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SC-FDMA LTE Performance through High Altitude Platforms Communications (HAPS) Channel

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Abstract

It is known that high altitude platform system (HAPS) is one of the promising wireless technologies that exploit many advantages from cellular satellite system as well as from cellular terrestrial system. HAPS is envisaged to be a novel technology for communication, broadcasting, internet backbone, earth observation and surveillance, and also for navigation. One of upcoming technologies for communication is a long term term evolution (LTE) of a cellular forth generation (4G). Many techniques have been developed to make LTE come into real in the environment of cellular terrestrial. However, LTE that deployed through HAPS is a challenging due to different its geometry and channel. This paper aims at evaluating the performance of a pilot-based channel estimation for uplink LTE using SC-FDMA over Ricean HAPS communication channel. Pilot-based channel estimation is used to estimate an uplink channel of LTE users who transmit the data to HAPS as a base transceiver station (BTS). Analysis is performed to determine the effect of user's elevation angle with respect to user position inside HAPS coverage, LTE channel bandwidth, modulation type, and the Doppler frequency shift effect. We found that user's elevation angle contribute major effect to the pilot-based channel estimation of LTE SC-FDMA performance. System capability to overcome fading effect that users with low elevation angle would be needed to increase the performance. In particular to keep an acceptable performance, in this paper we compensate the channel bandwidth, changing modulation type, and limit the Doppler Effect through vehicle speed limitation.

Keywords: *Long Term Evolution, SC-FDMA, High Altitude Platforms, pilot-based channel estimation, Ricean fading channel.*

1. Introduction

Long Term Evolution (LTE) is the latest generation of mobile cellular communications technology which is developed by 3rd Generation Partnership Project (3GPP) [1-3]. LTE is designed to be an efficient cellular technology on the use of frequency spectrum, high transmission data rate (more than 50 Mbps on the uplink and 100 Mbps on the downlink), simple architecturally, support high mobility communications, low delay, and high throughput. LTE uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink and Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink. LTE technology has many options to use spectrum bandwidth, starting from 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz. This bandwidth flexibility brings LTE to be the best technology ever of cellular communication and potential to offer high-speed data rate [4-5].

Transmission infrastructure technology plays an important role in the reliability of the system. Cellular LTE terrestrial system commonly used eNB as the radio access network. Therefore, in cellular terrestrial system, it needs the ground allocation and a large numbers of towers to cover large areas. This could be a problem in the cost of investment to maintain a high quality of services and coverage. An idea of LTE deployment via HAPS must be proven as an infrastructure solution that utilizes a transceiver stations placed in the stratosphere. The network architecture for cellular LTE deployed via HAPS can be shown in Figure 1. HAPS advantages are high elevation angle which broaden Line of Sight (LOS) and coverage areas, lower propagation delay compared to satellite system, relatively low operational costs and easy to mobilize in emergency conditions. HAPS also minimize the problems of multipath. As an infrastructure that utilizes the medium of air, characterization of the channel is important,

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because it greatly affect the performance of the system. Meanwhile, channel estimation technique by using pilot signal is used to compensate channel characteristic to the system. Integrating HAPS on LTE provide a positive impact on the world of mobile communications today. These two technologies are expected to answer the need of safety, reliable and revolutionary telecommunication technology with high bit rates at low cost.

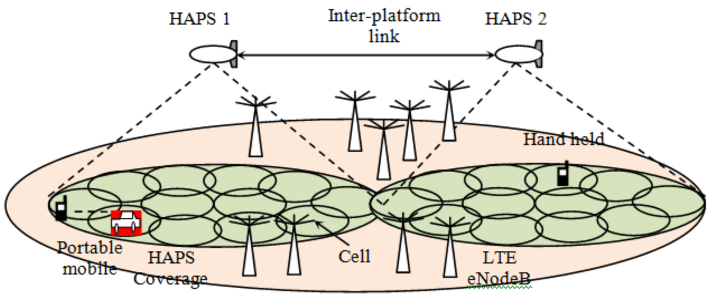

Figure 1. Network architecture of cellular LTE via HAPS.

There is very few contributions deal with LTE that deployed via HAPS which has a unique geometry channel compared with cellular terrestrial channel. Uplink and downlink of LTE performance is discussed in [6]. Downlink performance of multiple access using OFDMA has been discussed in [7]. However, those papers deal with cellular communication for terrestrial system which is based on terrestrial tower. The channel characteristic must be different from that of HAPS channel characteristic. In this paper, SC-FDMA's performance on HAPS with pilot-based channel estimation will be analyzed [8-10]. In our previous work, we have studied the downlink LTE characteristic over HAPS channel using channel estimation algorithm [11]. However, for the uplink, LTE uses another multiple access scheme namely SC-FDMA to save the power transmit so that it can save the battery life of the UE terminal. SC-FDMA's performance on a HAPS channel is evaluated based on a computer simulation. The result will be analyzed to determine the effect of elevation angle, channel bandwidth, modulation type and Doppler frequency on system's performance. Characteristic of channel is taken from research of HAPS in Hokkaido, Japan [12]. HAPS is using Ricean channel that modeled the condition of Line of Sight (LOS) and multipath due to user's location and landmark circumstances. K factor is used as a parameter to indicate LOS ratio.

The possible configuration between cellular network provided by HAPS and terrestrial tower will be very interesting. However, we have to be carefully designed the network from interference. The cell coverage of HAPS must be separated away with enough distance from cell coverage of terrestrial BTS to avoid co-channel interference. An area called blank spot of terrestrial tower will be covered by HAPS. We found that the performance evaluation of LTE downlink over the HAPS channel has not been much investigated.

The rest of paper is organized as follows. Section 2 reviews SC-FDMA on LTE while in section 3 we review High Altitude Platforms channel model and characteristic. In Section 4, we explain simulation model for signal transmission of LTE uplink over HAPS channel. Then simulation results are analyzed in Section 5. We focus our analysis on the effect of user's elevation angle, LTE spectrum bandwidth, modulation type, and Doppler frequency shift. Finally, conclusions are drawn in Section VI.

2. Pilot-based SC-FDMA in LTE-HAPS Channel

SC-FDMA is LTE's multiple access schemes for uplink. SC-FDMA can be regarded as DFT-spread orthogonal frequency division multiple access, where time domain data symbols are transformed to frequency domain by DFT before going through subcarrier mapping process. The only different between OFDMA and SC-FDMA is an additional DFT block on the transmitter and IDFT block on the receiver.

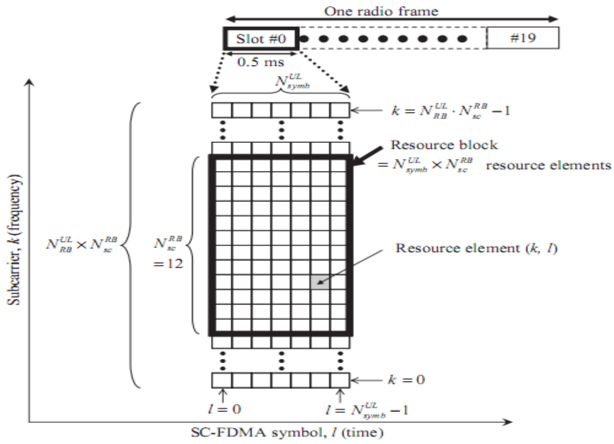

Figure 2. SC-FDMA resource grid [8].

Resource block structure on SC-FDMA can be described as in Figure 2. A resource block has duration of 0.5 ms and bandwidth of 180 kHz (12 subcarriers). All the resource blocks constitute of a resource grid. The number of blocks in the resource grid ranges from 6 to 100 for 1.4 MHz channels to 20 MHz channels, respectively. Each uplink slot carries seven SC-FDMA symbols. The smallest element in a resource block is called Resource Element which contains a subcarrier for the duration of one SC-FDMA symbol [13-14].

Pilot signal is used as reference signal that is required to perform channel estimation at the receiver output [15]. Pilot signal is inserted at specific symbol and when it pass through the channel, it will be processed with a method that estimates channel condition and then compensate it to another symbols. Pilot signal is generated based on Zadoff-Chu sequence. Zadoff-Chu sequence commonly referred as Constant Amplitude Zero Auto Correlation (CAZAC) sequence with the following equation.

$$x_q(m) = e^{-j\frac{mqm(m+1)}{N_{ZC}}}, 0 \le m \le N_{ZC-1} \qquad (1)$$

Where q is Zadoff-Chu sequence root index, Nzc is sequence length and m = 0,1,….Nzc – 1. Zadoff-Chu has constant amplitude, so does it’s Nzc-point DFT and PAPR.

High Altitude Platforms located in the stratosphere, at an altitude between 17 and 22 km above the earth surfaces. HAPS have a rapid roll-out capability and the ability to serve a large number of users, using considerably less communications infrastructure than required by a terrestrial network. HAPS located in the stratosphere which has constant temperature rise and constant wind speed rise. There is no weather phenomenon occurs in this layer because this layer has low content of water. That is also this layer is stable with only slight turbulence. No clouds on this layer thus allow effective use of solar power.

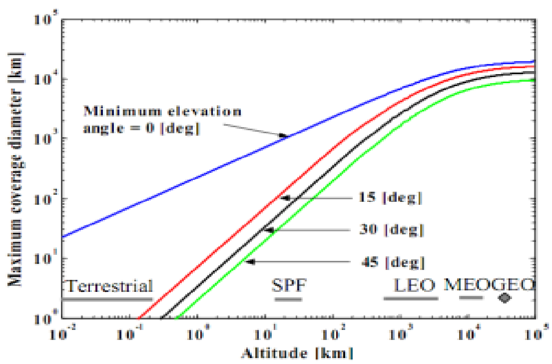

Figure 3. Altitude vs HAPS coverage

HAPS coverage depends on several factors such as altitude, user's elevation angle, and earth dimension [16]. In Figure 3, we can see relation between altitude and HAPS coverage. HAPS coverage is expressed in maximum diameter of LOS communication. Figure 2 shows the diameter of LOS communication at altitude ranging from 1 to 10^5 km as a function of elevation angle. The graph was made with the assumption that the propagation is straight, so it can be said that the higher HAPS, the broader the scope, but with a limitation that the coverage area is smaller than earth diameter.

In case of HAPS channel, Ricean fading is a general case of fading channel model that there are two components of signal arrive at the receiver. First component arrives at receiver through line of sight (LOS) path while the second comes from scattered signal. In SPF communication scenario, it is probably to get both components because SPF is highly located above the ground.

Consequently, it was found that the Ricean fading channel is an appropriate model for the case of SPF link with K factor varies depending on the elevation angle and the frequency. SPF channel can be characterized using Rician distribution as follows. Where *K* is Rice factor, θ (*t*) is the users elevation angle, f_D is Doppler shift from receiver movement, and *h*(i) is the scattered component. If the total power of scattered signal is denoted by $2\sigma^2$ and power of LOS signal represented as A^2, then the total received power and *K* factor are given by:

$$x(t) = \sqrt{\frac{K}{K+1}} e^{j(2\pi f_D \cos(t)} + \sqrt{\frac{1}{K+1}} h(t) \quad (2)$$

$$E[x^2(t)] = A^2 + 2\sigma^2 \quad (3)$$

$$\mathrm{K} = \frac{\mathrm{A}^2}{2\sigma^2} \quad (4)$$

Then the Equation (1) can be rewritten as follows:

$$\mathrm{H} = \sqrt{\frac{\mathrm{K}}{\mathrm{K}+1}} \mathrm{H_d} + \sqrt{\frac{1}{\mathrm{K}+1}} \mathrm{H_s} \quad (5)$$

Where H_d is LOS component, and H_s is scattered component.

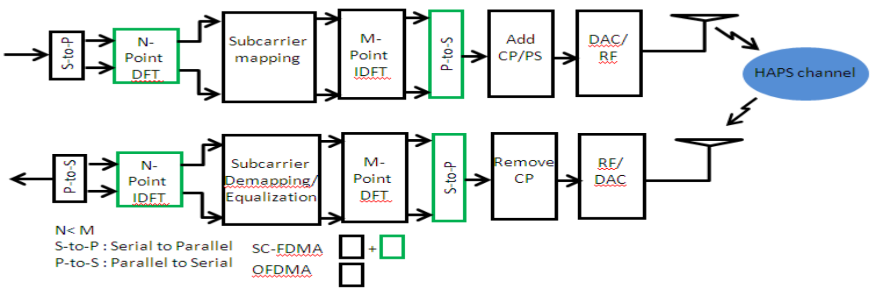

Figure 4. SC-FDMA simulation model.

Table 1. SC-FDMA LTE HAPS Simulation Parameters.

Specification Parameters	Value
Channel bandwidth (MHz)	1.4, 3, 5, 10, 15, and 20
Number of Subcarrier	1200
Number of resource block	25, 75, and 100
DFT size	1024 and 2048
CP	108 and 144
Carrier frequency (GHz)	2.4
Signal constellation	QPSK and 16-QAM
Channel model	AWGN and Ricean fading channel
Doppler shift (HRz)	50, 100, and 15
Users-to-HAPS elevation angle	10-to-90 degrees

3. SC-FDMA in HAPS Channel Simulation Model

The processing of SC-FDMA signal is transmitted very similar to that of OFDMA. The sequence of bits transmitted for each user, is mapped into a complex constellation of symbols such as BPSK, QPSK or M-QAM. Then different transmitters (users) are assigned different Fourier coefficients. This assignment is carried out in the mapping and de-mapping blocks. Pilot-based channel estimation, which is used to estimate the performance of signal transmission of SC-FDMA LTE on HAPS channel, was evaluated through computer simulations. The structure of simulation model is depicted in Figure 4. At the transmitter, the series of bit is generated and converted from serial to parallel, then modulated into symbol. Pilot signal is then inserted at each first symbol in all subcarrier. These modulated symbols and pilots perform M-point Discrete Fourier Transform (DFT) to produce a frequency domain representation of the symbols. It then maps each of the M-point DFT outputs to one of the orthogonal subcarriers mapping that can be transmitted.

The receiver side includes one de-mapping block, one IDFT block, and one detection block for each user signal to be received. Just like in OFDM, guard intervals (called cyclic prefixes) with cyclic repetition are introduced between blocks of symbols in view to efficiently eliminate inter-symbol interference from time spreading (caused by multi-path propagation) among the blocks. In SC-FDMA, multiple access among users is made possible by assigning different users different sets of non-overlapping Fourier-coefficients (sub-carriers). This is achieved at the transmitter by inserting (prior to IFFT) silent fourier-coefficients (at positions assigned to other users), and removing them on the receiver side after the FFT.

In this paper, distributed method is used for subcarrier mapping. In this method, the outputs are allocate/d equally spaced subcarrier with zeros occupying the unused subcarrier in between. Then IDFT block followed by Cyclic Prefix (CP) insertion. Cyclic prefix is a copy of the last part of symbol that placed in front of symbol that can eliminate Inter Symbol Interference (ISI). Then the signal is transmitted through the HAPS Ricean channel. At the receiver, the opposite set of the operation is performed. CP is removed then the signal is processed by the DFT. Pilot signal then being extracted to get the channel condition. Channel condition then being compensated to the other symbols.

Table 2. Simulation parameters of channel bandwidth investigation

Specification Parameters	Sample#1	Sample#2	Sample#3	Sample#4	Sample#5	Sample#6
Channel bandwidth (MHz)	1.4	3	5	10	15	20
Modulation	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK
Number of resource block	6	15	25	50	75	100
Number of sub-carrier	72	180	300	600	900	1200
CP	9	18	36	72	108	144
DFT size	128	256	512	1024	1536	2048
Doppler shift (Hz)	50	50	50	50	50	50
Bit rate (Mbps)	0.9	2.2	3.6	7.2	10.8	14.4

The received signals are de-mapped, then IDFT operation is performed. These received signals are demodulated to get the bit stream. Bit stream in the receiver is then compared with bit stream in the transmitter to get Bit Error Rate (BER). In order to know the performance of SC-FDMA LTE transmitted in HAPS channel we then proposed the following parameter of simulation as in Tabel 1. These parameters are based on LTE specification and also HAPS channel parameter which is derived from our previous experiment [4]. According to the results, multipath fading are observed and shown that the fading depth would have to vary between 1 dB and more than 25 dB depending on the elevation angle. Note that in the measurement we used an omnidirectional antenna. We then characterize the stratospheric platform channel by using method of moment to find Rice parameter (K). Another propagation parameter that we have found from the data of measurement is local mean received power. Both K factor and local mean received power are evaluated under the variation of elevation angle. Our evaluation show that the K factor would have to vary from 0.9 to 18.6 dB for a frequency carrier of 1.2 GHz in the measurement and 1.4 to 16.8 dB at frequency 2.4 GHz. Standard deviation of local mean received power is found to decrease as elevation angle increase indicating little multipath in high elevation angle. Up to this point we have described the channel characteristic in stratospheric platform communication.

4. Performance Analysis

4.1. Users Elevation Angle Analysis

Simulation parameters of the SC-FDMA LTE on HAPS are summarized in Table 1 and the results is shown in Figure 5. This figure shows that the higher the elevation angle, the performance of SC-FDMA will be better. This is consistent with the notion that the greater the LOS signal power received by the receiver, then the better the performance of SC-FDMA. High elevation angle means high K factor, because K factor is the ratio between average LOS power and average multipath signal's power. When the elevation angle is high, the probability of LOS communication link is also high. It means more LOS signal will be received by the receiver. Performance differences due to changes in elevation angle will be more significant when Eb/No is more than 6 dB. Eb/No represents the ratio between signal with noise, so when Eb/No is less than 6 dB, influence of the elevation angle is less clearly visible because the signal to noise ratio is too small. When Eb/No is more than 6 dB, significant differences will be shown between 10^0-40^0 elevation angle and 50^0-90^0 elevation angle. Therefore communication will be optimum if elevation angle between the transmitter and HAPS is more than 40^0 and Eb/No is more than 6 dB. At that condition, we can obtain BER difference about 0.0182 to 0.090546 at same elevation angle.

4.2. Channel Bandwidth Analysis

Another result of our investigation on SC-FDMA scheme based on pilot-aided channel estimation on a HAPS channel is an effect of channel bandwidth. Our simulation is performed at 6 channel bandwidth, which are 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz. Simulation parameters are summarized in Table 2. Figure 6 shows that the greater the bandwidth of the channel, then the performance will be worse. BER decreases ranging from 1.4 MHz to 20 MHz. This is because the greater the channel bandwidth, the greater the noise power contribute to the channel. SC-FDMA is a multiple access scheme that has low peak to average power ratio (PAPR). Based on simulation results, performance will be decreased from half to 12 times when compared with 1.4 MHz bandwidth performance. Large channel bandwidth with poor performance can be solved with increasing the power transmit on the user equipment side. A compromise between elevation angle (coverage) and the channel bandwidth usage will lead us to an advantage wireless system brought by HAPS.

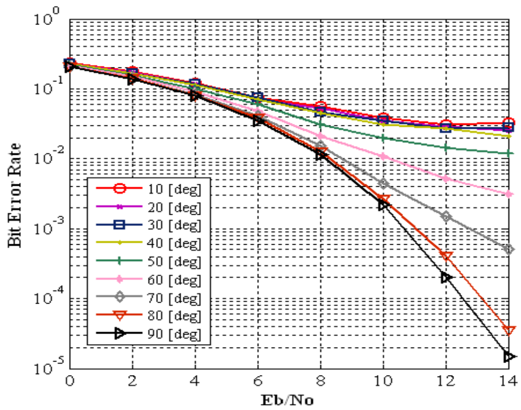

Figure 5. SC-FDMA scheme performance through HAPS channel as a function of elevation angle

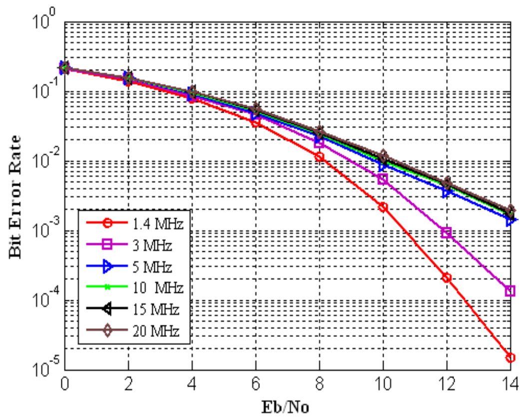

Figure 6. SC-FDMA scheme performance through HAPS channel as a function of Channel bandwidth

4.3. Modulation Type Analysis

We consider modulation type dependency in our observation of SC-FDMA scheme performance in a HAPS channel to look at the possibility of user equipment hardware power efficiency. Simulation performed at two different modulations of QPSK and 16-QAM to represent low level and high level modulation respectively. Figure 7 shows the simulation results using 40^0 and 90^0 elevation angle in order to know their performance in a good and bad conditions of the channel. The result is that there is a big difference between performance of SC-FDMA with QPSK modulation and with the 16-QAM modulation. This is because QPSK only use 2 bits per symbol while the 16-QAM uses 4 bits per symbol, so the 16-QAM will be more susceptible to noise during transmission. In the 16-QAM modulation, constellation of each point is closer to the other point than QPSK, so that the noise would be more likely to occur. Average distance of points on QPSK constellation is 2√2 while 16-QAM average distance is 2√10. If that distance is compared on dB, we will get 7 dB differences. This means that to get the same BER, 16-QAM requires approximately 7 dB from the QPSK need. From the simulation results, for QPSK with 90^0 elevation angle with E_b/N_0 = 0 dB, we get 0.2067 of BER. So, 16-QAM will need E_b/N_0 = 7 dB to get the same BER. However, because in the simulation, E_b/N_0 is increasing by 2 dB, then the closest E_b/N_0 is 8 dB which have 0.2277 BER Difference between the simulation results with the calculation because the simulations carried out with Eb/No increase per 2 dB, so the results are not very accurate.

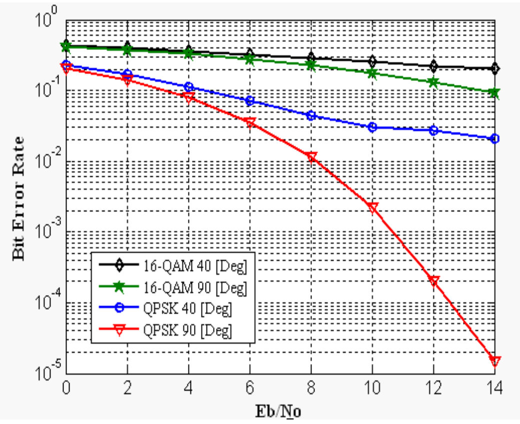

Figure 7. SC-FDMA scheme performance through HAPS channel as a function of modulation type using 40^0 and 90^0 elevation angle

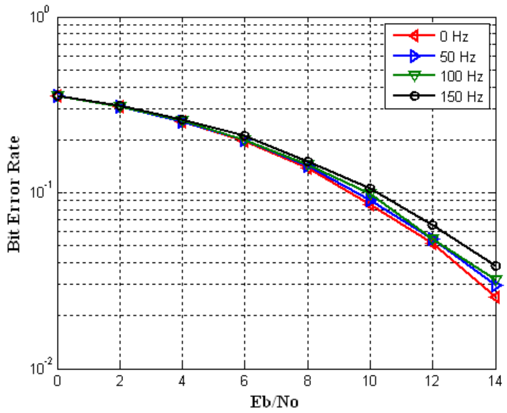

Figure 8. SC-FDMA scheme performance through HAPS channel as a function of Doppler frequency using 70^0 elevation angle

4.4. Doppler Frequency Analysis

The last investigation in SC-FDMA performance via HAPS channel is an effect of Doppler shift to investigate the mobility characteristic of the user equipment. Simulation performed with parameter shown in Table 1, but with 4 different Doppler frequencies which is 0, 5, 10 and 150 Hz. Figure 8 shows the simulation result. It shows that the performance is better when the Doppler frequency is smaller. Doppler frequency of HAPS is less influential on greater elevation angle. This is due to the Doppler Effect is influenced by transmitter movement toward or away from HAPS. The greater the angle, the effect will be less significant, just like what we get from elevation angle analysis. In 2.4 GHz frequency, the speed of user equipment for the Doppler shift of 150 Hz will be around 200 km/h. We again will have a trade-off between HAPS coverage which is determined by an elevation angle and the mobility of user equipment. Without Doppler compensation technique, LTE with tens Mbps of data transmission rate in a HAPS system would have moderate performance. It is required compensation technique to improve the performance in a high bit rate transmission while user is moving with a very high speed. This is our challenge for future investigation of LTE deployed via HAPS.

5. Conclusion

We have investigated and proposed an analysis of SC-FDMA LTE signal performance transmitted via HAPS channel in which it's fading follow Ricean distribution based on experimental data collection. Simulation was carried out to evaluate an effect of user elevation angle, LTE channel bandwidth, modulation type, and Doppler shift effect. We found that as user elevation angle increase, SC-FDMA LTE system's performance is also increase. The increasing of the channel bandwidth causes the larger noise bandwidth, therefore the system's performance decreased when the channel bandwidth is increased. Modulation types which have fewer bits per symbol have a better performance. Finally, with Doppler shift of 70 Hz the particular system performance of SC-FDMA LTE reach an unacceptable performance.

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