Proposal of Multi-Stage Interference Canceller Against Adjacent Channel Interferences in NTNs

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***Abstract*— NTNs (Non-Terrestrial Networks) for extreme coverage extension in Beyond 5G/6G have attracted satellite communications with wide coverages compared to terrestrial mobile systems. In satellite communications, ones of the NTN elements, LEO (Low Earth Orbit) systems such as satellite constellations are under investigation added to conventional GEO (Geostationary Orbit) systems. Although separate frequency bands are assigned in this time for GEO/LEO systems, it is assumed that they would use the same frequency bands in the future. If they would use the same frequency bands, they must operate under adjacent channel interference conditions, so interference compensation schemes are significantly important. In adjacent channel interference environments, the GEO receiver can use a high-power LEO signal canceller to improve the degradation due to the interference from the high-power LEO signal as same as a NOMA (Non-Orthogonal Multiple Access) canceller in terrestrial 5G mobile systems. On the other hand, in LEO receivers, conventional cancellers cannot be applied. Therefore, we propose a new multi-stage canceller that cancels low-power GEO signal in addition to the high-power LEO signal cancelation at the LEO receiver. In this paper, we clarify the performances of the proposed multi-stage canceller to expand the applicable ranges and increase frequency utilization efficiencies of both the GEO/LEO systems in against adjacent channel interference environments by computer simulations.**

Keywords*— *Beyond 5G/6G, NTN, satellite communication, GEO, LEO, interference canceller

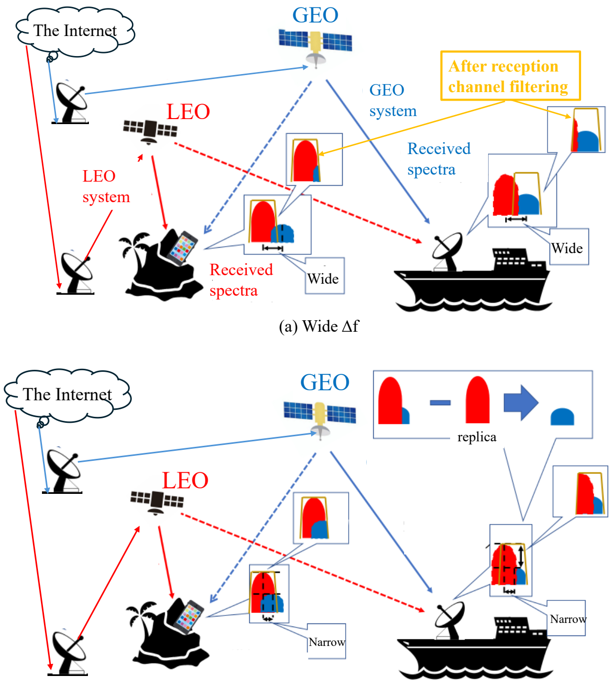
I. Introduction

In recent years, NTNs (Non-terrestrial networks) have been considered for super coverage expansion, aiming to expand communication ranges to all places including air, sea, and space for Beyond 5G/6G [1]. NTNs consist of GEO (Geostationary Orbit), LEO (Low Earth Orbit), HAPS (High Altitude Platform Station) function and UAV (Unmanned Aerial Vehicle), defined in 3GPP (3rd Generation Partnership Project) [2]. By using NTNs, it is expected that mountainous areas, remote areas, sea, sky and outer space, which cannot be covered by terrestrial networks, will be made into communication areas. In this research, we focus on satellite communications, ones of the NTN elements. They have excellent wide area coverages. There are examples of practical applications such as ESV (Earth Station on board Vessels) [3] for a GEO systems and SpaceX for a LEO system which uses a satellite constellation [4],[5]. Currently, GEO/LEO systems are assigned different frequency bands, respectively. However, considering the current situation where frequency bands are depleted, it is predicted that the future GEO/LEO systems would have to use the same frequency bands. In that case, depending on the frequency band assignments of both signals, it would lead adjacent channel interference environments. When the center frequency offset of the GEO and the LEO signals might be wide, both signals can be directly demodulated from the received signal by reception channel filters. However, if the center frequency offset might be narrow, interference compensation techniques are required for each. The LEO signal reception power is relatively larger than that of the GEO signal due to the height difference in the satellite orbits, so the GEO receiver uses a high-power LEO signal canceller to improve the degradation due to the interference from the high-power LEO signals. This technique is as same as a NOMA (Non-Orthogonal Multiple Access) canceller in terrestrial 5G mobile systems [6],[7]. On the other hand, in the LEO receivers, conventional interference cancellers cannot be applied. Therefore, a new interference canceller technology must be required to be used on the LEO receiver. In addition, since the high-power LEO signal received power fluctuates as the LEO satellite moves, the received power differences between GEO/LEO systems change in the both receivers. It is also necessary to consider this situation.

In this paper, we propose a new multi-stage canceller that cancels the low-power GEO signal in addition to the high-power LEO signal cancelation at LEO receivers. The BER (Bit Error Rate) performances both of the GEO and LEO signals are obtained, and we quantitatively evaluate the applicable ranges and the frequency utilization efficiencies of both the GEO/LEO systems using the proposed multi-stage canceller under adjacent channel interference environments through computer simulations.

II. ASSUMED SYSTEM AND ITS PROBLEMS

Fig.1 shows the images of the assumed satellite systems. In this figure, as the adjacent channel interference parameters, the center frequency offset between the GEO and LEO signals is defined as Δf, and the received power ratio of the high-power



(a) Wide Δf

(b) Narrow Δf

Fig.1 Images of the assumed satellite system.

LEO signal to the low-power GEO signal is defined as HS/LS. Due to the difference of the satellite orbits between LEO and GEO, the received LEO signal power might be relatively larger than the received GEO signal power. Therefore, HS/LS becomes larger than 0dB. When Δf is wide as shown in Fig.1(a), the influence of the interfering high-power LEO signal is reduced by applying a reception channel filter in the GEO receiver, so the low-power GEO signal can be directly demodulated. Similarly, in the LEO receiver, by applying a reception channel filter, the influence of interfering the low-power GEO signals can be reduced, and the high-power LEO signals can be directly demodulated. On the other hand, if Δf is narrow as shown in Fig.1(b), the overlapped bandwidth between the high-power LEO signal and the low-power GEO signal becomes wide, so interference cannot be ignored even by using reception channel filters. Therefore, interference compensation technologies must be needed. In the GEO receiver, by applying a high-power LEO signal canceller, the high-power LEO signal can be canceled and the desired low-power GEO signal can be extracted. This technique is as same as a NOMA (Non-Orthogonal Multiple Access) canceller in terrestrial 5G mobile systems [6],[7]. On the other hand, in the LEO system, when Δf is narrow, the interference from the low-power GEO signal cannot be ignored even by using a received channel filter. However, interference from the low-power GEO signals has not been considered until now. Therefore, a new canceller is required in the LEO receivers. Moreover, depending on the LEO satellite position, the high-power LEO signal's received power decreases and interference from the low-power GEO signal may not be ignored. In this paper, we propose a new multi-stage canceller that cancels the low-power GEO signals in addition to the high-power LEO signal cancelation at the LEO receivers.

III. PROPOSED CANCELLER

Fig.2 shows the block diagram of the proposed multi-stage canceller. The multi-stage canceller operates at the LEO receiver according next three steps.

Step A: The received signal is directly demodulated and a high-power LEO signal is regenerated. In this case, regenerated LEO signal includes error bits due to the interference from the low-power GEO signal disappointedly. Although high-power LEO signal replica is generated by re-modulating the detected LEO signal, this replica of high-power LEO signal also includes error bits. It is subtracted from the received signal but there is the residual interference of high-power LEO signal after cancelling it.

Step B: The signal canceled high-power LEO signal with the residual interference is demodulated, and the low-power GEO signal is regenerated. Of course, the GEO signal has error bits, too. A low-power GEO signal replica with error bits is generated by re-modulating the detected GEO signal, and this replica is subtracted from the received signal. Similarly, there is the residual interference of low-power GEO signal after cancelling low-power GEO signal.

Step C: The signal canceled low-power GEO signal with the residual interference from the low-power GEO signal is demodulated and the high-power LEO signal is regenerated.

Here, the high-power LEO signal canceller in Step A is the same method as the high-power LEO signal canceller used on the GEO receiver. However, the high-power LEO signal replica contains error bits, so the high-power LEO signal cannot be completely canceled in Step A. It is expected that the interference power of the high-power LEO signals will be reduced. In Step B, the low-power GEO signal replica contains error bits due to the residual interference from the high-power LEO signal, so the low-power GEO signal cannot be completely canceled in Step B. But it is expected to improve the degradation due to the interference from the low-power GEO signal.

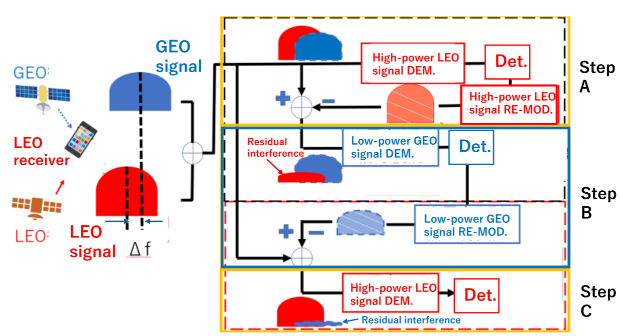


Fig.2 Block diagram of the proposed multi-stage canceller.

IV. Simulation Model

Fig.3 shows the simulation block diagram of the proposed multi-stage canceller. Table 1 shows the major simulation parameters. The modulation method is single-carrier QPSK for both low-power GEO signal and high-power LEO signal. The root roll-off filter uses a raised cosine characteristic with a roll-off factor α=0.2. The FEC (Forward Error Correction) is Convolutional coding and 3-bit soft-decision Viterbi decoding with coding rate r=1/2 and constraint length K=7. The required bandwidth is 10MHz. These parameters are selected according to the popular satellite systems in current operation. Δf is set to be from 0 to 10MHz, and HS/LS is set to be from 0 to 10dB. The high-power LEO signal canceller is used for the GEO receiver, and the proposed multi-stage canceller is used for the LEO receiver. Moreover, assuming the GEO and LEO systems are independent operations, the computer simulations are performed in asynchronous conditions between the high-power LEO signal and low-power GEO signal.

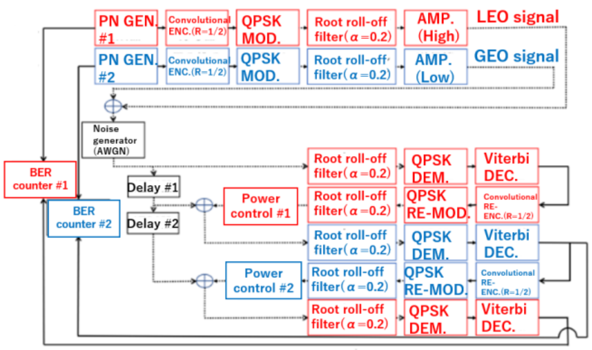


Fig.3 Simulation block diagram of the proposed multi-stage canceller.

Table 1 Major simulation parameters

Parameter	GEO signal	LEO signal
Modulation	Single carrier QPSK	
Root roll-off filter	129 tap FIR filter(band pass) Raised cosine characteristics (α=0.2)	
FEC	Convolutional coding-Viterbi decoding (R=1/2, K=7, 3bits soft-decision)	
Bandwidth	10MHz	
Δf	0~10MHz	
HS/LS	0~10dB	
Interference canceller	High-power LEO signal canceller	Multi-stage canceller
HPA	Linear	
Propagation path	Free space path loss model	

V. Simulation Results

A. Performances of the low-power GEO signal

SNR (Signal to Noise power Ratio) of the low-power GEO signal at the GEO receiver is defined as SNR_{GEO}. Fig.4 shows the averaged power spectra before/after canceling the high-power LEO signal. This is an example of the adjacent channel interference conditions of Δf =7MHz, HS/LS =2dB and SNR_{GEO} =3dB. Although the spectra in this figure are drawn in noise-free condition, when generating a high-power LEO signal replica, it is performed under the condition of SNR_{GEO} =3dB. From Fig.4, the high-power LEO signal canceler reduces the high-power LEO signal power by approximately 14dB.

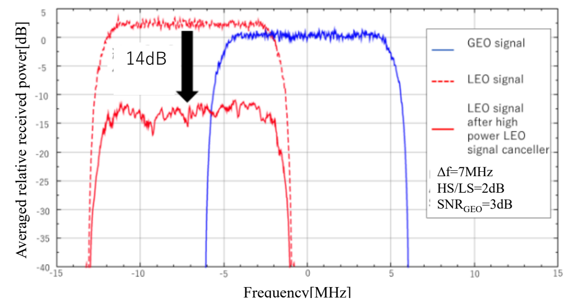
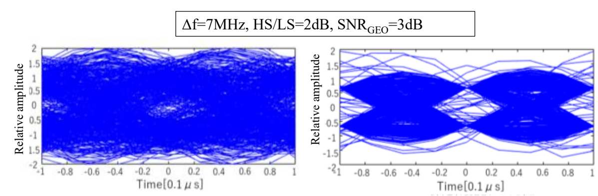


Fig.4 Averaged power spectra before/after canceling the high-power LEO signal.

Next, Fig.5 shows eye patterns of the low-power GEO signal with/without high-power LEO signal cancel. The adjacent channel interference conditions are Δf =7MHz, HS/LS=2dB and SNR_{GEO} =3dB. From Fig.5, the eye pattern without the high-power LEO signal canceller is significant degraded. On the other hand, the eye pattern with the high-power LEO signal canceller is improved. Although it contains residual interference, the eye is opened and the transmission quality is improved.



(a) Without LEO signal canceller (b) With LEO signal canceller

Fig.5 Eye patterns of the low-power GEO signal with/without LEO signal canceller.

Fig.6 shows the time waveform of the low-power GEO signal after the high-power LEO signal canceller. The adjacent channel interference conditions are Δf =7MHz, HS/LS=2dB SNR_{GEO} =3dB. The amplitude values are plotted symbol by symbol. The corresponding symbol error of the high-power LEO signal replica are also shown in this figure. The relative amplitude is normalized by the amplitude of the decision point without interference. The relative amplitude value of 1 is shown as a dashed line. As shown in Fig.6, it can be seen that there are parts where the amplitude values are larger than the dashed line. Furthermore, from the symbol errors of the high-power LEO signal replica, it is found that there is a correlation between the symbol error in the high-power LEO signal replica and the GEO signal time waveform after LEO signal cancellation. The part where the amplitude values are significantly different from the dashed line corresponds the residual interference of the eye pattern in Fig.5(b).

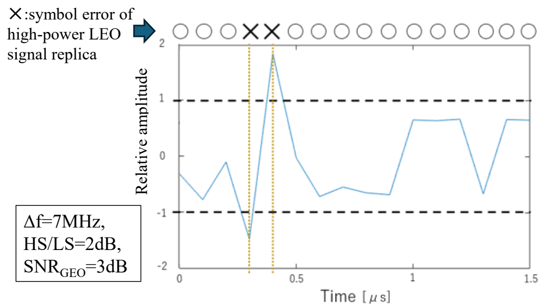


Fig.6 Time waveform of the low-power GEO signal after LEO signal cancelation.

Fig.7 shows BER_{GEO} (BER of the low-power GEO signal) performances with Δf as a parameter. HS/LS is set to 2dB. The high-power LEO signal canceller improves the BER_{GEO} performances for all SNR_{GEO}s. It is also seen that as Δf increases, the influences of adjacent channel interference are reduced, so the BER_{GEO} performances by a high-power LEO signal canceler can be improved. As an example, when Δf = 4MHz, the required SNR_{GEO} at the BER_{GEO} $=10^{-3}$ is 5.6dB by using a high-power LEO signal canceller. But when Δf = 8MHz, the required SNR_{GEO} is reduced to 3.2dB. Additionally, compared to the case without adjacent channel interference, the required SNR_{GEO} degradation is only 0.2dB.

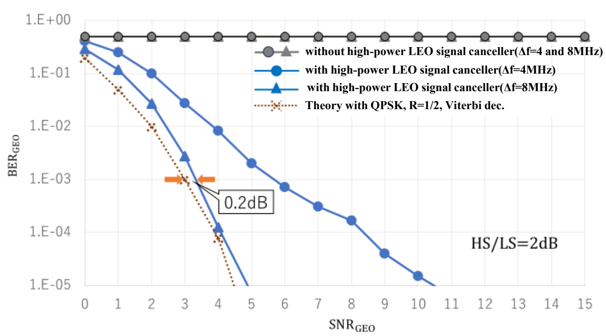


Fig.7 BER_{GEO} performances of the low-power GEO signal.

B. Performances of the high-power LEO signal

The SNR of the high-power LEO signal is defined as SNR_{LEO}. Fig.8 shows the averaged power spectra before/after the proposed multi-stage canceller. This is an example of the adjacent channel interference conditions of Δf =7MHz HS/LS=2dB and SNR_{LEO} =5dB. Although the spectra in this figure are drawn in noise-free condition, when generating a high-power GEO signal replica, it was performed under the condition of SNR_{LEO} =5dB. From Fig.8, it can be seen that the interference caused by the low-power GEO signal is reduced by about 16dB by the proposed multi-stage canceller.

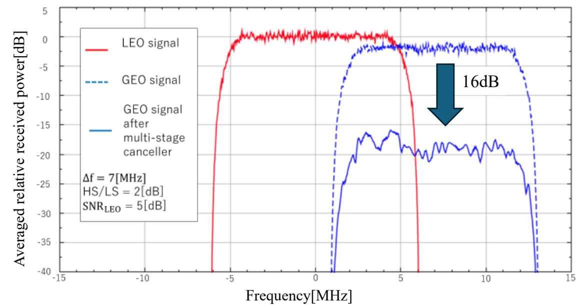


Fig.8 Averaged power spectra before/after canceling the low-power GEO signal.

Fig.9 shows the eye patterns of the high-power LEO signal using the proposed canceller. Adjacent channel interference conditions are Δf =7MHz, HS/LS =2dB and SNR_{LEO} = 5dB. Comparing the eye patterns with and without the proposed canceller, the transmission quality of the high-power LEO signal is improved by the proposed canceller. The residual interference after canceling the low-power GEO signal is almost similar to the reason when canceling the high-power LEO signal described in Fig.6.

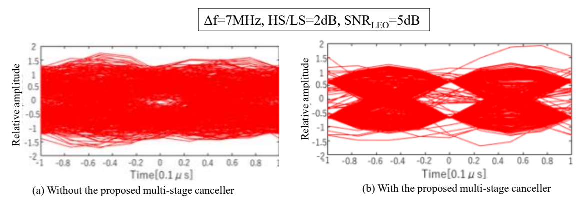


Fig.9 Eye patterns of the high-power LEO signal with/without the proposed multi-stage canceller.

Next, Fig.10 shows the BER_{LEO} (BER of the high-power LEO signal) performances with Δf as a parameter. HS/LS is set to 5dB. From Fig.10, it can be seen that as Δf increases, the degradations due to the adjacent channel interference are improved. As an example, when Δf =4MHz, the required SNR_{LEO} at the BER_{LEO} $=10^{-3}$ is 7.5dB by using the proposed canceller. But when Δf =8MHz, the required SNR_{LEO} can be reduced to 3.8dB. It is also seen that the proposed canceller improves the transmission quality compared to the case without the proposed canceller. As an example, when Δf =8MHz, the required SNR_{LEO} is improved by 0.5dB compared with and without the proposed canceller.

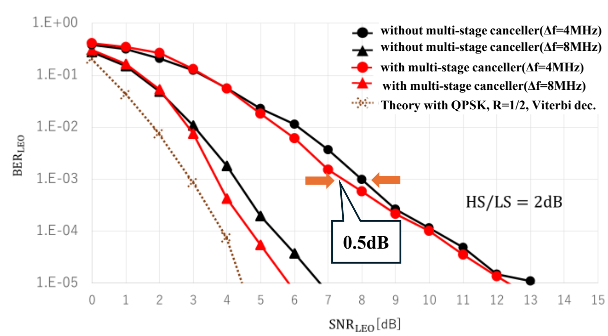


Fig.10 BER_{LEO} performances of the high-power LEO signal.

C. Applicable range in adjacent channel interference environments

Next, we clarify the influence of Δf for the both BER performances of the low-power GEO signal and high-power LEO signal. Fig.11 shows the relationship between Δf and the required SNR_{GEO}. HS/LS is set to 2dB. From this figure, it can be seen that by using a high-power LEO signal canceller, the required SNR_{GEO} becomes equivalent to the case where there is no adjacent channel interference at Δf =10MHz. Moreover, if the required SNR_{GEO} degradation is allowed to be 1dB from the no adjacent channel interference of 3dB, it can be seen that the applicable range of the GEO system is $\Delta f \geqq$ 6MHz when HS/LS =2dB.

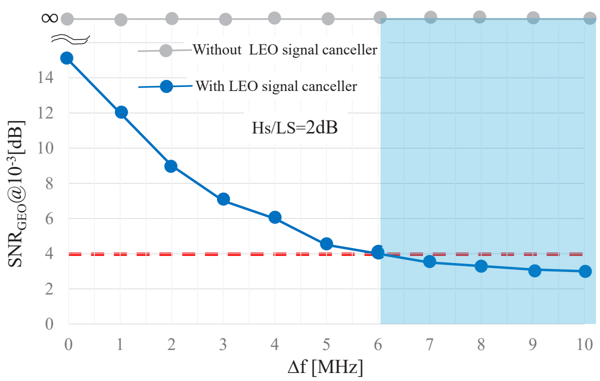


Fig.11 Relationship between Δf and the required SNR_{GEO}.

Next, Fig.12 shows the relationship between Δf and the required SNR_{LEO}. HS/LS is set to 2dB. From Fig.12, it can be seen that by using the proposed canceller, the required SNR_{LEO} is equivalent to no adjacent channel interference at Δf = 10MHz. As in the evaluation of the low-power GEO signal, if we allow 1dB degradation in the required SNR_{LEO} from no adjacent channel interference of 3dB, the applicable range of the LEO system without the proposed canceller is $\Delta f \geqq$ 8.5MHz. On the other hand, with the proposed canceller, the applicable range expands to $\Delta f \geqq$ 7.5MHz

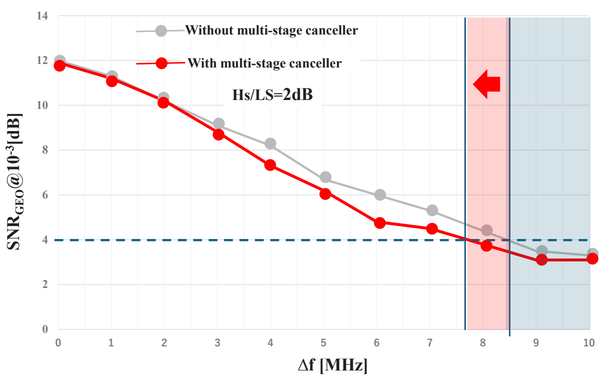


Fig.12 Relationship between Δf and the required SNR_{LEO}.

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Fig.13 shows the relationship between Δf and limits of HS/LS according to the applicable ranges of both the GEO/LEO systems. Comparing with and without the proposed canceller when the allowable required SNR degradation of 1dB from the required SNR =3dB at the BER=10^{-3} when there is no adjacent channel interference, the applicable range can be expanded by the proposed canceller. It can be seen that Δf = 9 to 8MHz and HS/LS = 4 to 0dB, which are indicated by blue area in this figure. Therefore, the proposed canceller has the effect of expanding the applicable range of both the GEO/LEO systems.

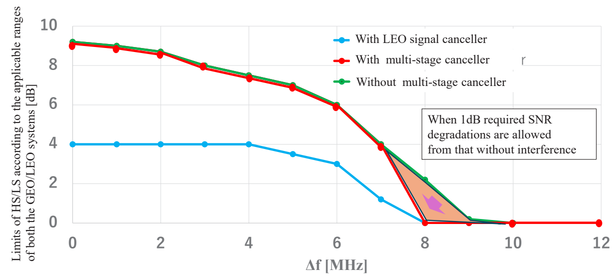

Fig.13 Relationship between Δf and limits of HS/LS.

D. Total frequency utilization efficiency

Finally, we evaluate the total frequency utilization efficiency of the GEO/LEO system. Fig.14 shows the relationship between Δf and the total frequency utilization efficiency when HS/LS =2dB, SNR_{GEO} = 4dB and SNR_{LEO} = 6dB. The total frequency utilization efficiency is defined by Equation (1).

$$Total\ frequency\ utilization\ efficiency = \frac{T_{GEO} + T_{LEO}}{B_{all}} \quad (1)$$

Here, T_{GEO} is the GEO signal throughput, T_{LEO} is the LEO signal throughput and B_{all} is the total required bandwidth of the LEO signal and GEO signal. B_{all} can be calculated by Equation (2).

$$B_{all} = \frac{B_{GEO}}{2} + \Delta f + \frac{B_{LEO}}{2}$$
$$(0\text{MHz} \leq \Delta f \leq 10\text{MHz}) \quad (2)$$

Here, B_{GEO} is the required bandwidth of the GEO signal and B_{LEO} is the required bandwidth of the LEO signal. From Fig.14, for an example at Δf =7MHz, the proposed multi-stage canceler can increase the total frequency utilization efficiency by 0.11bit/sec/Hz compared to that without the multi-stage canceller. This frequency utilization efficiency improvement is equivalent to 1.1Mbps gain with 10Msymbol/sec of the popular satellite systems.

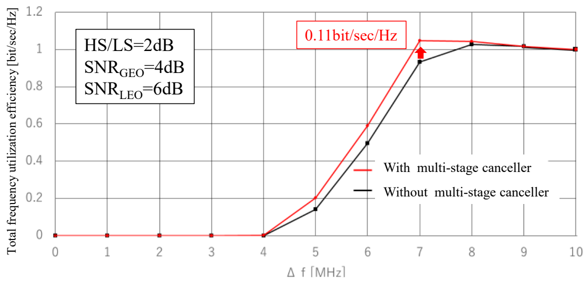

Fig.14 Total frequency utilization efficiency.

VI. CONCLUSION

Assuming GEO and LEO systems will use the same frequency bands in the future NTNs, a new multi-stage canceller has been proposed. The proposed multi-stage canceller cancels the low-power GEO signals in addition to the high-power LEO signal canceller at LEO receivers. Quantitative evaluation by simulation of the effect of expanding the applicable range of LEO/GEO systems by the proposed canceller under adjacent channel interference conditions. As a result, if we allow 1dB from the theoretical value of the required SNR at the BER=10^{-3}, adjacent channel environments are expanded of Δf=9 to 8MHz and HS/LS=4 to 0dB and. Moreover, the proposed multi-stage canceller can increase frequency utilization efficiency by 0.11[bit/sec/Hz] compared to that without the multi-stage canceller. Therefore, it has been shown that the proposed multi-stage canceller has the effect of expanding the applicable range and increased total frequency utilization efficiency of the both GEO/LEO systems.

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