Outage Probability of Communication Link in LTE-TDD System Operating at Spectrum Block 13 and 14

Kanalebe, H. 1*, Christianto, H. 2, Darian Pratama, A. 3

1Telecommunication Lab Universitas Pelita Harapan; 2Alumnus Electrical Engineering Department Universitas Pelita Harapan; 3Electrical Engineering Department Universitas Pelita Harapan

*For correspondence: herman.kanalebe@uph.edu

Abstract Communication failure in a mobile radio system occurred due to large and small scale fading as well as interference in the communication channel. Fading may cause the received signal to drop below the receiver sensitivity while the interference reduces the SIR (Signal to Interference Ratio) level. In this study we analyze the outage probability of a communication link due to the impact of pathloss, fading and interference in the frequency range of 2300-2400 MHz used in LTE TDD mobile communication system. Two propagation models and 4 interference scenarios are considered in this work. From our simulation result, in scenario 2 MS to MS interference, reducing 50% in guardband between interferer and interference victim from 10 MHz to 5 MHz will increase the outage probability from 78 to 82 %. While for the same condition, 50 m distance between the interferer and the interference victim, as the number of interferers increases from 1 to 2 interferers the outage probability will increase from 30 to 45 %.

Keywords: LTE-TDD, Interference, Guardband, MSD, SIR, Sensitivity, Outage Probability.

Introduction

LTE (Long Term Evolution) communication system is the existing and most used in mobile communication system today. Two different access techniques are used, FDD (Frequency Division Duplex) known as LTE-FDD and TDD (Time Division Duplex) known as LTE-TDD system. Two different frequency slots are used for the communication link in LTE-FDD while in LTE-TDD system uses two different time slots [1]. The interference between communication devices is higher in LTE-TDD compared to LTE-FDD system. In wireless communication, interference occurred when two or more electromagnetic waves used the same frequency are transmitted in the air. The interference level reduces the SIR (Signal to Interference) that can break the communication link between communication devices although the expected received signal strength is higher than the receiver sensitivity level.

The communication link is also affected by the propagation environment. As the travelling distance of the transmitted electromagnetic wave increases, the loss in the communication link increases as well. This loss is known as pathloss not only depends on the travelling distance but also on the operating frequency of the transmitted electromagnetic wave. In addition to that shadowing effect such as from trees and high building may also block the transmitted wave and hence reduce the received signal strength at the input of a receiver. If the received signal drops below a specified receiver sensitivity level, it will cause a communication link failure.

In evaluating the communication link failure some random variables are used to represent the shadowing effect. This is the reason why the outage probability terminology is used instead of communication link failure in analyzing the impact of interference level and pathloss on the performance of an LTE-TDD system operating on Block 13 (2360-2375 MHz) and Block 14 (2375-2390 MHz) in this paper [2,6].

Materials and methods

Two important parameters, receiver sensitivity and SIR level are taken into account to justify the outage probability on an LTE-TDD system. The predicted signal strength at the input of a device obtained from a pathloss calculation is compared to a standardized receiver sensitivity to evaluate the outage probability of the communication link of that device. Three different basic methods are used to obtain pathloss. Empirical method based on observation, Deterministic method based on laws governing electromagnetic wave propagation and stochastic method based on environment condition (shadowing effect) that used statistics approach. The accuracy
of the pathloss prediction will depend on the appropriate propagation model used [5,8]. There are several propagation models developed by many researchers such as Okumura, Hata, COST-231 and SUI (Stanford Universities Interim) models to predict the pathloss in wireless communication. Two propagation models are used in this work, Okumura and SUI (Stanford University Interim) model.

**Okumura Propagation Model**

In his experiment Yoshihisa Okumura measured the signal attenuation from BS (base station) to MS (mobile station) around Tokyo city in 1986. Several charts are produced to predict the pathloss for different areas such as urban, sub-urban and open area. The range of operating frequency, antenna’s height, distance between transmitter and receiver have to be carefully examined to ensure those conditions suit to our case to obtain an accurate predicted pathloss. The Okumura pathloss equations [4] are as follows:

\[
P_L(dB) = L_f + A_{m,n}(f, d) - G(h_{Tx}) - G(h_{Rx}) - G_{area}
\]

\[
L_f = 20 \log_{10}\left(\frac{\lambda}{4\pi d}\right)
\]

\[
G(h_{Tx}) = 20 \log_{10}\left(\frac{h_{Tx}}{200}\right)
\]

\[
G(h_{Rx}) = 10 \log_{10}\left(\frac{h_{Rx}}{3}\right), \quad 1 \text{ m} \leq h_{Rx} \leq 3 \text{ m}
\]

\[
G(h_{Rx}) = 20 \log_{10}\left(\frac{h_{Rx}}{3}\right), \quad 3 \text{ m} \leq h_{Rx} \leq 200 \text{ m}
\]

where:

- \(P_L\) = pathloss (dB)
- \(L_f\) = Free Space loss (dB)
- \(\lambda\) = wavelength (m)
- \(d\) = Transmitter and Receiver distance (km)
- \(A_{m,n}\) = Attenuation Median (dB)
- \(h_{Tx}\) = Transmitter antenna height (m)
- \(h_{Rx}\) = Receiver antenna height (m)
- \(G(h_{Tx})\) = Transmitter antenna gain (dB)
- \(G(h_{Rx})\) = Receiver antenna gain (dB)
- \(G_{area}\) = area environment gain (dB)

The values of \(A_{m,n}\) and \(G_{area}\) in equation (1) are obtained from several charts produced from Okumura experiment. Attempts to derive the Okumura Charts into a curve fitting have been made in our work [11]. Some of the samples of Curve fitting of Attenuation Median and \(G_{area}\) for sub-urban area are shown in Figure 1a and Figure 1b respectively. From those pictures, we can see the accuracy of the
developed curve fitting equation is very high and can be used to replace the graphs produced in Okumura propagation model.

![Figure 1. Curve fitting of Okumura propagation model chart](image)

On the other hand, the curve fitting equation is very helpful to simplify the Matlab programming in calculating the pathloss values by neglecting the complexity of graph produced by Okumura propagation model.

**Stanford University Interim Propagation Model**

SUI (Stanford University Interim) model [5] developed by a working group in Stanford University intended to develop a propagation model for IEEE 802.16 Broadband Wireless Access operated on the spectrum below 11 GHz. The model is intended to predict the pathloss in the range of propagation radius as low as 100 m where the accuracy of Okumura model could not be maintained. The interference analysis such as in scenario 2, MS to MS interference will involve shorter distance communication link between the interferer and the victim.

The SUI propagation model equation is as follows:

\[
L_{LOS} = 4.62 + 20 \log_{10} \left( \frac{4\pi d}{\lambda} \right) - 2.24h_{TX} - 4.9h_{RX} + 29.6 \log_{10}(d) \quad (6)
\]

where:

\[
L_{LOS} = \text{pathloss (dB)}
\]

\[
\lambda = \text{wavelength (m)}
\]

\[
d = \text{Transmitter and Receiver distance (km)}
\]

\[
h_{TX} = \text{Transmitter antenna height (m)}
\]

\[
h_{RX} = \text{Receiver antenna height (m)}
\]

There is no chart or graph required to calculate the pathloss using SUI propagation. Equation 6 of SUI propagation model is used for short distance interference analysis such as MS to MS interference.
**Minimum Coupling Loss**

As the distance between transmitter and receiver getting shorter the pathloss value also getting smaller. There is a minimum value of pathloss known as MCL (Minimum Coupling Loss) [13]. When the predicted pathloss value obtained from SUI model is less than the MCL value then the predicted pathloss value is equal to MCL value. Beside the configuration of transmitter and receiver pair, several parameters that affect the MCL values are the transmitter power, spurious emission, blocking level and interference threshold [12]. For an LTE-TDD system, a table is given as shown in Table 1 for selecting the valid value of an MCL [7, 9].

**Table 1. MCL values for different BS-MS pair**

<table>
<thead>
<tr>
<th>Item</th>
<th>MCL\text{emission} (dB)</th>
<th>MCL\text{blocking} (dB)</th>
<th>MCL\text{final} (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-BS</td>
<td>70</td>
<td>58</td>
<td>70</td>
</tr>
<tr>
<td>MS-MS</td>
<td>82</td>
<td>57</td>
<td>82</td>
</tr>
<tr>
<td>BS-MS</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>MS-BS</td>
<td>72</td>
<td>35</td>
<td>72</td>
</tr>
</tbody>
</table>

The MCL value in column MCL\text{final} in Table 1 is used when the pathloss calculated value using the SUI propagation model drops below the corresponding MCL\text{final} value.

**Interference scenarios**

All possible interference scenario between BS and MS or vice versa is shown in Table 2. The received signal strength and the interference level at victim’s receiver are evaluated to find the outage probability.

**Table 2. All possible interference scenario**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Interferer</th>
<th>Victim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>BS\text{B}</td>
<td>BS\text{A}</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>MS\text{A}</td>
<td>MS\text{B}</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>BS\text{B}</td>
<td>MS\text{A}</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>MS\text{B}</td>
<td>BS\text{A}</td>
</tr>
</tbody>
</table>

The interference scenarios are illustrated in Figure 2. From those pictures the blue arrow represents the communication link while the brown one for the interference link. In scenario 1 (BS to BS interference) shown in Figure 2.a, BS\text{A} becomes the interference victim (brown arrow) of BS\text{B} while BS\text{A} is listening (blue arrow) to MS\text{A}. The arbitrarily placement of BS that is quite close to other BS in certain area could produce strong interference to the victim BS.

In scenario 2 (MS to MS interference) is shown in Figure 2.b, MS\text{B} becomes the interference victim (brown arrow) of MS\text{A} while MS\text{B} is listening (blue arrow) to BS\text{A}. In a crowded area where many people use their MS to communicate such as in the airport the interference level between MS is quite high.

In scenario 3 (BS to MS interference) is shown in Figure 2.c, MS\text{B} becomes the interference victim (brown arrow) of BS\text{A} while MS\text{B} is listening (blue arrow) to BS\text{B}. The interference level in MS\text{B} could be high in an area where many closed BSs are located.

In scenario 4 (MS to BS interference) is shown in Figure 6, BS\text{B} becomes the interference victim (brown arrow) of MS\text{A} while BS\text{B} is listening (blue arrow) to MS\text{B}. The interference level in BS\text{B} in this scenario is not as high as other scenarios since the MS transmitted power is quite low and distance between the interfere and victim is usually quite far [10, 13].
Figure 2. All possible interference scenario

**Outage Probability Flow Chart**

The step and procedure to find the outage probability is shown in Figure 3 [3]. Prior to that we need to specify the BS and MS following the standardized LTE-TDD system as shown in Table 3.

**Table 3. Standardized LTE-TDD system**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Base Station</th>
<th>Mobile Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Tx Power</td>
<td>46 dBm</td>
<td>23 dBm</td>
</tr>
<tr>
<td>Noise floor</td>
<td>-116.4 dBm</td>
<td>-97.5 dBm</td>
</tr>
<tr>
<td>SIR</td>
<td>7 dB</td>
<td>9 dB</td>
</tr>
<tr>
<td>Receiver Sensitivity</td>
<td>-123.4 dBm</td>
<td>-106.4 dBm</td>
</tr>
</tbody>
</table>
As shown in Figure 3, random variables which representing the shadowing effect are added to the deterministic part of pathloss calculation which is based on Okumura or SUI propagation model. The added random variables which is following the normal distribution causes pathloss value to vary as a new random variable is added. Variation of pathloss values will vary the received signal strength and SIR level at the input of the victim receiver. If those values are less than the standardized SIR and receiver sensitivity of an LTE-TDD system then an outage probability is counted. In this simulation more than 30,000 iterations for each scenario is conducted to obtain an accurate and valid outage probability percentage.
Results and discussion

The simulation results of outage probabilities of all possible interference scenario in an LTE-TDD system are discussed in this section.

**Scenario 1 Outage Probability simulation result**

Two simulations are conducted for scenario 1, BS to BS interference. In the first simulation the number of interferers is varied while the guardband and distance between the interferer and the victim is maintained constant. Results are shown in Figure 4.a.

![Graph showing outage probability as a function of MSD with different number of BS interference](image1.png)

a. Scenario 1 Outage probability as a function of MSD with 10 MHz guardband for different number of BS interference

![Graph showing outage probability as a function of MSD for different values of deviation standard of shadowing effect density function.](image2.png)

b. Scenario 1 Outage probability as a function of MSD for different values of deviation standard of shadowing effect density function.

*Figure 4. Simulation result on scenario 1 BS to BS interference*

As the number of interferers increase, the outage probability percentage on an interference victim is also increasing which is expected. Similar trend occurred when the MSD (Minimum Separation Distance) between interferer and victim BS is getting shorter. This is shown in Figure 4.a. Note that the increment of outage probability percentage on an interference
victim is not linearly proportional to the increment of interferers. Increasing interferer from 5 to 6 interferers will have less impact on the outage probability compared to increasing from 4 to 5 interferers. Simulation result of varying the deviation standard of shadowing effect for 10 interferers in Figure 4.b will also vary the victim outage probability. Greater change in the value of deviation standard, will have greater change in the value of outage probability percentage as well.

**Scenario 2 Outage Probability simulation result**

As in scenario 1, the number of interferes in scenario 2 (MS to MS inference) is also analyzed in this simulation. Additional parameter, the guardband between interferer and victim is also taken into account.

**Figure 5.** Simulation result on scenario 2 MS to MS interference
The simulation result trend in Figure 5.a is similar to Figure 4.a. As the number of interferers increased, the outage probability percentage is also increasing. The main difference is the distance between the interferer and the victim is shorter less than 100 m. Result in Figure 5.b for 10 interferers shows that reducing the guardband between the interferer and the victim from 15 MHz to 10 MHz affected the outage probability is less than 5% On the other hand reducing the number of interferers from 6 to 4 interferers reduces the outage probability 9%.

a. Scenario 3 Outage probability as a function of MSD with 10 MHz guardband for different values of deviation standards.

b. Scenario 4 Outage probability as a function of MSD with 10 MHz guardband for different values of deviation standards.

**Figure 6.** Simulation result on scenario 3 BS to MS interference and scenario 4 MS to BS interference

It is interesting to compare the simulation result of scenario 3 (BS to MS interference) in Figure 6.a with scenario 4 (MS to BS interference) shown in Figure 6.b. It looks strange. In the range of less than 2.5 km between interferer and the victim, the transmitted power of an MS shown in Table 3 which is 23 dBm very much lower than transmitted power of a BS (46 dBm) does not have significant impact to the outage probability. A spontaneous expectation may conclude that the greater the transmitted power may cause greater interference. This is not the case in the above simulations. In this range the change of propagation model occurred and the MCL play important role besides the SIR difference between
the MS (9 dB) and the BS (7 dB) as interference victim as shown in Table 3 is only 2 dB. This SIR difference reduces the impact of big difference in transmitted power between BS and MS on the outage probability. For the distance above 2.5 km and as the deviation standard of shadowing effect increasing, the outage probability percentage of scenario 3 and scenario 4 starting to differ considerably significant. Other interesting result, in a certain condition every 5 MHz increasing in the guardband separated the interferer and the interference victim from 5 MHz to 15 MHz improves the outage probability less than 5% in scenario 2 (MS to MS interference). While as the number of interferers increases from 1 to 2 interferers can worsen the outage probability more than 10%. But in a higher interferer environment, (> 6 interferers) the impact on the outage probability for every additional interferer is less than 4%.

Conclusions
Outage probability in a communication link due to interference in an LTE-TDD System operating at Spectrum Block 13 and 14 has been analyzed in this work. Several link scenarios between BS and MS are simulated using two different propagation models Okumura and SUI accordingly. Four parameters, number of users, guardband, shadowing effect and distance between BS and MS are considered to evaluate the impact of those parameters to the outage probability. From the simulation in scenario 1 where one BS interferes a victim BS separated 5 km from the interferer, it can be concluded that as the deviation standard of the shadowing effect increased from 4 dB to 8 dB outage probability is also increasing almost twice from 32% to 60, The outage probability is also increasing when the number interferer BS is increased which is expected. On the other simulation result in scenario 4, for a distance between the interferer and victim is around 3 km, the impact of the interferer transmitted power is less significant (< 10%). In this situation, the MCL specified for this simulation started to affect the simulation result. Approach in this work may be implemented to evaluate similar interference impact on several communication systems coexisted in the same geographical area.

Conflicts of interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

References