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THE USE OF CONVOLUTIONAL CODE FOR NARROWBAND INTERFERENCE SUPPRESSION IN OFDM-DVBT SYSTEM

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ABSTRACT

The problem of mitigating narrowband interference (NBI) due to coexistence between Digital Video Broadcasting-Terrestrial (DVB-T) and International Mobile Telecommunication-Advanced (IMT-A) system is considered. It is assumed that a spectrum of IMT-A system between 790-862 MHz interfere the spectrum of the OFDM signal in DVB-T band. Two types of convolutional code (CC) which is non-systematic convolutional code (NSCC) and recursive systematic convolutional code (RSCC) are proposed to mitigate NBI. The performance of the two techniques is compared under additive white Gaussian noise (AWGN) channel. It is observed that NSCC has a better bit error rate (BER) performance than RSCC. The result showed good performance for low SNR (≤ 5dB).

Keywords: OFDM, convolutional code, narrowband interference, DVB-T.

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a popular multiplexing scheme used for transmission of high data rates in various communication standards such as DVB-T, WLANS, WMANs and WiMAX [1, 2]. For certain standards such as WLANs and WMANs, an OFDM system has the ability to operate in unlicensed frequency bands. As a result, there is a possibility that they have to share the same frequency band with other communication systems such as cordless telephones, garage door openers and baby monitors. This leads to narrowband interference (NBI) in the systems [3]. Another example of systems sharing the same frequency band is WiMAX and UWB systems. According to [4], UWB system is required to modify its spectrum to avoid interference with WiMAX. In WRC-07 conference, ITU-R has allocated the 790-862MHz frequency for IMT-A system. This also suggests that the DVB-T system which operates between 470-862MHz have to share its upper frequency band with the IMT-A system [5].

There are several techniques proposed to mitigate NBI such as using orthogonal codes, frequency domain cancellation, receiver windowing and excision filtering [3, 4].

Although orthogonal codes is found to give better performance compared to error control code (ECC), this method does not comply with the current OFDM standard such as DVB-T and IEEE [3]. On the other hand, frequency domain cancellation technique is not suitable to be implemented in broadcasting because the channel and interference information from the receiver needed to be fed back to the transmitter periodically for update. A limitation of receiver windowing method is that it is suitable to be used together with frequency domain cancellation to reduce the effect of sinc shape side lobes from spreading to adjacent channel while excision filtering method provides less benefit with quadrature amplitude modulation (QAM) [4].

ECC is a suitable candidate to mitigate NBI as it is able to protect the data using a specific code. The data which is corrupted during transmission in the noisy channel will be recovered by the specific decoding method. Theoretically, ECC has the capability to lower the bit error rate of an uncoded system by a certain coding rate [6]. In brief, there are three types of ECC known as block, convolutional and modern codes. In this work, convolutional code (CC) is proposed as it is suitable to be used in broadcasting, deep space communication, digital speech and also for Gaussian channel condition [7, 8]. Two types of convolutional code proposed to mitigate NBI in DVB-T system are non-systematic convolutional code (NSCC) and recursive systematic convolutional code (RSCC).

Section 2 describes the OFDM system and NBI model used. Section 3 explains about the proposed ECC techniques. Section 4 provides the simulation results and discussion while section 5 concludes this paper.

SYSTEM MODEL

The OFDM simulation model of a DVB-T system under narrowband effect is as shown in Figure-1. It is referred from a MATLAB simulation by [9]. The simulation model is modified by adding ECC as a narrowband mitigation technique and using different carrier frequency. ECC acts as encoder in the transmitter and decode the signal back for recovery in the receiver.

At baseband, ECC is applied at the stream of binary data $k=\{k_1\ k_2\ k_3 \ldots\ldots k_n\}$. Then, the coded binary data $c=\{c_1\ c_2\ c_3\ c_4 \ldots\ldots\ldots c_n\}$, is converted into symbols to be modulated with M number of Quadrature Amplitude Modulation (QAM). Each serial modulated symbols $S=\{S_1\ S_2\ S_3\ S_4 \ldots\ldots\ldots S_n\}$, are mapped into N number of parallel subcarriers. The modulated symbols $X(k)$, appeared as a complex signal in frequency domain:

$$X(k)=R(k)+jI(k) \tag{1}$$

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The modulated symbols are passed to inverse fast Fourier transform (IFFT) processing block to create a time domain OFDM signal for transmission. 2*N*-IFFT processing is used to center the subcarriers and processed the discrete signal *x(n)*,

$$x(k) = 1/N \sum_{k=0}^{N-1} X(k) e^{j2\pi nk/N} \tag{2}$$

where n = 0,1, …, N-1, k = 0,1,2,3………N-1; N being the number of subcarriers.

An OFDM symbol of N subcarriers is to be transmitted in an OFDM symbol period duration. The next processing block is to sample the OFDM discrete signal *x(n),* within the OFDM symbol period duration. It will undergo filteration process in digital-to-analog (DAC) converter to obtain continuous time domain signal *x(t)*. Finally, the signal *x(t*), is modulated with its RF transmit signal carrier and ready for transmission. The receiver system is the reverse process of the transmission system. After demodulation, a decoder recovered the data based on ECC scheme applied. After the data is recovered, it is compared with the original data for bit error rate (BER) calculation. From Figure-1, the received signal and the effect of channel can be written as follows:

$$r(t) = x(t) + n(t) + i(t) \tag{3}$$

where *r(t)* is the received signal consist of transmitted signal *x(t),* Gaussian noise (AWGN) *n(t)* and narrowband interference *i(t)*.

Figure-2 shows the theoretical model of OFDM-DVBT band adopted from [2] which is used to represent general scenario in this work. For all the channels that are used for transmission, there are 49 channels in the DVB-T frequency band. From equation (3), *i(t)* has a frequency range between 790-862 MHz interfered with the upper channel in DVB-T band. In this work, the 48th channel in the DVB-T band which has carrier frequency of 850MHz is chosen as simulation parameter with the unwanted NBI signal of frequency 851MHz.

The narrowband interference (NBI) signal is modeled as sinusoidal signal $i(t)$,

$$i(t) = I\cos(2\pi f_i + \theta) \quad 0 < \theta < 2\pi \tag{4}$$

where I is the amplitude of the NBI signal and is the phase angle. The value of considered in this work is $\theta = \pi$ Substituting (4) into (1), the received signal $r(t)$, is derived as:

$$r(t) = A\cos(2\pi f_c t) + n(t) + I\cos(2\pi f_i t + \theta) \tag{5}$$

where A is the amplitude and $f(c)$ is the carrier frequency of the OFDM signal. The performance of an OFDM system is degraded when a strong NBI signal f_i with carrier frequency close to the OFDM signal's carrier frequency $f(c)$ overlapped,

$$f_i = f_c + \Delta f \tag{6}$$

and that the amplitude of the NBI signal is greater than the amplitude of the OFDM signal $(I > A)$. Further details can be found in simulation part-4.

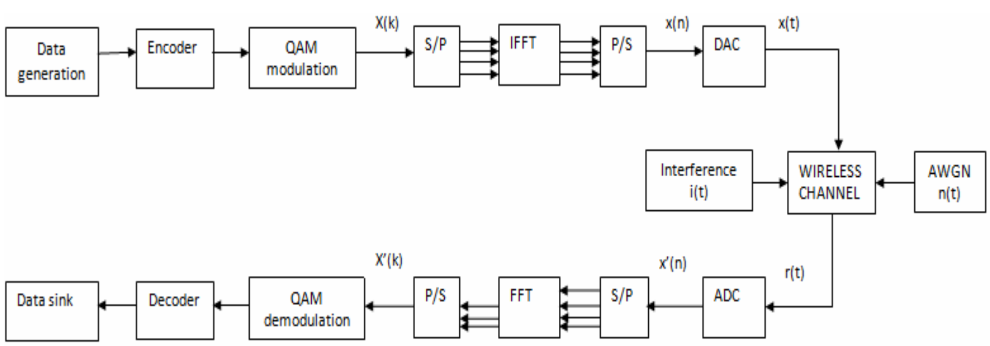

Figure-1. OFDM simulation model with DVB-T parameters.

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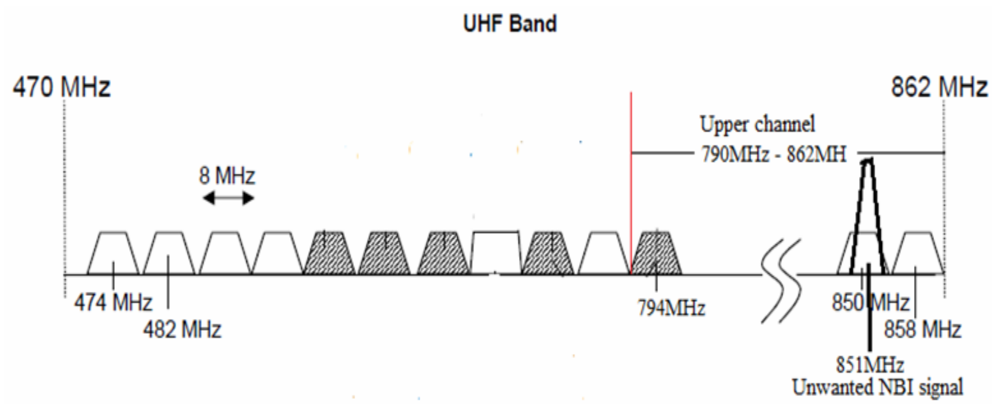

Figure-2. Theoretical model of OFDM-DVBT band adopted from [2].

THE PROPOSED TECHNIQUE

Non-systematic Convolution Code (NSCC)

Figure-3 shows the block diagram of 1/2 rate NSCC encoder which consist of *m* number of memory registers. It is used to store previous binary input data. If a binary data *k*, enters an encoder, it produces *n* coded bits at the output with code rate *R=k/n*. The code representation is written as *(n,k,m)*. The design of NSCC can be found in literatures such as [7, 8] and [10] with different generator polynomials. In this work, the generator polynomials used are different compared to the ones used in example [7, 8] and [10] because based on simulation result, it gave BER performance curve closest to the OFDM system without NBI effect. The generator polynomials used for 1/2 rate NSCC are g_1 = [1 1 1] and g_2 = [0 1 1].

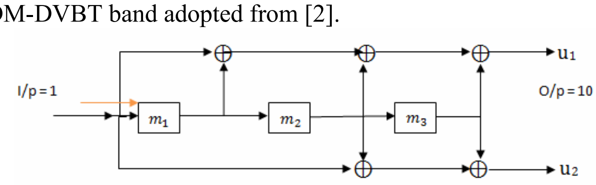

Figure-3. 1/2 rate convolutional encoder (2, 1, 3).

An input bit 1 which entered the encoder will be modulo-2 added with stored values in memory register to generate the coded bits u_1 u_2. The generator polynomials determine which stored values in memory register needed to be modulo-2 added with the input bit. Assuming the initial state of memory register is 000, the output is shown in Table-1 below.

Table-1. Example of truth table for 1/2 rate convolutional encoder (2, 1, 3).

Start state	Input	End state	U1	U2	Output
000	0	000	(0□0□0□0) = 0	(0□0□0)=0	00
000	1	100	(1□0□0□0) = 1	(1□0□0)=0	10
100	0	010	(0□1□0□0) = 1	(0□0□0)=0	10
100	1	110	(1□1□0□0) = 0	(1□0□0)=1	01

The input bit is then moved into shift register m_1 with all the bits in the memory register shifted. The oldest stored bit in m_3 is disappeared. The next input bit entered will be modulo-2 added with stored values in memory register which is 100 and the process will be repeated.

The system is then extended to 1/3 rate by addition of another generator polynomial, g_3 = [1 0 1] as shown in Figure-4. In the case of 1/3 rate encoder, one bit entered the encoder produced three output bits.

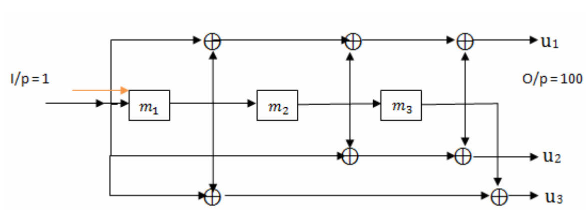

Figure-4. 1/3 rate convolutional encoder (3, 1, 3).

ARPN Journal of Engineering and Applied Sciences

NSCC gave better performance when Viterbi decoder is used [8]. The possible path that the encoder has undergone is represented in Trellis diagram as shown in Figure-5. All the memory register's possible state is written at the first column. The input bit (in bracket) is written next to the matched output bits referred to encoder's truth Table. Usually, the process will start at state 000. The branch metric is calculated by comparing the number of bit agreement with the coded bits. The process is repeated for all the coded bits. The path which has the highest number of branch metric is chosen as 'survivor path' and the decoded bits are determined.

Coded bits	00	01	Branch metric
State			
000	00(0)	00 (0)	3
001			
010		10(0)	1
011			
100	10 (1)	10 (1)	2
101			
110		01(1)	3
111			

Figure-5. Example of Trellis diagram for 1/2 rate convolutional code.

Recursive systematic Convolution Code (RSCC)

RSCC, also known as turbo code is developed from NSCC. Compared to NSCC, RSCC is formed by concatenating in parallel two RSCCs separated by an interleaver. It is a systematic coding because one of the message bit itself is called systematic bit and the other two are the parity bits generated by the two RSCC encoders. Since the aim of this research is to determine which type of convolutional code performs better in mitigating NBI, the design of RSCC used in this paper is adopted from [11]. Its coding rate *R*, is 1/3 with generator polynomial g_1 = [101], g_2 =. [111], and g_3 = [101]. Iterative decoding is used to decode the message.

SIMULATION RESULTS

The performance of convolutional codes in OFDM system under NBI effect is simulated using MATLAB based on the DVB-T parameters for 2k mode [9]. Figure-6 shows the illustration of the OFDM signal in the presence of Gaussian effect and unwanted NBI signal.

The BER performance curve of the OFDM system with and without the presence of NBI is presented in Figure-7. The initial OFDM curve (without interference) has average signal power value of -10dB. The value obtained is calculated based on simulation according to [1]. The NBI signal is added to the initial OFDM system and simulated in two conditions i.e. with sinusoidal amplitude *I*=10V and

I=20V. Referring to [6], the NBI signal power for the case of equation (4) is,

$$P_i = I^2 / 2 \tag{7}$$

where *I* is the amplitude of the narrowband sinusoidal signal.

The NBI signal power for sinusoidal amplitude *I*=10V and *I*=20V are approximately 17dB and 23dB respectively. For NBI signal power less than 17dB, it has a small effect on the OFDM system. In Figure-7, at SNR=5dB, the bit error rate is 0.06631 for system under NBI signal power of 17dB and 0.1332 for NBI signal power of 23dB compared to 0.03815 for initial system. The difference of about 0.02816 between system with 17dB NBI power and initial system is due to the fact that the system performance is affected by the NBI signal. When the NBI's signal amplitude is increased to *I*=20, the difference with initial system is 0.09505 which implies further degradation of the system performance due to the increased in NBI signal power.

Figure-8 shows the performance of convolutional coded (CC) OFDM with the presence of 17dB NBI signal power. For the case of SNR = 5dB, the bit error rate is about 0.04577 for 1/2 rate NSCC which is close to the initial system. As the SNR increased, the performance of 1/2 rate NSCC did not follow the curve of initial OFDM system. RSCC obtained BER of 0.09507 at SNR=5dB which showed worst performance compared to the OFDM system with NBI. On the other hand, 1/3 rate NSCC gave faulty result because it achieved BER of 0.01819 at SNR=5dB which is lower than the BER of initial system.

The convolutional coded OFDM under 23 dB NBI signal power effect is shown in Figure-9. Based on the figure, 1/3 rate NSCC outperformed 1/2 rate NSCC and RSCC. At SNR=5dB, an error of 0.04401 is obtained by 1/3 rate NSCC which is similar to the initial system. As the SNR increased, the performance of 1/3 rate NSCC also did not follow the curve of the initial system. 1/2 rate NSCC showed less performance as it followed the curve of OFDM system under NBI effect whereas RSCC showed the worst performance with error rate 0.2019 at SNR=5dB.

Based on observations on Figure-8 and Figure-9, at low SNRs (5dB), the performance curve of NSCC followed the curves of initial system (without interference) compared to high SNR (>5dB). This implies that the performance of NSCC with Viterbi decoder is different at low and high SNR. According to [7], for a convolutional code, the error correction and detection capability *t*, is

$$t = \left(d_{free} - 1\right) / 2 \tag{8}$$

Where d_{free} is free distance which is the smallest Hamming distance between all possible code sequences of the code? At high SNR, the performance is limited by the capability of Viterbi decoder to correct more than t number of errors in n bits. Power, bandwidth constraint and nature of noise in the channel can also affect the performance of the coding scheme. Based on the simulation results, the proposed NSCC has good performance for low SNR (5dB) to mitigate NBI compared to RSCC. The performance of this code also showed considerable result at low SNR when compared with time windowing method for NBI mitigation under DVB-T system [9].

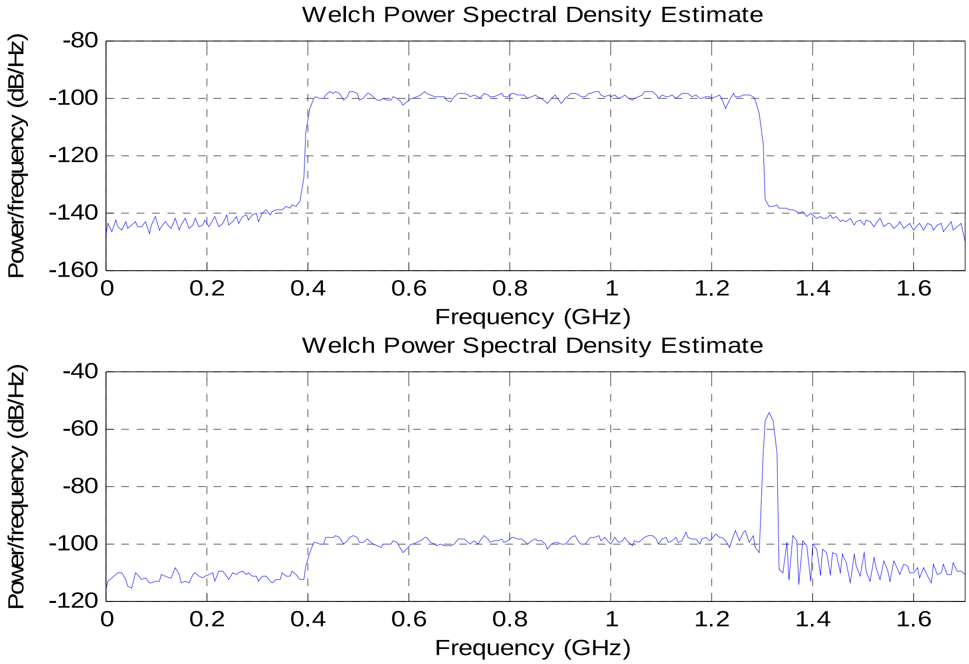

Figure-6. An OFDM signal spectrum appears between 0.4MHz-1.25MHz along the x-axis for 850MHz carrier frequency, showing OFDM transmitted signal spectrum (top) and OFDM received signal spectrum with Gaussian noise and the presence of 851 MHz NBI signal (bottom).

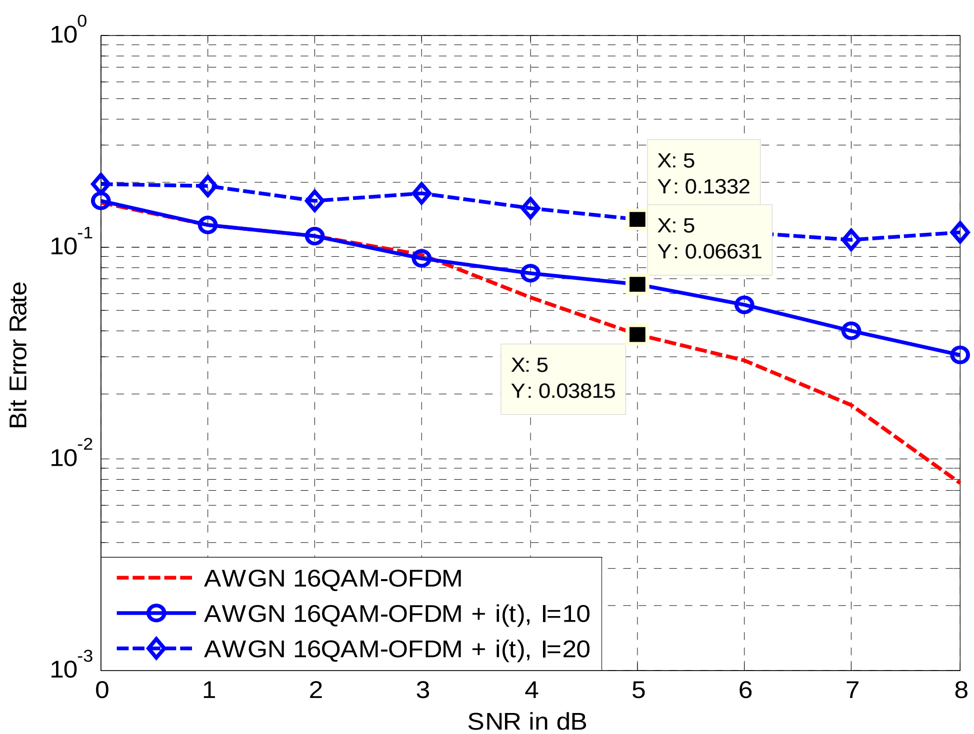

Figure-7. BER performance of OFDM system with NBI effects (blue) and initial system without interference (red). The simulation also shows comparison of the system performance when the unwanted sinusoidal amplitude is varied (I=10V and I=20V), having different signal power.

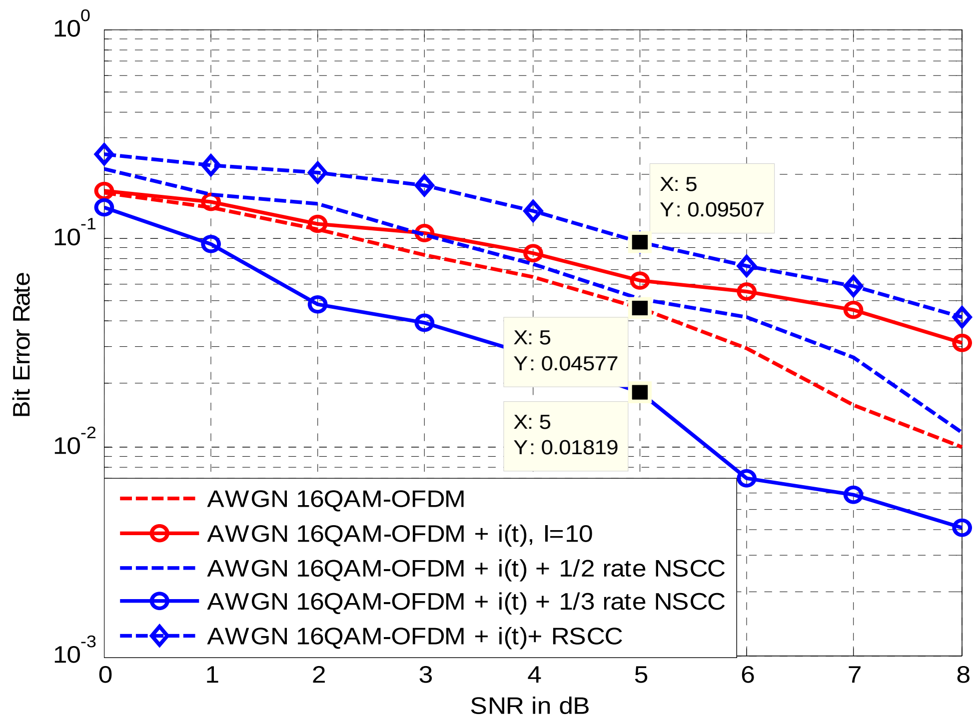

Figure-8. Performance comparison of convolutional coded OFDM (blue) with the presence of 17dB NBI signal power with uncoded system (red).

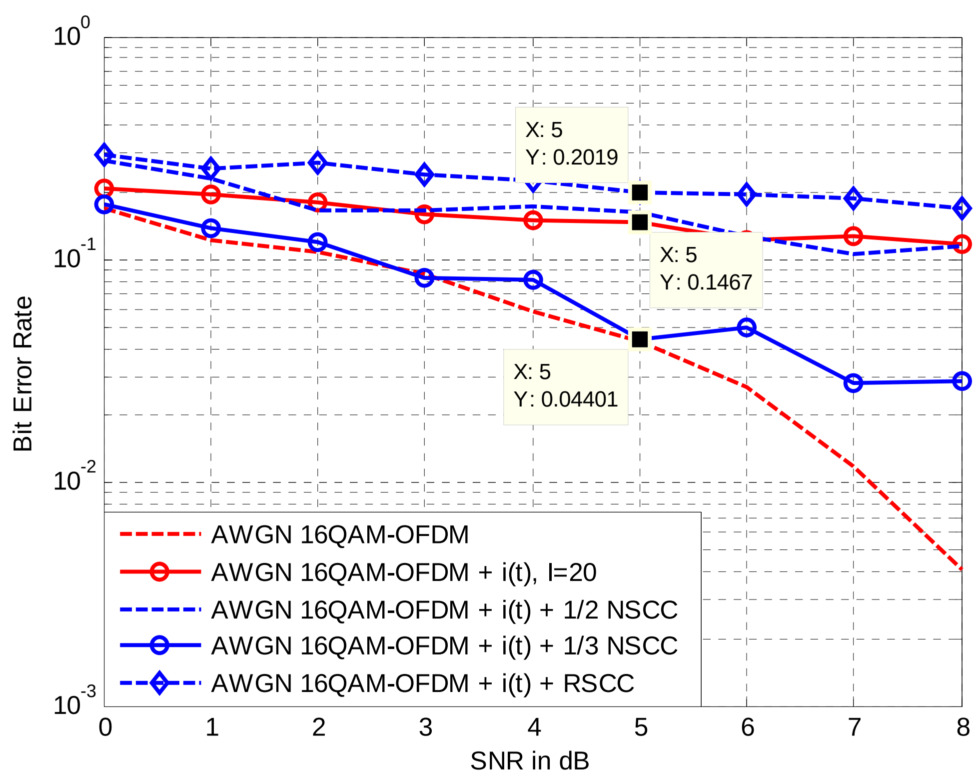

Figure-9. Performance comparison of convolutional coded OFDM (*blue*) with the presence of 23dB NBI signal power with uncoded system (*red*).

CONCLUSIONS

In this paper, a narrowband mitigation technique is proposed using convolutional code. NSCC and RSCC are presented as two different ECC techniques suitable for NBI mitigation for DVB-T transmission under Gaussian channel. The interference is assumed coming from IMT-A services affected the upper channel of the DVB-T band. The simulation showed that 1/2 rate NSCC can mitigate the 17dB NBI signal power while 1/3 rate NSCC suited for 23dB NBI signal power at low SNR ($\leq$5dB). The performance result for RSCC showed that it is not effective in mitigating the NBI for this work.

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