Impact of DSSS in LTE Link-Level Modelling

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***Abstract*—Long Term Evolution (LTE) system has higher PAPR value at OFDM Downlink. The 3GPP standard stated that PAPR of LTE OFDM is 12dB. There are various interference management methods have been proposed to improve PAPR performance and most known methods are clipping and filtering. In this work, we proposed DSSS in LTE link-level system. The DSSS is added before Modulator at LTE Transmitter and after Modulator at LTE Receiver. The proposed LTE link-level system is investigated on PAPR and BER performance. The results gave 8.333% of PAPR improvement compare to LTE original and BER performance has robustness against errors.**

***Index Terms*—Direct Sequence Spread Spectrum, Interference Management Method, Long Term Evolution.**

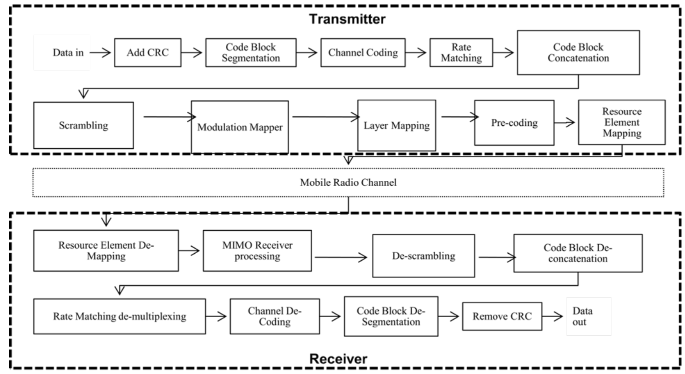

Fig. 1. Block diagram of LTE downlink [4]

I. Introduction

LONG TERM EVOLUTION (LTE) is an enhanced from Universal Mobile Terestrial System (UMTS). It has various advantages compares to UMTS such as new architectures, new air interface and additional features such as wide range of channel bandwidth from 1.4MHz to 20MHz, advanced antenna methods and beam-forming [1], supports both Time-Division Duplex (TDD) and Frequency-Division Duplex (FDD), using Orthogonal Frequency-Division Multiple Access (OFDMA) on the downlink and the Single-Carrier Frequency-Division Multiple Access (SC-FDMA) on the uplink. The OFDMA has a drawback which is high generated Peak-to-Average Power Ration (PAPR). PAPR is related on the power amplifier efficiency at the transmitter. The high value of PAPR means an increase of the power amplifier hence increases complexity design and an expensive User Equipments (UEs) [2]. Theoretically, the PAPR for OFDM is 12 dB [3]. The OFDM of LTE can be model on LTE link-level consisting on several block diagrams as shown in Fig. 1 consists of channel coding, turbo coding, rate matching, modulator, OFDM and MIMO [1].

There are various interference management methods to improve PAPR performance at downlink part. According to [5] , the author proposed interference mitigation method using Code Division Multiplexing (CDM) using Pseudo-noise sequence in LECIM system. The method is used to avoid interference from coexistence with other LECIM or Zigbee. By using the proposed method, BER performance improved to 2dB at BER=10^{-3}. However, when number of users increased, the BER performance degraded. In addition, the author in [6] investigated interference mitigation management using DSSS and FHSS methods in Aeronautic Communication Link (ACL) system to avoid unintentional and intentional Radio Frequency Interference (RFI). The results shown that the proposed DSSS gave more robustness in BER performance compare to FHSS method, hence interference can be mitigated. However, this system uses 110 MHz for ACL which is relatively low frequency bandwidth than LTE network. The proposed method had mitigated In literature [7], G. Yoshizaki published a paper which proposed inter-cell Carrier Aggregation (CA) method using Variable Spreading Factor (VSF) Spread Spectrum (SS) by additionally applied the SS transmission to the communications between UEs and their adjacent eNB in the inter-cell CA. The method discussed transmission data rate for both narrow band SS and wide band SS of next generation mobile network. This method considers outdoor environment. In addition, by applying this method, it can increase the received SIR at the UEs without transmission power increase in the 2nd communications. The author used SF values varies from 1 to 8. However, the SS transmission only applied at second communication only.

In this work, we adopted DSSS in LTE link-level system to improve PAPR performance. The DSSS is added before modulator at LTE Transmitter and after modulator at LTE Receiver. The information signal is mixedd with PN sequence signal to smooth the interference signal. The remainder of this

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paper is the information signal is mix with PN sequence signal to smooth the interference signal. The remainder of this paper is the brieft explanation on Direct Sequence Spread Spectrum (DSSS), PN sequence generator with code sequence, methodology and results.

II. DIRECT SEQUENCE SPREAD SPECTRUM

The DSSS PHY layer is depends on chip rate and spreading factor [5]. A typical DSSS transmitter is represented in Fig. 2 which composed of a PN code generator, digital multiplayer (XOR logic gate) and balanced modulator [8]. The waveform of each signal is shows in Fig. 3. For DSSS receiver, it consists of a balanced modulator, a digital multiplayer (XOR logic gate), a PN code generator and an integrator unit as shows in Fig. 4.

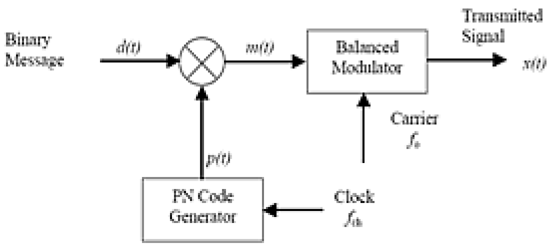

Fig.2. Direct Sequence Spread Spectrum Transmitter [8]

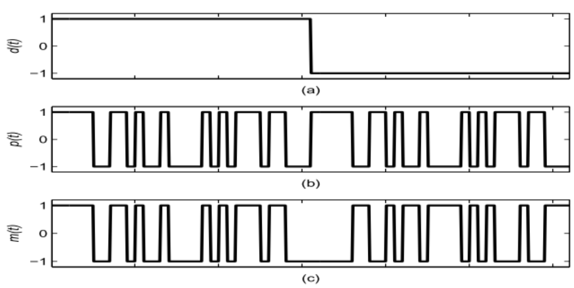

Fig. 3. Waveform of (a) data bit stream *d(t)*, (b) PN code *p(t)* and (c) product sequence, *m(t)* [8]

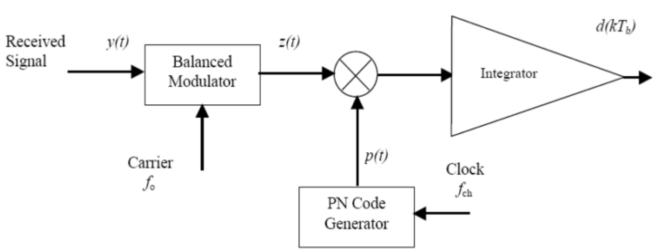

Fig.4. Direct Sequence Spread Spectrum Receiver [8]

For a DSSS transmitter, the binary message ($d(t)$) is expressed by

$$d(t) = \sum_{n=-\infty}^{\infty} a_n g_T(t - nT_b) \tag{1}$$

where $a_{(n)}$ is sequences having the values ±1 in range $\{-\infty < n < \infty\}$, $g_{(T)}$ is rectangular pulse of duration T_b and T_b is symbol interval in unit seconds where it plays an important role on the binary message.

From the T_b, the symbol rate (R_b) can be expressed as

$$R_b = \frac{1}{T_b} \tag{2}$$

where R_b is symbol rate in unit bit per seconds (bps).
In addition, the PN code generator signal ($p(t)$) is expressed by

$$p(t) = \sum_{n=-\infty}^{\infty} C_n p(t - nT_c) \tag{3}$$

where $C_{(n)}$ is PN code sequence in range $\{-\infty < n < \infty\}$, $p_{(t)}$ is rectangular pulse of duration T_c and T_c is chip interval in unit seconds where it plays an important role on the PN code generator signal. From the T_c, the chip rate (R_b) can be expressed as

$$R_c = \frac{1}{T_c} \tag{4}$$

where R_c is chip rate in unit chips per seconds (cps).
Subsequently, the spreading factor (SF) can be expressed as:

$$SF = \frac{R_c}{R_b} \tag{5}$$

The SF is also known as processing gain. In [7], the author varied the SF value from 1 to 8. When SF = 1 (minimum value), the R_c is equal to R_b means there is no SS transmission. On the other hand, when SF = 8 (maximum value), the R_c is equal to $8R_b$ means the chip rate is 8 times larger than symbol rate.

Spread sequence design is very important in DSSS. Spreading sequence can be categorized into a long code and a short code, [9]. For long code system, the period of the spreading sequence is generally longer than the symbol period, and the correlation value between users is different from bit to bit. On the other hand, the short code system has the period of the spreading sequence is generally equal to the symbol period. The spreading sequence should have good auto-correlation and cross-correlation properties. There are several well-known codes such as Barker, Kasami, Gold and Complete Complementary Sequences (CC-S) Codes as shows in Table I.

TABLE I
LIST OF PN SEQUENCE GENERATOR AND ITS ADVANTAGES

PN sequence generator	Advantages	Disadvantages	References
Barker sequence	uniformly low auto-correlation lobes (≤1)	size of these families is small	[10]
Gold sequence	• good auto-correlation • Cross-correlation functions with largest value • Between codes are		[6], [5]

	uniform and bounded • May generate large numbers of codes		
CC-S [11]	Low BER, better with more users	No difference when user is 1	[11]

From the Table I, Gold Sequence is the most common sequence use for DSSS because it has good auto-correlation, has largest values in cross-correlation and good with long sequences. For this work, the Gold Codes has been chosen for the propose PN sequence generator. The codes are generated by the modulo-2 operation of two different m-sequences of same length (L) [10]. Fig. 5 shows the Gold sequence generator block diagram.

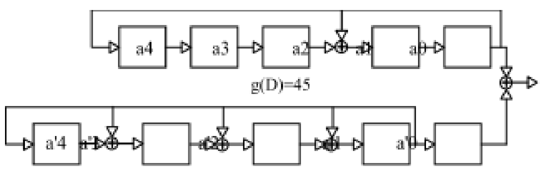

Fig. 5. Gold sequence generator block diagram [10]

The Gold code can generate sequences (N_c) as follows

$$N_c = 2^L - 1 \qquad (6)$$

It has certain pairs of m-sequences of L where the pairs exhibit a three-valued cross-correlation function known as Preferred Pairs of Gold Codes.
The preferred pairs produce sequences which have good cross-correlation properties. Table II shows the preferred pairs of Gold Codes.

TABLE II
PREFERRED PAIRS OF GOLD CODES [12]

L	Nc	Preferred Polynomial-1	Preferred Polynomial-2
5	31	[5 2 0]	[5 4 3 2 0]
6	63	[6 1 0]	[6 5 2 1 0]
7	127	[7 3 0]	[7 3 2 1 0]
9	511	[9 4 0]	[9 6 4 3 0]
10	1023	[10 3 0]	[10 8 3 2 0]
11	2047	[11 2 0]	[11 8 5 2 0]

III. METHODOLOGY

To mitigate co-channel interference in LTE system, DSSS is adopted to LTE link-level model. The DSSS has many advantages as mentioned in [6][13]. The DSSS is added before Modulator and after De-modulator of LTE link level model, hence the proposed method is known as Enhanced DSSS (EDSSS). Fig. 6 shows the flowchart of LTE link-level with DSSS simulated using MATLAB.

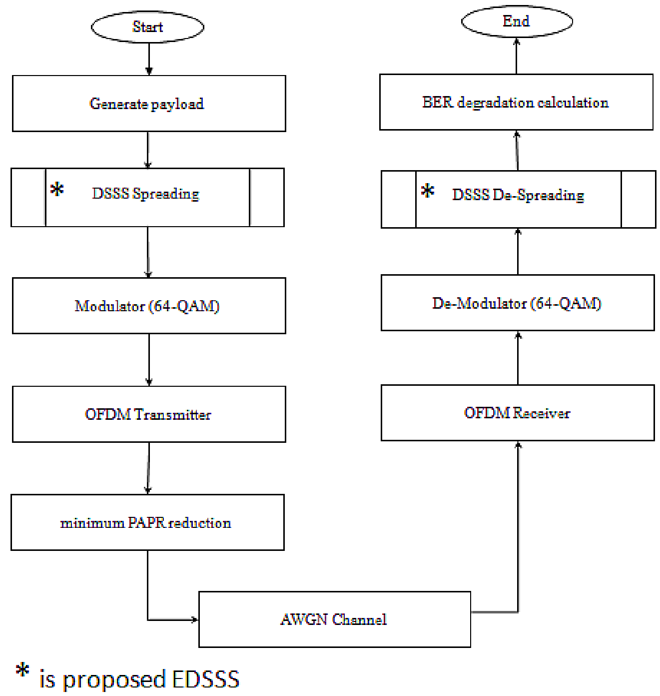

Fig. 6. Flowchart of the Proposed LTE Link-Level Model with DSSS

From the flowchart in Fig. 6, the LTE link-level model begins with generate payload or information. The payload signal is then becomes the input of DSSS Spreading. The details of DSSS Spreading is explained later. Next, the output of DSSS Spreading becomes the input to the modulator. To mitigate co-channel interference in LTE system, DSSS is added before Modulator. The output of DSSS Spreading becomes the input to the modulator. In this work, 64-QAM is used for modulator. The output of the modulator is undergoing OFDM Transmitter. In this work, the LTE OFDM of 2048 different sub-carrier with a spacing of 15 kHz is used. The output of OFDM Transmitter becomes the transmitted signal of LTE link-level with DSSS. The PAPR is used to investigate performance of LTE link level with DSSS model at the transmitter part. The equation of PAPR can be expressed as [14][15]:

$$PAPR = \frac{max|x[n]|^2}{E[|x[n]|^2]} \qquad (7)$$

where $max|x[n]|^2$ is maximum signal power and $E[|x[n]|^2]$ is the average signal power. Average signal power of OFDMA system calculated by

$$\mathrm{E} = \frac{\text{Sum of the magnitude of all OFDMA symbols}}{\text{Number of OFDMA symbols}} \qquad (8)$$

Complementary Cumulative Distribution Function (CCDF) is one of the most used to check the PAPR by estimating the probability of PAPR when it exceeds a certain level $PAPR_0$. The CCDF can be expressed by [16]

$$CCDF = P(PAPR > PAPR_0) \qquad (9)$$

Then, the transmitted signal is undergoing AWGN Channel. For receiver part, the signal is undergoing OFDM Receiver, 64-QAM De-modulator and DSSS De-spreading. The details of DSSS De-Spreading is explained later. The BER is used to investigate performance of overall LTE link level with DSSS model. The equation of BER can be expressed as:

$$\mathrm{BER} = \mathrm{Error\ bits}/\mathrm{Number\ of\ Transmitted\ Bits} \quad (10)$$

The DSSS Spreading is added before 64-QAM modulator [8] [5] [6]. Flowchart of DSSS Spreading is shows in Fig. 7. The DSSS Spreading is begins with information symbols from generate payload and PN sequences generator chips using Gold Code. The preferred pairs of Gold codes are used with variable Length as mentioned in Table II [12]. In this example, Gold Code with length 5 is used. Finally, both information symbols and PN sequence generator chips are mixed by using XOR process. The output of XOR is logical. The pseudo code for DSSS spreading sequences is shows in Table III for Gold Sequence Length L= 5.

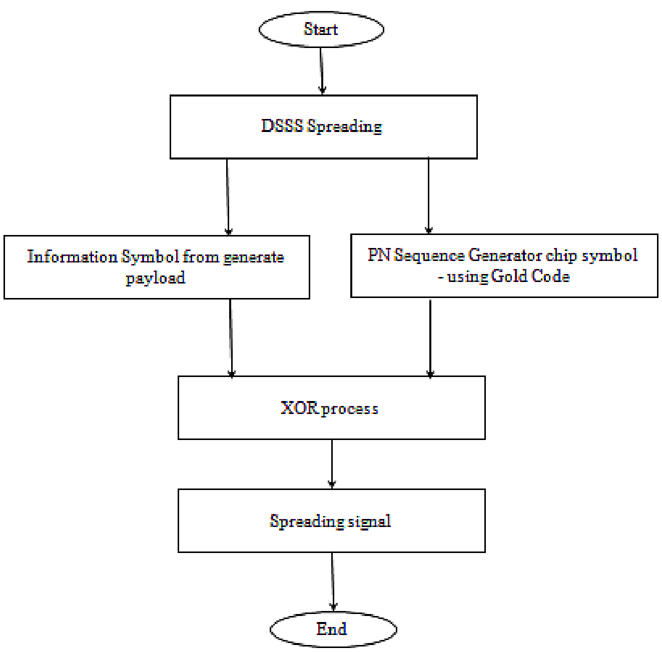

Fig.7. Flowchart of DSSS Spreading at Transmitter part of LTE link-level with DSSS Model

TABLE III
DSSS SPREADING OF LTE LINK-LEVEL WITH EDSSS PSEUDO-CODE

```
% Generating the pseudo random bit pattern for spreading
% for L=5
b=(in); ← Information Signal from generate payload
goldseq = comm.GoldSequence('FirstPolynomial','z^5 + z^2 + 1',...
    'SecondPolynomial','z^5 + z^4 + z^3 + z^2 + 1',...
    'FirstInitialConditions',[0 0 0 0 1],...
    'SecondInitialConditions',[0 0 0 0 1],...
    'Index',4,'SamplesPerFrame',12222);
c = step(goldseq); ← PN sequence generator using Gold code
chip_l = 8; ← Defined SF=8
total_l = length(c);
no_symbol = ceil(total_l/chip_l); ← PN sequence chip has 8 times
(SF=8)
symbol = no_symbol;
signal_l = zeros(1,total_l);
for i = 1:chip_l
    signal_l(i:chip_l:end)=symbol;
end
chip_signal = signal.';

DSSS = xor(b,chip_signal); ← XOR process
```

The DSSS De-Spreading is added after 64-QAM De-modulator [8] [5] [6]. Flowchart of DSSS De-Spreading is shows in Fig. 8. In DSSS De-Spreading, received symbols are data signal from Transmitter. Gold Sequence is used as the PN sequence generator in this work. The optimal preferred pairs Gold sequence are used for LTE system as mentioned in Table IV [12]. In this example, Gold Code with length 5 is used as same with the DSSS Spreading. Finally, both received symbols and PN sequence generator chips are mixed together using XOR process. The output of XOR process is logical and needs to convert to 'double' for received signal of LTE link-level with EDSSS model. The pseudo code for DSSS De-spreading sequences is shows in Table IV for Gold Sequence Length 5. Table V shows the simulation parameters for the LTE link-level model.

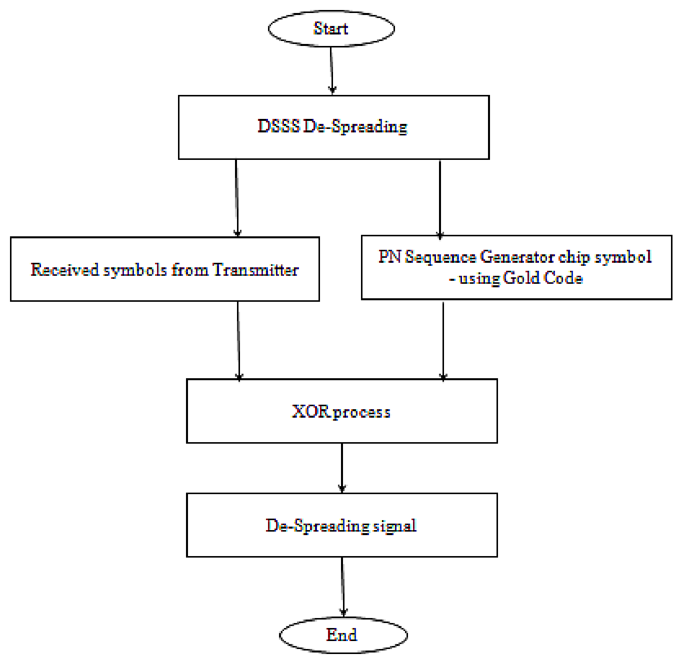

Fig.8. Flowchart of DSSS De-Spreading at Receiver part of LTE link-level with EDSSS Model

TABLE IV
DSSS DE-SPREADING OF LTE LINK-LEVEL WITH EDSSS PSEUDO-CODE

```
% Generating the pseudo random bit pattern for de-spreading
% for L=5
rx=(in); ← Received Signal from Transmitter
goldseq = comm.GoldSequence('FirstPolynomial','z^5 + z^2 + 1',...
    'SecondPolynomial','z^5 + z^4 + z^3 + z^2 + 1',...
    'FirstInitialConditions',[0 0 0 0 1],...
    'SecondInitialConditions',[0 0 0 0 1],...
    'Index',4,'SamplesPerFrame',12222);
c = step(goldseq); ← PN sequence generator using Gold code
chip_l = 8; ← Defined SF=8
total_l = length(c);
no_symbol = ceil(total_l/chip_l); ← PN sequence chip has 8 times
(SF=8)
```

```
symbol = no_symbol;
signal_l = zeros(1,total_l);
for i = 1:chip_l
    signal_l(i:chip_l:end)=symbol;
end
chip_signal = signal_l.';

despread= xor(rx,chip_signal); ← XOR process
y = double(despread);
```

TABLE V
SIMULATION PARAMETERS FOR LTE LINK-LEVEL MODEL

Parameter	Value
Modulator	QAM-64 with M=64
Bandwidth	20MHz with numSC=2048 and cpLen =512
Frequency, fc	2400 MHz
SF	1 and 8
PN Generator	Gold Code
Channel	AWGN Channel
Simulation Time	2000
Maximum Bit Errors	10 000 000
Maximum Number Bits	10 000 000
Eb/No	0 to 10 dB for PAPR and 10 dB for BER
SNR or Eb/No	EbNo + 10*log(k) + 10*log(numDC/numSC)
powerDB	10*log(var(txSig)) where txSig is transmitted signal

IV. RESULT AND DISCUSSION

We simulated LTE link-level with our additional DSSS spreading / de-spreading. The results of PAPR reduction for LTE transmitter is shown in Fig. 9.

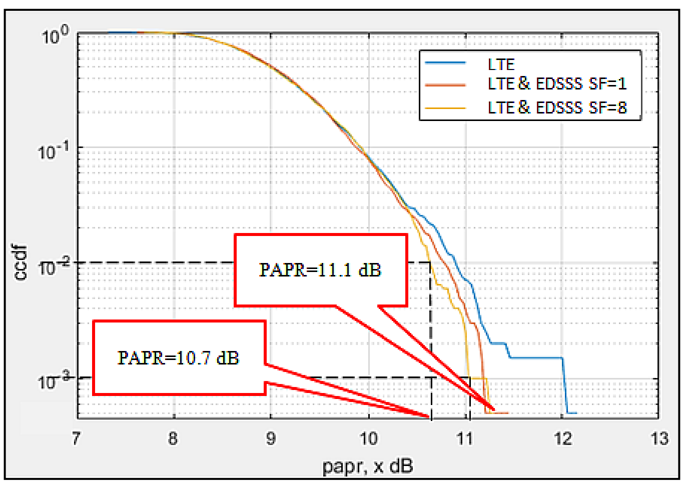

Fig. 9. CCDF Plot of PAPR reduction for DSSS L=5

As can be seen in Fig. 9, the result was compared between LTE without and with EDSSS models. The result demonstrated that the proposed DSSS with SF=8 gives the best result in the PAPR reduction compares to others. Even though the differences are small, it is affected on the model to minimize the peak power in the LTE Link-Level Transmitter Model. The reason is due to the proposed method mixed the information signal with PN generator and smoothed out the interference, hence reducing the PAPR at the transmitter. In terms of SF value, a higher SF will provide a much higher processing gain and high signal resistance to the interference. On the other hand, the SF= 1 provides much lesser resistance to interference and has less processing gain to the system. In addition, all L with SF=8 provide lowest PAPR value when compared to others. Table VI shows the threshold values of PAPR at PAPR=10^{-2} and PAPR=10^{-3} for LTE Link-Level Transmitter Model to show the PAPR improvement of the proposed method.

TABLE VI
PAPR VALUES AT 10^{-2} dB AND 10^{-3} dB FOR LTE TRANSMITTER

L	CCDF	PAPR [dB] LTE only	PAPR [dB] LTE with EDSSS SF=1	PAPR [dB] LTE with EDSSS SF=8
5	10^{-2}	10.90	10.80	10.70
	10^{-3}	12.10	11.25	11.10

Table VII shows the difference of PAPR reduction (dB) of EDSSS with SF=8 and LTE only models.

TABLE VII
DIFFERENCE OF PAPR REDUCTION (dB) OF LTE MODEL

L	DIFFERENCE OF PAPR REDUCTION (dB)	
	CCDF=10^{-2}	CCDF=10^{-3}
5	0.20	1.00

According to 3GPP, the PAPR value of standard LTE OFDM downlink is 12 dB. As conclusion, by adding the EDSSS method to the LTE link-level model with higher SF, the PAPR value reduces in comparison to LTE only. From the result, by using EDSSS with SF=8, the lowest PAPR values is 10.7 dB at CCDF=10^{-2} and 11.1 dB at CCDF=10^{-3}. The PAPR improvement is approximately 1 dB compare to standard LTE OFDM downlink.

Next, BER performance is used to investigate overall performance of LTE with proposed DSSS link-level model as shown in Fig. 10.

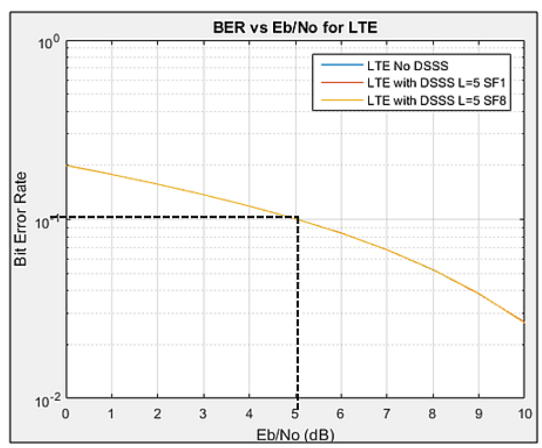

Fig. 10. BER versus Eb/No for LTE model with DSSS L=5

The result of Fig.10 demonstrated that the proposed LTE with EDSSS model has the same performance or redundant as original LTE model. The BER graphs shown that by adding DSSS to LTE link-level model, it did not affect the overall model and no BER degradation occurred. This is due to DSSS components did not generates additional interference such as pulse interference at the receiver. The pulse interference can occurred in a receiver by a signal with any of center frequency.

V. CONCLUSION

As conclusion, by adding the DSSS using Gold Code with Length=5 to LTE link-level model had improved the PAPR performance by 8.333% compare to standard LTE system. In addition, the spreading factor (SF) has impact on PAPR where with high SF, the PAPR resulted with lower values than lower value of SF. On the other hand, according to BER graph, the proposed model has robustness against errors like original LTE system (without EDSSS). As for future work, the proposed method can be integrate with LTE-Wi-Fi system to create coexistence network.

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