

Performance Evaluation of Digital Television Broadcasting with Orthogonal Frequency-Division Multiplexing

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ABSTRACT

The current global trend in broadcast communication is the transition from analogue broadcasting to digital broadcasting. Digital technology involves the use of binary digits to represent information instead of a continuous wave of the analogue technology. This work investigates the signal quality and energy efficiency of digital and analogue Television (TV) signals under the same channel conditions and scenarios. The Phase Alternating Line (PAL) standard was used for the analogue TV transmission while the Digital Video Broadcasting Terrestrial (DVB-T) standard was used for the digital TV transmission. Both the DVB-T and PAL system models were developed. The Orthogonal Frequency Division Multiplexing-Quadrature Phase Shift-Keying (OFDM-QPSK) modulation scheme was used in the DVB-T system while Amplitude Modulation (AM) scheme was used in the PAL system. The investigation was carried out by computer simulation using signal processing approach from both modulation and coding perspectives. System performance was evaluated using Peak Signal-To-Noise Ratio (PSNR) and energy efficiency as performance metrics. The simulation results show that in terms of PSNR, the PAL system gives 22.0361 dB while the DVB-T system gives 37.5479 dB; and in terms of energy efficiency, DVB-T provides 53.86% while PAL provides 29.48%. The results of the investigation reveal that digital TV system gives superior signal quality and energy efficiency than the analogue TV system.

1. INTRODUCTION

The growing demand for more frequency spectrum for new services such as security, emergency and mobile broadband applications has led to the decision of the International Telecommunication Union (ITU) to direct all member countries to switch over from analogue to digital broadcasting (ITU, 2016). The Digital Television (DTV) switchover is the process of converting from the analogue TV standards like PAL, National Television Standard Committee (NTSC) and Sequential Color and Memory (SECAM) to digital TV standards like Digital Television Multimedia Broadcasting (DTMB), Integrated Services Digital Broadcasting (ISDB) and DVB (Immink *et al.*, 1984; ETSI, 2009; DVB Factsheet, 2012; Wikipedia,

2016). Analogue broadcast transmissions first started in 1936 while DVB project was formed in 1993 (Almeida *et al.* 2008).

Digital terrestrial television broadcasting (DTTB) was introduced in the UK in 1998; however, Luxembourg was the first country to completely switch over to digital broadcasting on September 1, 2006 and June 12, 2009 was the analogue shut-off date in the USA (CRTC, 2009). Quite a number of developed countries have completely switched over to digital broadcasting. Nigeria is joining the other countries in the digital switch with the first successful digital TV broadcasting in Jos, Plateau State on April 30, 2016 with the hope of complete digitalization of the broadcasting industry in the nearest future.

Digitalization of broadcasting industry has led to what experts refer to as digital dividend. Digital dividend is the creation of more free frequency spectrum for communication, which translates to more revenue for the government (CRTC, 2009). Digital switchover makes more Very High Frequency (VHF) and Ultra High Frequency (UHF) spectrum available because in DTV, there is no need for leaving empty channels to protect stations from each other as in the case of analogue TV (Liu *et al.*, 2010).

The adoption of DTV broadcasting enables broadcasters to offer more programming options, and with the possibility of transmitting numerous stations using the same channel; thereby providing bandwidth efficiency (Biro and Borbely, 2004; Wikipedia, 2016). The use of same channel by different stations is termed Single Frequency Network (SFN), which involves the transmission of TV signals of neighboring broadcast stations using the same frequency to many users. This is made possible by the Orthogonal Frequency-Division Multiplexing (OFDM) – a secondary digital modulation technique (Biro and Borbely, 2004; Kurjenniemi and Vartiainen, 2008; Ajayi *et al.*, 2018). Another advantage of DTV is that broadcast stations can make their programmes available on the internet for mobile viewers using standards like HDTV, DVB-H and DVB-T (Almeida *et al.*, 2008; ETSI, 2009; Ajayi, 2013; Li *et al.*, 2016).

Analogue broadcasting involves the use of analogue modulation techniques while digital broadcasting involves the use of digital modulation techniques (Sharma *et al.*, 2010). Some investigations have been carried out in the area of digital transmission technology. Attempts have been made to combine digital audio signal with NTSC and PAL (Immink *et al.*, 1984). Pursley and Shea (1999) designed a modulation strategy for broadcast transmissions based on non-uniform M-ary PSK signal constellations. Performance comparisons of different DTV standards, mobile TV and integration of technologies have been carried out (Almeida *et al.*, 2008; Catrein *et al.*, 2008; Liu *et al.*, 2010). More attention is shifting towards three-dimensional (3D) video coding as an extension to High Efficiency Video Coding (HEVC) which has led to the design and improvement of 3D-HEVC system for very high visual quality (Li *et al.*, 2016; Zhang *et al.*, 2016).

This paper presents the advantage of digital TV transmission over analogue TV transmission in terms of peak signal-to-noise ratio and the amount of energy or power required for transmitting quality pictures over wireless fading channel using signal processing approach.

2. METHODOLOGY

DVB-T System Model

The DVB-T system is based on the OFDM signaling scheme. An OFDM symbol consists of K subcarriers. The symbols are transmitted in frames, and a frame consists of OFDM symbols. The information bits, representing the TV data, to be transmitted are arranged in subcarriers and all the data carriers are mapped onto QPSK constellation. A sample of the OFDM symbol after applying N-points IFFT is given in Equation 1 as:

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$$s(n) = \frac{1}{\sqrt{N}} \sum_{k \in \Gamma_n} S_k e^{j2\pi nk/N}, \quad n = 0, 1, \dots, N-1 \quad (1)$$

where Γ_n is the set of indices of all the subcarriers; S_k is the data symbol on the k^{th} subcarrier and N is the IFFT size. After inserting a cyclic prefix (CP) of length T_g between two consecutive frames, Equation 1 can be rewritten in block form, expressed in Equation 2 as:

$$\tilde{s}_T(i) = G_N s_N(i) \quad (2)$$

where $\tilde{s}_T(i)$ is the i^{th} block of the symbols to be transmitted; $s_N(i)$ is an $N \times 1$ complex vector whose elements are complex symbols from QPSK modulation; G_N is an $N \times N$ FFT matrix with $(n, k)^{th}$ entry $\frac{1}{\sqrt{N}} e^{j2\pi nk/N}$ with the $(N + T_g) \times N$ matrix representing the CP. At the receiving end, the CP is first removed from the received DVB video signal as shown in Fig. 1. This helps to eliminate the inter-carrier interference (ISI). After applying FFT, Equation 3 represents the received block given by:

$$y_N(i) = \sqrt{N} \text{diag}(G_N h_N) s_N(i) + z_N(i) \quad (3)$$

where $\text{diag}(\cdot)$ denotes the elements in the diagonal matrix; $G_N h_N$ is the frequency response of the multipath Rician channel and z_N is the additive white Gaussian noise (AWGN).

PAL System Model

Phase Alternating Line (PAL) is a colour encoding system for analogue TV. A PAL video signal is a combination of luminance (or luma) and chrominance (or chroma) signals. Luma carries the brightness information (black-and-white) in the signal while chroma carries the colour information (hue and saturation). The luma is denoted by Y . The chroma consists of two components U and V which are Quadrature Amplitude Modulation (QAM) modulated. The Y is AM modulated. The PAL system uses YUV colour space. The YUV components are obtained from the γ -corrected RGB (Red, Green, Blue) components of the picture to be transmitted and are given by Jack (2007) and expressed in Equation 4 as:

$$\begin{aligned} Y &= 0.299R' + 0.587G' + 0.114B' \\ U &= 0.492(B' - Y) \\ V &= 0.877(R' - Y) \end{aligned} \quad (4)$$

where $R' = R^{\gamma}$, $B' = B^{\gamma}$, $G' = G^{\gamma}$, $\gamma = 2.2$. The RGB values are normalized to have a range of 0 to 1. The modulated chroma signal is expressed in Equation 5 as:

$$s_c(t) = V \cos(2\pi f_{sub} t) + U \sin(2\pi f_{sub} t) \quad (5)$$

where f_{sub} is the subcarrier frequency, t is the time instants, U and V are the γ -corrected colour-difference signals. The chroma carrier, $s_c(t)$, is added to the luma carrier, $s_l(t)$, to form a composite video signal given in Equation 6 as:

$$s(t) = s_l(t) + s_c(t) \quad (6)$$

At the receiver, the received passband signal is given in Equation 7 as:

$$y(t) = h(t)s(t) + z(t) \quad (7)$$

where $h(t)$ is the multipath Rician fading channel (Ajayi, 2013) and $z(t)$ is the Additive White Gaussian Noise (AWGN). The luma signal is separated from the received composite video signal using low-pass filter with cutoff frequencies of 4.5 MHz to obtain the Y component. The U and V signals are obtained from the chroma signal by coherent detection, and the outputs of the detectors are expressed in Equations 8 and 9 as:

$$s_c(t) \cos(2\pi f_{sub} t) = \frac{1}{2} V [1 + \cos(4\pi f_{sub} t)] + \frac{1}{2} U \sin(4\pi f_{sub} t) \quad (8)$$

and

$$s_c(t) \sin(2\pi f_{sub} t) = \frac{1}{2} U [1 - \cos(4\pi f_{sub} t)] + \frac{1}{2} V \sin(4\pi f_{sub} t) \quad (9)$$

The signals U and V are recovered by low-pass filtering which removes the $4\pi f_{sub} t$ components. The YUV colour space is converted back to the primary colours (RGB) and the expression is given in Equation 10 by Jack (2007) as:

$$\begin{aligned} R' &= Y + 1.14V \\ G' &= Y - 0.395U - 0.581V \\ B' &= Y + 2.032U \end{aligned} \quad (10)$$

Energy Efficiency and Signal Quality

A communication system is said to be energy efficient if the ratio of average number of data transmitted to average energy consumed is relatively high. The energy efficiency, η , formula used in this work is given in Equation 11 as:

$$\eta = \frac{N_{avg}}{P_{avg}} \quad (11)$$

where N_{avg} is the average number of data transmitted, P_{avg} is the average power consumed during the transmission. The signal quality is a function of the PSNR (dB) of the picture signal obtained at the receiving terminal. The PSNR formula used in this work is given in Equation 12 as:

$$PSNR = 10 \log_{10} \left(\frac{255^2}{\frac{1}{RC} \sum_{i=1}^R \sum_{j=1}^C (I_{i,j} - \hat{I}_{i,j})^2} \right) \quad (12)$$

where I is transmitted picture, \hat{I} is the received picture, R and C are the number of rows and columns in the image, respectively. The higher the PSNR value, the higher the signal quality of the system.

System Simulation Setup

The two systems (DVB-T and PAL) were implemented using MATLAB software package. A video is made up of frames, which are still images. Eight picture frames were acquired from an MP4 video one at a time as Joint Photographic Experts Group (JPEG) images. Each image data, in RGB, was then coded into YUV for PAL transmission and Moving Pictures Expert Group-2 (MPEG-2) for DVB-T transmission separately as shown in Figure 1. The resultant PAL and DVB-T video signals were then passed through the Rician fading channel plus the AWGN to give the received video signals. The received TV signal was then processed by the respective receivers to recover the transmitted pictures. The block model for the receiver

of the DVB-T signal is shown in Figure 2 assuming perfect synchronization of the local oscillator. The DVB-T receiver model consists of the OFDM demodulation aspect as well as MPEG-2 decoding to recover the estimate of the original transmitted pictures. The simulation parameters for the PAL and DVB-T systems are presented in Table 1.

Table 1. System Simulation Parameters

Parameter	Specification	
	DVB-T	PAL
RF carrier frequency (UHF)	826 MHz	826 MHz
Signal bandwidth	8 MHz	8 MHz
Modulation	QPSK, OFDM	AM, QAM
OFDM FFT size	2048	-
Subcarrier frequency	4.462 kHz	4.4336 MHz
OFDM symbol duration	224 μ s	-
Length of CP	56 μ s	-
Reed-Solomon coding	RS(204, 118, t=8)	-
Code rate of convolutional coding	1/2	-
Channel	Rician fading channel	Rician fading channel
Target SINR	6 dB	6 dB

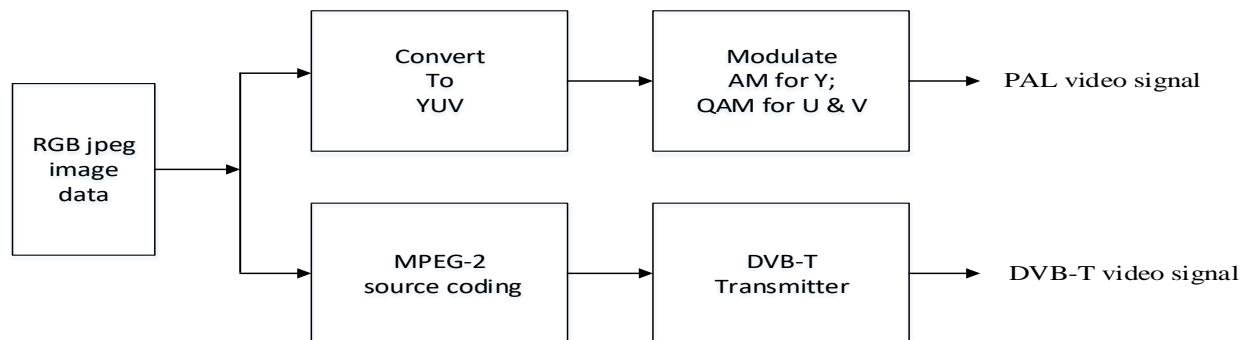


Figure 1: Generation of PAL and DVB-T video signals at the transmitter

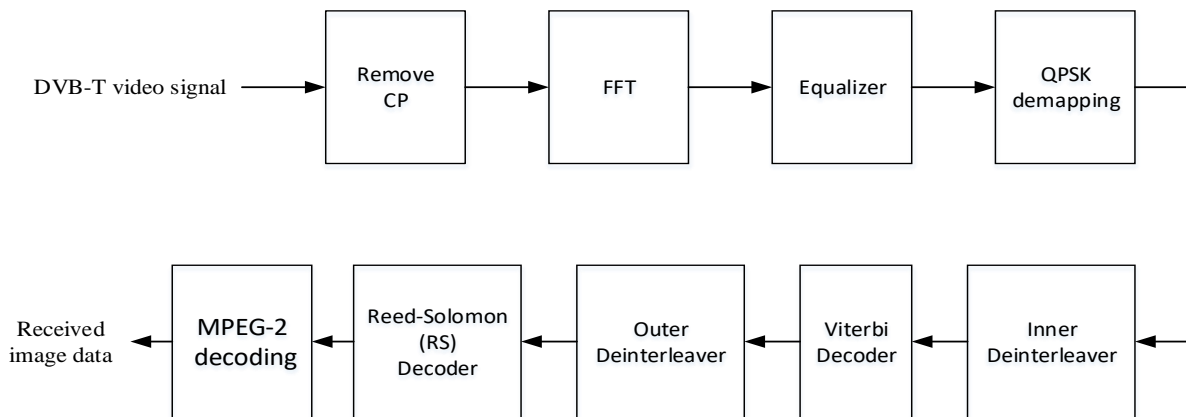


Figure 2: Block diagram of DVB-T TV receiver

3. RESULTS AND DISCUSSION

The performance comparison of the simulated DVB-T and PAL systems are presented in form of plotted graphs. Figure 3 presents the PSNR versus Rice factor (K). The Rice factor, K, depicts the degree of Line-of-Sight (LoS) component in the multipath channel between the transmitter and the receiver. If $K = 0$, the channel is transformed into the Rayleigh fading channel and if $K = \infty$ it is transformed into a simple AWGN channel with no fading. The recovered image is compared with the transmitted image to calculate the PSNR. At $K=0$, the worst case fading scenario, the PAL system gives PSNR of 22.0361 dB while DVB-T gives 37.5479 dB. This reveals that the digital TV (DVB-T) improves the PSNR of the TV picture and invariably the signal quality by 41.31%. The improvement in signal quality provided by the DVB-T is as a result of the resistance of OFDM to multipath or frequency-selective fading.

The graph of average transmission power (P_{avg}) versus number of frames transmitted is shown in Figure 4. The signal to interference noise ratio (SINR) target is set to 6 dB for every number of frames transmitted. The result of the transmission of 8 video frames gives 3.85 dBm for PAL and 3.56 dB for DVB-T. This reveals that DVB-T gives about 7.53% lower transmission power than PAL for the same communication channel. The overall energy efficiency obtained with DVB-T is 53.86% while PAL gives 29.48%. This reveals that the DVB-T system is 24.38% more energy efficient than the PAL system. The energy efficiency improvement provided by DVB-T over PAL is as a result of the effective bandwidth utilization provided by data coding in DVB-T.

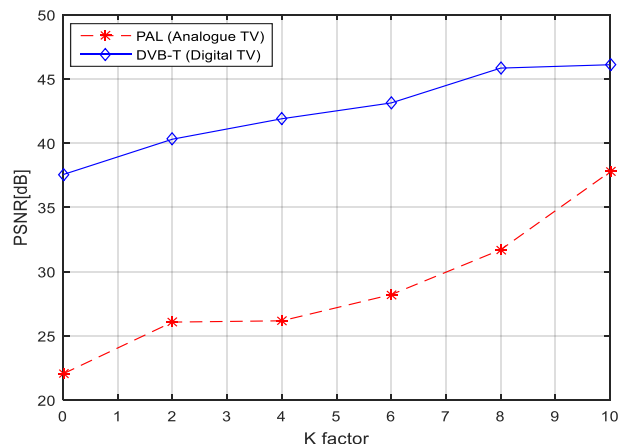


Figure 3: Peak signal-noise-ratio (PSNR) of a received video frame

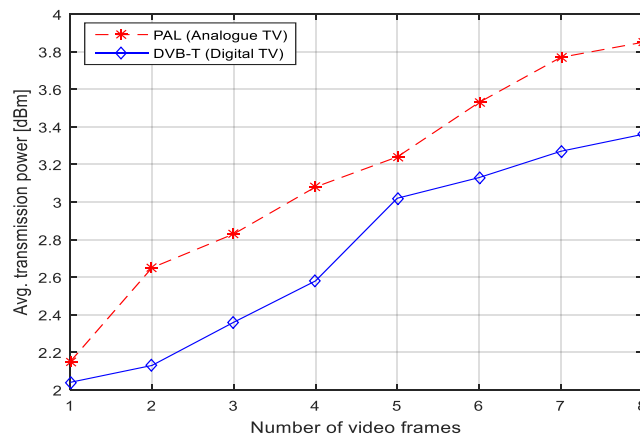


Figure 4: Transmission power consumption with respect to number of video frames transmitted

4. CONCLUSION

This paper investigates the energy efficiency and signal quality of DVB-T, a digital TV system, and PAL, an analogue TV system. The comparison was done by computer simulation under the same channel condition. A short video of 8 frames was transmitted in the simulation using both DVB-T and PAL standards separately. The results reveal that digital TV system outperforms the analogue TV system in terms of both the energy efficiency and signal quality; thereby making digital TV system more economical. An energy efficient system implies an efficient utilization of energy resource, which is good for environmental sustainability.

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