Master's Thesis

석사 학위논문

Performance Analysis of High Throughput Mobile Satellite Services (MSS) in High Frequency Bands

Yonghwa Lee (이 용 화 李 勇 和)

Department of Information and Communication Engineering

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Advisor : Professor Jihwan Choi
Co-Advisor : Professor Cheol Song

by

Yonghwa Lee
Department of Information and Communication Engineering
DGIST

A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science in the Department of ICE. The study was conducted in accordance with Code of Research Ethics[1].

01.06. 2017

Approved by

Professor Jihwan Choi (Signature)
(Advisor)

Professor Cheol Song (Signature)
(Co-Advisor)

1) Declaration of Ethical Conduct in Research: I, as a graduate student of DGIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

Performance Analysis of High Throughput Mobile Satellite Services (MSS) in High Frequency bands

Yonghwa Lee

Accepted in partial fulfillment of the requirements for the degree of Master of Science.

01. 06. 2017

Head of Committee______________(Signature)
Prof. Jihwan Choi
Committee Member______________(Signature)
Prof. Cheol Song
Committee Member______________(Signature)
Prof. Kyung-Joon Park

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Abstract

Future satellite communication systems should be optimized for mobile services at high frequency bands. In order to keep up with the terrestrial mobile radio communication network and to surmount frequency saturation and scarcity problems, it is an important challenge to consider the property of user mobility and high frequency bands above Ka band in the satellite channel. In this paper, with the movement of terminals into account, we compare and evaluate the performance of satellite communication systems according to the change of the carrier frequency bands and the channel states which are expressed by the location of the receiver and the surrounding environments for traditional land mobile satellite (LMS) channel models, Lutz's LMS model and Loo's LMS model, with 2-state Markov chains. The movement of terminals incurs the Doppler effect, which changes the channel condition faster than the weather effect and influences on the carrier frequency shift. Therefore, channel models are analyzed to verify the performance degradation according to the factors that make channel variation in the mobile satellite services (MSS) environment with information theoretical perspective. And then, we compare the difference of performance degradation between traditional communication systems which use low frequency bands and future communication system which use high frequency bands. According to the simulation results, the Lutz's and Loo's channel model are investigated for suitability and usefulness in satellite communications at high frequency bands. To propose the solution which solves the problem related to delayed feedback CSI (channel state information), power margins and wastes are investigated and analyzed in the channel depending on the coherence time (velocity of moving user).

Keywords : satellite communication systems, frequency saturation problem, Ka band, land mobile satellite (LMS) channel model, mobile satellite service (MSS).

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I. INTRODUCTION

1.1 Satellite communication systems

Previous systems for space communications have primarily used the low frequency bands at L (1-2 GHz) or S (2-4 GHz) bands. However, in current and future satellite systems, high frequency bands such as Ka (26.5-40/18-20 GHz) and V (40-75 GHz) bands should be utilized to provide stable broadband services due to saturation of the radio spectrum for new satellite communication systems. In addition, the satellite communication systems should consider the movement of users to keep up with the terrestrial mobile network because current land mobile communication systems including long-term evolution (LTE) technology have achieved the great developments and advanced rapidly for recent years. The mobile satellite service (MSS) is a system, which provide the radio communication services in satellite communication systems between mobile earth station and one or more space station, or between space stations used by this service [11]. There are three kinds of MSS which are land MSS for space to terrestrial communications, maritime MSS for space to marine communications, and aeronautical MSS for space to airship communications depending on the location of mobile earth station (MES) [24].

The satellite communication systems in the high frequency bands have some weaknesses: The first is the weather impairments and moisture absorption such as the rain attenuation, to which satellite communications in high frequencies are very sensitive. The second is long latency, a main characteristic of geostationary orbit (GEO) satellite communication systems, which can be critical for high frequency mobile service of communication performances with fast time-varying channels. However, it is not easy to reflect the fast time-varying channel and to overcome the performance degradation by movement of users because the channel variation by the multipath and mobility of mobile environments is faster than round-trip delay (500 ms) of satellite communication link in GEO condition. Therefore, the MSS at the high frequency above Ka band is required to solve the aforementioned problems and to obtain competitiveness to ground communications by showing the performance which satisfies new-generation 5G user demands.

1.2 Related work

There are previous works that have conducted to measure satellite channel or to analyze performances of satellite communications. Some studies concentrate on the fragmentary parts of influence factors in the satellite communication systems such as weather effect or the atmospheric phenomenon according to the environment as exploiting traditional channel models. Wenzhen Li has two studies for land mobile satellite (LMS) channels in the Ka band with weather impairments [18,19]. The channel performance is evaluated by comparing with Loo's land satellite mobile (LSM) channel model and their channel model with weather effects such as rain attenuation. By the probability distribution function (PDF) of the received signal, performance degradation is shown due to weather impairments, and the bit error rate (BER) performance of a binary phase shift keying (BPSK) receiver is evaluated in non-shadowing states under different weather conditions. In Ali M. Al-Saegh's study [1], the research uses Lutz's LMS channel model and Markov chains, considering cloud and rain impairments. The performance of channel models, represented by PDF or cumulative distribution function (CDF) of received signal levels, was analyzed according to environments and frequency bands. The channel status is observed by total columnar content of liquid water (Kg/m^2, liquid water content, LWC). Sandro Scalise's [14] and Erwin Kubista's [9] study investigated the performance of channels by CDF according to the channel capacity in bits per symbol and received signal levels relative to Line of Sight (LOS) respectively by the obtained actual measurement data in Germany. First, in Sandro's study, though the study is conducted in Ku band (12~18 GHz), they obtain and analyze the actual measurement data by classifying the environments as rural, suburban, urban, and highway according to the conditions of thoroughfare and velocities of moving. And, in Erwin's study, many parameters of propagation impairments are considered to analyzing the effects and satellite channel. The received signal is observed according to the environment and speed. And, the channel performance is investigated in terms of PDF and power margins.

1.3 Background scenario

In the scenario, we assume geostationary orbit (GEO) system and the Ka band (20 GHz) which is a comparison carrier frequency band against the traditional communication systems. Traditional satellite communication channel models use low frequency bands such as 2 GHz or L and S bands. Thus, we consider 2 GHz and 20 GHz condition to compare with the channel performances. The two types of channel for fixed and mobile situation are considered to compare fixed satellite services (FSS) and MSS which represent slow time-varying channels caused by weather change and fast time-varying channels caused by multipath and the movement of user, and to check the channel status and performance by the difference condition according to the highway environment and urban environment, respectively. In each environment, we assume that velocities of moving are 40 Km/h and 120 Km/h, respectively, which scenario is illustrated in Fig. 1. The channel states and channel performances are investigated in traditional satellite channel model for assumption and consideration condition. In satellite communications, the channel state information (CSI) is essential to maximize the utilization of precious system resource. The traditional channel model mainly for fixed satellite services (FSS) can utilize CSI with complete feedback due to slow variation, on the other hand, channel models for MSS should be based on the incomplete CSI because of the fast-varying channels caused by the user movements and small scale fading. Before comparing the channel performance between perfect-CSI (P-CSI) and imperfect CSI, we analyze the difference of channel status and channel performance according to the environment, highway and urban, and carrier frequency bands, 2 GHz and 20 GHz in P-CSI condition. And then, we analyze performance degradation which is taken place by imperfect CSI conditions and suggest method to reduce the degradation. The suitability and usefulness in high frequency bands of both channel models is investigated.

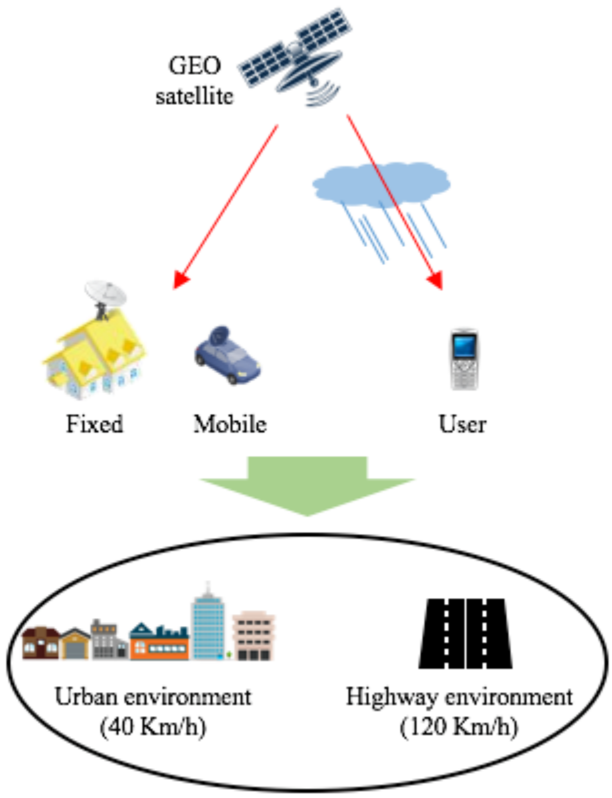


Fig. 1. The basic scenario for analysis

II. Analysis of Satellite Channel Models

2.1 2-state Markov chain model

In probability theory and statistics, the Markov chain model [5] is a stochastic process that satisfies the Markov property as a memorylessness that Markov property is the key assumption of underlying Markov chain model. The Markov property is that the transition probability p_{ij} apply whenever stat i appear, no matter what happened in the past in (1). We consider discrete-time Markov chain model in which the state changes at certain discrete time instants. At each time step n, the state of the chain is denoted by X_n, and belongs to a finite set $S = \{1, \dots, n\}$ of possible states, called the state space. The Markov chain is described in terms of its transition probabilities p_{ij}. The Markov property and transition probability is given by

$$\mathrm{P}(X_{n+1} = j | X_n = i, X_{n-1} = i_{n-1}, \dots, X_0 = i_0) = \mathrm{P}(X_{n+1} = j | X_n = i) = p_{ij}, \quad \text{for all times n,} \quad i, j \in S. \tag{1}$$

The transition probabilities p_{ij} must be nonnegative and sum to one;

$$p_{ij} > 0, \qquad \sum_{j=1}^{n} p_{ij} = 1, \qquad for\ all\ i. \tag{2}$$

In this paper, 2-state Markov chain model is considered [7]. Thus, the state space $S = \{G, B\}$. In this case, i and j, in transition probability p_{ij}, is presented by channel state of good or bad. The transition probabilities can be obtained by parameter D_g and D_b in red box of the Table. 1 which is citied by Lutz's paper [8].

Satellite Elevation	Environment	Antenna	A	$10 \log c$	μ	σ	D_g	D_b	ϵ_g	ϵ_b
13°	Highway	C3	0.24	10.2 dB	−8.9 dB	5.1 dB	90 m	29 m	$1.6 \cdot 10^{-3}$	0.23
	City	C3	0.89	3.9 dB	−11.5 dB	2.0 dB	9 m	70 m	$1.4 \cdot 10^{-2}$	0.29
18°	City	C3	0.80	6.4 dB	−11.8 dB	4.0 dB	8 m	32 m	$7.2 \cdot 10^{-}$[illegible]	0.29
	City	D5	0.80	5.5 dB	−10.0 dB	3.7 dB	8 m	33 m	$9.5 \cdot 10^{-3}$	0.25
21°	New City	D5	0.57	10.6 dB	−12.3 dB	5.0 dB	45 m	60 m	$1.3 \cdot 10^{-3}$	0.30
	Highway	D5	0.03	16.6 dB	−7.1 dB	5.5 dB	524 m	15 m	$1.1 \cdot 10^{-4}$	0.19
	Highway	S6	0.03	18.1 dB	−7.9 dB	4.8 dB	514 m	17 m	$7.6 \cdot 10^{-5}$	0.20

Table. 1. Parameters of the analog and digital channel model which is cited in Lutz's channel.

The transition probability matrixes according to the environments are expressed by

$$p_{ij,Highway} = \begin{bmatrix} p_{gg} & p_{gb} \\ p_{bg} & p_{bb} \end{bmatrix} = \begin{bmatrix} 0.989 & 0.034 \\ 0.011 & 0.966 \end{bmatrix}, \tag{3}$$

$$p_{ij,Urban} = \begin{bmatrix} p_{gg} & p_{gb} \\ p_{bg} & p_{bb} \end{bmatrix} = \begin{bmatrix} 0.889 & 0.037 \\ 0.111 & 0.963 \end{bmatrix}. \tag{4}$$

The transition probability graph is shown by Fig. 1. In the Fig. 1, the capital letter G and B mean channel state good and bad respectively.

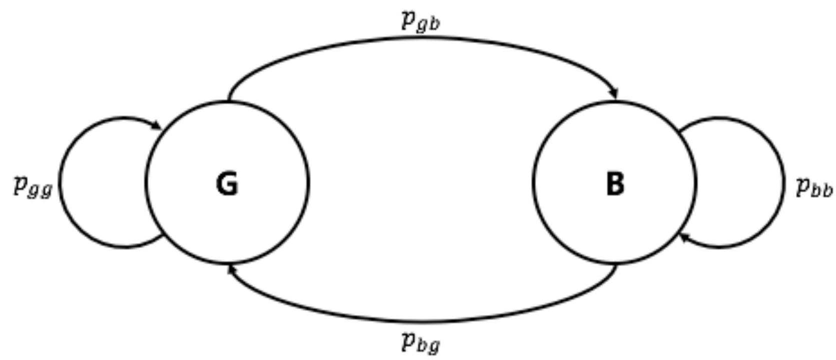


Fig. 2. 2-state Markov chain model for the good and bad channel states of LMS channel.

2.2 Setting for analyzing channel model

For analysis and simulation results, we consider some concepts and settings to present the channel status and to evaluate channel performances which are the Doppler effect with multipath fading, level crossing rate (LCR), coherence time, and channel capacity. In this subsection, we explain concepts or definitions previous considerations, one by one. The traditional channel models, which is Lutz's and Loo's LMS channel model, need to be analyzed in high frequency bands for high throughput because the channel models have been utilized mainly for the lower frequency bands. Although the traditional channel models consider the LMS channel, it does not apply the Doppler effect by the movement of terminals or users. Accordingly, the Doppler effect should be applied to fading channels for grafting the movement and satisfying demands of users. When the terminals or users move on the load, the Doppler effect [20] influence on the carrier frequency by the movement which changed frequency due to the Doppler effect is given by

$$f_d = f_0 \frac{v}{c}. \tag{5}$$

where the f_d is the shifted frequency which is called by the Doppler frequency, f_0 is the carrier frequency of the transmit signal at the satellite, c is the velocity of light, v is the velocity of terminals which assume the constant speed and θ is the angle of incidence of received signal by multipath fading which is used in calculating fading channel. In this case, the changed carrier frequency can be presented by summation between carrier frequency and shifted value, $f_0 + f_d$. If the Doppler effect is included in the fading models, the channel formula $r(t)$ is fundamentally presented by

$$r(t) = \sqrt{\frac{1}{M}} \sum_{i=1}^{M} \exp[j(2\pi(f_0 + f_d)t \cos\theta_i + \phi_i)]\,. \tag{6}$$

where M is the number of multipath, f_d is the Doppler frequency which causes frequency change and ϕ_i is a relative component phase which follows Wiener processes. Through the formula of received signal, the received signal of fading models of Rician $r_{Rician}(t)$ and Rayleigh $r_{Rayl.}(t)$ [12] is given by

$$r_{Rician}(t) = [(A + k)\cos(2\pi f_0 t)] - B\sin(2\pi f_0 t)\,, \tag{7}$$

$$r_{Rayl.}(t) = A\cos(2\pi f_0 t) - B\sin(2\pi f_0 t)\,. \tag{8}$$

where $A = \sqrt{\frac{1}{M}} \sum_{i=1}^{M} \cos(2\pi f_d t \cos\theta_i + \phi_i)$ and $B = \sqrt{\frac{1}{M}} \sum_{i=1}^{M} \sin(2\pi f_d t \cos\theta_i + \phi_i)$ which divide the received signal $r(t)$ in terms of trigonometric functions of cosine and sine. In the expression of fading, the number of multipath M is no less than 8 [21]. Under conditions of large M, the A and B will be independent identically distributed (i.i.d.) Gaussian random variables of zero mean. The random variables are calculated to obtain values of the channel envelopes in the fading models. The Clarke model [16] which is designed for the mobile radio communication environments including the Doppler effect is chosen to apply the Doppler frequency in the scenario.

To express the channel variation and channel status, we use the concept of LCR and coherence time in the channel. The basic formula of LCR N_R [13] of fading channel is given by

$$N_R = \int_0^{\infty} \dot{r} p(R, \dot{r}) ds_0 = \sqrt{2\pi} f_d \rho e^{-\rho^2} . \tag{9}$$

where $\dot{r}$ is time derivative of $r(t)$, R denotes a specific value of r, and ρ is the fading envelope normalized by the local root mean square (RMS) amplitude of the fading envelope. In this formula, we assume that the parameter ρ is 1 for easy calculation. The formula of coherence time [3] T_0 is given by

$$T_0 = \sqrt{\frac{9}{16\pi f_d}} = \frac{0.423}{f_d} . \tag{10}$$

As shown in the formulas (9) and (10), the both parameters of LCR and coherence time are determined by the Doppler effect. Thus, we obtain the value of parameters to present the channel. The reverse LCR is calculated to express channel variation with respect to time because the value of LCR presents the number of changing signal level. Those values of parameters are summarized in the Table. 2 with regard to environments and carrier frequency bands.

Parameter		$\frac{1}{LCR}$		**Coherence Time**	
Environment		Highway	Urban	Highway	Urban
MSS	**2 GHz**	4.88 ms	14.64 ms	1.903 ms	5.71 ms
	20 GHz	488 µs	1.46 ms	190.3 µs	571 µs

Table. 2. The parameter of reverse LCR and coherence time according to the surrounding environments and carrier frequency bands

The both values of reverse LCR and coherence time of 20 GHz are shorter than those of 2 GHz and parameters of highway environment are also shorter than those of urban environments. These parameters are reflected in the channel to present the channel fluctuation and to show impact of movement and high frequency band on the channel. Therefore, in this results, we can know the possibility that channel is being changed because changing time of channel level (LCR) and the coherence time are shortened according to the changing environments and carrier frequency bands.

In the GEO satellite communication systems, the P-CSI is not available in the satellite due to the fast varying-channel because of propagation delay time. However, when using channel information, the we assume that communication systems has P-CSI in order to check channel status such as performance degradation by the movement. In the simulation, we consider channel capacity to evaluate the channel performance. In terms of the information theoretical perspective [10], the channel capacity is defined by maximization of mutual information between input and output signals basically which C is given by

$$C = \max_{p(a)} I(A;B)\,. \tag{11}$$

where $I(A;B)$ is the mutual information between input (A) and output (B) and $p(a)$ is the probability of input components a. And we simply use the Shannon's channel capacity formula which equals to case of using information capacity of the Gaussian channel, which C_S is given by

$$C_S = BW * log_2\left(1 + \frac{h^2 P}{BW * N_0}\right)\,. \tag{12}$$

where BW is the channel bandwidth, N_0 is the noise power, h^2 is the power attenuation due to shadowing and P is the transmitted signal power. To evaluate and confirm the channel performance, ergodic capacity is applied because the channel has fluctuation due to multipath fading and the movement of users depending on the environments. The ergodic capacity is obtained by averaging channel capacities from simulated trial data for 1000 times over the distributed of signal to noise ratio (SNR) [2,15]. the ergodic capacity formula C_{Erg} is given by

$$C_{Erg} = \int_0^\infty BW * log_2(1 + SNR)\,p(SNR)dSNR = E\left[BW * log_2\left(1 + \frac{h^2 P}{BW * N_0}\right)\right]. \tag{13}$$

Jensen's inequality [17] is deployed to compare the channel performance with the Gaussian approximation:

$$E\left[BW * log_2\left(1+\frac{h^2P}{BW * N_0}\right)\right] \le BW * log_2\left(1+\frac{E[h^2]P}{BW * N_0}\right). \tag{14}$$

The inequality states that the expectation of whole capacities is smaller than the channel capacity of the expectation of power attenuations. In right side formula, we consider the Gaussian channel to obtain the upper bound for comparing with performance of ergodic capacity through the Jensen's inequality. In the next sections, we obtain the channel envelopes and compare the channel states for the fixed stations and mobile terminals to analyze system performances for each channel model.

2.3 Lutz's land mobile satellite (LMS) channel model

The Lutz's LMS channel model is applied for the mobile communication channel. The channel model basically uses multipath fading and lognormal fading. Aforementioned fading channels, Rician and Rayleigh, represent the multipath fading, and lognormal fading represents the impairments by weather. This narrowband model of the LMS channel distinguishes two channel states which are good and bad through the Markov chain model, respectively. The channel distribution following the Rician fading model indicates good channel states while the channel distribution based on joint of Rayleigh fading and lognormal fading model indicates bad states. The Lutz's channel model is depicted by Fig. 2 and cited by Lutz's paper [8].

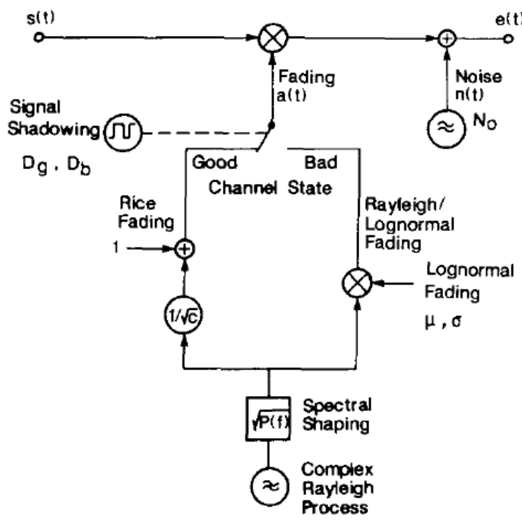


Fig. 3. Dynamic model of the Lutz's LMS channel model.

The received signal of Lutz's LMS channel model in Fig. 3 is

$$e(t) = s(t) \cdot a(t) + N_0 \,. \tag{15}$$

where the signals $e(t)$ and $s(t)$ are received signal and transmit signal, respectively, and fading process value $a(t)$ are complex valued. In case of fading channel, channel state transition presents 2-state Markov chain model. The fading process of Lutz's channel model divides the channel state into good state and bad state. The $a(t)$ is defined as channel states, Rician fading and joint of Rayleigh and lognormal fading in Lutz's LMS channel with signal shadowing. When the multipath signal has a dominant direct signal component, it means that channel state is good state and follows the Rician distribution. The probability density function (PDF) of Rician fading model is given by

$$p_{Rician,Lutz}(S) = ke^{-k(S+1)} I_0\left(2k\sqrt{S}\right). \tag{16}$$

where S is the signal power, k is the power ratio of the dominant direct signal component which raito compares the level of the dominant component (LOS) to the level of other multipath fading components in the multipath signal of fading channel and $I_0(\cdot)$ is the modified Bessel function of zeroth order which can be expressed by $I_n = \frac{1}{2\pi}\int_{-\pi}^{+\pi} e^{i(n\tau - x\sin(\tau))} d\tau$. When the channel state is bad, shadowing is severe and the multipath signal has no dominant direct signal component. It means that channel is bad condition and follows the Rayleigh/lognormal distribution. It can be presented by joint PDF of Rayleigh distribution and lognormal distribution in Lutz's LMS channel model in which the received power is conditioned on the mean power S_0. The Rayleigh PDF function $p_{Rayl.,Lutz}(S|S_0)$ is given by

$$p_{Rayl.,Lutz}(S|S_0) = \frac{1}{S_0}\exp\left(-\frac{S}{S_0}\right). \tag{17}$$

The lognormal PDF function $p_{LN,Lutz}(S_0)$ is given by

$$p_{LN,Lutz}(S_0) = \frac{10}{\sqrt{2\pi}\sigma_{dB}\ln 10} \cdot \frac{1}{S_0}\exp\left[-\frac{(10\log S_0 - \mu_{dB})^2}{2\sigma_{dB}{}^2}\right]. \tag{18}$$

where the μ_{dB} is the average power in dB scale and σ_{dB} is the variance of the power due to shadowing in dB scale. In this model, when the channel state is bad, the received power is described by the joint PDF of Rayleigh and lognormal distribution which is called by Suzuki fading channel model $p_{Suzuki,S}(s)$ and is given by

$$p_{Suzuki,S}(s) = \int_0^\infty p_{Rayleigh}(s|s_0) \cdot p_{lognormal}(s_0) ds_0 \, . \tag{19}$$

Even though the Rician and Rayleigh fading channels are obtained by stochastic modeling, the models use it as it is because which are typical method to express the channel represent channel conditions. The lognormal fading component is also stochastic model which represents attenuation or shadowing factors and, in Lutz's LMS channel model, the lognormal component presents the weather effect. We devised replacing the lognormal component to a mathematical model for rain attenuation or shadowing. Thus, in this paper, more actual applicable model than lognormal component, which is ITU-Recommendation P.838-3 model [23] is utilized. The ITU-R model gives rain attenuation factor. In the rain attenuation model, the important parameter is rain attenuation factor γ_R, because it is the underlying parameter of rain attenuation model and it can obtain regardless of other details. whereas, other parameters such as effective path length or angles of elevation can be different according to the assumption for conditions or location of receivers and the parameters makes difference results of rain attenuation model. The formula of rain attenuation factor is given by

$$\gamma_R = bR^\alpha \, . \tag{20}$$

where b and α are rain attenuation coefficient parameters which are presented by $b = \frac{[b_H + b_V + (b_H - b_v) \cdot cos^2\theta \cdot \cos 2\tau]}{2}$ and $\alpha = \frac{[b_H \alpha_H + b_V \alpha_V + (b_H \alpha_H - b_v \alpha_v) \cdot cos^2\theta \cdot \cos 2\tau]}{2c}$, and R is the rain rate. The rain attenuation coefficient parameters for 2 GHz and 20 GHz are given in the Table. 2. To calculate the rain attenuation, we assume the availability exceeds 0.01% of the time in any year, for a point rain rate of 50 mm/h and the elevation angle of 45^{o}. The value of rain attenuation for 2 GHz is about 0.055 dB. However, the rain attenuation affects about 40.36 dB in our example for 20 GHz condition. The both results show large difference depending on the carrier frequency bands and The rain attenuation has more influence according to the increasing carrier frequency bands. Accordingly, the changing carrier frequency is very impactful in the channel status.

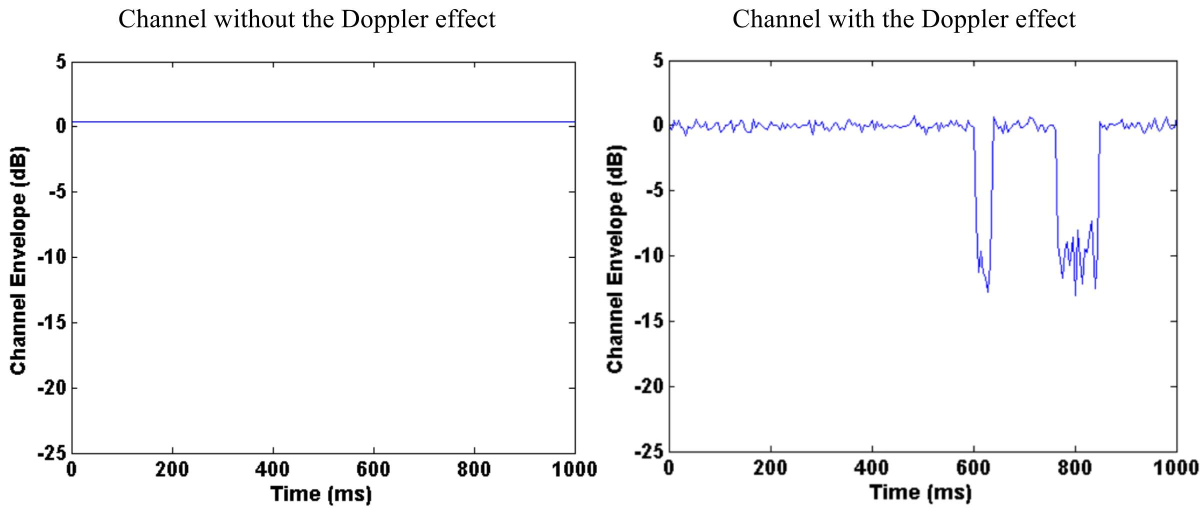
Rain attenuation coefficient	$\mathbf{b_H}$	$\mathbf{b_V}$	$\boldsymbol{\alpha_H}$	$\boldsymbol{\alpha_V}$
2 GHz	0.0000847	0.0000998	1.0664	0.9490
20 GHz	0.09164	0.09611	1.0568	0.9847

Table. 3. Rain attenuation coefficients at the carrier frequency of 2 GHz and 20 GHz. H and V denote horizontal and vertical polarization, respectively.

We apply the rain attenuation to the Lutz's channel model instead of lognormal component in Suzuki fading model and investigate the changing channel level by influence of rain attenuation. And, the channel status such as channel fluctuations is observed based on the LCR, coherence time, and the Doppler effect because channel can be changed by impact of moving and situations. In addition, the variation and difference of channel performances are evaluated according to the changing surrounding environments (changing velocity of moving) and carrier frequency bands. In the following subsection, the simulation results and performance evaluation are shown.

2.3.1 Simulation results and discussions for Lutz's LMS channel model

In this section, we verify the channel performances for mobile satellite communication services based on the traditional channel models of Lutz's channel model with the Doppler effect. As mentioned in section 2.2.1, channel conditions are distinguished as four different types based on the existence of the Doppler effect and the line-of-sight (LOS) component. We consider the carrier frequency bands of 2 GHz and 20 GHz, 30 multipath, channel bandwidth of 32 MHz, and the ergodic capacity that is adopted to confirm the performance of channel models according to power increase. In case of path-loss model, it does not consider in calculation procedure because it influences on both uplink and downlink. Accordingly, we evaluate the factors that influence on channel states and communication system performances. Before the performance evaluation, we check the channel statuses for each condition. In Fig. 4 and Fig. 5, the channel envelope for 2 GHz is depicted according to the surrounding environment of highway environment and urban environment respectively, and presence of the Doppler effect to compare the channel status. In the all channel envelope figures, if the level of channel envelopes locates near by the 0 dB, it denotes that the channel state is good, while if the level of channel envelopes locates nearby the -10 dB or less than -10 dB, it means that channel state is bad.

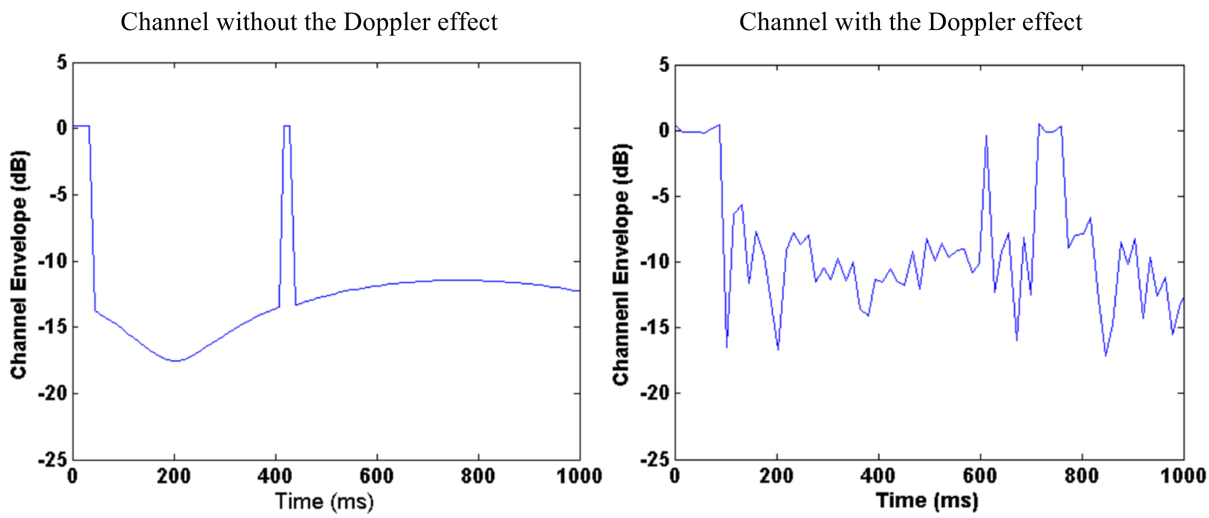


a)

b)

Fig. 4. The channel envelope is distinguished by highway environments for 2 GHz in Lutz's channel model.

In the Fig. 4, the figures present channel envelope graph of highway environment for 2 GHz according to the existence of the Doppler effect by the movement. The channel envelope in the Fig. 4a) looks like flat because the channel is observed for a short time, 1000 ms. In Appendix, we show the channel envelope result of channel without the Doppler effect which observe the channel for a longer time than 1000 ms. On the other hand, in case of the channel with the Doppler effect, the fluctuation occurs in the channel due to the movement, and channel variation happen a lot because coherence time is shorter than 2 ms.



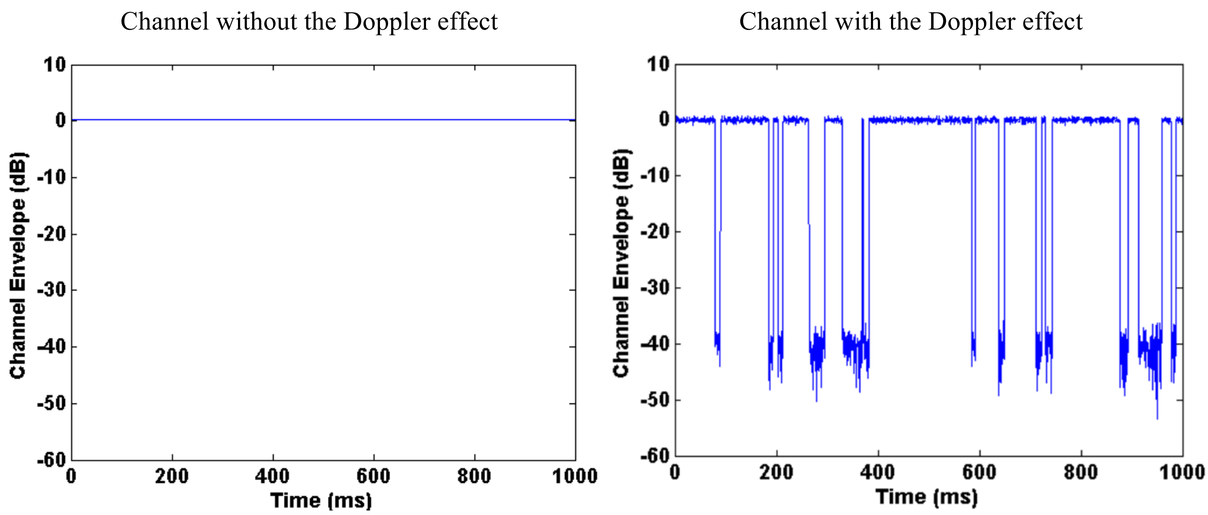
a)

b)

Fig. 5. The channel envelopes are distinguished by urban environments for 2 GHz in Lutz's model

In the Fig. 5, the figures present channel envelopes of urban environment for 2 GHz according to the existence of the Doppler effect by the movement. In case channel without the Doppler effect, although channel has bad state mostly because of the fixed condition, there are good channel state due to the impact of multipath. When comparing highway to urban environment, the channel fluctuation in each states of highway environment is faster than those of urban environment, because the coherence time of highway environment is very shorter than that of urban environment about three times in section 2.2. And, both conditions of without and with the Doppler effect in urban environment have more bad states than highway environment because of surrounding environment such as buildings or large structures.

And we also plot the channel envelope for 20 GHz condition to compare with difference of channel status of 2 GHz depending on the surrounding environment of highway environment and urban environment, and presence of Doppler effect. This analysis is preliminary research for future satellite communication system which use the high frequency bands above 20 GHz.



a) b)

Fig. 6. The channel envelopes are distinguished by highway environments for 20 GHz in Lutz's model

In the Fig. 6, the figures present channel envelope of highway environment for 20 GHz according to the existence of the Doppler effect by the movement. We see that the channel is flat in channel without the Doppler effect. The reason is the same that of 2GHz. In case of channel with the Doppler effect, when the channel state is bad, the channel envelope is worsened around or below -40 dB because of the influence of rain attenuation which result also occurs in urban environment.

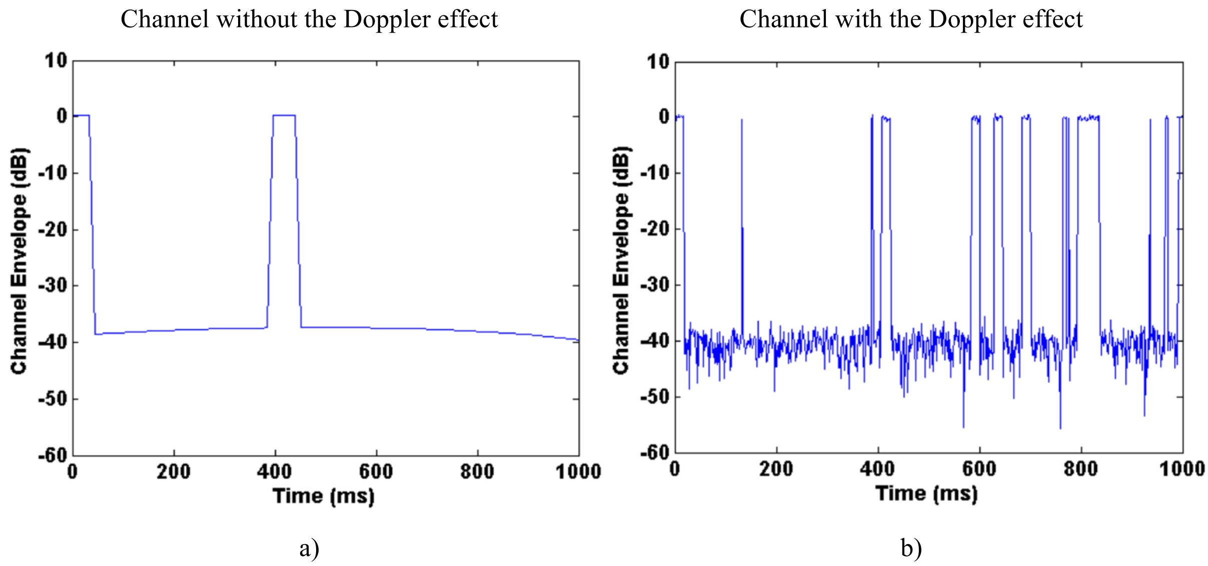
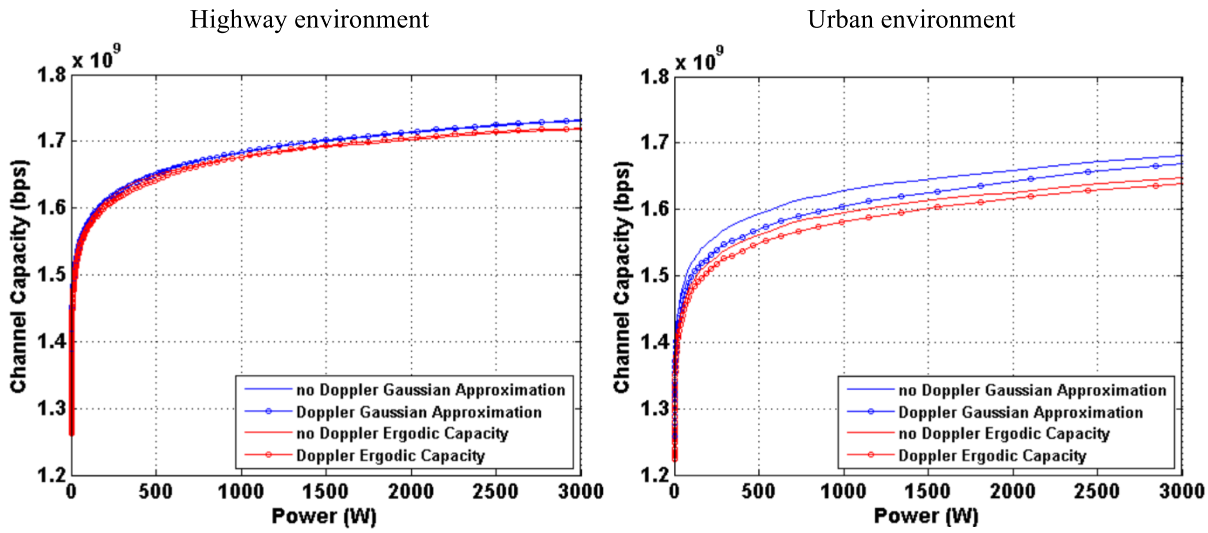


Fig. 7. The channel envelopes are distinguished by urban environments for 20 GHz in Lutz's model

In the Fig. 7, the figures present channel envelope of urban environment for 20 GHz according to the existence of the Doppler effect by the movement. In the Fig. 7a), the channel also has the good state despite fixed condition in urban environment due to the impact of multipath. When comparing highway and urban environment, we can see that the channel variation of highway environment is also faster than that of the urban environment due to the coherence time and the Doppler effect in mobile condition (channel with the Doppler effect).

In addition, in 20 GHz condition, the channel variation is faster than those of 2 GHz because the coherence time and LCR is shorter than that of 2 GHz because of the Doppler effect which is strongly affected by carrier frequency band. Through the previous results for channel envelope graphs, we can verify that the Doppler effect influences on the change rate of channel (variation of channel state and channel fluctuation) depending on the environments and carrier frequency bands. Both 2 GHz and 20 GHz condition show the similar results which are the change rate of channel of highway environment is faster than those of urban environment and the channel looks like flat. If these results of channel envelope are analyzed in terms of mobility, the coherence time is shortened, Doppler effect is deepened, and the channel variation is faster according to the increasing velocity of moving users and carrier frequency band. Therefore, we can confirm that the velocity of moving user (or the surrounding environment) and carrier frequency bands are very impactful in the channel because which elements influence on the Doppler effect directly.

We compare and analyze the channel performance for changed channel state in terms of channel capacity. And, the following graphs show comparison between the Gaussian approximation and ergodic capacity in same environment according to the existence of the Doppler effect.



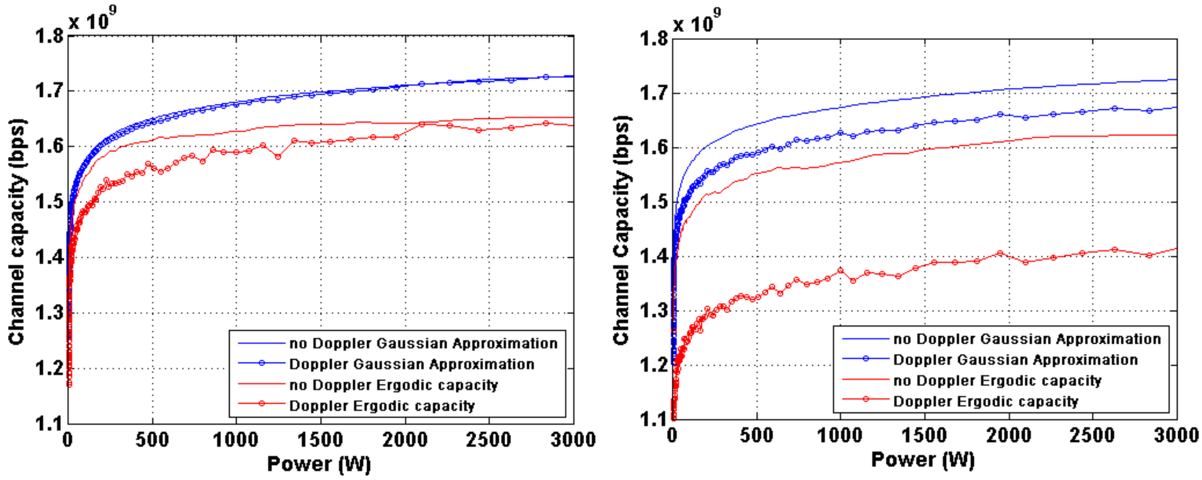
a) b)

Fig. 8. The channel capacity of channel without and with the Doppler effect for 2 GHz.

In the figure, the blue line denotes Gaussian approximation and red line denotes ergodic capacity. If there are no markers in the line, it means that the Doppler effect does not influence on the channel in other words it is fixed condition. While, if line has the round markers, it means that the Doppler effect influences on the channel in other words it is mobile condition. In Fig. 8, the figures present the channel performance of highway and urban environment for 2 GHz according to the presence of the Doppler effect. when lines of same color are compared, we can verify that the performances of Gaussian approximation and ergodic capacity are very similar between channel without and with the Doppler effect in highway environment. In urban environment, the performances of have little gaps between Gaussian approximation; 0.61 % and ergodic capacity: 0.45 % of channel without and with the Doppler effect, respectively. When condition changes from highway to urban environment, the performance degradation occurs: 2.87 % and 3.45 % for without the Doppler effect, and 4.14 % and 4.52 % for with the Doppler effect according to the Gaussian approximation and ergodic capacity, respectively.

In 20 GHz condition, the channel capacity is also plotted to evaluate degradation. In the Fig. 9, the channel performances with and without the Doppler effect are shown in highway and urban environments. When the lines of same color are compared, the simulation results are different from those of 2 GHz and it shows the performance degradation due to the movement and changing environment.

Highway environment　　　　Urban environment



a)　　　　b)

Fig. 9. The channel capacity without and with the Doppler effect for 20 GHz.

Despite the performance loss due to the Doppler effect in the highway environment, the performances show no large difference between without and with the Doppler effect; 0.078 % for Gaussian approximation and 0.98 % for ergodic capacity, respectively, between Fig. 9a). The performance loss in the urban environment is bigger than that in the highway environment. By comparing to line without markers and line with circle markers in Fig 9b), we can observe that the Doppler effect incur more performance degradation. Performance differences between channel without and with the Doppler effect are 2.78 % for Gaussian approximation and 12.61 % for ergodic capacity, respectively which results of performance difference are summarized in the Table 4. In addition, if we compare different environments between the Fig. 9a) and 9b), degradation occurs due to the non LOS condition. The results of comparison with highway environment and urban environment are follows; 0.24 % for without the Doppler effect and 2.94 % for with the Doppler effect in Gaussian approximation, and 1.84 % for without the Doppler effect and 13.37 % for with the Doppler effect in ergodic capacity, respectively which results of performances difference are summarized in the Table 5.

Accordingly, when comparing with existence of the Doppler effect, in the urban environment, it has more losses than in the highway environment, because the non-LOS condition along with the impact of the Doppler effect causes more severe degradation and in case of ergodic capacity of urban environment, degradation is caused seriously more than 12 %. These simulation results for degradation are summarized again in the Table. 4. And, when comparing with changing environment, the degradation is caused more than 13 % which simulation results are analyzed to check the difference of channel performance depending on the changing environment from highway to urban environment which results are summarized in the Table. 5 with that of 2 GHz.

	Changing condition (between without and with Doppler effect)	**Degradation**
Gaussian approximation	Highway	0.078 %
	Urban	2.78 %
Ergodic capacity	Highway	0.98 %
	Urban	12.61 %

Table.4. The rate of performance degradation according to the changing condition between without and with the Doppler effect in Lutz's LMS channel model in 20 GHz condition.

	Changing environment (between highway and urban environment)		**Degradation**
2 GHz	**Gaussian approximation**	Without Doppler effect	2.87 %
		With Doppler effect	4.14 %
	Ergodic capacity	Without Doppler effect	3.45 %
		With Doppler effect	4.52 %
20 GHz	**Gaussian approximation**	Without Doppler effect	0.24 %
		With Doppler effect	2.94 %
	Ergodic capacity	Without Doppler effect	1.84 %
		With Doppler effect	13.37 %

Table. 5. The rate of performance degradation according to the changing environment between highway and urban environment in Lutz's LMS channel model.

2.4 Loo's LMS channel model

The Loo's LMS channel model [4] is applied to investigate the traditional LMS communication channel model. The channel model basically uses multipath fading and lognormal fading like the Lutz's channel model. Aforementioned fading channels in section 2.2, the Rician and Rayleigh represent channel model by the multipath fading model according to the existence of LOS, and lognormal fading model represents the foliage attenuation (shadowing). In the Loo's LMS channel model, the lognormal fading component is utilized, which does not mean same effect of Lutz's LMS channel model. The lognormal component influences on the good channel state (Rician fading model). The channel distribution following the joint of Rician and lognormal fading model indicates good channel state while the channel distribution based on Rayleigh fading model indicates bad channel state. When obtaining the channel amplitude and phase, this channel model considers the sum of a lognormally distributed random phasor and a Rayleigh phasor which is given by

$$r \cdot exp(j\theta) = z \cdot exp(j\phi_0) + w \cdot exp(j\phi), \qquad z, w > 0\,. \tag{21}$$

where the phases ϕ_0 and ϕ are uniformly distributed between 0 and 2π, z is lognormally distributed, and w has Rayleigh distribution basically. In the Loo's channel model, the channel states also divide into good and bad which states are determined by the amplitude of channel and this model define the channel distribution for channel state depending on the channel amplitude. This channel model utilizes three fading models (Rician fading, Rayleigh fading, and lognormal fading) to define the channel distribution. The Rician PDF function $p_{Rician,Loo}(r|z)$ is given by

$$p_{Rician,Loo}(r|z) = \frac{r}{b_0} exp\left[-\frac{(r^2+z^2)}{2b_0}\right] I_0\left(\frac{rz}{b_0}\right). \tag{22}$$

where the r is the signal power, z is dominant direct signal component with lognormal fading component, b_0 is average scattered power due to the multipath, and $I_0(\cdot)$ is the modified Bessel function of zeroth order. And the lognormal PDF function $p_{LN,Loo}(z)$ is given by

$$p_{LN,Loo}(z) = \frac{1}{\left(\sqrt{2\pi d_0} z\right)} exp\left[-\frac{(\ln z - \mu)^2}{2d_0}\right]. \tag{23}$$

where the $\sqrt{d_0}$ and μ are the standard deviation and mean, respectively. In the (22), the conditional probability is used to graft the shadowing by the lognormal fading components in Ricain fading channel. Therefore, When the channel state is good, the channel distribution follows joint PDF of Rician fading model which presents main channel and lognormal fading components which present the attenuations or shadowing.

Thus, substituting formula (23) into (22), one obtains

$$p(r) = \int_0^{\infty} p(r,z)\,dz = \int_0^{\infty} p(r|z)p(z)\,dz$$
$$= \frac{r}{\left(b_0\sqrt{2\pi d_0}\right)} \int_0^{\infty} \frac{1}{z} exp\left[-\frac{(\ln z-\mu)^2}{2d_0} - \frac{(r^2+z^2)}{2b_0}\right] I_0\left(\frac{rz}{b_0}\right)\,dz\,. \tag{24}$$

And, Rayleigh PDF function $p_{Rayl.,Loo}(r)$ is given by

$$p_{Rayl.,Loo}(r) \;= \frac{r}{b_0} exp\left[-\frac{r^2}{2b_0}\right]. \tag{25}$$

When the channel state is bad, the channel distribution follows Rayleigh fading model. As aforementioned, the previous formulas are used to determine the channel state good and bad by comparison with channel amplitude r and standard deviation of average scattered power due to the multipath b_0. The channel distribution $p(r)$ depending on the channel amplitude, is given by

$$p(r) = \begin{cases} \dfrac{1}{r\sqrt{2\pi d_0}} exp\left[-\dfrac{(\ln r-\mu)^2}{2d_0}\right], & for \;\; r \gg \sqrt{b_0} \\ \dfrac{r}{b_0} exp\left[-\dfrac{r^2}{2b_0}\right] \quad\quad\quad\quad\quad, & for \; r \ll \sqrt{b_0}\,. \end{cases} \tag{26}$$

In the formula (26), the channel distribution is made a judgement. But, deciding the $\sqrt{b_0}$ can be different depending on the environments. Therefore, in this paper, we also use the 2-state Markov chain model to divide the channel state, good and bad for easy approach. The Markov chain model is used by the same way as that used on the Lutz's channel model. In this model, we use the lognormal fading component as it is because the lognormal fading represents blockage of foliage and this blockage has no available replacing mathematical models. We assume that the surrounding environments are highway and urban to compare the different impacts of the Doppler frequencies according to the surrounding environments and carrier frequency bands. As the Doppler effect influences on the channel, the change rate of channel envelopes and coherence time are altered. Thus, the level crossing rate (LCR) is employed to reflect the rate of change of channel envelopes and to represent the channel coherence time. In the following subsection, channel simulation and performance evaluation are shown.

2.4.1 Simulation results and discussions for Loo's LMS channel model

In this section, we verify the channel performances by the channel envelope and channel capacity for mobile satellite communication services based on the traditional channel models with the Doppler effect by the Loo's channel model which is one of the representative satellite channel model. As mentioned in section 2.2.1, channel conditions are distinguished as four different types based on the existence of the Doppler effect and the line-of-sight (LOS) component. And the assumptions for channel bandwidth, the number of multipath and two kinds of carrier frequency bands are same as that of Lutz's channel model. And the concept of coherence time and LCR also apply to the channel model.

In the Fig. 10 and Fig. 11, the channel envelopes for 2 GHz are depicted to compare and evaluate the channel status by some factors according to the surrounding environment of highway environment and urban environment, and presence of the Doppler effect, respectively.

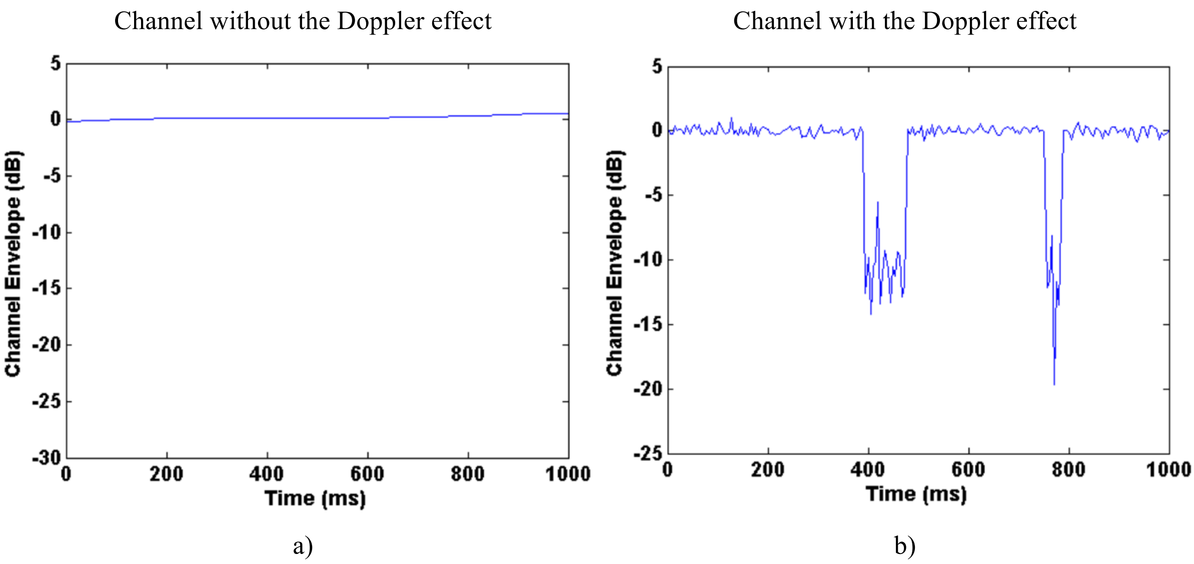
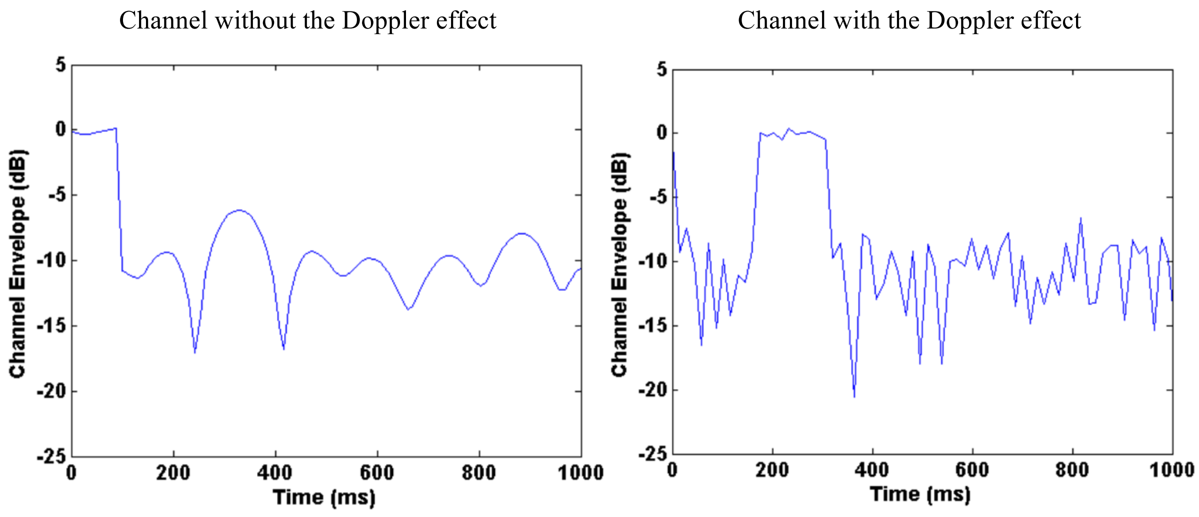


Fig. 10. The channel envelopes are distinguished by highway environments for 2 GHz in Loo's model

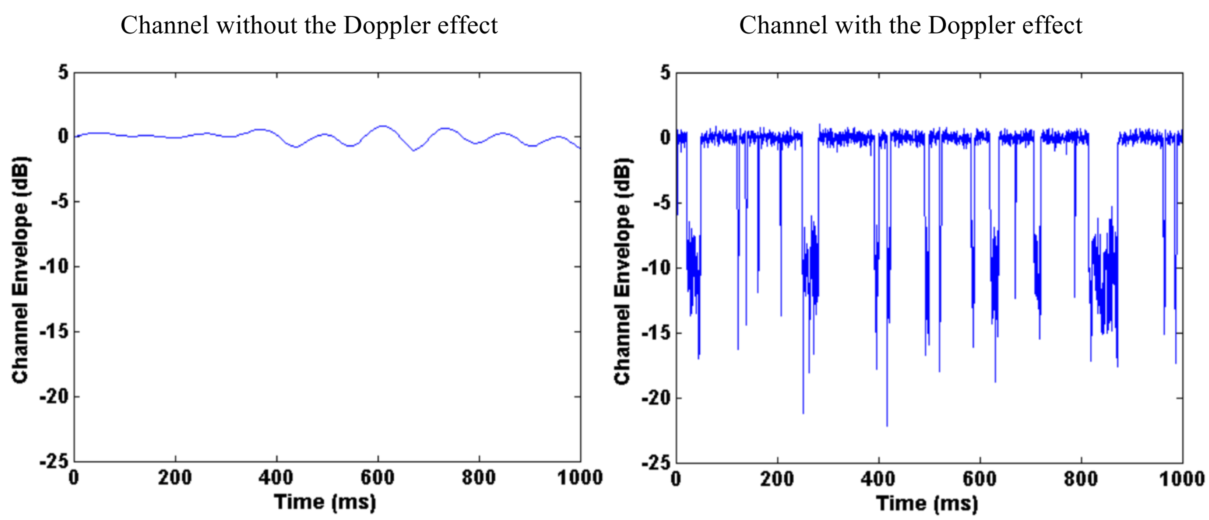
The channel envelope graph of Fig. 10a) also looks like flat. The reason of flat shape is same as other channel envelope for channel without the Doppler effect in highway environment. And, when we check the channel with the Doppler effect, the fluctuations occur in the channel by the movement in Fig. 10b).



a) b)

Fig. 11. The channel envelopes are distinguished by urban environments for 2 GHz in Loo's model

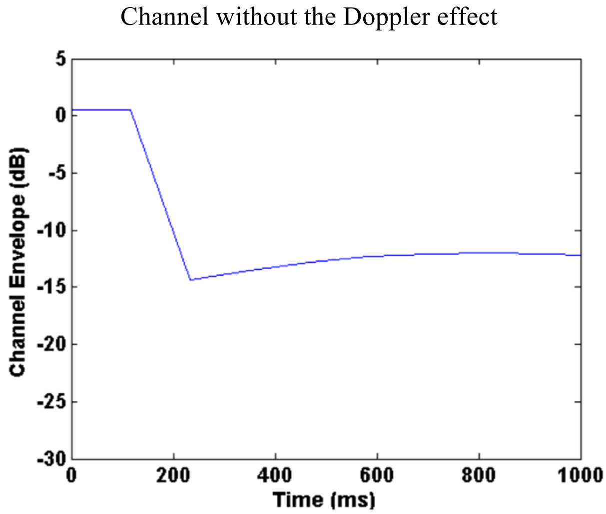
In the Fig. 11, the figures present channel envelope of urban environment for 2 GHz according to the existence of the Doppler effect by the movement. The channel fluctuation of the bad in the Fig. 11a) is the phenomenon by the multipath fading due to the buildings or structures. In the case of Loo's channel model, when comparing the channel variation of highway and urban environment the channel variation of highway environment is faster than that of urban environment. But, urban environment has more bad state than highway environment.



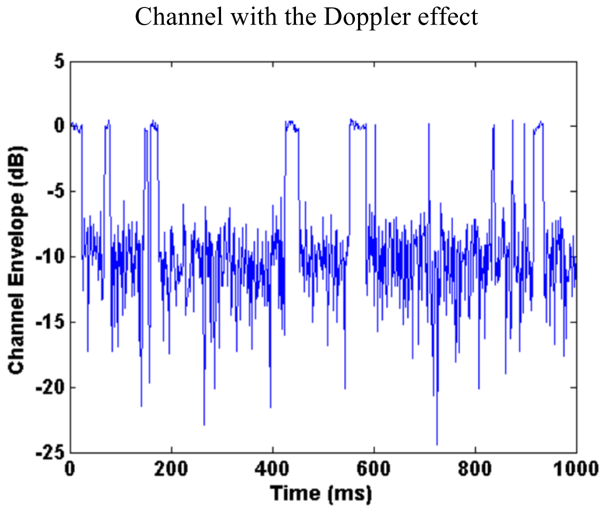
a) b)

Fig. 12. The channel envelopes are distinguished by highway environments for 20 GHz in Loo's model

We also plot the channel envelope for 20 GHz to compare with channel model which apply the 2 GHz. In the Fig. 12, the figures present channel envelope of highway environment for 20 GHz according to the existence of the Doppler effect by the movement. The channel fluctuates around 0 dB which result in impact of shadowing by lognormal fading in the Fig. 12a). In this case, the channel envelope differs from that of Lutz's channel model because The channel envelopes are worsened from around -10 dB to below -20 dB despite 20 GHz condition with the result that any other attenuation factors such as atmospheric loss or rain attenuation are not applied or considered to bad channel state in the Loo's channel model. The Loo's channel model does not consider other attenuation factors such as rain attenuation in bad channel state.



a)



b)

Fig. 13. The channel envelopes are distinguished by urban environments for 20 GHz in Loo's model

In the Fig. 13, the figures present channel envelope of urban environment for 20 GHz according to the existence of the Doppler effect by the movement. In the case of 20 GHz condition of highway and urban environment, there are no large difference in the level of channel amplitude, when comparing with that of 2 GHz condition. The difference of results between 2 GHz and 20 GHz condition is rate of channel variation according to the coherence time and LCR in circumstance of the channel with the Doppler effect. Through the previous results for channel envelope, we also can verify that the Doppler effect influences on the change rate of channel state (channel variation) depending on the environments and carrier frequency bands. Both 20 GHz and 2 GHz condition show the same result that is the change rate of channel of urban environment is faster than that of highway environment. In this channel model, if analyzing previous results in terms of mobility, the coherence time is shortened, Doppler effect is deepened and the fluctuation of the channel is faster according to the increasing velocity of moving users and carrier frequency band. As mentioned, the channel envelope is worsened until minimum -25 dB.

By this channel model, we can confirm that the variation or level of channel can be different according to the considerations for attenuation or impairment factors. The velocity of moving (or the surrounding environments) and carrier frequency bands are very impactful in the channel in Loo's LMS channel model because the channel has different situations. Based on the previous channel envelope result, channel performance of Loo's channel model is obtained. The channel performance for changing surrounding environment of channel is compared and evaluated in terms of channel capacity. The following graphs show comparison with the Gaussian approximation and ergodic capacity for same environment, respectively.

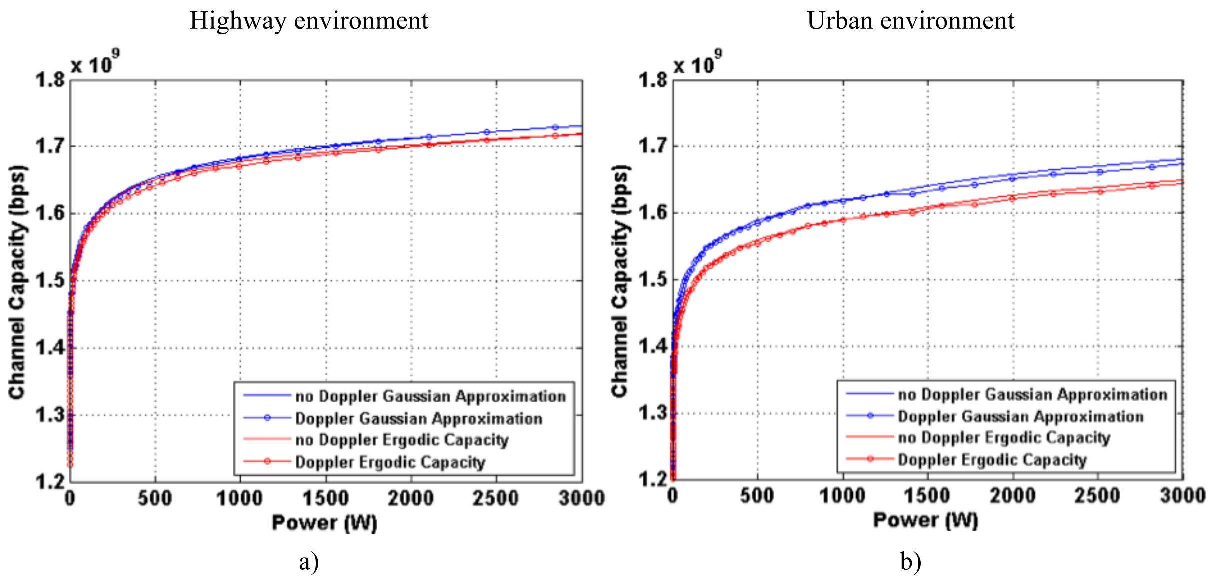


Fig. 14. The channel capacity without and with the Doppler effect for 2 GHz in Loo's model

In the figures, the lines are also defined by existence of markers. The blue line means Gaussian approximation and red line means ergodic capacity. If there are no markers in the line, it means that channel without the Doppler effect. While, if line has the round markers, it means that the Doppler effect influences on the channel. The Fig. 13 presents the channel performance of highway and urban environment for 2 GHz condition. In the Fig. 13a), when the lines of same color are compared, we can verify that performances of Gaussian approximation and ergodic capacity are very similar between channel without and with the Doppler effect in both highway environment and urban environment.

In 20 GHz condition in Loo's LMS channel model, the channel capacity is also plotted to evaluate channel performance for degradation. In the Fig. 14, the channel performances are compared between without and with the Doppler effect for highway and urban environment. When the lines of same color are compared, the simulation results are so similar to those of 2 GHz and it shows the little performance degradation compared to Lutz's LMS channel model. The reason for this result is impact of attenuations or shadowing in the bad channel state.

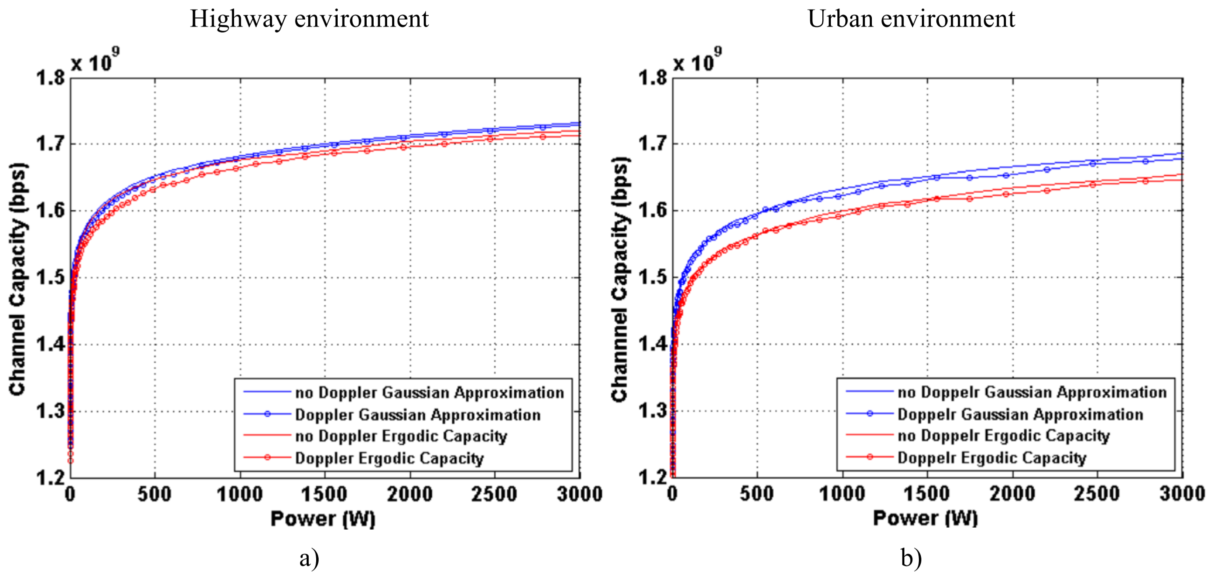


Fig. 15. The channel capacity without and with the Doppler effect for 20 GHz in Loo's model

Despite the performance loss due to the Doppler effect in the both environment, the performance shows no large difference between without and with the Doppler effect. But, there are little performance degradation. First, in case of highway environment, the performances show no large degradation between without and with the Doppler effect; 0.18 % for Gaussian approximation and 0.42 % for ergodic capacity in Fig. 14a). In case of urban environment, we can observe the performance degradation by comparing with between without and with the Doppler effect in Fig. 14b); 0.52 % for Gaussian approximation and 0.61 % for ergodic capacity, respectively. In this channel model, the performance degradation is so smaller than the Lutz's LMS channel model and the simulation results are summarized in Table. 6.

	Fixed → Mobile (between without and with Doppler effect)	Degradation
Gaussian approximation	Highway	0.18 %
	Urban	0.52 %
Ergodic capacity	Highway	0.42 %
	Urban	0.61 %

Table. 6. The rate of performance degradation according to the changing condition between without and with the Doppler effect in Loo's LMS channel model.

If we compare different environments between the Fig. 14a) and 14b), degradation occurs due to the non LOS condition. The results of comparison with highway environment and urban environment for 2 and 20 GHz condition are follows; In 2GHz condition, 2.87 % for without the Doppler effect and 3.45 % for with the Doppler effect in Gaussian approximation, and 4.14 % for without the Doppler effect and 4.52 % for with the Doppler effect in ergodic capacity, respectively, and In 20 GHz condition, 2.67 % for without the Doppler effect and 2.94 % for with the Doppler effect in Gaussian approximation, and 3.45 % for without the Doppler effect and 3.63 % for with the Doppler effect in ergodic capacity, respectively which results are summarized in the Table. 7.

	Changing environment (between highway and urban environment)		Degradation
2 GHz	**Gaussian approximation**	Without Doppler effect	2.87 %
		With Doppler effect	3.45 %
	Ergodic capacity	Without Doppler effect	4.14 %
		With Doppler effect	4. 52 %
20 GHz	**Gaussian approximation**	Without Doppler effect	2.67 %
		With Doppler effect	2.94 %
	Ergodic capacity	Without Doppler effect	3.45 %
		With Doppler effect	3.63 %

Table. 7. The rate of performance degradation according to the changing environment between highway and urban environment in Loo's LMS channel model.

In results of Table. 7, the degradation is similar between 2 and 20 GHz, and that of 2 GHz is bigger than 20 GHz. The difference of results in the Table. 7 is smaller than that of Lutz's channel model. Therefore, in this channel model, when comparing presence of the Doppler effect according to the environments and carrier frequency bands, there are no large differences in analysis results of channel performances. However, we can verify that moving of users is very impactful in this channel model by fluctuation in channel envelope graph.

2.5 Comparison between Lutz's and Loo's LMS channel model

In this section, the difference of channel models is summarized for representative characteristics. The channel models are compared for different characteristics. First, the channel states are divided into good and bad which states are represented by the distribution of Rician and joint model between Rayleigh and lognormal in Lutz's model, and joint model between Rician and lognormal, and Rayleigh in Loo's model. In case of the lognormal component, which is used as a different sense. First, the lognormal component of Lutz's model is represented to weather effect. While that of Loo's model is represent shadowing of foliage. Thus, in Lutz's model, we adopt the rain attenuation to replace lognormal component and, in Loo's model, the lognormal component is used as it is. And, the attenuation factor which affects the channel apply the different period. In case of weather effect, we assume that the weather influences on the channel at 8-hour interval, and the shadowing of foliage affects the channel at the interval for a shorter time than weather effect. The differences are summarized in the Table. 8.

		Lutz model	**Loo model**
Channel state	**Good state**	Rician distribution	Rician/lognormal distribution
	Bad state	Rayleigh/lognormal distribution	Rayleigh distribution
Meaning of lognormal		Weather effect	Shadowing of foliage

Table. 8. The comparison with difference characteristics of channel models.

Due to the difference of lognormal fading component, level distinction of channel envelope occurs in bad state. The channel envelope of Lutz's model is worsened below -40 dB, but that of Loo's model is worsened around -10 dB to -25 dB. Accordingly, the performance degradation by movement is different depending on the channel model, and the degradation of Lutz's model happens over 12 %, while that of Loo's model occurs over just 0.6 %.

III. DELAYED FEEDBACK PROBLEM

In case of the satellite communication, the propagation length is very longer than that of any other wireless communication systems. By the long propagation length, it is the preliminary research to overcome the performance degradation which is presented by delayed feedback system. In case of the satellite communication, CSI is served to transmitter through the delay feedback system and this case can present that channel has the memory []. So, the case of memoryless channel can be defined that the output is influenced on generated input at the same time. While channel with the memory denotes that transmitter utilizes the CSI that has been retransmitted by the feedback system of the ground station. According to the channel memory, the different transition probability is applied to channel which transition probabilities [10] are given by

$$
{p_{ch,tans}}^{d} = \begin{bmatrix} 1 - \dfrac{p_{bg}}{p_{gb} + p_{bg}}(1-\mu^{d}) & \dfrac{p_{bg}}{p_{gb} + p_{bg}}(1-\mu^{d}) \\ \dfrac{p_{gb}}{p_{gb} + p_{bg}}(1-\mu^{d}) & 1 - \dfrac{p_{gb}}{p_{gb} + p_{bg}}(1-\mu^{d}) \end{bmatrix}. \tag{27}
$$

where the $p_{ch,tans}$ is transition probability which is changed by delay time, d denotes delayed feedback time, p_{gb} and p_{bg} are transition probability to another channel state and, μ denotes the channel memory. As aforementioned, the channel memory is incurred by delayed feedback system which give the channel information data to satellite from ground station. In case of the satellite communication with GEO, the feedback delay time is very long due to the long propagation length. So, we check and analyze the channel performance depending on the coherence times (moving velocity) and feedback delay times. The coherence times are 22.84 ms, 11.42 ms, 5.71 ms, 0.38 μs and, 0.19 μs (1, 2, 4, 60 and, 120 km/h) and delayed feedback times assumed 1, 5, 20, 125, 250 and, 500 ms. And in case of 1, 2 and, 4 km/h, we added 10 and 40 ms delay time for detailed analysis. Before the analyzing, we assume that when the given feedback CSI is good, the satellite system uses transmit power as it is, while if the CSI is bad, the transmit power is compensated. However, communication resource such as transmit power may be wasted due to the margin that occur by compensation. When the systems have perfect-CSI, we analyze the performance difference which is incurred by delayed feedback CSI to serve same performance like case of the perfect-CSI in information theoretical and we assume that satellite communication systems use the OBP system which processes the channel data on the satellite board to serve the less delayed channel information data. That performance differences are generated by difference of point of delayed CSI.

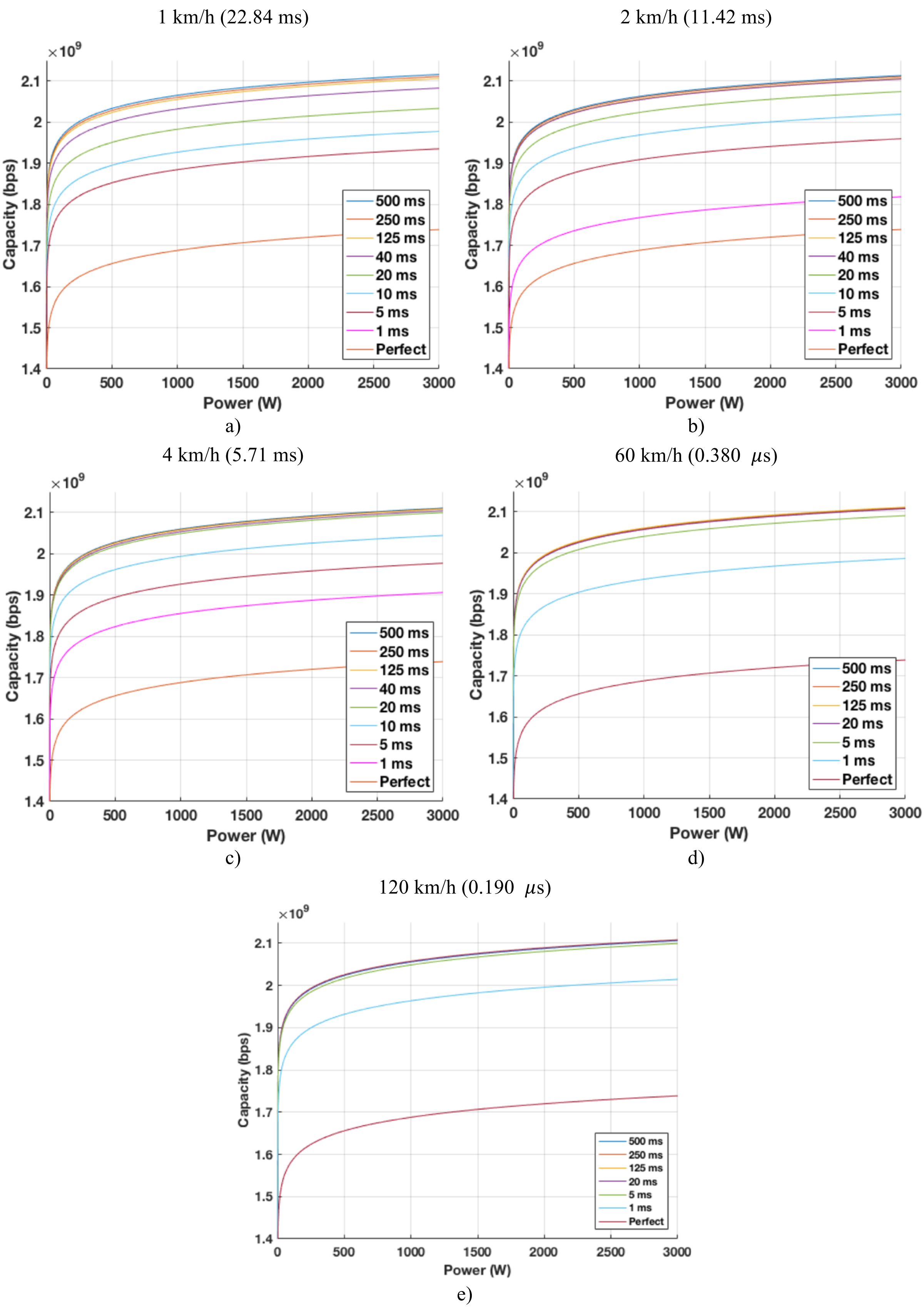


Fig. 16. Performance analysis for resource waste according to the feedback delay times and coherence

In Fig. 16, we can check the saturation to some value according to the delaying the feedback time in the graphs. In case of Fig .16a), the coherence time 22 ms is longer than any other cases because it moves slow speed in 1 km/h. So, we can see the separated graphs until 40 ms delayed feedback time. And, in the same vein, we can also see the saturation of capacity and graph until 20 ms delayed feedback time according to decreasing coherence time as 11 ms in Fig. 16b). Like this, if the coherence time become 0.190 μs, almost case of delayed feedback times are saturated to 500 ms delay time. If the simulation results are verified in terms of correlation coefficient, correlation coefficient of case of coherence time 22 ms is 0.69 and case of coherence time 0.190 μs is 0.42, representatively. We can see that having small correlation coefficient equals receiving random signal data. The correlation coefficient [5] N is given by

$$N = \frac{E[WJ] - E[W]E[J]}{\sqrt{E[W^2] - \left[E[W]\right]^2}\sqrt{E[J^2] - \left[E[J]\right]^2}}. \tag{28}$$

where the W and J are value of comparison target.

IV. CONCLUSION

In this paper, the traditional channel models which are Lutz's LMS channel model and Loo's LMS channel model, is considered. We analyze the channel in terms of the channel envelope for checking channel status and channel capacity to compare and evaluate the channel performance according to the surrounding environments and carrier frequency bands. For providing mobile communications, the fast-time varying channel by mobility is big problem in the satellite communication system because of the long latency by long round-trip delay. First, the variance for fluctuation of channel amplitude and channel state due to the movement of user is analyzed. We can verify that fluctuation of the channel level of highway environment is faster than that of urban environment and transition of the channel state of urban environment is faster than highway environment through the both channel model of Lutz's and Loo's. Therefore, the carrier frequency bands and velocity of moving user based on the surrounding environment are very impactful in both channel model by change of channel variation. And, the channel performances are investigated according to the channel variations in terms of channel capacity.

In performance analysis, the degradation of channel performance is caused by movement depending on the changing velocity of moving and carrier frequency bands. The incurred performance degradations are difference depending on the condition and environment. And, the Jensen's inequality is utilized to compare performance difference between Gaussian approximation and ergodic capacity according to the condition for presence of the Doppler effect. In case of the Lutz's LMS channel model, the losses are follows; up to 2.78 % in Gaussian approximation and up to 12.61 % in ergodic capacity. In case of the Loo's channel model, the losses are obtained; up to 0.52 % in Gaussian approximation, and up to 0.61 % in ergodic capacity. The reason of differences between Lutz's and Loo's model is impact of attenuation which is applied in bad channel state. The performance distinctions are incurred by comparing highway and urban environment according to the approximation and ergodic capacity, respectively. Performance of urban environment is lower than that of highway environment because of the surrounding environments of buildings or large structures which make multipath fading. Especially, in high frequency band and urban environment, the performance loss is incurred seriously. The satellite communication systems are very vulnerable to mobile communication in high frequency bands and surrounding environments.

However, in graph of channel capacity, the performances are very similar in lower power for all conditions. Recently, the studies of digital video broadcasting via satellite second generation (DVB-S2), DVB return channel via satellite second generation (DVB-RCS2) and multi-beam satellite systems have studied animatedly and the studies are focused on utilizing the lower SNR regime [6,22]. At low SNR, performance differences between the ergodic capacity and the channel capacity of Gaussian approximation are decreased and comparable while the channel capacities at high SNR show large difference. Therefore, at low SNR the performance bounds can be derived from the Gaussian approximation easily, because the Gaussian approximation which calculates performance in terms of the power budget is easier to use in system design than the ergodic capacity which calculates the performance in terms of the transmission bits.

As a result of investigating suitability and usefulness of both channel models, the channel models are suitable for basic theoretical channel modeling and analyzing. However, if the channel is observed experimentally, the Loo's LMS channel model is not suitable for high frequency bands because the models does not consider actual attenuation models such as atmospheric losses or ionospheric effect in bad channel state. The communication in high frequency bands is very sensitive to attenuation such as atmospheric losses or rain attenuation. If channel is investigated in realistic aspect, practical attenuation models have to be considered.

We assume the OBP system which can signal processing for CSI, which have been served by delayed feedback system in tradition system, in the satellite board. And the performances are compared and analyzed based on previous channel investigation and evaluation depending on the transition probabilities and feedback delay times in highway environment. As a result, we can check that the delayed feedback CSI which is far point from changed coherence time by moving environments. For the improve the performance, we need to algorithm of resource allocation to effective and efficient method of resource utilization.

Appendix

In the highway environment without the Doppler effect condition, variation of channel envelope can be shown that transition of channel state for 10000 ms (10 s) in the Fig. 15. The channel variations can be caused by attenuation factors such as tropospheric effects. Although the graph is example for 20 GHz in highway environment and channel without the Doppler effect, channel variation of another condition for 2 GHz in highway environment and channel without the Doppler effect can be shown as Fig. 15 which has different channel level.

Highway environment without the Doppler effect

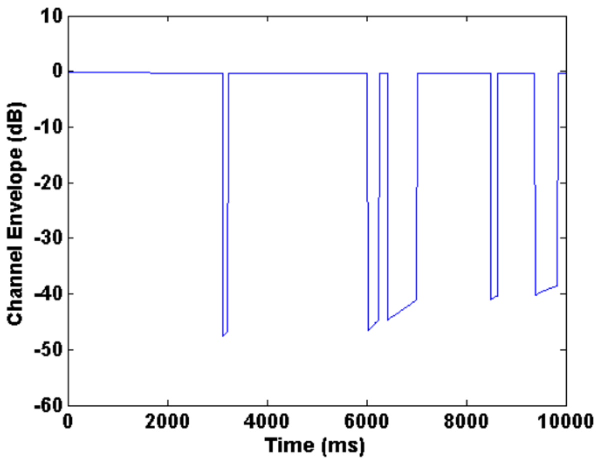


Fig. 17. The channel envelope without the Doppler effect for long time of 10000 ms.

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요 약 문

고성능 이동 위성 서비스 (MSS)를 위한 성능 분석

미래의 위성 통신 시스템은 저주파 대역의 포화로 인한 주파수 대역 부족 문제를 해결하기 위해 고주파 대역을 사용해야하고, 지상의 이동 통신 시스템의 비약적 발전으로 위성 통신도 이동 통신 서비스를 제공하기 위해 시스템을 최적화해야하는 문제에 직면해 있다. 그리하여, 본 논문에서는 사용자나 터미널의 이동을 고려하고 고주파 대역에서의 위성 통신 시스템의 성능과 채널의 상태를 평가, 비교하기 위해 반송 주파수를 변화시키고, 수신기 주변 환경을 다르게 가정하여 연구를 진행하였다.

위성 통신 시스템에서 대표적으로 날씨의 영향에 의한 느린 시변 채널과 움직임에 의한 빠른 시변 채널에 따라 다른 차이를 보인다. 앞으로 분석하게 될 움직임에 의한 빠른 시변 채널의 경우, 움직임에 의한 채널 변화는 위성통신에서 지상과 위성의 왕복 지연 시간 (round-trip delay) 보다 빠르기 때문에 위성 채널에 적용하기 힘들다는 문제점이 있다. 본 논문에서는, 이러한 문제점으로 인해 채널과 성능에 발생되는 한계점을 분석하였다.

먼저 대표적인 위성 통신 채널 모델인 Lutz와 Loo의 land mobile satellite (LMS) 채널을 사용하며 사용자의 이동성을 고려하기 위해 채널에 Doppler effect를 접목시켰다. 또한 기존의 시스템과 고주파 대역을 각각 분석하기 위해 반송 주파수를 각각 2 GHz와 20 GHz로 가정하여 주파수 변화에 따른 성능의 차이를 분석하였고, 수신기의 주변 환경 또한 고속도로와 도시의 2 가지 경우에 대해 각각 앞의 채널 모델에 적용하여 분석을 진행하였고, 각각의 상황에 따른 채널 상태와 성능에 대한 분석을 진행하였다. 그 채널 성능을 분석한 결과에 따라 각 채널 모델이 고주파 대역의 위성 통신에 대한 적합성과 사용가능성에 대해 조사하였다.

핵심어: 위성 통신 시스템, 주파수 포화 문제, Ka 대역, 이동 위성 채널, 이동위성서비스 (MSS