A Derivation of Comprehensive Protection Ratio and Its Applications for Microwave Relay System Networks

Kyoung-Whoan Suh

Abstract

This paper suggests an efficient and comprehensive algorithm of the protection ratio derivation and illustrates some calculated results applicable to the initial planning of frequency coordination in the fixed wireless access networks. The net filter discrimination associated with Tx spectrum mask and overall Rx filter characteristic has been also examined to show the effect of the adjacent channel interference. The calculations for co-channel and adjacent channel protection ratios are performed for the current microwave frequency band of 6.7 GHz including Tx spectrum mask and Rx filter response. According to results, fade margin and co-channel protection ratio reveal 41.4 and 75.2 dB, respectively, for 64-QAM and 60 km at BER 10^{-6}. It is shown that the net filter discrimination with 40 MHz channel bandwidth provides 28.9 dB at the first adjacent channel, which yields 46.3 dB of adjacent channel protection ratio. In addition, the protection ratio of 38 GHz radio relay system is also reviewed for millimeter wave band applications. The proposed method gives some advantages of an easy and systematic extension for protection ratio calculation and is also applied to frequency coordination in fixed millimeter wave networks.

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

Ⅰ. Introduction

In order to get spectrum resources needed for upcoming wireless businesses such as a system beyond IMT-2000, next generation broadcasting, u-sense network, telematics, and public safety and disaster relief, the Ministry of Information and Communication in Korea has been studying a plan for frequency movement and its rearrangement below 6 GHz, especially for some radio relay frequency bands. Those bands have been mainly used for a long-haul high capacity transmission of voice, video, and data information. However, demand for those applications is rapidly decreasing during the last decade due to the optical transmission system and its nationwide deployment. Hence, in advance to make proper frequency coordination for new service systems in conjunction with existing wireless networks such as radio relay, cellular, satellite, and radar, the protection criteria for interference analysis must be performed to meet good quality of service recommended by ITU-R.

As a basic method of frequency coordination in the wireless network, a criteria based upon the concept of a protection ratio has 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 receiving system. In general, two types of interference such as co-channel and adjacent channel are considered[1]. The co-channel protection ratio is expressed as a function of S/N of modulation scheme, interference-to-noise ratio, multiple interference allowance, fade margin of multi-path or rain attenuation[2]~[4]. On the other hand, the variables of the adjacent channel protection ratio include the net filter discrimination(NFD) as well as ones of co-channel protection ratio. NFD is entirely depending upon the transmitting spectrum mask and the overall receiving filter responses.

Since the mid-1990's, two main works relevant to protection in the fixed wireless network have been studying in view of defining a minimum interference limit and a predictable protection ratio based upon a fade margin[5],[6]. The former, worked by FCC, ETSI, and RA, has illustrated practical applications based upon system parameters such as EIRP, noise figure, occupied channel bandwidth, transmission capacity, signal degradation caused by interference. The latter, conducted by ACA, has shown the initial frequency coordination method based upon the protection ratio by using the fade margin including interference limit with a fixed S/N, and however S/N of modulation was not taken into consideration as a variable even if it actually varies from modulation schemes.

In this paper, in order to provide a comprehensive solution for protection ratio calculation, we suggest an

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Dept. of Electronics Engineering, Kangnam University, Youngin, Kyounggi, Korea.

efficient and systematic derivation of protection ratio needed for initial planning of frequency coordination. Moreover, the net filter discrimination associated with Tx spectrum mask and overall Rx filter characteristic has been examined to obtain the adjacent channel protection ratio. To show calculation procedure and practical application, some computations for co-channel and adjacent channel protection ratios are performed in the actual radio relay frequency band of 6.7 GHz including Tx spectrum mask and Rx filter responses, and several results are illustrated here as a guidance of initial planning of frequency coordination for the digital radio relay networks.

Ⅱ. Dispersive and Flat Fade Margins

Two main factors that cause the wanted signal to fade are multi-path clear air fading and flat fading due to rainfall. First, let's consider the dispersive fade margin caused by multi-path fading in the radio relay link as shown in Fig. 1[7]. It is well known that multi-path fading in the atmosphere is more frequent at night and in the first morning hours and it is seldom felt at mid-day or during periods of intense rain.

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$$P(p \le p_0) = Kd^{3.6} f^{0.89} (1 + |\varepsilon_p|)^{-1.4} \times \frac{p_0}{p_n} \times 10^{-2} \tag{1}$$

where p_n is a received power at no fading, and $|\varepsilon_p| = \frac{1}{d}|h_r - h_t|$ is the absolute value of the path inclination in milliradians where d is path length in km, and h_t and h_r are altitude of the transmitter and receiver antennas in meters, respectively. The geoclimatic factor K for the average worst month from p_L based upon empirical relation ship of ITU-R Rec. p.530-10 is shown as Table 1.

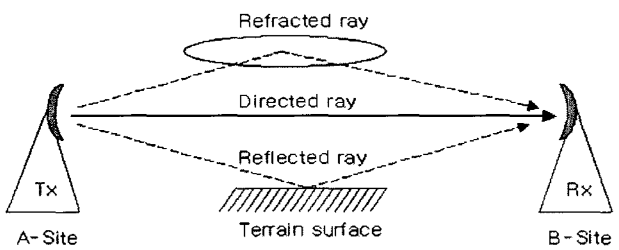

Fig. 1. Concept of frequency selective fading caused by multi-path.

Table 1. Geoclimatic factor.

$K=10^{-6.5}\ p_L^{1.5}$	Overland links for which the lower of the transmitting and receiving antennas is less than 700 m above mean sea level;
$K=10^{-7.1}\ p_L^{1.5}$	Overland links for which the lower of the transmitting and receiving antennas is higher than 700 m above mean sea level;
$K=10^{-5.9}\ p_L^{1.5}$	Links over medium-sized bodies of water, coastal areas beside such bodies of water, or regions of many lake; and
$K=10^{-5.5}\ p_L^{1.5}$	Links over large bodies of water, or coastal areas beside such bodies of water.

The p_L means the percentage of time that the average refractivity gradient in the lowest 100 m of the atmosphere is less than -100N in units/km, N is called the refractivity of the atmosphere and its contour maps are provided ITU-R Rec. p.453-9. According to its document, the p_L of Korea has 10 for the worst month of August[10].

To obtain a guarantee for transmission quality with a predefined percentage of time for unavailability for a given link, the required fade margin due to multi-path fading is equal to fade depth exceeded for the percentage of time (p_w) in the average worst month. So, Eq. (1) may be expressed by

$$FM = 10\log_{10}(Kd^{3.6} f^{0.89}(1 + |\varepsilon_p|)^{-1.4}) - 10\log_{10}(p_w) \tag{2}$$

The ratio of signal-to-noise(S/N) varies from modulation and error correction schemes, and therefore S/N for M-ary QAM at BER 10^{-6} uses ITU-R F.1101 as a reference data.

Second, let's examine the flat fade margin due to rainfall. The specific attenuation due to rain based upon ITU-R Rec. p.838 is given by[11]

$$r_R = kR^{\alpha} \text{ (dB/km)} \tag{3}$$

where R is rainfall intensity in mm/hr, and k and α denote frequency dependent coefficients.

For any given path the attenuation due to rain is calculated for an effective path length, which account for the distribution of the rain intensity rate. The attenuation $A_{0.01}$ due to rain, exceeded for 0.01 % of the worst month is

$$A_{0.01} = r_R \times \frac{d}{1 + \frac{d}{d_0}} \text{ (dB)} \tag{4}$$

where d is an actual path length in km, and d_0 is given by

$$d_0 = 35e^{-0.015R_{0.01}}, \text{ for } R_{0.01} \leq 100 \text{ mm/hr} \quad (5)$$

However, the value 100 mm/hr for $R_{0.01}$ in Eq. (5) is used for $R_{0.01} > 100$ mm/hr. The attenuation due to rain exceeded for other percentage of time p % (0.001~1) of the worst month is

$$A_p = A_{0.01} \times 0.12 \times p^{-(0.546+0.043\log_{10}p)} \quad (6)$$

Eq. (6) is valid for radio links located in latitudes equal to or greater than 30 degrees (North or South).

Ⅲ. Protection Ratio and Net Filter Discrimination

A typical case of a potential interference scenario for one direction of transmission with a single frequency is depicted in Fig. 2. Assuming that link AB means an existing service and link CD is a proposed new service, the potential interference paths of AD and CB marked by dotted lines with the corresponding transmit and receive antenna discrimination angles (θ and θ') relative to the respective antenna bore-sight azimuth are also presented. Then, the received wanted or unwanted signal power can be expressed as

$$P_r = P_t + G_t + G_r + L_t + L_r + L_f \quad (7)$$

where P_r is RF signal power at the input of the receiver (dBm), P_t is RF signal power at the output of the transmitter (dBm), G_t means the gain of the transmitting antenna in the azimuth of the receiver (dBi), G_r means the gain of the receiving antenna in the azimuth of the transmitter (dBi), L_t is feeder and branching losses associated with the transmitter (dB), L_r is feeder and branching losses associated with the receiver (dB), and L_f denotes the total transmission loss between the transmitter and receiver antennas (dB).

For instance, let's consider link AB-sites in Fig. 2. The power ratio of wanted-to-unwanted signal at the input of a potential victim receiver of B-site can be expressed by

$$C/I = P_{wntd} - P_{unwntd} \text{ (dB)} \quad (8)$$

In consequence, in order to make successful frequency coordination, Eq. (8) is compared with the relevant protection ratio(PR), defined by a minimum relative power ratio of wanted and unwanted (interference) signals at the input of the victim receiver. Therefore, the power ratio of wanted-to-unwanted signal should be greater than the protection ratio, which is given by

$$C/I \geq PR \quad (9)$$

The protection ratio is given by[12],[13]

$$PR = S/N(BER10^{-y}) + N/I + MIA + FM - NFD \quad (10)$$

where *S/N* is dependent of modulation scheme at a given BER of 10^{-y}, *N/I* means noise-to-interference ratio such as 10, 6 or 3 dB which brings about 0.5, 1 or 2 dB degradation in signal level due to interference, respectively. An *MIA* is multiple interference allowance related with multiple interference source, which usually permits 4.0 dB, *FM* is the fade margin of dispersive or flat fade fading, and *NFD* is a net filter discrimination depending upon Tx spectrum mask and overall Rx filter characteristics. In order to understand parameters related with Eq. (10), the pictorial concept of protection ratio is characterized in Fig. 3, and I_t means a maximum allowable interference power referenced to noise power of interfered receiver system, which may include a single or multiple interference sources.

It is common practice in co-existence studies between transmitters and receivers of different symbol rate and modulation formats to use the concept of Net Filter Discrimination(NFD) and its definition is given by[3]

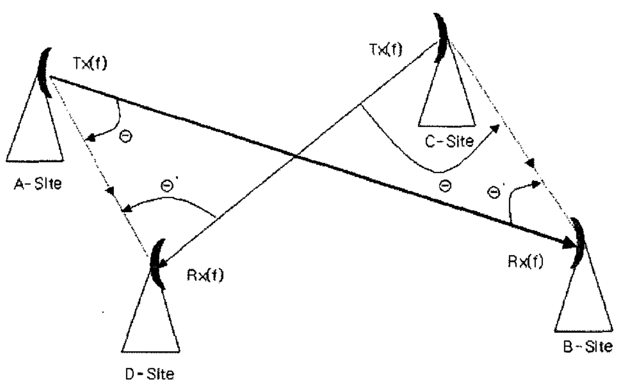

Fig. 2. Wanted signal (AB and CD sites) and interference paths (AD and CB sites).

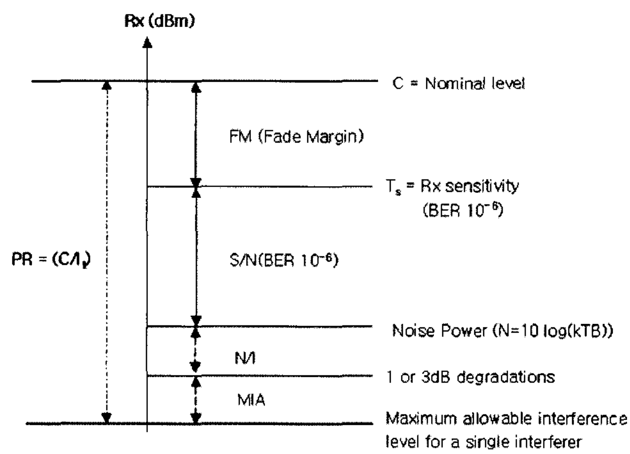

Fig. 3. Pictorial concept for protection ratio.

$$NFD = 10\log\left(\frac{P_c}{P_a}\right) \tag{11}$$

$$P_c = \int_{-BW/2}^{BW/2} G(f)|H(f)|^2 df \tag{12}$$

$$P_a = \int_{-BW/2}^{BW/2} G(f-\triangle f)|h(f)|^2 df \tag{13}$$

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 Tx spectrum mask and overall Rx filter responses, respectively, and $\triangle f$ denotes the frequency separation between a desired signal and an interference signal. As pointed out in ITU-R Rec. F.746, this value is produced purely by Tx spectrum and by the overall Rx filtering, and it does not comprise any other decoupling such as antenna discrimination or the actual interfering power level.

As a consequence, the calculation for protection ratio mentioned above can be summarized as seen in Fig. 4, and it also describes that in order to make proper frequency coordination, the resultant protection ratio should be compared with *C/I* obtained in the input of victim receiver.

Ⅳ. Simulated Results and Discussion

Prior to protection ratio calculation, let's consider parameters involved in Eq. (10) for radio relay frequency band of 6.7 GHz. So, N/I=6 dB, MIA=4.0 dB, p_L=10, p_w =0.01 %, ε_p=0 are chosen, and S/N is referred from ITU-R F.1101, for instance, which gives S/N=23.8 dB for 64-QAM at BER 10^{-6}[14]. The value of N/I of 6.0 dB equals to 1.0 dB degradation in received signal due to interference. In addition, to find out net filter discrimination for a given system, the overall receiver

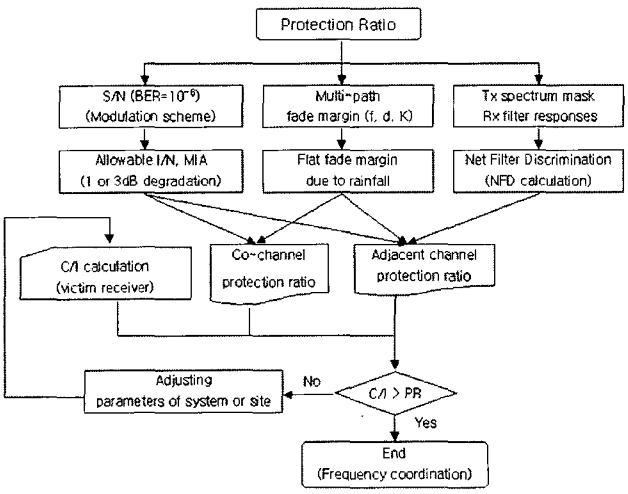

Fig. 4. Algorithm for protection ratio calculation.

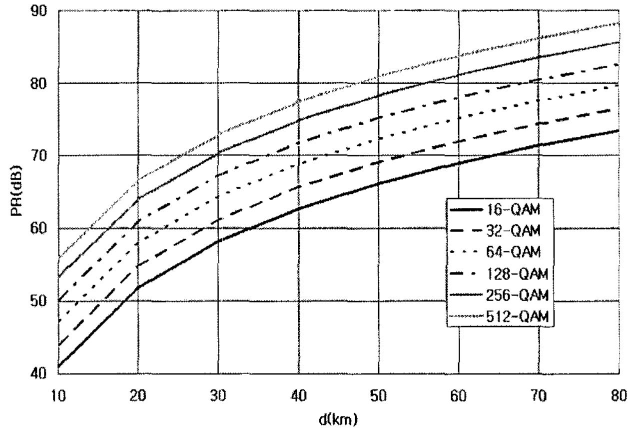

Fig. 5. Co-channel protection ratio at 6.7 GHz.

selectivity, given by the resultant response of RF, IF, and base band filtering, is required. However in the absence of related data, it is assumed to have the same as Tx spectrum mask for the sake of convenience here.

Fig. 5 shows the protection ratio for co-channel interference as a function of distance and M-ary QAM, and it illustrates protection ratio of 75.2 dB for 64-QAM and 60 km. The physical meaning of this value is that *C/I* at the victim receiver in the existing network should have more than 75.2 dB to assure co-existence for a new radio relay link design.

Next, to find adjacent channel protection ratio, let's examine net filter discrimination in advance. According to channel allocation of radio relay link in Korea, 40 MHz per channel is assigned for high capacity transmission only except 6.2 GHz band. The Tx spectrum mask used for calculating net filter discrimination is the response of c) in Fig. 6[15], and the receiver spectrum mask noted by $|H(f)|^2 = R_{ci}$ (dB) is the square of the overall receiver filter response, which is also taken as the same transmitter spectrum mask with a view to showing the calculation procedure for convenience. The calculated NFD for frequency offset $\triangle f$ is illustrated in Fig. 7 and gives 4.2 and 28.9 dB at offset frequency 20 and 40 MHz, respectively. Since NFD at $\triangle f$=40 MHz in Fig. 7 is 28.9 dB, adjacent channel protection ratio at the first adjacent channel 40 MHz can be easily obtained as 46.3 dB, subtracting NFD of 28.9 dB from co-channel protection ratio of 75.2 dB. From those data, it is possible to summarize the resultant protection ratios corresponding to co-channel and adjacent channel as seen in Table 2. Hence, if one applies the same procedure to the rest of QAM or other modulation schemes, a variety of protection ratio are easily produced by only adding or subtracting S/N difference of 64-QAM.

In order to see the effect of protection ratio due to

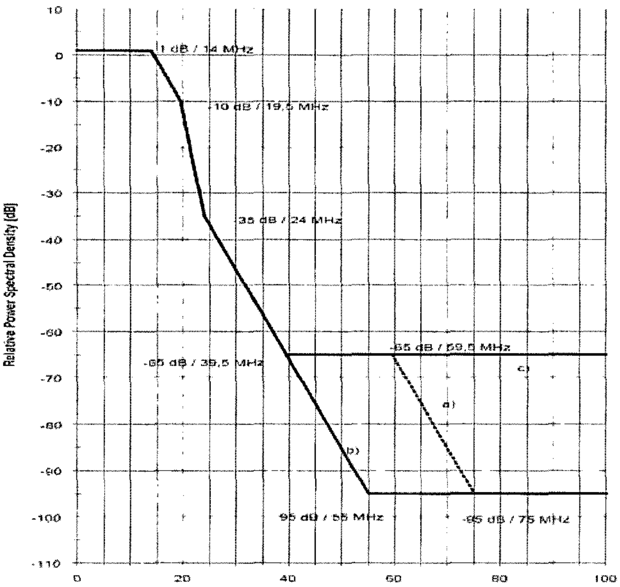

Fig. 6. Tx spectrum mask with 40 MHz channel.

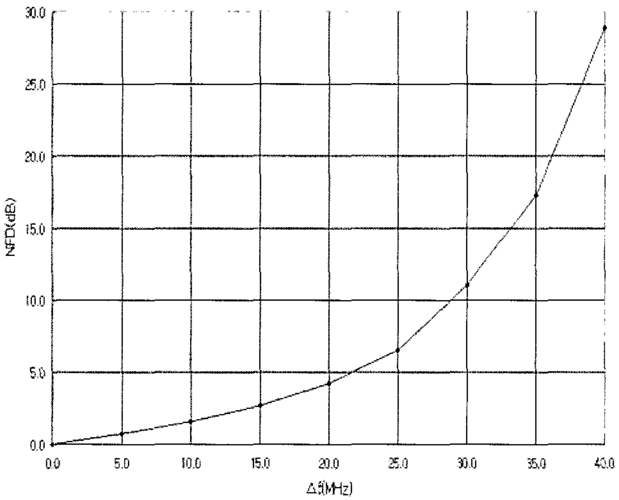

Fig. 7. NFD with channel bandwidth of 40 MHz.

rainfall, Fig. 8 illustrates co-channel protection ratio caused by rainfall as well as multi-path fade at 11 GHz under the same conditions in Fig. 5, where rain intensities of 40, 60, and 80 mm/hr are taken to be 0.01 percentage of time in the worst month. Protection ratio due to multi-path fading gives 66.2 dB for 30 km and 64-QAM, which is larger than that due to any rain intensity. If one considers protection ratio due to rain with 80 mm/hr, it leads to about 58.0 dB reduced by 8.2 dB from protection ratio caused by multi-path fading. It is known that multi-path fading in the atmosphere and flat fading due to intense rain does not occur simultaneously. So, from two results above, it implies that a link designer should make much account of the pro-

Table 2. Adjacent and co-channel protection ratios.

Frequency offset (MHz)	Protection ratio (dB)	Other parameters
0 (co-channel)	75.2	*f*: 6.7 GHz, 64-QAM, *d*: 60 km, p_L: 10
40 (1st adjacent channel)	46.3	

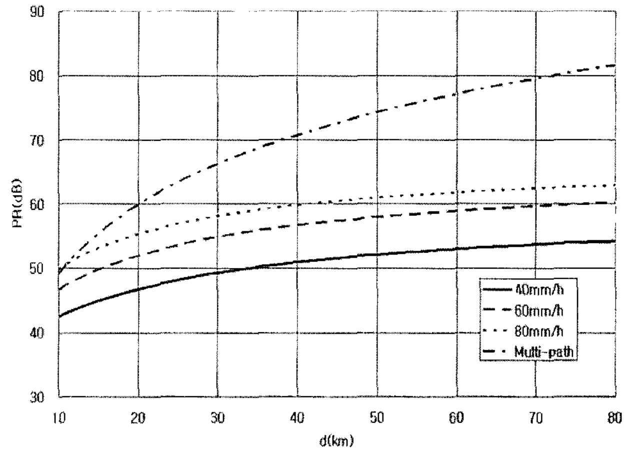

Fig. 8. Co-channel protection ratio at 11 GHz.

tection ratio caused by multi-path fading because fade margin of rain is still less than that of multi-path fading. However, if frequency increases up to millimeter wave, rain attenuation is rapidly increasing and the effect of multi-path fading is negligibly small in comparison to rain fading because of short distance transmission.

In addition, to examine the required fade margin due to multi-path or rainfall for assuring an availability in percentage of time, Fig. 9 depicts a sort of correction factor of protection ratio with 4 curves corresponding to one multi-path and 3 rain intensities, respectively, at 11 GHz. As the multi-path fade margin is dominant, its fade margin of 32.4 dB at 30 km is referenced as 0 dB, and then the others are relatively plotted. If one wants to find protection ratio for a chosen variable of rain intensity, its value can be easily derived by means of Fig. 9 because parameters in Eq. (10) are constant except for fade margin. So, it is worth noting that, for instance, even though the use of correction factor related with fade margin is illustrated, one may apply the same concept to various parameters such as modulation schemes, frequency, geoclimatic factor, *N/I*, percentage of time for unavailability, rain intensity etc. Consequently, this means that an easy and systematic extension of protection ratio calculation could be obtained by adopting correction factors presented here.

Finally, to examine the effect of flat fading only due to rainfall in a millimeter wave band, Fig. 10 shows the

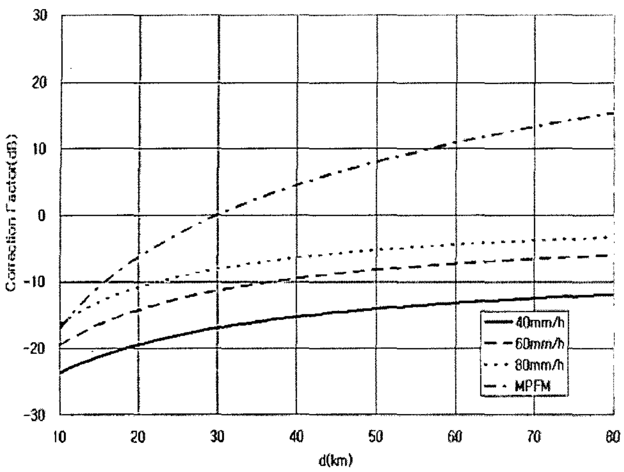

Fig. 9. Protection ratio correction factor at 11 GHz.

co-channel protection ratio for 38 GHz radio system with a simple modulation scheme such as 4-PSK or OOK, where rain intensities of 42, 60, and 80 mm/hr are taken to be 0.01 percentage of time for the worst month, resulting in availability of 99.99 %. That frequency band is greatly used for short distance radio links with low capacity for mobile base stations as well as high speed internet bridge. Since heavy rain attenuation in millimeter wave limits transmitting distance even up to a few km, one may make little account of the fade margin due to multi-path fading. The parameters involved in Fig. 10 are the same as Fig. 5 only except for S/N of 13.5 dB at BER 10^{-6} without coding and *M/A* =0 dB for convenience. It is shown that fade margins for 42, 60, and 80 mm/h are about 29.0, 39.0, and 48.4 dB at 3 km, respectively, and its corresponding protection ratios are 48.5, 58.5, and 67.9 dB. As a consequence, it is interesting to note that only fade margin caused by rain attenuation should be considered for the protection ratio calculation in millimeter wave.

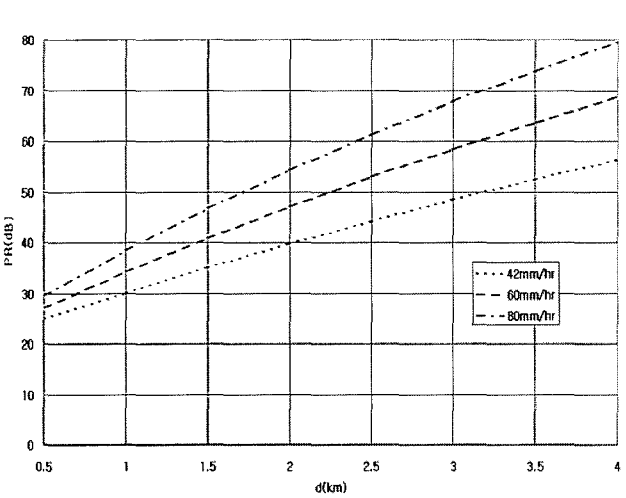

Fig. 10. Co-channel protection ratio at 38 GHz.

Ⅴ. Conclusions

In this paper, the efficient and generalized algorithm for protection ratio calculation has been suggested for the initial planning of frequency coordination for the fixed microwave networks, and some interesting results related with fade margins and protection ratios were shown in view of frequency coordination directly applicable to microwave system network. In addition, net filter discrimination depending upon Tx spectrum mask and overall Rx filter characteristics has been examined to obtain the adjacent channel protection ratio.

According to computed results with regard to 6.7 GHz, 64-QAM, and 60 km at BER 10^{-6}, it was shown that fade margin and co-channel protection ratio reveal 41.4 and 75.2 dB, respectively. For net filter discrimination with respect to 40 MHz channel bandwidth, it provided 28.9 dB at the first adjacent channel. This resulted in 46.3 dB of adjacent channel protection ratio. Moreover, by introducing protection ratio correction factor, it was possible to systematically expand protection ratio calculation with respect to various parameters such as modulation schemes, frequency, geoclimatic factor, *N/I*, percentage of time for unavailability, rain intensity etc. In addition, protection ratios for 11 and 38 GHz radio relay systems were calculated and reviewed to show the effect of fade margin caused by rainfall as frequency increases.

The suggested method leads to some advantages of easy and systematic extension for protection ratio derivation and is also capable of applying the same concept to frequency coordination of the fixed millimeter wave networks.

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Kyoung-Whoan Suh

received the B.S. degree in electronics engineering from Kyung-Pook 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 performed 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(B-WLL/LMDS) 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 planning of wireless networks and its performance evaluation.