A Protection Ratio with Composite Fade Margin for Detailed Frequency Coordination in Microwave Relay System Network

Kyoung-Whoan Suh

Abstract

In this paper, the formulation of the protection ratio based upon a composite fade margin and availability is newly presented for the detailed planning of frequency coordination in the microwave relay system network, and computed results for co-channel and adjacent channel protection ratios are illustrated over an actual system with 6.2 GHz. It is shown that the protection ratio to assure a quality of service can be expressed in terms of the composite fade margin, noise-to-interference ratio, net filter discrimination, and system parameters. In addition, the net filter discrimination, depending upon the transmitter spectrum mask and the overall receiver filter characteristic, has been examined to investigate the effect of the adjacent channel protection ratio caused by the adjacent channel interference.

Regarding simulated results for 6.2 GHz, 60 km, 64-QAM, and N/I=6 dB at the bit error rate of 10^{-6}, composite fade margin and co-channel protection ratio yield 25.14 and 50.3 dB, respectively. Also, the net filter discrimination of 26.5 dB and the adjacent channel protection ratio of 23.8 dB are obtained at the first adjacent channel of 30 MHz. The proposed method provides some merits in view of a comprehensive and practical application with more detailed and various system parameters needed to access the criteria for making the proper frequency coordination.

Key words : Microwave Relay System, Composite Fade Margin, Protection Ratio, Frequency Coordination, Net Filter Discrimination.

Ⅰ. Introduction

Due to limited spectrum resources as well as the trend of convergence between communication and broadcasting, microwave relay systems have been greatly issued in view of how to make better spectral efficiency under the frequency sharing. They are widely used for a long-haul transmission of digital signals in the frequency range of 3.9 to 11.0 GHz. According to the nationwide deployment of the optical fiber network and the fast growing of mobile communication services, the frequency bands below 6 GHz used for microwave relay systems, with relatively low spectrum utility in Korea, are supposed to be assigned for upcoming wireless service applications. From the reason of less economic efficiency in those bands, the remaining frequency bands above 6 GHz have been recommended for microwave transmission. So, to perform this basic plan related with frequency movement and channel reallocation, the analysis of co-existence between microwave relay systems is pre-requisite to make the proper frequency coordination from unwanted signals[1].

In general, as a basic method of the frequency coordination in the wireless network, some criteria based upon the concept of a protection ratio have been adopted with a generic interference management methodology. The protection ratio defines a minimum relative power ratio of wanted to unwanted signals in the victim receiver. In general, the co-channel and adjacent channel interferences are considered as unwanted signals[2]. The adjacent channel protection ratio associated with the adjacent channel interference includes the net filter discrimination(NFD) as well as variables relevant to the co-channel protection ratio. The NFD depends upon the transmitter spectrum mask and the overall receiver filter characteristic[3]. As a consequence, to make the proper frequency coordination, the resultant protection ratio should be larger than the ratio of carrier to interference powers at the input of the victim receiver.

Two main results relevant to the protection from interference in the fixed wireless network were studied to define a maximum allowable interference limit or a predictable protection ratio based upon a fade margin. The former, performed by NSMA(National Spectrum Managers Association), ETSI(European Telecommunications Standard Institute), and RA(Radiocommunications Agency), has illustrated practical applications based upon system parameters such as effective isotropic radiation power,

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Department of Electronics Engineering, Kangnam University, Yongin, Korea.

noise figure, occupied channel bandwidth, transmission capacity, and signal degradation due to interference[3]~[5]. The latter, accomplished by ACA(Australian Communications Authority), has shown the initial frequency coordination method based upon the protection ratio with the fade margin and interference limit[6].

Recently, to generalize and compensate the limited previous results, an efficient and comprehensive derivation of the protection ratio has been introduced[7],[8] for the initial planning of frequency coordination in the microwave relay system network. Also, the formulation of the protection ratio for a diversity system is presented to investigate how the diversity improvement factor has an effect on the protection ratio for a given availability [9]. Moreover, the criteria of error performance and availability degradation objectives from interference from emission/radiation of other sources have been studying under a co-primary basis including the diversity system[10].

However, regarding applications of the protection ratio, if the power ratio of wanted to unwanted signals in the potential victim receiver is less than the protection ratio obtained by the previous methods, the detailed analysis of the protection ratio should be subsequently done to check whether it possibly meets a criterion or not. In order to perform this, the detailed formulation of the protection ratio with various system parameters including availability is required for further evaluation. Generally, the transmission quality of microwave relay systems mainly depends upon channel status, system noise, and interference. For the given link, it is noted that major factors affecting the quality of service consist of a flat fade margin(FFM), dispersive fade margin (DFM), and interference fade margin(IFM). To correlate those fade margins with availability, a composite fade margin(CFM) was introduced[11], and by using this concept the availability prediction could be made for the proposed microwave link design[12].

In this paper, the formulation of the protection ratio based upon the composite fade margin and availability is proposed for the detailed planning of the frequency coordination in microwave relay system networks, and simulated results for the co-channel protection ratio are performed over an actual 6.2 GHz microwave relay system. Also, to show the effect of the adjacent channel protection ratio caused by the adjacent channel interference, the net filter discrimination depending upon the transmitter spectrum mask and the overall receiver filter characteristic are examined and calculated here.

Ⅱ. Formulation of Protection Ratio

2-1 Composite Fade Margin

For the given microwave link, the total outage time T_{out} during severe fading occurrence months is expressed by[13],[14]

$$T_{out}= T_N+ T_D \tag{1}$$

where T_N is the outage time caused by thermal noise and interference in case of no distortion in the spectrum, and T_D means the outage time caused by the dispersive spectrum with multipath fading without noise. So, as can be seen, some of outage time depends on signal power fading, and others mainly relay on the signal distortion.

The parameter T_N is given by

$$T_N= rL_f^2T_0 \tag{2}$$

where r is a multi-path occurrence factor related to carrier frequency, path length, and terrain type, which is given by

$$r= c\frac{f}{4}d^3 10^{-5} \tag{3}$$

where c is a climate-terrain factor with 0.25, 1, and 4 for mountains and dry climate, average terrain, over-water and gulf coast, respectively. f is frequency in GHz, and d is path length in miles.

L_f^2 is a specific limiting value of frequency fading caused by the sum of thermal noise and interference at a given bit error ratio(BER), and it is expressed as

$$L_f^2= \frac{S/N_i}{S/I}+\frac{S/N_i}{S/N} \tag{4}$$

where S/N_i is the power ratio of input signal to noise including interference at the given BER, which is a function of modulation scheme, noise, and interference. Variables S, I, and N are the average power of signal, interference, and noise at the input of receiver, respectively.

The inverse of the second term of Eq. (4) means the flat fade margin without interference, which is given by

$$L_f^2(I=0) = 10^{-FFM/10} \tag{5}$$

In addition, if the interference is taken into consideration, Eq. (5) can be written by

$$L_F^2(I\neq 0) = 10^{-FFM/10}+10^{-(C/I-S/N_i)/10} \tag{6}$$

And T_0 is expressed as[11],[13]

$$T_0= \frac{t}{50}\times 8\times 10^6 \tag{7}$$

where t is average annual temperature in degrees Fahrenheit. T_0 is a length of fade season in second, especially for the fading occurrence period of 3 months.

On the other hand, like Eq. (2) the outage time T_D caused by the dispersive spectrum is also given by

$$T_D = r10^{-DFM/10}T_0 \quad (8)$$

where DFM means a dispersive fade margin.

In consequence, the total outage time can be written by

$$T_{out} = r10^{-CFM/10}T_0 \quad (9)$$

where CFM is the composite fade margin.

Therefore, the required composite fade margin to assure the transmission quality is given by

$$CFM = 10\log_{10}(r) - 10\log_{10}(T_{out}/T_0) \quad (10)$$

where T_{out}/T_0 means an unavailability for the given microwave link.

2-2 Protection Ratio

To attain the transmission quality of the pre-defined objectives, let's consider the formulation of the protection ratio with the minimum power ratio of carrier to interference. Combining Eqs. (2), (6), (8) and (9) with (1), then required C/I can be expressed by[15]

$$(C/I)_{rqd} = PR = S/N_i - 10\log_{10}(10^{-CFM/10} - 10^{-FFM/10} - 10^{-DFM/10}) \quad (11)$$

where FFM is a relative difference value between nominal and threshold received signals in the absence of interference, and DFM is a fade margin for the dispersive spectrum caused by multi-path fading, depending upon the tap number of the equalizer and its structure. Consequently, C/I asking for the proper frequency coordination can be readily obtained from system parameters and a geoclimatic factor from Eq. (11).

FFM in dB is given by

$$FFM = P_t + G_t + G_r - L_{fr} - L_{others} - p_{revr(10^{-n})} \quad (12)$$

where P_t is a signal power at the output of the transmitter, G_t and G_r are transmitting and receiving antenna gains in the azimuth of the transmitter and the receiver, respectively. L_{fr} is free space loss, L_{others} complies the total losses resulting from feeder, branching, and stacking associated with transmitter and receiver, and $Prevr(10^{-n})$ is a receiver sensitivity at BER 10^{-n}, which is given by

$$P_{revr(10^{-n})} = 174\ dBm + 10\log(BW) + NF + S/N_0 \quad (13)$$

where BW denotes a IF bandwidth in Hz, NF is noise figure in dB, and S/N_0 means the power ratio of signal to noise in dB at BER 10^{-n}.

DFM is given as[12],[16]

$$DFM = 17.6 - 10\log(S_w/158.4) \quad (14)$$

and

$$S_w = \int_{-39.6}^{+39.6}[e^{-B_n(f)/3.8} + e^{-B_m(f)/3.8}]df \quad (15)$$

where B_n and B_m are notch depth values of the signature curve in conjunction with minimum phase and non-minimum phase fades, respectively.

For the adjacent channel interference, the protection ratio can be readily written by

$$PR = (S/N_i) - 10\log_{10} \cdot (10^{-CFM/10} - 10^{-FFM/10} - 10^{-DFM/10}) - NFD \quad (16)$$

where NFD is the net filter discrimination related to the transmitter spectrum mask and the overall receiver filter characteristic. NFD is given by[3],[8]

$$NFD = 10\log\left(\frac{P_c}{P_a}\right) = 10\log\left(\frac{\int_0^\infty G(f)|H(f)|^2 df}{\int_0^\infty G(f-\triangle f)|H(f)|^2 df}\right) \quad (17)$$

where P_c is the total power received after co-channel RF, IF, and base band filtering, and P_a is the total power received after offset RF, IF, and base band filtering. The functions of $G(f)$ and $H(f)$ are the transmitter spectrum mask and the overall receiver filter response, respectively, and $\triangle f$ denotes the frequency separation between the desired and the interference signals.

2-3 Frequency Coordination

The power ratio of wanted to unwanted signals at the input of the potential victim receiver can be expressed by

$$C/I = P_{wntd} - P_{unwntd} \quad (18)$$

The block diagram for calculating the protection ratio can be summarized as shown in Fig. 1. To achieve the successful frequency coordination, Eq. (18) should be compared with the protection ratio obtained by Eq. (16). The power ratio of wanted to unwanted signals should be greater than the protection ratio, which is given by

$$C/I \geq PR \quad (19)$$

From the protection ratio derived above, an overview of the basic procedure for the frequency coordination can be summarized like Fig. 2. In step 8, if the protection ratio is less than the power ratio of wanted to unwanted signals, then do following step 9 and others. Otherwise, stop here because the frequency coordination for spectrum sharing is successfully done.

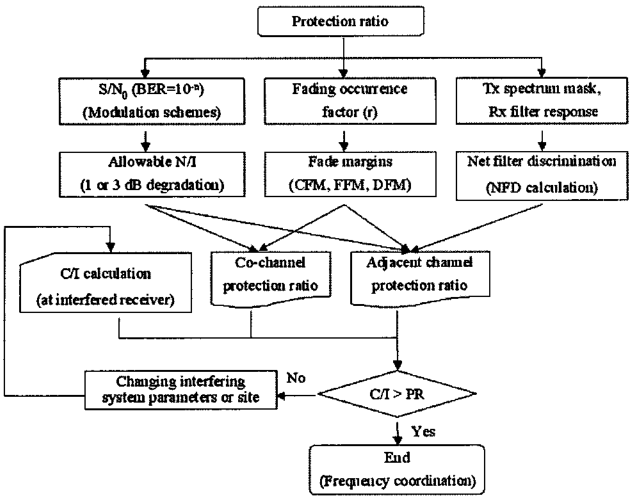

Fig. 1. The block diagram for calculating the protection ratio.

Ⅲ. Simulated Results and Discussion

3-1 System Parameters

Prior to calculation of the protection ratio, for instance, the parameters of microwave system for high capacity transmission in the lower 6 GHz band are taken as shown in Table 1. Since S/N_0 means the ratio of signal to noise powers in the absence of the interference, depends upon the modulation and coding scheme for the given BER, the document of Rec. ITU-R F.1101 is referred for M-ary QAM at BER of 10^{-6}[17]. The total transmission capacity is about 161.5 Mbps, consisting of STM-1(155.520 Mbps) signal and redundancy bits of 3.85 % related to a forward error correction(FEC). N/I is the ratio of noise to interference powers such as 10, 6 or 3 dB, which results in 0.5, 1

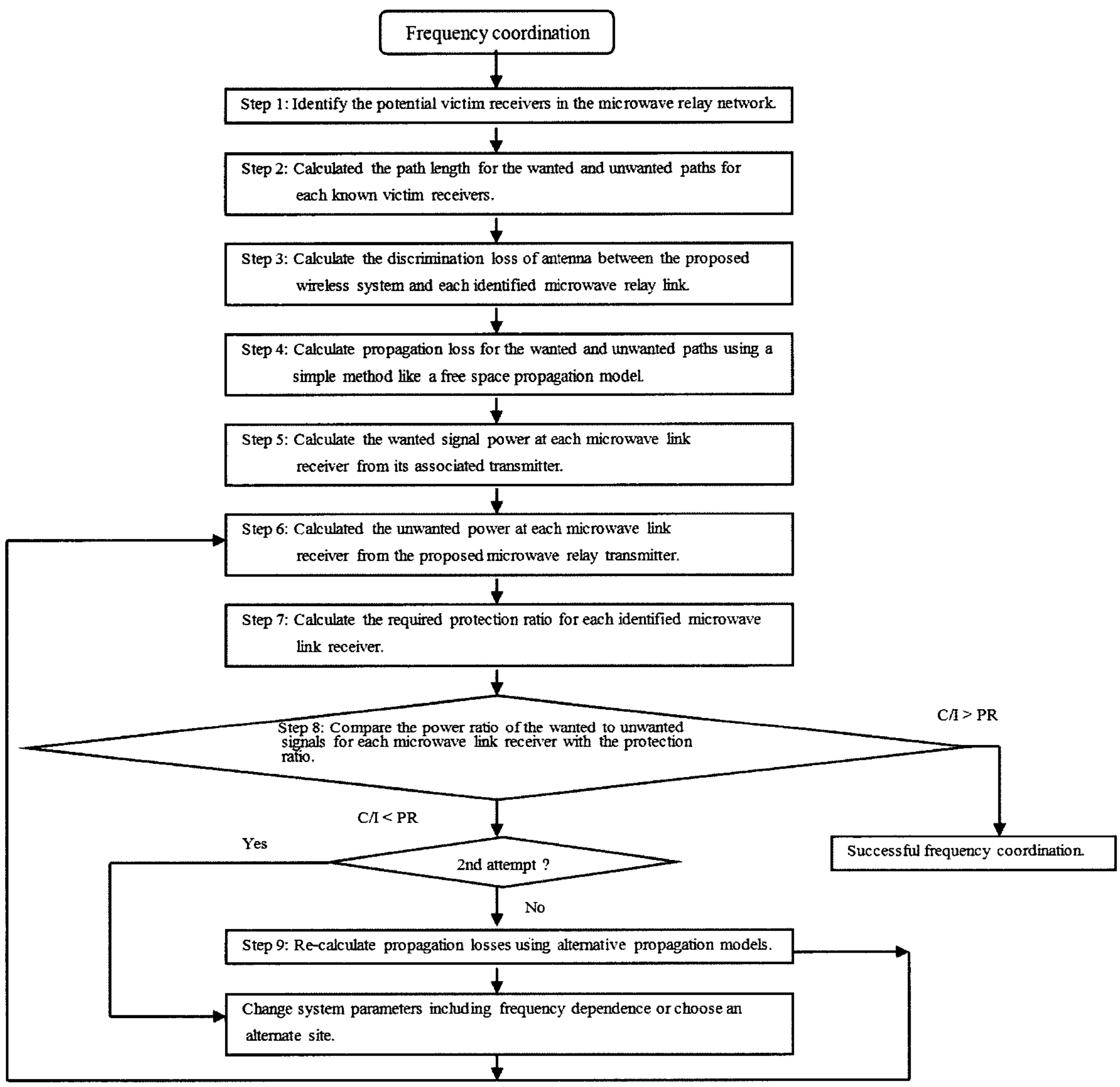

Fig. 2. An overview of basic method for frequency coordination.

Table 1. Parameter and its value needed for simulation.

Frequency	6.2 GHz
Transmitter power	1 Watt (0 dB or 30 dBm)
Other losses	2 dB (including Tx /Rx feeding losses)
Noise figure	2.0 dB
Tx/Rx Antenna gain	40 dBi (for each)
Transmission capacity	161.5 Mbps=(155.520+5.98) Mbps (FEC redundancy bits: 3.85 % of STM-1)
Occupied bandwidth	35 MHz @ 64-QAM 30 MHz @ 128-QAM 26.24 MHz @ 256-QAM
S/N_0	23.8 dB @ 10^{-6} BER, 64-QAM 26.7 dB @ 10^{-6} BER, 128-QAM 29.8 dB @ 10^{-6} BER, 256-QAM
S/N_0	24.8 dB @ N/I=6.0 dB, 10^{-6} BER
Availability	99.99 % @ 10^{-6} BER
Geoclimatic factor	c=4.0 (link over coast)
Flat fade margin (FFM)	36.9 dB @ 60 km, 64-QAM
Dispersive fade margin (DFM)	48 dB @ 9-tap linear equalizer

or 2 dB degradation in the receiver threshold level caused by the interference, respectively. So, 64-QAM and N/I of 6 dB are taken for the interfered system.

The calculation of FFM gives 36.9 dB based upon Eq. (12) by using Table 1, where the receiver threshold level is -72.76 dBm at BER. As for DFM in Table 1, microwave relay system usually employs the time domain equalizer to counteract the frequency selective fading. The equalizer is classified into a linear or nonlinear type with the tap number of 9 to 11. About 48 dB is used for DFM in Table 1 for the case of 9-tap linear equalizer.

On the other hand, in order to obtain the adjacent channel protection ratio it is necessary to calculate the net filter discrimination in advance. The transmitter spectrum mask with 30 MHz channel bandwidth shown in Fig. 3 is taken from ETSI, which is required for transmitting STM-1(155.520 Mbps) signal in conjunction with 64-QAM[18]. The receiver spectrum mask noted by $|H(f)|^2$ is the square of the overall receiver filter response, which is also taken as the same one as Fig. 3 for the sake of convenience. The resultant NFD in Fig. 4 provides about 26.5 dB at the first adjacent channel of 30 MHz for the integration interval from -30 to +30 MHz.

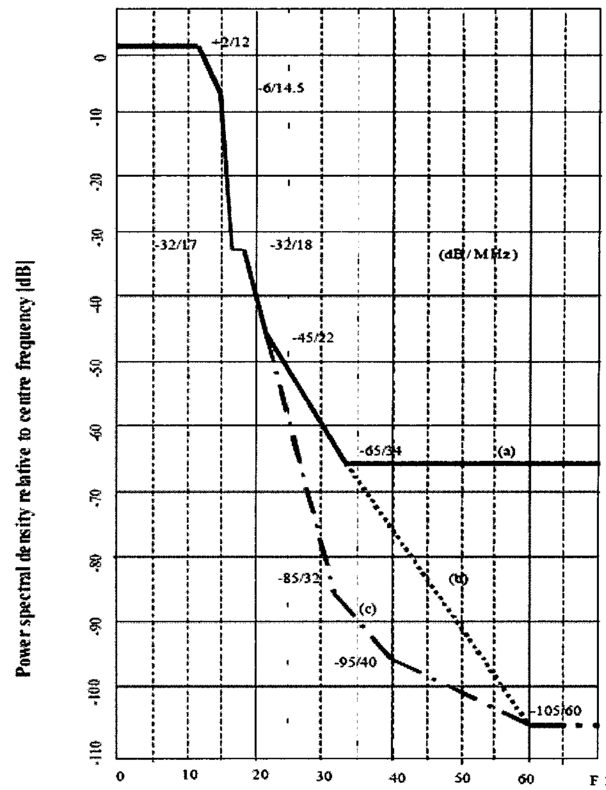

Fig. 3. Transmitter spectrum mask with 29.65 MHz channel bandwidth from Doc. ETSI EN 301 127.

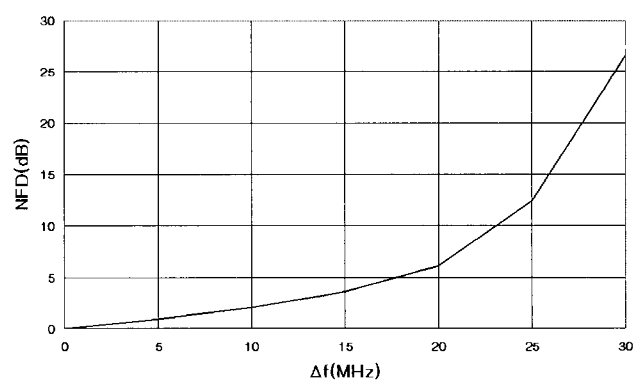

Fig. 4. Calculated values of net filter discrimination as a function of offset frequency.

3-2 Protection Ratio

Fig. 5 shows the composite fade margin based upon Table 1 as a function of frequency and distance. For 6.2 GHz, 60 km, and unavailability of 0.01 %, CFM yields 25.14 dB, and it is noted that CFM also gets more as frequency increases. For other percentage of unavailability such as 0.001 %, CFM can be easily obtained by

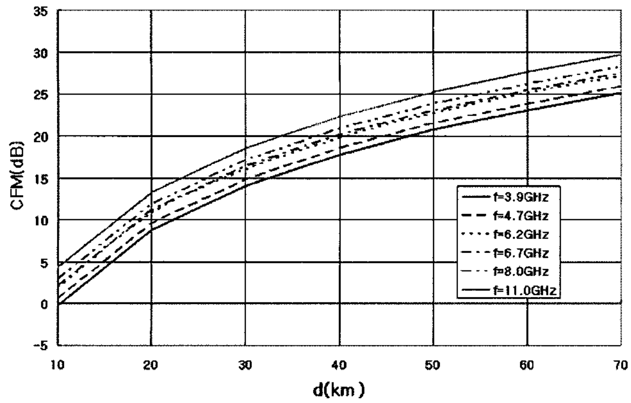

Fig. 5. Simulated results of composite fade margin.

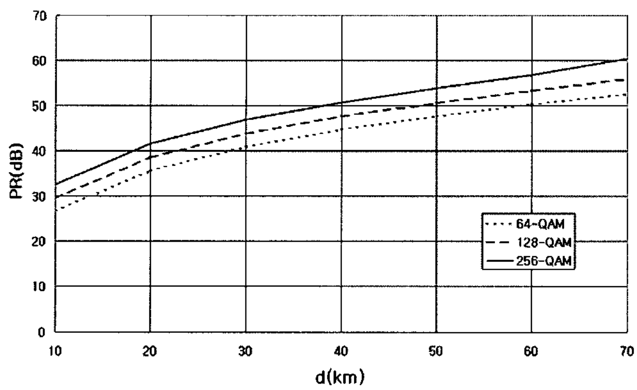

Fig. 6. Simulated results of protection ratios for *M*-ary QAM and 6.2 GHz.

adding 10 dB to each result in Fig. 5.

In order to find the protection ratio under the conditions of Fig. 5, the protection ratio for the co-channel interference is shown in Fig. 6 as a function of distance and M-ary QAM. It illustrates the protection ratio of 50.3 dB for 60 km and 64-QAM. The physical meaning of this value is that *C/I* of the victim receiver in the existing network should have more than 50.3 dB to attain the frequency sharing with respect to the proposed microwave relay system. Due to different values of signal to noise ratio, the protection ratio becomes larger as higher modulation is adopted.

Fig. 7 shows the protection ratio for the different geoclimatic factor and gives about 44.0 dB for average terrain(c=1) at 60 km and 6.2 GHz, which is about 6.1 dB greater than that for mountains and dry region(c= 0.25).

Finally, let's consider how to find the adjacent channel protection ratio from the net filter discrimination and the co-channel protection ratio. Since NFD is about 26.5 dB at the first adjacent channel of 30 MHz from Fig. 4, the adjacent channel protection ratio can be

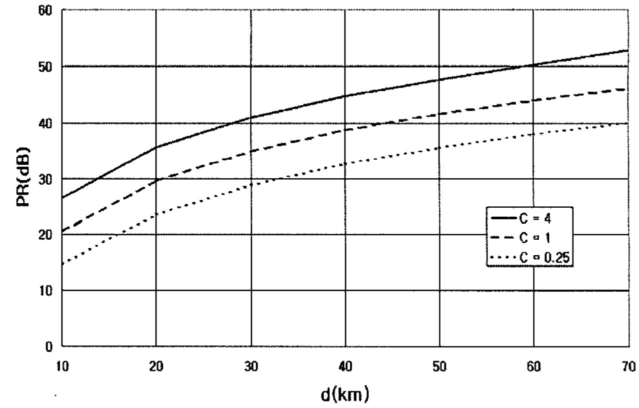

Fig. 7. Simulated results of protection ratio for different geoclimatic factors.

Table 2. Simulated protection ratios for co-channel and adjacent channel.

Parameters	Co-channel	Adjacent channel @ 30 MHz
NFD (dB)	0	26.5
PR (dB)	50.3	23.8

obtained by subtracting NFD from the co-channel protection ratio of 50.7 dB as shown in Table 2.

Ⅳ. Conclusion

In this paper, the formulation of the protection ratio based upon the composite fade margin and availability was proposed for the detailed planning of frequency coordination applicable to the microwave relay system network, and simulated results for co-channel and adjacent channel protection ratios were illustrated over the actual system in the lower 6 GHz band. It was shown that the protection ratio needed for attaining the frequency sharing can be expressed by the composite fade margin, noise-to-interference ratio, net filter discrimination, and system parameters. In addition, the net filter discrimination, depending upon the transmitter spectrum mask and the overall receiver filter characteristic, was examined to see the effect of the adjacent channel protection ratio caused by the adjacent channel interference.

Regarding simulated results for 6.2 GHz, 60 km, 64-QAM, and N/I=6 dB at BER of 10^{-6}, composite fade margin and co-channel protection ratio yielded 25.14 and 50.3 dB, respectively. Also, the net filter discrimination of 26.5 dB and the adjacent channel protection ratio of 23.8 dB were obtained at the first adjacent channel of 30 MHz. The proposed method provides some advantages in computing the protection ratio by considering more detailed and various system parameters, which can be directly applied to checking the frequency sharing for co-existence.

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Kyoung-Whoan Suh

received the B.S. degree in electronics engineering from Kyungpook National University, Korea, in 1983, and the M.S. and Ph.D. degrees in electrical and electronics engineering from Korea Advanced Institute of Science and Technology in 1988 and 1991, respectively. From 1985 ~1991, his main research areas include microwave engineering, antenna and propagation, and he per-formed several projects relevant to microwave remote sensing: radar system design and its signal processing, non-destructive testing for target identification and its imaging. During 1983-1998 he worked at Samsung Electronics Co. as a principal engineer and was in charge of developing wireless network products such as microwave radio relay system and broadband wireless local loop system. Since 1999 he is a professor of electronics engineering of Kangnam University, and his research areas are the system design of point-to-point and point-to-multipoint applications up to a millimeter-wave band including multi-level modem, time and frequency domain equalizers, and frequency coordination of wireless networks.