Coexistence of OFDM-Based IMT-Advanced and FM Broadcasting Systems

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Coexistence analysis is extremely important in examining the possibility for spectrum sharing between orthogonal frequency-division multiplexing (OFDM)-based international mobile telecommunications (IMT)-Advanced and other wireless services. In this letter, a new closed form method is derived based on power spectral density analysis in order to analyze the coexistence of OFDM-based IMT-Advanced systems and broadcasting frequency modulation (FM) systems. The proposed method evaluates more exact interference power of IMT-Advanced systems in FM broadcasting systems than the advanced minimum coupling loss (A-MCL) method. Numerical results show that the interference power is 1.3 dB and 3 dB less than that obtained using the A-MCL method at cochannel and adjacent channel, respectively. This reduces the minimum separation distance between the two systems, which eventually saves spectrum resources.

Keywords: Sharing analysis, IMT-Advanced systems, power spectral density analysis, FM broadcasting, interference power.

I. Introduction

The 470 MHz to 862 MHz frequency band is currently allocated to broadcasting services. Simultaneously, ITU-R sector Working Party 8F has allocated sub-bands within 470 MHz to 862 MHz for IMT-Advanced service [1]. Orthogonal frequency-division multiplexing (OFDM) is considered the most promising modulation scheme to support upcoming wireless multimedia communications systems, including IMT-Advanced systems [2]. Therefore, this study on the impact of the intersystem interference of OFDM-based IMT-Advanced on broadcasting service is the first consideration for both services.

The basic methods for a sharing analysis of the interference potential between systems, including the minimum coupling loss (MCL) method, have been addressed in [3]. The advanced-MCL (A-MCL) approach of IMT-Advanced with point-to-point fixed services (FS) was derived to solve the limitation of MCL [4], [5]. However, A-MCL approach is not suitable for evaluating interference from IMT-Advanced to analogue frequency modulation (FM) broadcasting service signal because the power spectral density (PSD) shape of FS is rectangular while the PSD shape of analogue FM broadcasting service is triangular [6]. The main goal of this letter is to develop an analytical model that overcomes the limitations of the MCL and A-MCL schemes for evaluating interference coming from OFDM-based IMT-Advanced systems into FM broadcasting service.

II. Coexistence Method

The evaluation of spectrum frequency sharing depends on the concept of maximum allowable interference power at the antenna of an interfered victim receiver. The required minimum attenuation loss (L_m), in dB, of the interfering system on the victim system can be determined from the following equation [4]:

$$L_{\mathrm{m}} = P_{\mathrm{t}} + G_{\mathrm{t}} + G_{\mathrm{r}} + L_{\mathrm{att}} - I_{\max}. \tag{1}$$

Here, P_t is the transmit power of the interfering system in the

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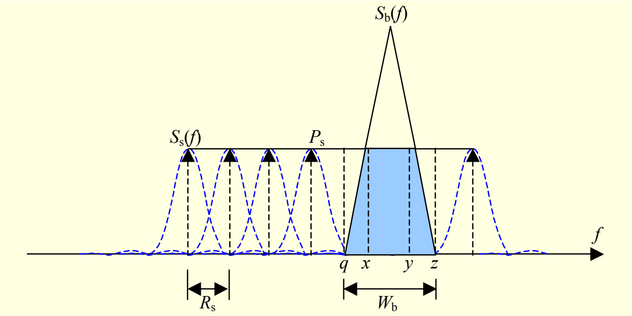

Fig. 1. PSD of OFDM-based interferer $S_s(f)$ overlapping PSD of FM broadcasting $S_b(f)$ (victim) system.

reference bandwidth (BW) in dBW, and G_t and G_r are the interfering transmitter and the victim receiver antenna gains in dBi, respectively. The interfering signal power loss caused by BW overlapping with the victim receiver is represented by L_{att}, and I_{max} is the maximum allowable interference power at the antenna of the victim receiver. From the pathless equation, L_m is converted to a geographical separation, namely minimum separation distance.

The interfering signal power loss L_{att} for the IMT-Advanced interfering system can be derived through a power spectral density analysis of the OFDM signals in this method. The cyclic prefix (CP) of OFDM makes the mainlobe of the power spectrum for each subcarrier narrow. This means that no CP increases out of band emission, which results in higher interference to victim FM. Thus, no CP is the worst case analysis assumed (the highest separation distance), which is more important than best or general case because the worst case guarantees frequency sharing between systems. Assuming an OFDM system having M subcarriers and a rectangular pulse, the PSD of the OFDM signal is represented as

$$S_s(f) = \sum_{i=0}^{M-1} \frac{P_s}{R_s} \mathrm{sinc}^2\left(\frac{f}{R_s} - i\right), \tag{2}$$

where P_s is the power of a single OFDM subcarrier, R_s is the subcarrier spacing, and $\mathrm{sinc}(x)=\sin(\pi x)/\pi x$. The PSD of the analogue FM broadcasting system is triangular and given as

$$S_b(f) = \frac{2P_b}{W_b} \mathrm{tri}\left(\frac{2f}{W_b}\right), \tag{3}$$

where P_b and W_b are the transmit power and BW of broadcasting systems, respectively. Figure 1 shows that the PSD of OFDM-based IMT-Advanced system overlaps the PSD of FM broadcasting systems.

The interfering signal power loss can be expressed by the BW overlapping ratio, which is computed by integrating the composite received PSD over the receiver's BW and dividing by the total power in the original transmitter PSD. Therefore, from Fig. 1, L_{att} is expressed as (4), where $S_s(f)$ is defined in (2). The points, q, x, y, and z in Fig. 1, determine the overlapping area between OFDM's PSD and FM's PSD, and they are respectively given as $f_c-(W_b/2)$, $f_c-(W_b/4)$, $f_c+(W_b/4)$, and $f_c+(W_b/2)$, where f_c represents the center frequency of the victim receiver.

Note that

$$L_{att} = 10\log_{10} \frac{\frac{1}{2}\left[\int_q^x S_s(f)df + \int_y^z S_s(f)df\right] + \int_x^y S_s(f)df}{P_t}. \tag{4}$$

From (2)-(4),

$$\begin{aligned}
&\frac{1}{2}\left[\int_q^x S_s(f)df + \int_y^z S_s(f)df\right] + \int_x^y S_s(f)df \\
&= \frac{1}{2}\left[\sum_{i=0}^{M-1} \frac{P_s}{\pi} \int_{\pi(h_1-i)}^{\pi(h_2-i)} \frac{\sin^2 u}{u^2} du + \sum_{i=0}^{M-1} \frac{P_s}{\pi} \int_{\pi(h_3-i)}^{\pi(h_4-i)} \frac{\sin^2 u}{u^2} du\right] \\
&+ \sum_{i=0}^{M-1} \frac{P_s}{\pi} \int_{\pi(h_2-i)}^{\pi(h_3-i)} \frac{\sin^2 u}{u^2} du,
\end{aligned} \tag{5}$$

where $u=\pi(f/R_s)-i$, $h_1=f_c/R_s-(W_b/2R_s)$, $h_2=f_c/R_s-(W_b/4R_s)$, $h_3=f_c/R_s+(W_b/4R_s)$, and $h_4=f_c/R_s+(W_b/2R_s)$. Then, by using trigonometric functions, $\sin^2(x)=(1-\cos(2x))/2$, the integral in (5) can be evaluated using (6) as

$$\begin{aligned}
\int_a^b \frac{\sin^2 u}{u^2} du &= \frac{1}{2}\int_a^b \frac{1-\cos 2u}{u^2} du \\
&= \frac{1}{2}\left[\frac{1}{a} - \frac{1}{b} - \frac{\cos 2a}{a} + \frac{\cos 2b}{b} + 2\int_a^b \frac{\sin 2u}{u^2} du\right].
\end{aligned} \tag{6}$$

From [7], we get

$$\int_a^b \frac{\sin^2 u}{u^2} du = \sum_{k=1}^{\infty} \frac{(-1)^{k-1}}{(2k-1)(2k-1)!} \times [(2b)^{2k-1} - (2a)^{2k-1}]. \tag{7}$$

Therefore, the interfering signal power attenuation, in dB, is

$$\begin{aligned}
L_{att} = 10\log_{10} \Bigg\{ \sum_{i=0}^{M-1} \frac{P_s}{2\pi P_t} \Bigg[& \frac{1}{A} + \frac{1}{B} - \frac{1}{C} - \frac{1}{D} \\
& - \frac{\cos 2A}{A} - \frac{\cos 2B}{B} + \frac{\cos 2C}{C} + - \frac{\cos 2D}{D} \\
& + \sum_{k=1}^{\infty} \frac{(-1)^{k-1}\left[(2C)^{2k-1} - (2A)^{2k-1} + (2D)^{2k-1} - (2B)^{2k-1}\right]}{(2k-1)\times(2k-1)!} \Bigg] \Bigg\},
\end{aligned} \tag{8}$$

where $A=\pi(h_1-i)$, $B=\pi(h_2-i)$, $C=\pi(h_3-i)$, and $D=\pi(h_4-i)$.

III. Parameters and Assumptions

The acceptable interference power, I_{max}, for analog TV receiver is considered to be –146 dBW/6 MHz [1]. Currently, the specifications for the IMT-Advanced systems are under

Table 1. OFDM-based IMT-Advanced and FM broadcasting coexistence parameters.

Parameter	Symbol	Value
Carrier frequency	f_c	800 MHz
Transmitted power	P_t	0 to 15 dBW
Subcarrier freq. spacing	R_s	10.24 kHz
No. of subcarriers	M	1,024
Subcarrier power	$P_s=(P_t/M)$	$(P_t/1{,}024)$ W
OFDM channel BW	$W_s= R_s \times M$	10.48576 MHz
Victim channel BW	W_b	6 MHz
Transmitter ant. gain	G_t	14.5 dBi
Transmitter ant. height	30 m	
Receiver ant. gain	G_r	12 dBi
Receiver ant. height	10 m	

consideration. We assumed a cellular OFDM/OFDMA of IMT-Advanced system operates at center frequency of 800 MHz and uses TDD duplex. TV utilizes directional antennas, while an IMT-Advanced base station (BS) may employ a sectored antenna [8]. However, antenna patterns are not considered at all except for the maximum antenna gain in link budget, so it is assumed they are considered as omnidirectional to study the worst case scenario. The assumed channel model agreed by CEPT and ITU-R for sharing studies includes free space path loss as well as the height-gain model or clutter loss effects, and in the simulation, it assumes that the communication path suffers clutter loss of 20 dB [9]. Antenna discrimination loss is also considered, and the cases of 20 dB, 30 dB, 50 dB, and 70 dB are taken into account. Because IMT-Advanced is expected to support high data rates, high BW is required. Therefore, Fig. 1 shows that the BW of the IMT-Advanced system (W_s) is assumed to be greater than that of FM broadcasting service (W_b). The other parameters for IMT-Advanced BS and TV services are shown in Table 1.

IV. Numerical Results and Discussion

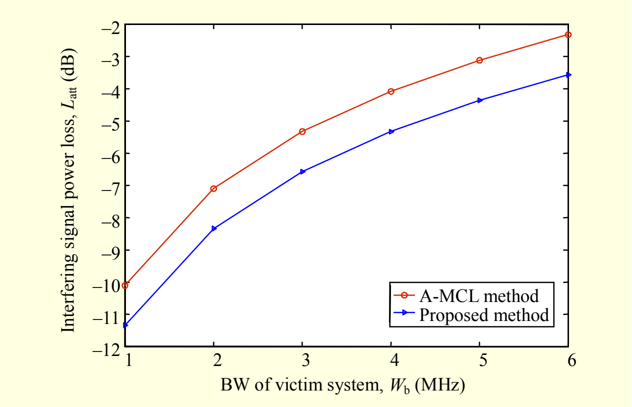

Fig. 2. Interfering power loss vs. BW of victim system at cochannel for proposed and A-MCL methods.

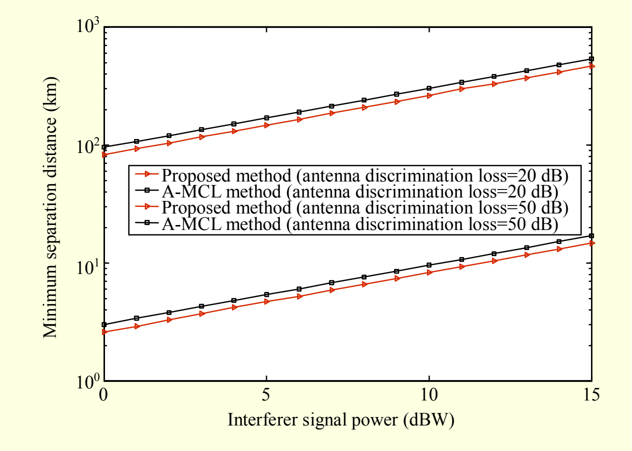

Fig. 3. Comparison of minimum separation distances by proposed and A-MCL methods at cochannel.

Based on the system parameters of FM and IMT-Advanced systems, Fig. 2 shows the interfering signal power loss L_{att} given in (8) attenuation for different channel BWs of victim system at cochannel frequency. The resultant attenuation by the proposed method is 3.6 dB which is higher than 2.3 dB given from the A-MCL method. Interfering signal power loss increases as BW of victim system decreases. This is because small BW of victim system causes its less overlapping with the BW of interfering system, which reduces interference power at the victim system. Figure 3 shows that the difference of the required separation distance between our proposed method and the A-MCL method is approximately 13.1 km to 72 km and 0.4 km to 2.3 km for 20 dB and 50 dB discrimination loss for an interferer power range of 0 dBW to 15 dBW, respectively. Accordingly, the proposed scheme is more effective for the larger interference power. The results are expected because the BW overlapping between PSD of both IMT-Advanced and FM of the proposed method is smaller than that of A-MCL method. Furthermore, the results show that, by using the proposed method, the interference power at the victim system linearly increases with interfering signal power but is less compared to A-MCL method.

Figures 3 and 4 indicate that the proposed method obtains more exact interference power than the A-MCL method does. It is important to note that more exact received power reduces the minimum separation distance, which in turn leads to save the spectrum resource.

Figure 4 depicts the required minimum geographical separation distance versus BS transmit power of an IMT-

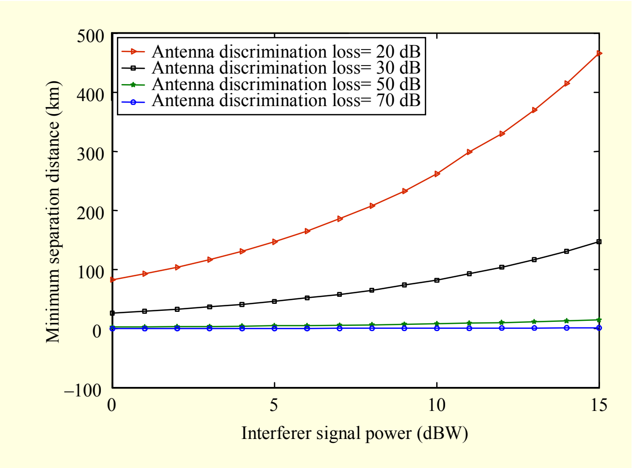

Fig. 4. Minimum separation distances vs. interferer signal power at cochannel.

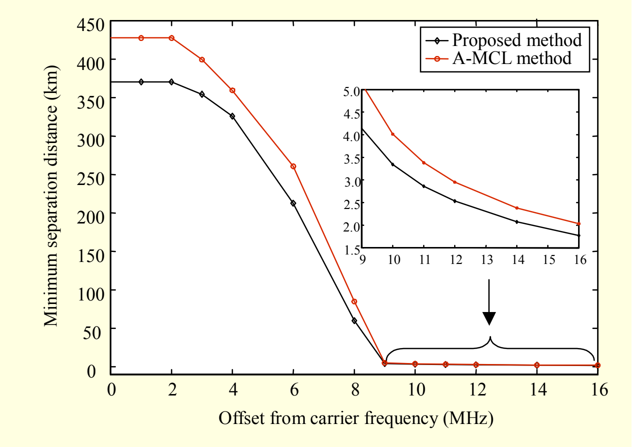

Fig. 5. Comparison of minimum separation distances by proposed and A-MCL methods at adjacent channel.

Advanced system for this analytical model as an alternative to the A-MCL method when the victim receiver has an analogue FM broadcasting signal. The minimum separation distance is determined to be 370 km when antenna discrimination loss is 20 dB at 13 dBW (43 dBm), while it is minimized to 117 km, 11.7 km, and 1.17 km for antenna discrimination losses of 30 dB, 50 dB, and 70 dB, respectively. The results suggest that the coexistence of IMT-Advanced systems with FM broadcasting systems is feasible with proper adjustment of both the antenna direction and the transmit power of IMT-Advanced systems.

Studying the coexistence at adjacent frequencies is also important and power evaluation at these frequencies is needed. Therefore, the resultant attenuation, using (8), in interfering power due to BW overlapping between the two systems at different spectral offsets from the carrier frequency is derived. It is found that power is highly attenuated as frequency offset shifts away from the carrier frequency. The proposed method can be viewed as a more stringent spectral mask than A-MCL for an interfering signal which can better reduce the interfering signal at adjacent channels. In Fig. 5, the frequency offset 0 to 16 MHz between IMT-Advanced system and TV FM receiver, antenna discrimination loss of 20 dB, and interfering power of 13 dBW are taken into consideration in analyzing the minimum separation distance.

In Fig. 5, the minimum separation distance of the proposed method at the cochannel is 370 km whereas it equals 427 km for the A-MCL. However, the distance becomes smaller at adjacent frequencies. For example, at the frequency offset of 8 MHz, which represents zero guard band, the minimum distance is 60 km and 84 km for the proposed and A-MCL methods, respectively. Furthermore, these distances further decrease to be 1.77 km and 2.03 km when 8 MHz is added as a guard band between the two systems for the proposed and A-MCL methods, correspondingly.

V. Conclusion

The proposed method rigorously evaluates the interference power, thereby providing smaller minimum separation distance than A-MCL does. This implies that the proposed method facilitates coexistence between OFDM-based IMT-Advanced and FM broadcasting services.

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