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Broad-Spectrum Model for Sharing Analysis between IMT-Advanced Systems and FSS Receiver

Lway Faisal Abdulrazak[1], Kusay F. Al-Tabatabaie[2]
[1&2]Lecturer at the Computer Science Dep., Cihan University –Sulaimanyia Campus, Iraq

Abstract: *An appraisal of orthogonal frequency division multiplexing (OFDM) accredited for IMT-Advanced has been well thought-out in this letter. Derivation of the power spectral density (PSD) produce new model which easily assess the interfering signal power that appears in the band of a victim system without a spectrum emission mask. Furthermore, the broad-spectrum investigative model (BIM) can assess the interference from the 4G systems into FSS systems, when transmit power is unallocated to some sub-carriers overlapping the band of the victim system. Closed form is derived to create the model.*
Keywords*: IMT-Advanced; Fixed satellite services; coexistence; OFDM; spectrum.*

I. Introduction

Three basic schemes dedicated to analysis of the interference potential between systems that have been addressed in previous work [1] [2], namely, the minimum coupling loss (MCL) method, the advanced minimum coupling loss (A-MCL) and the Monte Carlo method. First, the MCL method utilizing diagnostic estimation is simple to use and can be constructed in less time than the other models. The method does not require a computer for implementation. However, this method can be only adopted as a special case of the "static" interference situations [3].

The coexistence study [4] applied a spectrum emission mask, an essential parameter for adjacent frequency sharing analysis, to calculate the attenuation of the interference signal power in the band of the victim system. However, that method can not be utilized in assessing interference caused by 4G systems for which there is no spectrum emission mask. Moreover, MCL not capable to evaluate the 4G interference with other systems even if there is a spectrum mask in a case that transmit power is not allocated to some subcarriers overlapping the band of the victim system to mitigate 4G interference to other systems. The aim of this study is the maturity broad-spectrum investigative model for evaluation the interference from 4G OFDM-based systems. In South Korea they invented advanced minimum coupling loss method (AMCL) but they ignored the complexity of real sinusoidal signal, this paper will tune there vision into a more applicable way through triangular technique [5].

II. Proposed Method

According The minimum required loss in dBW is described by

Lmin = Pt + Gt + Gr + Lr - Imax (1)

where Pt is the transmit power of interferer (dBW) in the reference bandwidth and Imax is the maximum permissible interference power (about -166 dBW) in the reference bandwidth to be exceeded for no more than ρ % of the time at the terminals of the antenna of receiving FSS. The antenna gains are to be Gt and Gr for the interfering transmitter and the victim receiver in dBi, respectively. Lr is the interfering signal power loss, which accounts for the fraction of interfering signal power that appears in the band of the victim system with dBw scale. The interfering signal power loss Lr for the interfering system with OFDM is derived through a power spectral density (PSD) analysis of the OFDM signals. Figure 1 shows that the PSD of 4G OFDM-based system overlaps the PSD of FSS.

Assuming an OFDM system having M subcarriers and a rectangular pulse, the PSD of the OFDM signal is represented as

$$S_S(f) = \sum_{i=0}^{M-1} \frac{P_S}{R_S} \sin c^2\left(\frac{f}{R_S} - i\right) \tag{2}$$

Where Ps is the power of a single OFDM subcarrier and Rs is the subcarrier spacing. Here, the PSD of the broadcasting system is triangular.

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

Where P_b and W_b are the transmit power and bandwidth of broadcasting systems, respectively. Figure1 shows that the PSD of OFDM-based IMT-Advanced system overlaps the PSD of broadcasting satellite systems. The interfering signal power attenuation by the bandwidth overlapping ratio can be expressed by integration of the three areas shown in the above figure as

$$L_{att} = 10\log_{10}\left(\frac{\int_{f_c-W_b/2}^{f_c+W_b/2}\left[A_1(f)+A_2(f)+A_3(f)\right]df}{P_t} \right) \tag{4}$$

$$L_{att} = 10\log_{10}\left(\frac{\int_{f_c-W_b/2}^{f_c-W_b/4}A_1(f)df+\int_{f_c-W_b/4}^{f_c+W_b/4}A_2(f)df+\int_{f_c+W_b/4}^{f_c+W_b/2}A_3(f)df}{P_t} \right) \tag{5}$$

$$A_1(f)=\left(C_1 f + C_2\right)S_S(f)\ ,\ A_2(f)=S_S(f)$$

$$A_3(f)=\left(-C_1 f + C_3 + P_S\right)S_S(f)$$

C1=4PS/Wb, C2= (4PS/Wb)(fc –(Wb/2)) and C3=(4PS/Wb)(fC +(Wb/4))

$$\int_{f_c-W_b/2}^{f_c-W_b/4}A_1(f)df = \int_{f_c-W_b/2}^{f_c-W_b/4}\left(C_1 f + C_2\right)S_S(f)df$$

$$= \int_{f_c-W_b/2}^{f_c-W_b/4}\left(C_1 f + C_2\right)\sum_{i=0}^{M-1}\frac{P_S}{R_S}\sin c^2\left(\frac{f}{R_S}-i\right)df$$

$$= \sum_{i=0}^{M-1}\frac{P_S}{R_S}\left[\begin{array}{l} C_1\int_{f_c-W_b/2}^{f_c-W_b/4} f\,\dfrac{\sin^2\left[\pi\left(\frac{f}{R_S}-i\right)\right]}{\left[\pi\left(\frac{f}{R_S}-i\right)\right]^2}df \\ + C_2\int_{f_c-W_b/2}^{f_c-W_b/4} f\,\dfrac{\sin^2\left[\pi\left(\frac{f}{R_S}-i\right)\right]}{\left[\pi\left(\frac{f}{R_S}-i\right)\right]^2}df \end{array} \right] \tag{6}$$

In (6), let $u=\pi\left(\frac{f}{R_S}-i\right)$, $h_1=f_C/R_S$-$Wb/2\ R_S$, and $h_2=f_C/R_S$ -$Wb/4\ R_S$. Then (6) can be rewritten as follows:

$$\int_{f_c-W_b/2}^{f_c-W_b/4}A_1(f)df = \sum_{i=0}^{M-1}C_1\frac{P_S}{\pi}\left[\frac{R_S}{\pi}\int_{\pi(h_1-i)}^{\pi(h_2-i)}\frac{\sin^2 u}{u}du + iR_S\int_{\pi(h_1-i)}^{\pi(h_2-i)}\frac{\sin^2 u}{u^2}du\right]$$
$$+\sum_{i=0}^{M-1}C_2\frac{P_S}{\pi}\int_{\pi(h_1-i)}^{\pi(h_2-i)}\frac{\sin^2 u}{u^2}du \tag{7}$$

Using the trigonometric functions powers, sin2 x = (1-cos2x)/2, the integrals in (7) can be evaluated using [ref. 9] as follows,

$$\int_b^b\frac{\sin^2 u}{u}du = \frac{1}{2}\int_a^b\frac{1-\cos 2u}{u}du = \frac{1}{2}\left[\int_a^b\frac{1}{u}du - \int_a^b\frac{\cos 2u}{u}du\right] \tag{8}$$

$$\int_b^b\frac{\sin^2 u}{u^2}du = \frac{1}{2}\int_a^b\frac{1-\cos 2u}{u^2}du = \frac{1}{2}\left[\int_a^b\frac{1}{u^2}du - \int_a^b\frac{\cos 2u}{u^2}du\right] \tag{9}$$

Fro m (8) and (9), $\int_a^b \frac{1}{u}\,du = \ln b - \ln a$; and $\int_a^b \frac{1}{u^2}\,du = \frac{1}{a} - \frac{1}{b}$

Also using MacLaurine series in [9]

$$\int_a^b \frac{\cos 2u}{u}\,du = \ln b + \sum_{k=1}^{\infty} (-1)^k \frac{(2b)^{2k}}{2k\cdot(2k)!} - \left[\ln a + \sum_{k=1}^{\infty} (-1)^k \frac{(2a)^{2k}}{2k\cdot(2k)!}\right] \tag{10}$$

$$\int_a^b \frac{\cos 2u}{u^2}\,du = \frac{\cos 2a}{a} - \frac{\cos 2b}{b} - 2\int_a^b \frac{\sin 2u}{u^2}\,du \tag{11}$$

$$\int_a^b \frac{\sin 2u}{u^2}\,du = \sum_{k=1}^{\infty} \frac{(-1)^{k-1}}{(2k-1)(2k-1)!} \times \left[(2b)^{2k-1} - (2a)^{2k-1}\right] \tag{12}$$

Therefore, employing (10), (11), and (12), both (8) and (9) can be written as (13) and (14), respectively,

$$\int_b^b \frac{\sin^2 u}{u}\,du = \frac{1}{2}\sum_{k=1}^{\infty} (-1)^k \frac{(2a)^{2k} - (2b)^{2k}}{2k\cdot(2k)!} \tag{13}$$

$$\int_b^b \frac{\sin^2 u}{u^2}\,du = \frac{1}{2}\left[\frac{1}{a} - \frac{1}{b} - \frac{\cos 2a}{a} + \frac{\cos 2b}{b} + 2\sum_{k=1}^{\infty} \frac{(-1)^{k-1}[(2b)^{2k-1} - (2a)^{2k-1}]}{(2k-1)(2k-1)!}\right] \tag{14}$$

Employing (13) and (14), (7) can be represented as (15)

$$\int_{f_c-W_b/2}^{f_c-W_b/4} A_1(f)\,df = \sum_{i=0}^{M-1} \frac{P_S}{2\pi}\left\{\begin{array}{l} \frac{C_1 R_S}{\pi}\left[\sum_{k=1}^{\infty} \frac{(-1)^k\left[(2\pi(h_1-i))^{2k} - (2\pi(h_2-i))^{2k}\right]}{2k\cdot(2k)!}\right] + \\ \left[C_1 R_S i + C_2\right]\left[\begin{array}{l} \frac{1}{\pi(h_1-i)} - \frac{1}{\pi(h_2-i)} - \frac{\cos 2\pi(h_1-i)}{\pi(h_1-i)} + \frac{\cos 2\pi(h_2-i)}{\pi(h_2-i)} \\ + 2\sum_{k=1}^{\infty} \frac{(-1)^{k-1}[(2\pi(h_2-i))^{2k-1} - (2\pi(h_1-i))^{2k-1}]}{(2k-1)\cdot(2k-1)!} \end{array}\right] \end{array}\right\} \tag{15}$$

$$\begin{aligned}\int_{f_c-W_b/4}^{f_c+W_b/4} A_2(f)\,df &= \int_{f_c-W_b/4}^{f_c+W_b/4} S_S(f)\,df = \int_{f_c-W_b/4}^{f_c+W_b/4} \sum_{i=0}^{M-1} \frac{P_S}{R_S} \sin c^2\left(\frac{f}{R_S} - i\right) df \\ &= \sum_{i=0}^{M-1} \frac{P_S}{R_S} \int_{f_c-W_b/4}^{f_c+W_b/4} \frac{\sin c^2\left[\pi\left(\frac{f}{R_S} - i\right)\right]}{\left[\pi\left(\frac{f}{R_S} - i\right)\right]} df\end{aligned} \tag{16}$$

In (6), let $u = \pi\left(\frac{f}{R_S} - i\right)$, $h_2 = f_C/R_S - Wb/4R_S$, and $h_3 = f_C/R_S + Wb/4\,R_S$. Then (16) can be rewritten as follows:

$$\int_{f_c-W_b/4}^{f_c+W_b/4} A_2(f)\,df = \sum_{i=0}^{M-1} \frac{P_S}{\pi} \int_{\pi(h_2-i)}^{\pi(h_3-i)} \frac{\sin^2 u}{u^2}\,du \tag{17}$$

The equation (14) can be used to evaluate (17), so

$$\int_{f_c-W_b/4}^{f_c+W_b/4} A_2(f)\,df = \sum_{i=0}^{M-1} \frac{P_S}{2\pi}\left[\begin{array}{l} \frac{1}{\pi(h_2-i)} - \frac{1}{\pi(h_3-i)} - \frac{\cos 2\pi(h_2-i)}{\pi(h_2-i)} + \frac{\cos 2\pi(h_3-i)}{\pi(h_3-i)} \\ + 2\sum_{k=1}^{\infty} \frac{(-1)^{k-1}[(2\pi(h_3-i))^{2k-1} - (2\pi(h_2-i))^{2k-1}]}{(2k-1)\cdot(2k-1)!} \end{array}\right] \tag{18}$$

By the same way it is easy to get

$$\begin{aligned}
\int_{f_c+W_b/4}^{f_c+W_b/2} A_3(f)df &= \int_{f_c+W_b/4}^{f_c+W_b/2}\left(-C_1 f + C_3 + P_S\right)S_S(f)df \\
&= \int_{f_c+W_b/4}^{f_c+W_b/2}\left(-C_1 f + C_3 + P_S\right)\sum_{i=0}^{M-1}\frac{P_S}{R_S}\sin c^2\left(\frac{f}{R_S}-i\right)df \\
&= \sum_{i=0}^{M-1}\frac{P_S}{R_S}\left[\begin{array}{l}
-C_1\displaystyle\int_{f_c+W_b/4}^{f_c+W_b/2} f\,\frac{\sin^2\left[\pi\left(\frac{f}{R_S}-i\right)\right]}{\left[\pi\left(\frac{f}{R_S}-i\right)\right]^2}df \\
+\left[C_3+P_S\right]\displaystyle\int_{f_c+W_b/4}^{f_c+W_b/2} f\,\frac{\sin^2\left[\pi\left(\frac{f}{R_S}-i\right)\right]}{\left[\pi\left(\frac{f}{R_S}-i\right)\right]^2}df
\end{array}\right]
\end{aligned} \tag{19}$$

In (19), let $u=\pi\left(\frac{f}{R_S}-i\right)$, $h_3=f_C/R_S+Wb/4R_S$, and $h_4=f_C/R_S+Wb/2\,R_S$. Then by employing (13) and (14), (19) can be represented as (20)

$$\int_{f_c-W_b/2}^{f_c-W_b/4} A_3(f)df = \sum_{i=0}^{M-1}\frac{P_S}{2\pi}\left\{\begin{array}{l}
\dfrac{-C_1R_S}{\pi}\left[\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^k\left[(2\pi(h_3-i))^{2k}-(2\pi(h_4-i))^{2k}\right]}{2k\cdot(2k)!}\right]+ \\
\left[C_3-C_1R_Si+P_S\right]\left[\begin{array}{l}
\dfrac{1}{\pi(h_3-i)}-\dfrac{1}{\pi(h_4-i)}-\dfrac{\cos 2\pi(h_3-i)}{\pi(h_3-i)} \\
+\dfrac{\cos 2\pi(h_4-i)}{\pi(h_4-i)} \\
+2\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^{k-1}[(2\pi(h_4-i))^{2k-1}-(2\pi(h_3-i))^{2k-1}]}{(2k-1)\cdot(2k-1)!}
\end{array}\right]
\end{array}\right\} \tag{20}$$

By combine (15), (18), and (20), Therefore, Interfering signal power attenuation by bandwidth overlapping ratio can be expressed as:

$$L_{att}=10\log_{10}\left\{\sum_{i=0}^{M-1}\frac{P_S}{2\pi}\left[\begin{array}{l}
\left[\begin{array}{l}
\dfrac{C_1R_S}{\pi}\left[\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^k\left[(2\pi(h_1-i))^{2k}-(2\pi(h_2-i))^{2k}\right]}{2k\cdot(2k)!}\right]+ \\
\left[C_1R_Si+C_2\right]\left[\begin{array}{l}
\dfrac{1}{\pi(h_1-i)}-\dfrac{1}{\pi(h_2-i)}-\dfrac{\cos 2\pi(h_1-i)}{\pi(h_1-i)}+\dfrac{\cos 2\pi(h_2-i)}{\pi(h_2-i)} \\
+2\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^{k-1}[(2\pi(h_2-i))^{2k-1}-(2\pi(h_1-i))^{2k-1}]}{(2k-1)\cdot(2k-1)!}
\end{array}\right]
\end{array}\right] \\
+\left[\begin{array}{l}
\dfrac{1}{\pi(h_2-i)}-\dfrac{1}{\pi(h_3-i)}-\dfrac{\cos 2\pi(h_2-i)}{\pi(h_2-i)}+\dfrac{\cos 2\pi(h_3-i)}{\pi(h_3-i)} \\
+2\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^{k-1}[(2\pi(h_3-i))^{2k-1}-(2\pi(h_2-i))^{2k-1}]}{(2k-1)\cdot(2k-1)!}
\end{array}\right] \\
+\left[\begin{array}{l}
\dfrac{-C_1R_S}{\pi}\left[\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^k\left[(2\pi(h_3-i))^{2k}-(2\pi(h_4-i))^{2k}\right]}{2k\cdot(2k)!}\right]+ \\
\left[C_3-C_1R_Si+P_S\right]\left[\begin{array}{l}
\dfrac{1}{\pi(h_3-i)}-\dfrac{1}{\pi(h_4-i)}-\dfrac{\cos 2\pi(h_3-i)}{\pi(h_3-i)}+\dfrac{\cos 2\pi(h_4-i)}{\pi(h_4-i)} \\
+2\displaystyle\sum_{k=1}^{\infty}\frac{(-1)^{k-1}[(2\pi(h_4-i))^{2k-1}-(2\pi(h_3-i))^{2k-1}]}{(2k-1)\cdot(2k-1)!}
\end{array}\right]
\end{array}\right]
\end{array}\right]\right\} \tag{21}$$

Main contribution here that assuming the waveform of FSS signal is tringular, which is represents the real case of interfered scenario.

III. Simulation Results and Discussion

The IMT system occupies a bandwidth of 40 MHz assigned with a centre frequency of 3500 MHz. A dish-shaped parabolic antenna, having a diameter of 2.4 m and a maximum antenna gain of 42.5 dBi, is deployed. The permissible long-term interference power is considered to be -166 dBW/40 MHz, which is calculated based on I=N-10 dB for 20% of the time. Currently, the specifications for the IMT-Advanced systems are under consideration. We assume a cellular OFDM/OFDMA of IMT-Advanced systems. The other parameters for the base station (BS) of IMT-Advanced systems are assumed as time division duplex (TDD), 10.24 kHz subcarrier frequency spacing, 80 MHz channel bandwidth, 8192 subcarriers, and 13 dBW transmit power. The BS antenna pattern used for each sector is specified as 25 dB maximum antenna gain

Based on the system parameters of FSS and IMT-Advanced systems, the minimum separation distance to satisfy permissible interference power is analyzed and compared for both A-MCL and BIM due to the BS transmit power of the IMT-Advanced system. Here cluster loss is assumed as 20 dB. For antenna discrimination loss the cases of 50 dB are considered. Figure 2 depicts the required minimum separation distance against BS transmit power of an IMT-Advanced system for both a A-MCL and BIM. The BIM results show more stable values than the A-MCL at the same interference power on the victim system.

The maximum difference of the interfering signal power between A-MCL and BIM is 3 dB and the maximum difference of the required minimum separation distance between conventional MCL and A-MCL is approximately 12 km. The BIM method reflects the capability of flexible spectrum usage for OFDM-based IMT-Advanced systems and decreases the received.

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