of 12 subcarriers known as Resource Blocks (RB). The sample uses four subcarriers (M) over two symbol periods with data payload using the QPSK modulation. M symbols represent the modulating data, it is the parallel transmission of multiple symbols that creates the undesirable high PAPR.

2.4.1 Subcarrier Mapping

The subcarrier mapping is important operation in SC-FDMA, where the placement of the N-DFT symbol considers the subcarrier mapping method [21] .There are have two methods to map the subcarriers among users, the distributed mapping method (DFDMA) and localized mapping method (LFDMA). Where the distributed FDMA scheme with equidistance between occupied subcarriers in the whole band is called Interleaved FDMA scheme.

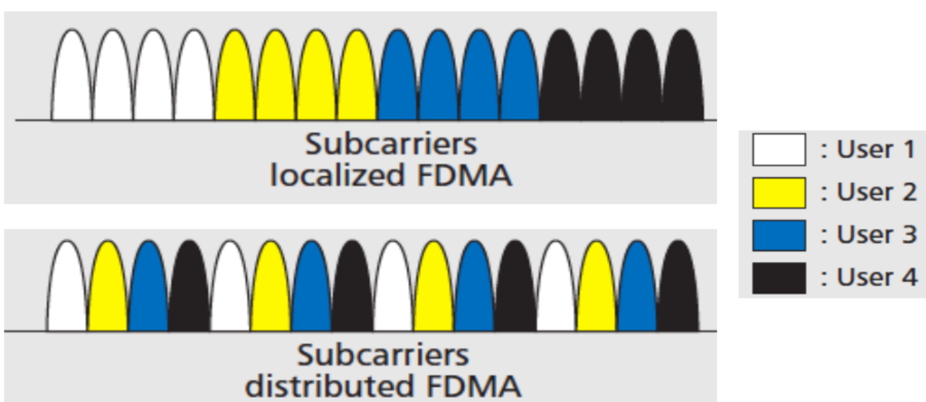

Figure 8. Subcarrier apportionment schemes of SC-FDMA

3. Proposed Method

3.1 Configuration

In this investigation, we prepared block diagrams to illustrate the sequence of transmission systems in the uplink system , from User Equipment (EU) to Radio Remote Head (RRH) until the central office. The principle block diagram of the SC-FDMA system is shown in Fig.9, we consider a baseband equivalent SC-FDMA uplink transmission system with localized subcarrier mapping, it has advantage of multi-user diversity and being used in the LTE uplink.

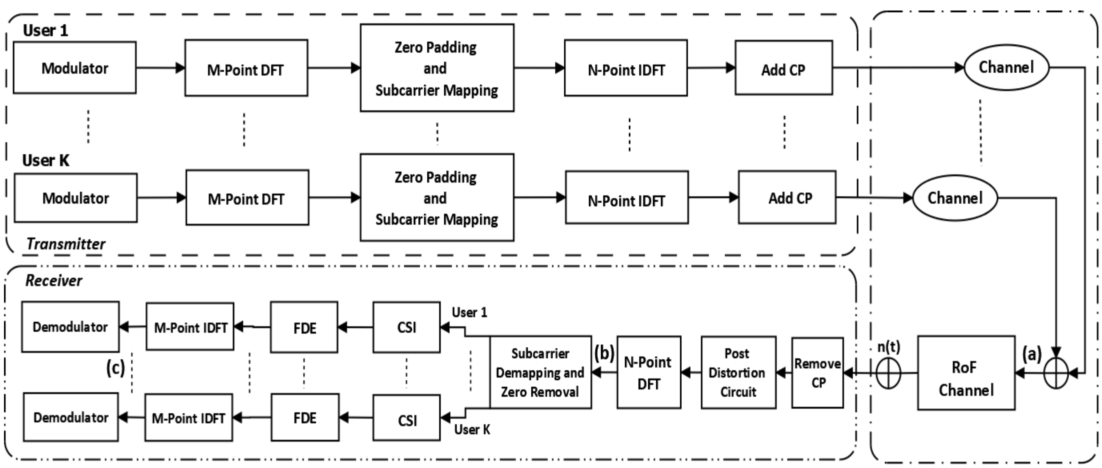

Figure 9. Block Diagram

The magnitude of the distortion depends on NOMI (Normalized Optical Modulation Index) and is expressed from the magnitude of the RF signal and the half-wave voltage of the optical modulator at the time of MZ modulator input. In point (a) we can evaluate g(t) as input RoF channel, point (b) will show spectrum baseband signal the linear and nonlinearity due to RoF Channel and point (c) for investigate the performance using EVM with parameter of NOMI [22]. From this block diagram, in channel site we use Additive White Gaussian Noise (AWGN) channel, where the relative strength of noise in an AWGN channel is typically described by the following quantities such as S/N ratio (SNR) for each sample. This is AWGN the actual input parameter to the function, ratio of energy per bit to noise power spectral density (EbN0) and Ratio between symbol energy and noise power spectral density (EsN0). In this configuration, we assumed that all power from each UE have same power, it means that not affected by fading, loss and propagation.

3.2 RoF channel

In this research, we transmit cellular digital radio waveforms. Instead of sending CPRI protocol, A-RoF is proposed. The characteristics the conversion of the Mach-Zehnder Modulator (MZM) used in analog radio over fiber, this characteristic degradation causes modulation distortion. In order to convert the optical phase change of the E/O effect due to lithium niobate (LiNbO3: LN) into an amplitude change, the operating principle of the MZ modulator using a MZ interferometer as part of RoF channel is shown in Fig.10.

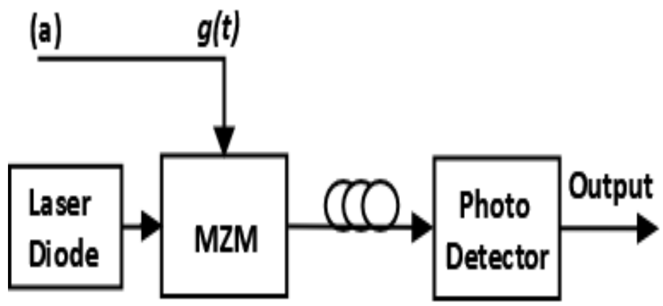

Figure 10. RoF Channel

External modulation applies to modulation schemes where the light source (laser) is driven by a constant-bias current that is higher then the threshold current, this bias current is usually optimized to get the best performance from the laser. MZM has dependence of the RF link gain on the optical power where the RF gain of a directly modulated link is not directly dependent on the mean optical power [23]. This investigation used NOMI as normalized optical power to transport SC-FDMA as the RF signal until it does not interfere with the electrical signal that has been converted into optical power.

3.3 Cross Modulation

Cross modulation is a special case of intermodulation phenomena and is related to the difference between 2 signals [24]- [25]. It can be applied to demodulation signals. The characteristic degradation due to IMD will explain with the NOMI and EVM that used to evaluate the transmission effect of modulation distortion. In this investigation, $g(t)$ represents the equivalent low-pass modulated signal after IFFT is performed on the mapped signal as SC-FDMA signal and through the air channel then summing up to become a RoF channel input. The magnitude of the distortion depends on NOMI and is expressed by the magnitude of root mean square the $g(t)$ and the half-wave voltage of the optical modulator at MZM input,

$$g(t) = \sum_{k=1}^{K} g_k(t) \tag{1}$$

where k is user index and K is maximum number of user index.

$$NOMI = r.m.s(g(t))/\left(\frac{V_\pi}{2}\right), \tag{2}$$

where $g(t)$ represents the equivalent low-pass signal and V_π is the half-wave voltage of the MZM, P_0 is maximum transmitted light intensity, which is assumed as 1 for simplicity, and α is dc component bias at photodetector output.

$$v(t) = \frac{1}{2}sin(\frac{\pi g(t)}{V_\pi})P_0 + \alpha, \tag{3}$$

For the calculated the linear and higher components in output of radio over fiber channel, where $v(t)$ is summation of harmonics shown as, $v(t) = \sum v_n(t)$ where the n is harmonic index. The $v_n(t)$ can be represented,

$$v_n(t) = a_n g(t)|g(t)|^{n-1}, \tag{4}$$

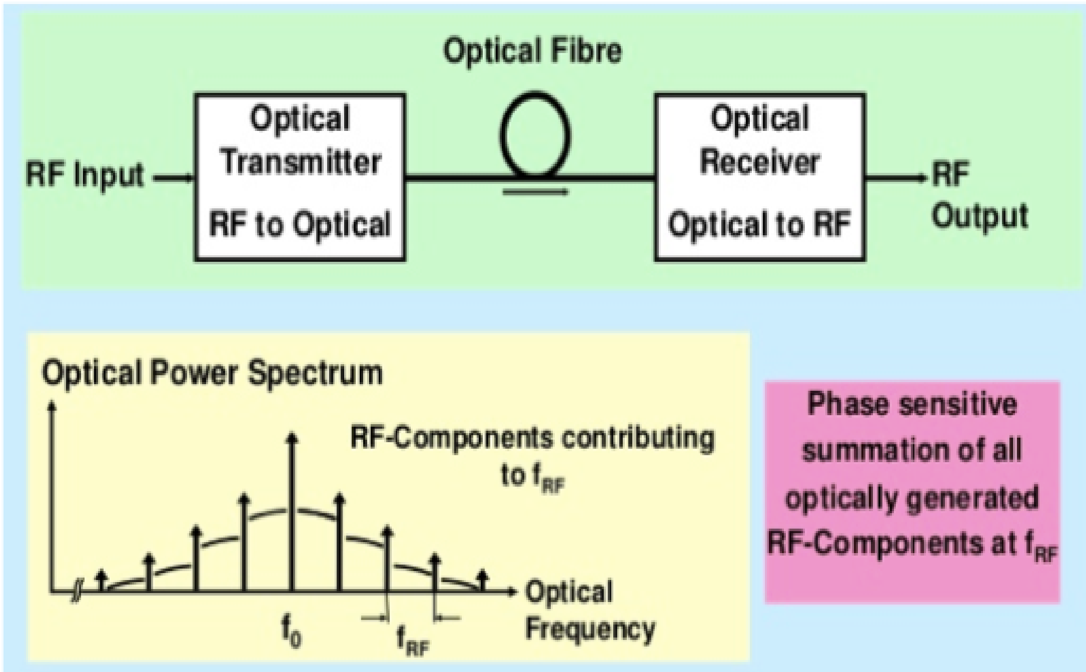

Figure 11. Optical Frequency

The conversion characteristic of the MZM is used Taylor expansion [26], where a_n is the coefficient of the n-th order when the modulation curve of MZM is expanded by polynomial, with with n = 1,2,3,4,5.... The optical frequency will smaller in higher order as shown in Fig.11.

$$a_n = \frac{\pi}{2V_\pi} - \frac{\pi^3}{12V_\pi^3} + \frac{\pi^5}{240V_\pi^5} - \frac{\pi^7}{10080V_\pi^7} + ... \tag{5}$$

to simplify the simulation, the taylor expansion becomes as below

$$a_n = \frac{1}{2}[(\frac{\pi}{V_\pi}), 0, -\frac{1}{6}(\frac{\pi}{V_\pi})^3, 0, -\frac{1}{120}(\frac{\pi}{V_\pi})^5, ... \tag{6}$$

In this case, for calculate the intermodulation distortion used until 5-th order, because in 7-th order is too small and not affected to signal, with the value a_0 = 0.5, a_1 = 0.3142, a_3 = 0.0207, a_5 = 0.00040803.

In order to evaluate, we use comparison BER linear and nonlinear degradation degree with BER performance of IMD and XM in linear and nonlinear channel. In this simulation, for investigate the effect of cross modulation we need to calculate the Signal to Noise Ratio in this configuration as shown in equation 7, that $n(t)$ is the noise after RoF channel and K is the number of user equipment.

$$SNR = \frac{E[v_{linear}(t)]}{KE[n(t)]} \tag{7}$$

3.4 Parameters for Investigate the Performance of the Transmitting SC-FDMA signal

Table 3 shows the simulation parameter, each users signal is arranged in order user index of k-th at frequency domain based on localized FDMA. 5 users were assumed. We have simulated the transmission of 5*16 block of symbols and used 1000 times oversampling to generate symbol for each block that every user simultaneously transmits 32 symbols of SC-FDMA per block.

Table 3. Simulation Parameter

Parameter	**Value**
Modulator	QPSK
Mapping	Localized FDMA
Channel	AWGN
Subcarrier Spacing	15 kHz
User, K	5
FFT point, N	512
CP size	20
V_π	5V
NOMI(dB)	-20 $\geq$ x $\leq$ 5

4. Simulation Results

4.1 Investigate Spectrum Baseband Signal

First, we need to confirm the spectrum of SC-FDMA symbol for each user to through the channel. Input symbol LFDMA illustrates in Fig.12 with number of subcarrier are 512. The different colors are indicates different user equipment with 16 symbols for each UE. The symbol becomes affected by distortion after passing through the channel as shown in Fig.13.

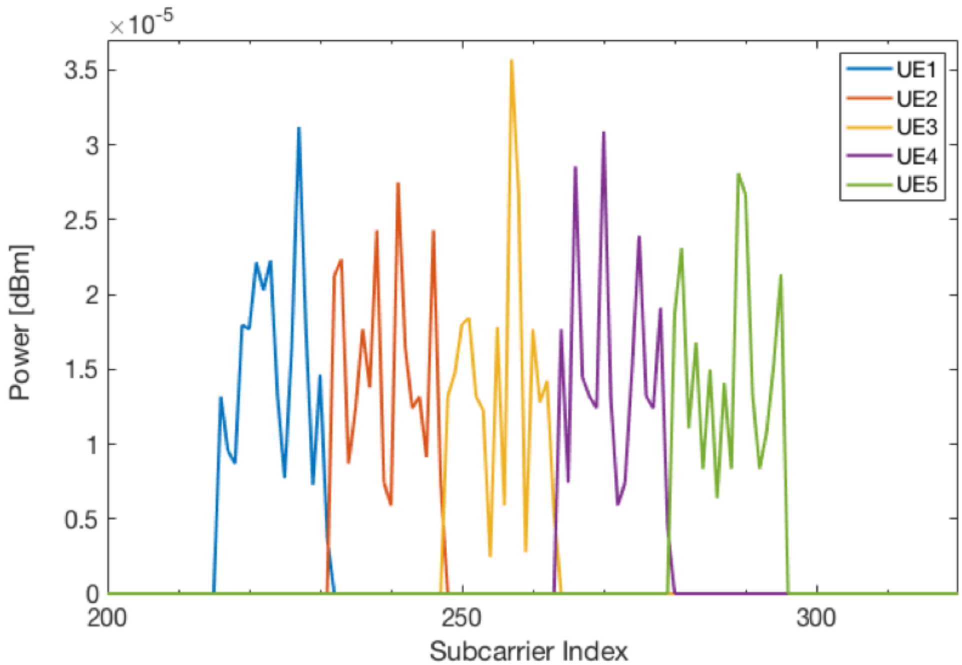

Figure 12. Input Symbol LFDMA

Furthermore, we need to cross check the power amplitude waveform. Fig.14 illustrates the power will be decrease, this condition in line with the power spectrum density, as the measure of signals power content versus frequency. Blue color is power in linear and red color for transmission with nonlinearity.

Thus, we compare linear and nonlinearity as the output of RoF channel, the spectrum of baseband signal at the output include noise, $n(t)$. Linear output,

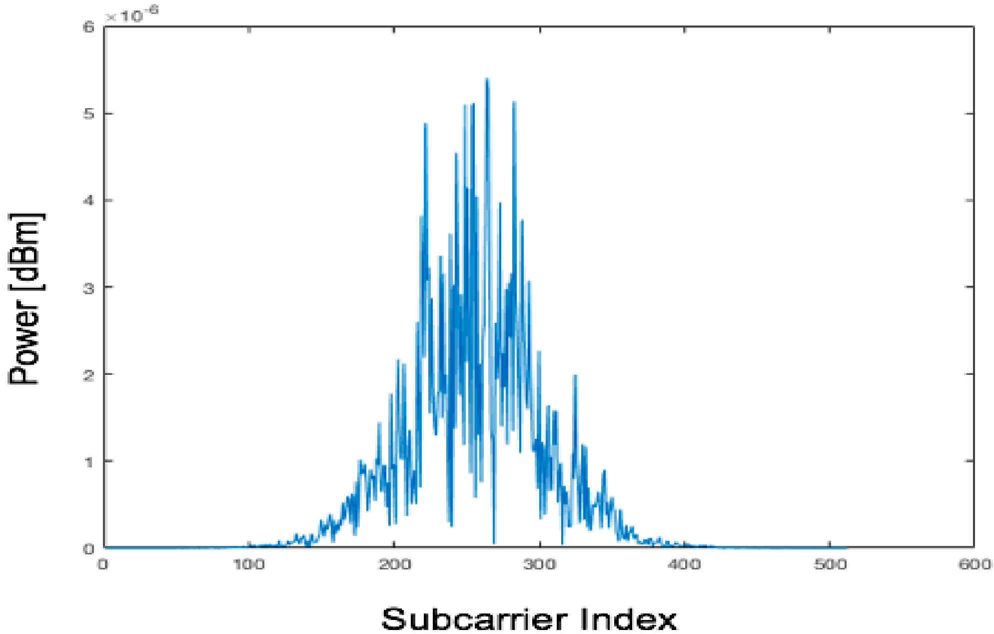

Figure 13. Output Symbol LFDMA

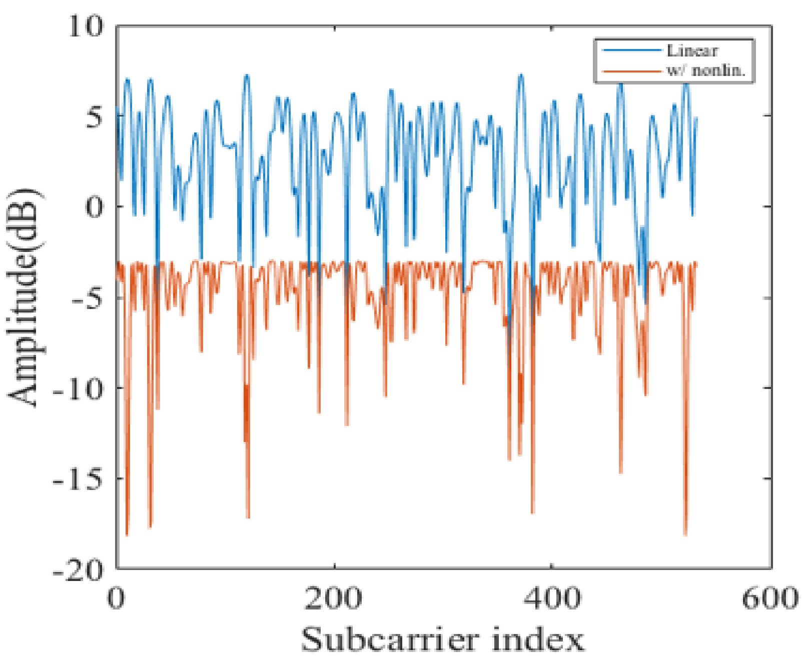

Figure 14. Power Amplitude

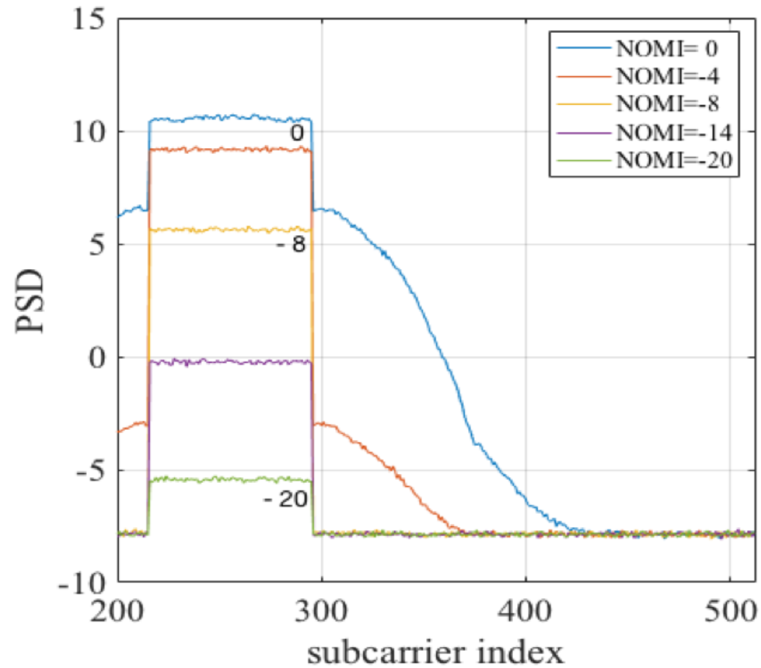

Figure 15. Spectrum of baseband signal

$v_{lin}(t)$ is shown in figure for the comparison, where $v_{lin}(t)$ is spectrum of baseband in normal conditions without nonlinearity while the NOMI is tuned in. In this research, started tuned in the NOMI from -20 dB to 5 dB. Fig.15 explained that different color indicate for each value of NOMI and distortion conditions, while starting from -4 dB already shows distortion, as well as at higher values. Not only the distortions caused by XM at in-band, but also spurious output at out-band is found. When nonlinearity is after through intermodulation inside RoF channel, the characteristic nonlinearity has been through the degradation performance, this is intermodulation distortion impact from RoF channel.

4.2 Error Vector Magnitude

The minimum EVM requirements based on the 3GPP standard are shown in the Table 4, when in uplink modulation mode using QPSK, the minimum value is 17.5% [27]. In order investigate the impact of cross modulation in RoF channel transmission.

Table 4. Minimum Requirement of EVM Uplink

Modulation	**EVM (%)**
QPSK	17.5
16QAM	12.5
64QAM	8

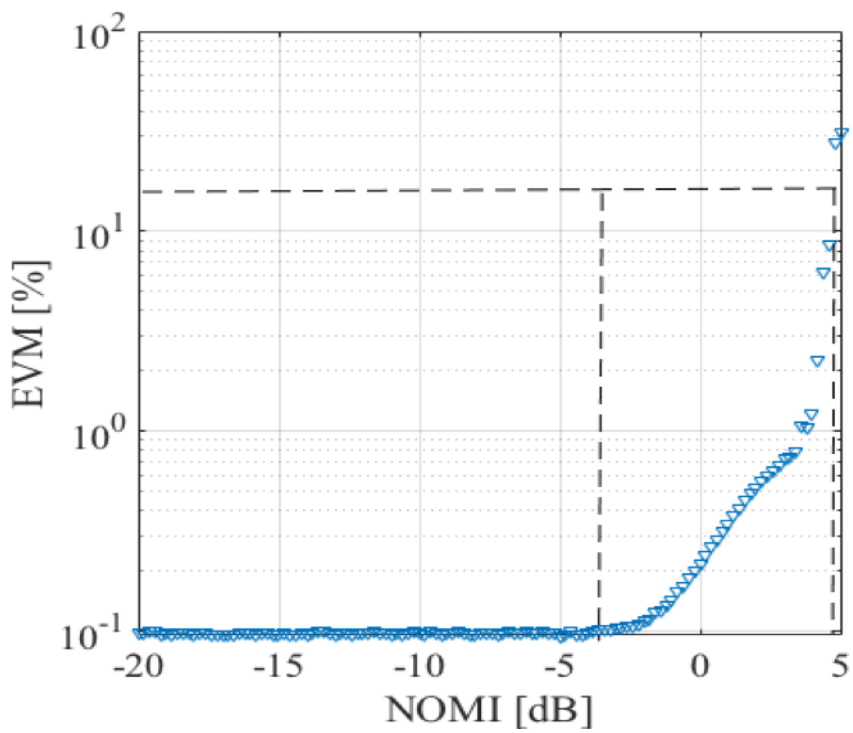

Figure 16. NOMI vs EVM

Fig.16 shown evaluate performance with NOMI vs EVM after subcarrier demapping and zero removal, when after around -4 dB will be degraded, this phenomena applies to all user not only for user in center of frequency. Even though experiencing degradation, but is still below the minimum value of required up to around 5 dB.

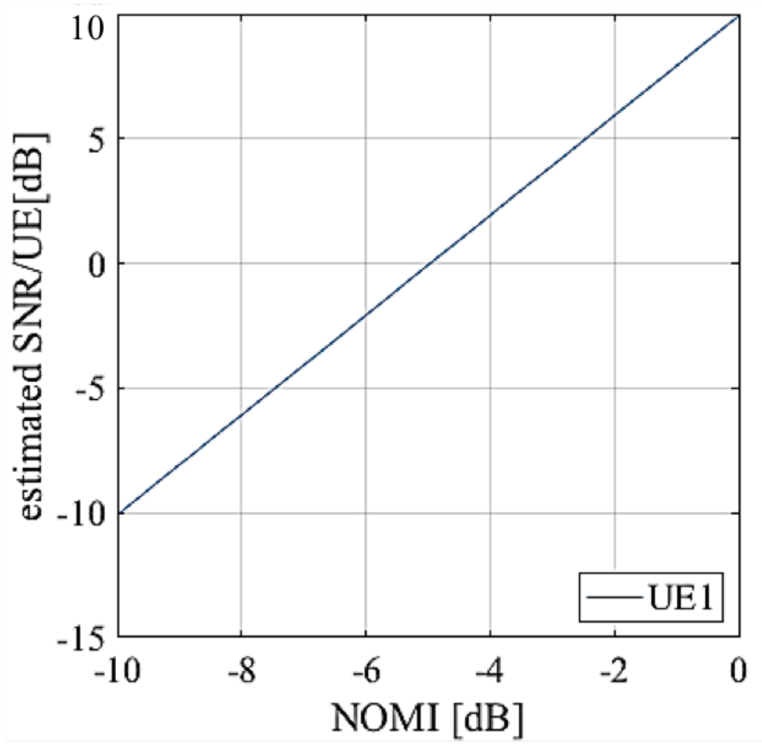

Figure 17. Estimated SNR/UE

4.3 Bit Error Rate

The BER is measure of the quality of transmitter - receiver devices, transmission path and its environment as it takes into consideration factors. The performance among users are depend on subcarrier mapping, when some users area assign in edge bandwidth and other user assign by center frequency. Fig.17 illustrates the estimated SNR per user equipment(dB), $SNR = 2 * NOMI + 10[dB]$, simulation shown bit error rate with cross modulation, SNR = 10 dB when NOMI = 0 dB. The purple imaginary line is representing the UE1 as a sampling of the existing UE, this needs to be done to get a reference on the impact of NOMI tuning with the quality of the UE signal on noise including AWGN.

Fig.18 illustrates the BER for evaluating performance of the system configuration. The blue line is theory curve of BER and dash curve for each mobile terminal. In this evaluate, shown by spreading point in BER performance with 5 users, the user have to 3 users or more to evaluate among user. The performance of all

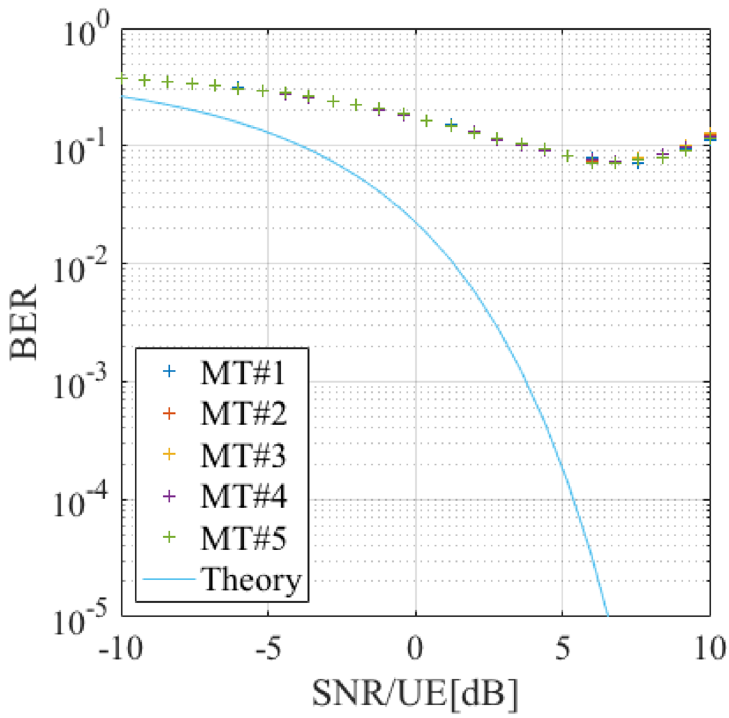

Figure 18. SNR vs BER

users is affected by distortion, not only the user in the center frequency, while SNR/UE around 7 dB will increase, that indicate the quality in high SNR will degrade.

5. Conclusions and Future Work

5.1 Conclusions

In this thesis, we investigated cross modulation for transporting the SC-FDMA system with the RoF channel. We carried out both theoretical analysis and simulations. The results obtained with the linear and nonlinearity characteristics show that any degradation is related to the IMD effect. For evaluating the transmission performance, we needed to consider the dependance between the EVM and the subcarrier mapping for each user, not the average around the center frequency. The performance evaluation, around -4 dB will degradade. For the improvement in this scheme, the post distortion circuit can be use to overcome the distortion after through the radio over fiber channel. Therefore, for SC-FDMA configuration, BER evaluation among each user depends on the number of users. The effect of cross modulation should not be taken lightly when the high value of NOMI is employed.

5.2 Future Work

The C-RAN with analog RoF fiber is a technology developed for future mobile networks with sufficient bandwidth requirements and availability accompanied by high growth of mobile access. The IMD effect in SC-FDMA scheme needs to be investigated because commercial networks have several bands with many operators using multiple bandwidth. This phenomenon have to be well prepared, one of them is the implementation of experiments need to be done using computer simulation and computer graphics, one of the graphical based programming that is rarely used for wireless communication modeling are Simulink and LabVIEW. It is used to confirm the technology can be running well in the mobile access network. Furthermore, the simulation needs to consider about the path loss, shadowing and fading to get the better result. The interference management is important because it will affect the input on RoF channel, especially in uplink system.

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