

Latest Trends in Worldwide Digital Terrestrial Broadcasting and Application to the Next Generation Broadcast Television Physical Layer

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Abstract

This paper summarizes key technologies and identifies trends in recent terrestrial broadcast standards. For robust service in urban canyons and mobile environments, Orthogonal Frequency Division Multiplexing (OFDM) has proven extremely advantageous and is employed in ISDB-T, DVB-T2, and DTMB standards. Strong Forward Error Correction (FEC) codes are also needed to increase signal robustness. Low Density Parity Check (LDPC) codes are strong codes that offer coding which enables reception approaching Shannon limit E_b/N_0 levels. They have been adopted in DVB-T2 and DTMB. Another trend is the expanding use of terrestrial broadcast for mobile reception, such as the ATSC-M/H standard. To increase flexibility one innovative technology known as Multiple Physical Layer Pipes (M-PLP) was introduced in DVB-T2, where the physical layer is divided into separate logical signals or “pipes”.

Based on these recent trends, key technologies suitable for Next Generation Broadcast Television (NGBT) are explored. Cutting edge technologies examined include the expansion of modulation constellations to 1024QAM, adoption of recent LDPC FEC coding schemes and the use of Multiple Input Multiple Output (MIMO) technology. We conclude that by using a combination of proven and cutting edge technology, ATSC can develop a world leading standard.

Introduction

Terrestrial broadcasting has evolved from analog to digital and there has been a flurry of second generation digital broadcasting standardization activity worldwide. Consumers have a desire for even higher definition TV, more content and to be able to reliably receive television programs wherever they are. In the near future, new and innovative services such as higher definition television (8K/4K), 3D video and multi sub-channel audio are envisaged. To achieve these desirable new features the physical layer specification must provide increased spectral efficiency, robustness as well as a high level of flexibility for the broadcaster. Each new broadcast standard has made progress towards this goal by applying the latest technological advances to the physical layer.

Recent Trends in Digital Terrestrial Television (DTT)

With larger screen sizes available in the market, higher picture quality is desired. The current industry standard for high quality television is High-Definition (HD) television, which offers up-to 1920x1080 resolution at 60 interlaced frames per second. In the next ten years even higher picture quality is envisaged for broadcast television, for example 4K2K/60p and even 8K4K/60p. In order to provide for this high quality picture, the current HD data rate will increase 8 times for 4K2K/60p, and increase by a factor of 32 compared to current HD television for 8K4K/60p, if using equivalent video compression codecs. Another very recent trend is 3D television. On the physical layer approximately twice the bit rate is desirable to transmit 3D television at the same level of quality. In addition, since spectrum is a scarce resource, the most spectrally efficient technologies should be employed.

Recent years have also seen a proliferation of mobile display and communication devices and consumers desire to receive television on these devices. Successful deployments in Japan using the ISDB-T (One-Seg) standard [3] and in Korea using the T-DMB standard [8] show that under certain conditions, mobile television can be a hit. The European mobile TV standard DVB-H [6] has been widely deployed, but with mixed results. The US has recently standardized mobile-DTV with ATSC A/153 (ATSC-M/H) [7]. To successfully broadcast mobile TV extremely robust modulation and coding methods should be examined.

Technology Trends for Robustness to Multi-path Fading

The terrestrial propagation channel is subject to a number of perturbations such as thermal and man-made noise, time variation and frequency selective fading. All these effects influence the selection and setting of broadcast parameters. Furthermore as it is impossible to guarantee a line-of-sight reception in a terrestrial channel, multi-path propagation is often unavoidable. Multi-path propagation causes inter-symbol interference (ISI) and frequency-selective fading. There exist two different options to minimize the effects of multi-path fading. First is to limit the broadcasters' choice of transmission scheme and parameters, such as by choosing OFDM and an extremely large guard interval. The second option is to design receiver algorithms to estimate the channel impulse response and reduce its effects using efficient channel equalization.

Table 1 illustrates the key parameters of recent DTT standards. They can broadly be categorized into two types: (i) single carrier (SC) and (ii) multi carrier (MC) or OFDM.

In OFDM the available bandwidth is divided into a number of narrowband sub-carriers. The partial allocation of the data payload to each sub-carrier protects it against frequency-selective fading. This is due to the fact that the channel over each sub-carrier can now be considered as flat-fading resulting in a low-complexity equalization using a simple one-tap equalizer. In SC transmission systems such as ATSC and DTMB (C1) [2] channel equalization is relatively complex, usually deploying multi-tap decision-feedback adaptations.

Two different OFDM schemes have been adopted in recent digital TV standards. In cyclic prefix OFDM (CP-OFDM) as used in DVB-T2 [1] and ISDB-T, the cyclic prefix is some samples of the OFDM symbol which are copied to the front of the symbol. In DTMB (C3780) [2], unique PN sequences are inserted at the front of each OFDM symbol. The creation of CP-OFDM and PN-OFDM symbols is shown in Fig.1. In CP-OFDM-based systems such as DVB-T2 and ISDB-T it is possible to cancel ISI completely by insertion of a cyclic prefix guard interval, provided that the channel delay spread is smaller or equal to the guard interval duration. Pseudorandom number sequences used in DTMB (3780) have good autocorrelation properties which assist in channel estimation, however ISI cannot be completely cancelled due to the interference caused by the delayed path's PN sequence into the first OFDM symbol.

Key Features of Recent World-Wide DTT Transmission Standards

Standard	DVB-T2 [1]	DTMB [2]		ISDB-T [3]	ATSC A/53 [4]
		(C1)	(C3780)		
Country of Origin	Europe	China		Japan	US
Year	2008	2006		2003	2005
Frequency Range (MHz)	470-862 and 174-230	470-862		470 – 770	54-72,76-88,174-216,470-698
Channel Spacing, B (MHz)	1.7, 5, 6, 7, 8, 10	8		6, 7, 8	6
Type	Multi-Carrier CP-OFDM	Single Carrier	Multi-Carrier PN-OFDM	Multi-Carrier CP-OFDM	Single Carrier
Number of Sub-Carriers (K = 1024)	1K ,2K, 4K, 8K, 16K, 32K	1	3780	2K, 4K, 8K	1
Sub-Carrier Modulation	QPSK, 16QAM, 64QAM, 256QAM	4QAM-NR, 4QAM, 16QAM, 32QAM, 64QAM		QPSK, 16QAM, 64QAM, DQPSK	8VSB
Useful Symbol Length, T_u (us)	112 to 3,584 (8 MHz Channel)	-	500	252 to 1008	0.092917
Guard Interval, T_g (fraction of T_u)	1/128, 1/32, 1/16, 19/256, 1/8, 19/128, 1/4	-	1/4, 595/3780, 1/9	1/4, 1/8, 1/16, 1/32	-
Sub-Carrier Spacing (Hz)	279 to 8,929 (8 MHz Channel)	-	2k (8MHz)	992 to 3968 (6 MHz Channel)	-
Net Bit Rate, R (Mbit/s)	40.2 (Typical), 50.3 (Max.)	4.81 - 32.49		3.651 - 23.23	19.392658
Link Spectral Efficiency, R/B (bit/s/Hz)	0.87 - 6.65	0.60 - 4.1		0.61 - 3.87	3.23
Inner FEC	LDPC {1/2, 3/5, 2/3, 3/4, 4/5, 5/6}	LDPC {0.4, 0.6, 0.8}		Convolutional Code {1/2, 2/3, 3/4, 5/6, 7/8}	Convolutional Code (2/3)
Outer FEC	BCH	BCH (762, 752)		Reed Solomon (204, 188)	Reed Solomon (207,187)
Time Interleaving Depth (ms)	80 ms (U.K. mode)	200 - 500		0 to 400	4
Main Unique Features	Rotated Constellations, FEFs, Multi-Pipes, MISO	TDS-OFDM (PN Sequence Insertion)		Segmented OFDM	Low C/N Requirement

Table 1. Key Features of Recent Worldwide DTT Transmission Standards

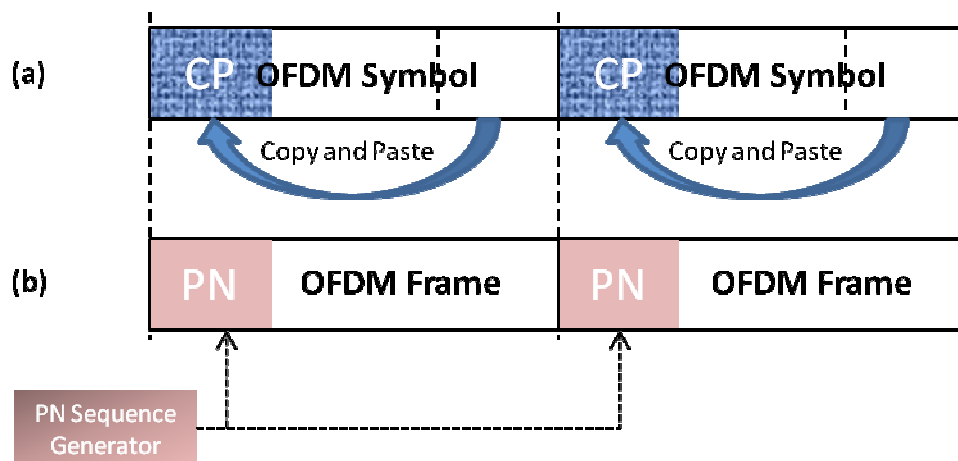


Fig. 1. Guard Interval Insertion, (a): Cyclic Prefix (CP-OFDM), (b): PN Sequence (PN-OFDM)

To mitigate the frequency selective effects of multi-path propagation the receiver needs to perform accurate estimation of the channel followed by efficient channel equalization. In DVB-T2 and ISDB-T, pilot sub-carriers, at regular grids which shift positions from one OFDM symbol to the next, are inserted in between the data carriers. The receiver makes use of the known pilot sub-carriers to first estimate the frequency response of the channel at these locations. Secondly, it extends the frequency response to full bandwidth by some form of interpolation such as frequency-only or time-frequency interpolation. In DTMB (C3780) the PN sequences are used to estimate the time-domain channel response which is then used for equalization of the data frame.

Table 1 shows that the most recent DTT standard, DVB-T2, is the most spectrally efficient at 6.65 bit/s/Hz. This system is currently used in the UK for transmitting free-to-air HDTV with a net data rate of greater than 40 Mbps. This high spectral efficiency is achieved due to the high number of sub-carriers, large constellation size (256QAM) and the minimum number of pilot symbols within the standard.

FEC Trends

Error control coding in a broadcasting scenario typically comes in the form of forward error correction (FEC) coding. The ratio of information to code symbols is reflected by the code rate. To meet the demand for high spectrum efficiency, FEC techniques are becoming more important and much research has been undertaken. Low density parity-check (LDPC) codes are known to achieve high capacity, high throughput, and have been adopted in DVB-T2 and DTMB. LDPC are the codes of choice for all recent second generation broadcast formats.

Density evolution is one powerful tool to analyze the asymptotic behavior of an LDPC ensemble (a set of LDPC codes of a certain degree profile and of infinite length) and it is usually used to guarantee the performance of the codes. Quasi-cyclic structure with unit circulant matrices in a parity-check matrix is very effective to reduce matrix ROM size and the randomness of memory accesses. This helps to maximize decoder parallelism so that higher throughputs can be realized. In order to simplify the encoding procedure, an accumulator structure is set in parity-check matrices, which enables calculation of parity bits with simple accumulators.

DVB-T2 adopts LDPC codes of length $N=64800$ (Normal mode) and 16200 (Short mode) with quasi-cyclic and accumulator structure in their parity-check matrices. Unit circulant matrix size l is equal to 360. In order to increase data rates, constellations of high order up to 256QAM are employed.

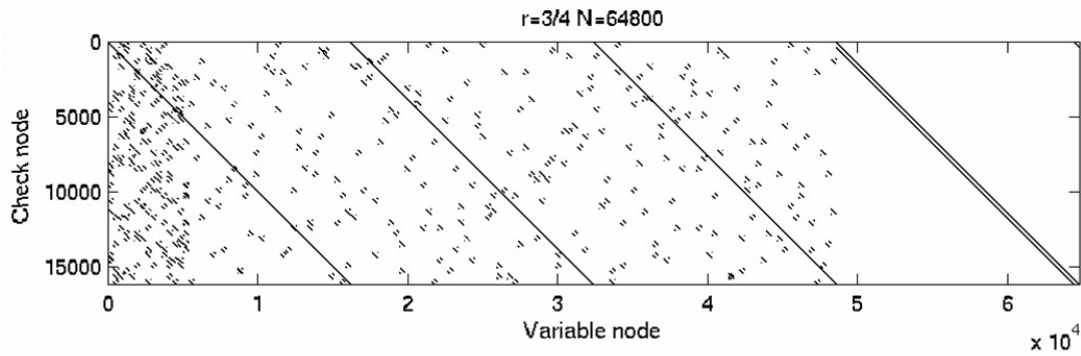


Fig. 2. One of DVB-T2 parity check matrices with quasi-cyclic and accumulator structure, in which each black dot means “1” and blank means “0” in the matrix ($N=64800$, rate= $3/4$, $l=360$). Two diagonal lines in the right hand side construct accumulators for encoding.

DTMB adopts LDPC codes of length $N=7493$ with quasi-cyclic structure, but without accumulators in its parity-check matrices. Generator matrices with the same cyclic structure are defined for encoding procedures, whose unit matrix size l is equal to 127. Constellations for the standard are up to 64QAM.

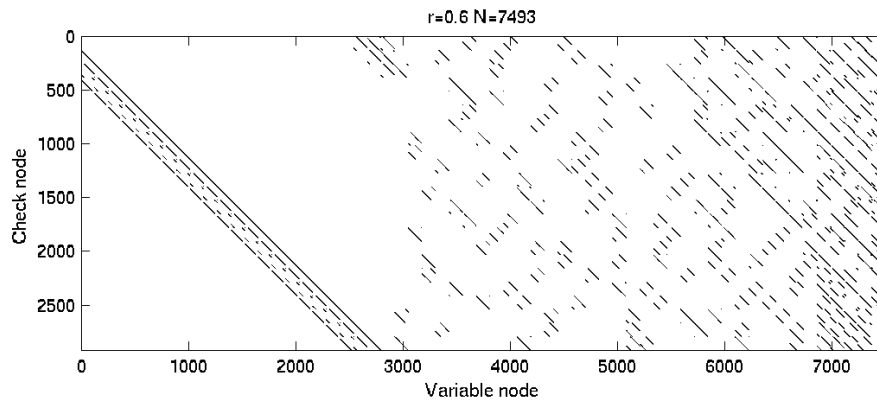


Fig. 3. One of DTMB parity check matrices with quasi-cyclic structure, in which each black dot means “1” and blank means “0” in the matrix ($N=7493$, rate= 0.6 , $l=127$). First 2921 columns correspond to parity bits.

Figure 4 shows the comparison of spectrum efficiency based only on FEC differences between DVB-T2 and DVB-T [6], the 1st generation European digital video broadcasting standard. DVB-T employed convolutional codes as its inner codes and Reed-Solomon codes as its outer codes. DVB-T2 obtains more than approximately 1.5 times as much capacity as DVB-T by employing LDPC codes with spectral efficiency approaching the Shannon limit.

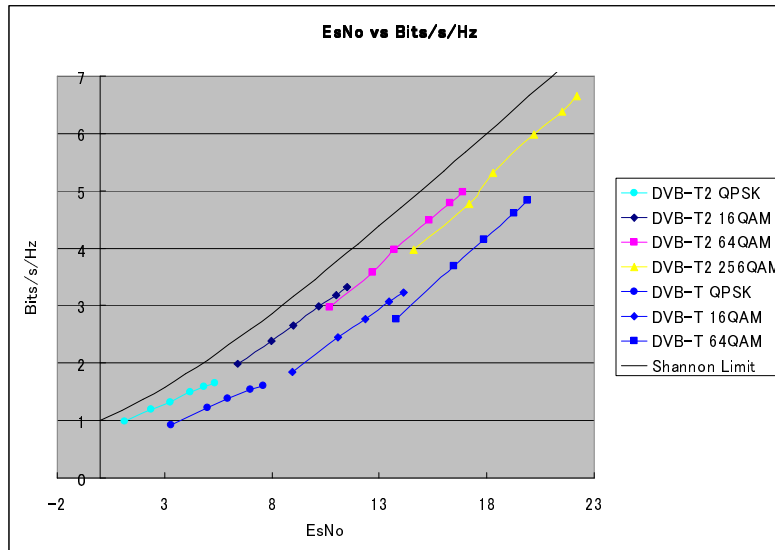


Fig. 4. Es/No vs. Bits/s/Hz graph for DVB-T2 [1] and DVB-T [6].

Technology Trends for Flexibility

Recent digital television standards have also addressed the issue of flexibility and multiple use broadcasts from a single transmission. DVB-T2 has incorporated the concept of physical layer pipes (PLP). When multiple physical layer pipes (M-PLP) are used, different modulation and coding rates can be applied to each PLP, enabling different levels of robustness. This way, not only high definition video with static reception but also radio, mobile and portable television can be accommodated in the same frequency channel.

DVB-T2 also introduced the concept of Future Extension Frames (FEF) which enables as-yet-unknown future services to be easily added without creating a new physical layer standard, but simply adding different signaling so that new receivers can demodulate the FEF part, while existing receivers will ignore the new section.

Application of New Technologies to NGBT

While many trends have been outlined from current digital television standards, we now examine adoption and extension of these technologies, as well as cutting edge technologies that have yet to be adopted for digital broadcast television and their applicability to NGBT.

A straightforward possibility to increase the data rates is to apply higher order QAM constellations to an OFDM based modulation. In DVB-T2 increasing the constellation size from 64QAM used in DVB-T to 256QAM has proved to be successful. This requires more SNR and more accurate channel estimation and frequency synchronization. In conjunction with powerful FEC and/or MIMO schemes for increased diversity, the possible use of 1024QAM should be considered. As an example, 1024QAM together with a 64k LDPC code from DVB-C2 of rate 2/3 would require a SNR of 24.8 dB over the AGWN channel [5]. Exploring how these large QAM sizes can be realistically applied to terrestrial broadcasting is a challenge.

Another challenge is to introduce new technologies in a broadcast environment. Multiple Input Multiple Output (MIMO) transmission is one such technology, in which multiple antennas at both transmitter and receiver can be used in a multi-path fading channel to increase the robustness of the system. Several well-

known types of MIMO exist including spatial multiplexing to increase the symbol rate and exploitation of spatial diversity by space-time coding. The performance of MIMO schemes worsens with increasing spatial correlation at the antenna arrays. To reduce this correlation, the transmit antennas should be spaced appropriately. One way to achieve this is to interpret different broadcasting towers as being part of the transmit antenna array. The spatial correlation is even higher at the receiver. In order to allow for co-located receive antennas an alternative approach is to use orthogonal polarization, broadcast from the same antenna. The exploration of how to create a robust and highly efficient MIMO broadcast system using orthogonal polarization is one direction for NGBT research and development.

Conclusion

Recent digital television standards have shown that there are many techniques that can be used to increase the data rate, spectral efficiency and robustness as well as provide for more flexibility in the physical layer. Particularly of note is the use of OFDM to provide robustness against multi-path fading and state-of-the-art FEC codes such as LDPC codes. We should explore more advanced technology based on OFDM and LDPC for use in NGBT, while also incorporating cutting edge technologies such as MIMO.

References

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