Next-Generation Digital Television Terrestrial Broadcasting Systems: Key Technologies and Research Trends

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ABSTRACT

In the last two decades, digital television terrestrial broadcasting (DTTB) systems have been deployed worldwide. With the approval of the fourth DTTB standard called Digital Television/Terrestrial Multimedia Broadcasting (DTMB) by International Telecommunications Union (ITU) in December 2011, the research on first-generation DTTB standards is coming to an end. Recently, with the rapid progress of advanced signal processing technologies, next-generation DTTB systems like Digital Video Broadcasting-Terrestrial-Second Generation (DVB-T2) have been extensively studied and developed to provide more types of services with higher spectral efficiency and better performance. This article starts from the brief review of the first-generation DTTB standards and the current status of emerging second-generation DTTB systems, then focuses on the common key technologies behind them instead of describing the specific techniques adopted by various standards. The state-of-the-art, technical challenges, and the most recent achievements in the field are addressed. The future research trends are discussed as well. In addition, the scheme of integrating DTTB and Internet is proposed to solve the crucial problem of information expansion.

INTRODUCTION

Digital television terrestrial broadcasting (DTTB) system could realize the revolutionary technology of high definition television (HDTV) with the quasi error free (QEF) performance at the bit error rate (BER) as low as 10^{-12}, which means that the uncorrectable error is less than one during one hour's continuous transmission of 5 Mb/s data stream [1]. After International Telecommunications Union (ITU) approved the fourth DTTB standard called Digital Television/Terrestrial Multimedia Broadcasting (DTMB) in December 2011, there are currently four international DTTB standards [1]: the one recommended by Advanced Television Systems Committee (ATSC) of the U.S., Digital Video Broadcasting-Terrestrial (DVB-T) proposed by European Telecommunications Standards Institute (ETSI), Integrated Service Digital Broadcasting-Terrestrial (ISDB-T) developed by Japan, and DTMB from China. In the last twenty years, those DTTB standards have been successfully adopted by many countries. Although HDTV could be delivered by all of them, information expansion makes our world in need of more powerful DTTB systems capable of providing more types of services more efficiently and reliably [2]. Thanks to the rapid progress of advanced modern signal processing technologies, next-generation DTTB systems have been extensively studied and developed to fulfill those requirements [3, 4].

It is significant to inform people from both academia and industry of the principles and key technologies of those emerging systems. Therefore, rather than discussing the specific techniques adopted by various standards, this article seeks to generalize the typical and common key technologies for next-generation DTTB systems, including the discussion about their current status, technical challenges, and more importantly, the future research trends.

The remainder of this article is organized as follows: we briefly review first-generation DTTB standards already deployed worldwide at first. Then, we outline the current development of next-generation DTTB systems, whose key technologies and research trends are discussed later. Finally, conclusions are drawn.

REVIEW OF FIRST-GENERATION DTTB STANDARDS

The general DTTB system architecture is shown in Fig. 1. Currently, there are four first-generation international DTTB standards approved by ITU, namely, ATSC, DVB-T, ISDB-T, and DTMB. Although they share similar system architecture, different technical features could be found.

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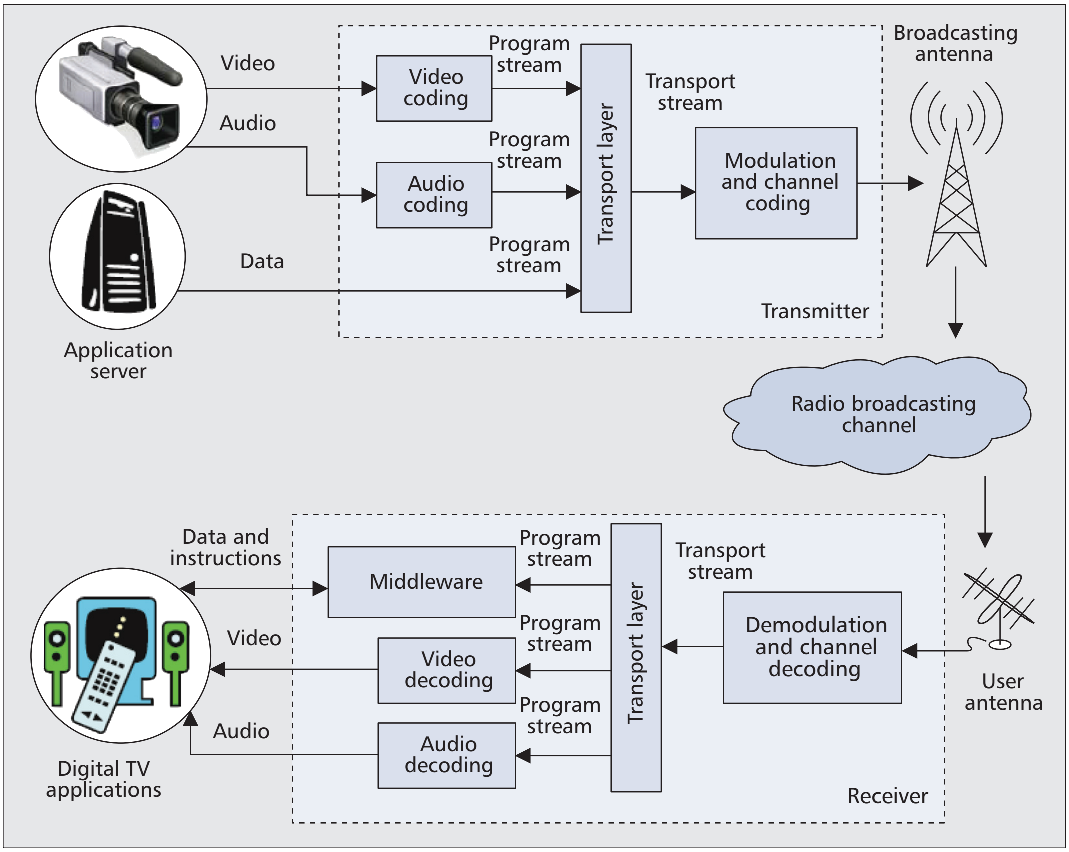

Figure 1. *System architecture of typical DTTB systems.*

After the deployment and successful application of various DTTB systems, novel advanced signal processing technologies are continuously emerging. Meanwhile, people are demanding more powerful DTTB systems with higher data rate and more reliable performance.

ATSC

As the first DTTB standard proposed by ATSC of the U.S. in September 1995, ATSC adopts single-carrier transmission technology. It has been deployed in the U.S., Canada, Korea and other five countries. The original design goal of ASTC is only to realize outdoor fixed HDTV reception over the 6 MHz channel at the data rate of 19.39 Mb/s. Although its transmitter power is low, due to the high complexity as well as the error propagation of the decision feedback equalization, ASTC is sensitive to multipath fading channels, and it is difficult to support mobile reception.

DVB-T

Announced by ETSI in March 1997, DVB-T is the most popular DTTB standard widely adopted by more than 60 countries. Its core technology is the coded orthogonal frequency division multiplexing (OFDM) multi-carrier transmission with excellent capability of combating wireless multipath channels. DVB-T could support indoor and outdoor fixed reception, as well as portable and mobile services over the 8 MHz channel at the date rate ranging from 4.98 to 31.67 Mb/s.

ISDB-T

ISDB-T developed by Japan in May 1999 is mainly applied in Japan, Brazil, Peru and other Central and South American countries. ISDB-T can be deemed as a derivative of DVB-T because of their similar technical features and system parameters. However, compared with DVB-T, ISDB-T has two major improvements. First, the interleaver with longer depth is used to improve the mobile reception performance. Second, the key technology called bandwidth segmented transmission OFDM (BST-OFDM) enables ISDB-T the capability of supporting multiple services.

DTMB

Formally launched by China in August 2006, DTMB has been adopted by China (including Hong Kong and Macao), Laos, Cambodia, and Cuba. The key technology of DTMB is the novel multi-carrier transmission scheme called time domain synchronous OFDM (TDS-OFDM), which uses a known pseudorandom noise (PN) sequence instead of cyclic prefix (CP) as the guard interval between consecutive data blocks to achieve higher spectral efficiency and faster synchronization [5]. DTMB also adopts the powerful low-density parity-check (LDPC) code cascaded by Bose-Chaudhuri-Hocquengham (BCH) code to further improve the system performance. DTMB could provide the data rate up to 32.49 Mb/s within the 8 MHz signal bandwidth.

Table 1 summarizes the main system parameters of those four DTTB standards.

Current Status of Next-Generation DTTB Systems

After the deployment and successful application of various DTTB systems, novel advanced signal processing technologies are continuously emerging. Meanwhile, people are demand-

	ATSC	DVB-T	ISDB-T	DTMB
Applicable Standard	A.52/A.53	EN 300 744	ARIB STD-B31	GB 20600-2006
System Bandwidth	6 MHz	6, 7, and 8 MHz		
Source Coding	MPEG-2 transport stream			
Transmission Scheme	Single Carrier	Coded OFDM with 2k and 8k FFT size	BST-OFDM with 2k, 4k and 8k FFT size	TDS-OFDM with 3780 FFT size + Single Carrier
Guard Interval	—	1/32, 1/16, 1/8 and 1/4		1/4 (PN945), 1/7 (PN595), 1/9 (PN420)
Channel Coding	Rate 2/3 trellis code + RS(207,187, t = 10)	Punctured convolutional codes with code rate	1/2, 2/3, 3/4, 5/6, 7/8 + RS(204,188, t = 8)	LDPC(7488, 3008/4512/6016) + BCH(762, 752)
Modulation Scheme	8-VSB	QPSK, 16QAM and 64QAM	DQPSK, QPSK,16QAM, and 64QAM	QPSK, 4QAM-NR,16QAM,32QAM and 64QAM
Interleaver	12 to 1 trellis code Interleaver	Bit-wise interleaver+ symbol interleaver	Bit-wise interleaver + time and frequency interleaver	Convolutional interleaver
Data Rate	19.39 Mb/s	4.98–31.67 Mb/s	3.65–23.23 Mb/s	4.81–32.49 Mb/s

Table 1. *Main system parameters of DTTB standards.*

ing more powerful DTTB systems with higher data rate and more reliable performance. Around 2000, the research work for next-generation DTTB standards was started worldwide, and recently three systems have been announced [3].

DVB-T2

In September 2009, ETSI formally announced the new-generation DTTB standard called DVB-Terrestrial-Second Generation (DVB-T2), whose updated version optimized for mobile reception was introduced in April 2012 [4]. Based on but not compatible with its preceding standard DVB-T, DVB-T2 allows a better use of the spectrum with the increased spectral efficiency by more than 30 percent, which is achieved by integrating plenty of edge-cutting signal processing technologies like enhanced OFDM transmission, flexible frame structure, LDPC/BCH code, bit-interleaved coded modulation with iterative decoding (BICM-ID), transmit diversity, constellation rotation, peak-to-average power ratio (PAPR) reduction, physical layer pipes (PLP), etc. Until now, DVB-T2 is the most advanced DTTB system with high spectral efficiency, reliable performance and flexible configuration.

ATSC-M/H

In April 2009, the U.S. launched a new standard for next-generation DTTB: ATSC-Mobile/Handheld (ATSC-M/H). ATSC-M/H is backward compatible with ATSC, and could support real-time interactive services. The most prominent feature of ATSC-M/H is the capability of mobile reception. Part of the available 19.39 Mb/s throughput in ATSC is used by ATSC-M/H to support portable and mobile services, whereby a more powerful error correction scheme called series concatenated convolutional code (SCCC) is adopted. In addition, by superimposing the orthogonal spreading sequences with the power of –30 dB on TV signals without affecting the normal TV program reception, ATSC-M/H could provide the capability of wireless localization.

ISDB-Tmm

In July 2010, Japan's new-generation DTTB standard named ISDB for Terrestrial multimedia broadcasting (ISDB-Tmm) was announced. ISDB-Tmm is highly compatible with ISDB-T. ISDB-Tmm could provide a variety of interactive services by improving the existing "one-segment" technology. Multi-media materials like e-books, news, music, pictures, and movies could be downloaded to mobile handsets with high speed. Through various combinations of the 13 segment groups (a total bandwidth of 5.61 MHz) and one segment (the bandwidth of 0.429 MHz), without the need of protection band, ISDB-Tmm could flexibly support variable transmission bandwidth ranging from 13 segments (a total bandwidth of 5.61 MHz) to 33 segments (the maximum bandwidth of 14.2 MHz). The receiver could realize partial reception within any segment. Meanwhile, Japan is studying the multiple-input multiple-output (MIMO) technology for DTTB systems, and taking into account the use of higher order modulation schemes, such as 1024 QAM, to maximize the system capacity.

Key Technologies and Research Trends of Next-Generation DTTB Systems

In this section, we generalize the common key technologies behind various next-generation DTTB systems. The future research trends of those technologies will be addressed as well.

OFDM-BASED TRANSMISSION

Due to its excellent robustness to frequency-selective fading channels and the capability of providing high-speed data rate, OFDM is becoming a standard component for upcoming DTTB systems and wireless communication systems [2, 4].

Similar to DVB-T, DVB-T2 adopts classical CP-OFDM technology where CP is used as the guard interval to alleviate inter-block-interference (IBI) as well as inter-carrier-interference (ICI) [2, 4]. Some frequency-domain pilots within the OFDM data block are used for synchronization and channel estimation to achieve reliable transmission. As the key technology of DTMB, TDS-OFDM differs from CP-OFDM by exploiting the known PN sequence instead of CP as the guard interval [5]. Furthermore, the PN sequence can be also used as a training sequence (TS) for synchronization and channel estimation. Consequently, TDS-OFDM outperforms CP-OFDM in spectral efficiency since no pilots are required [2].

However, channel estimation and data demodulation have to be iteratively implemented in TDS-OFDM to realize iterative inference cancellation between the TS and the unknown OFDM data block, so TDS-OFDM suffers from performance loss over frequency-selective multipath channels, especially when the channels are varying fast, i.e., the channels are doubly selective. One possible solution to this problem is the unique word OFDM (UW-OFDM) [6], whereby the TS is not independent of the OFDM block like that in TDS-OFDM, but is generated by the redundant frequency-domain comb-type pilots within the OFDM data block. In this way, the IBI from the TS to the OFDM data block can be naturally avoided. However, it does not solve the problem of the IBI from the OFDM data block to the next TS, and the redundant pilots usually have much higher average power than normal data.

Dual-PN padding OFDM (DPN-OFDM) is an effective solution to solve the interference problem of TDS-OFDM, whereby the TS is repeated twice to avoid the IBI from the OFDM data block to the second TS, which can be directly used to achieve reliable channel estimation [7]. Therefore, iterative interference cancellation could be avoided, leading to the reduced complexity and improved performance over doubly selective channels. However, DPN-OFDM obviously reduces the spectral efficiency since one extra TS is added. This issue becomes more severe when large TS length is required in single-frequency networks (SFN), which the main application scenario for next-generation DTTB systems. To sum up, it is challenging for OFDM-based transmissions to simultaneously achieve high spectral efficiency and reliable performance.

Very recently, based on TDS-OFDM, the time-frequency training OFDM (TFT-OFDM) scheme [7] for next-generation DTTB systems has been proposed. As illustrated by Fig. 2, every TFT-OFDM symbol has time-frequency training information composed of the time-domain TS and a very small number of frequency-domain grouped pilots. With the joint time-frequency channel estimation, the received TS without interference cancellation is directly utilized to merely acquire the path delay information of the channel, while the path coefficients are estimated by the frequency-domain pilots. It has been demonstrated in [7] that compared with conventional CP-OFDM, TDS-OFDM, UW-OFDM, and DPN-OFDM schemes, TFT-OFDM could provide the best solution to achieve high spectral efficiency, fast yet reliable synchronization, accurate channel estimation, and obviously improved bit error rate (BER) performance, especially over doubly selective fading channels. Applying the new groundbreaking compressive sensing (CS) theory [8] could further improve the reliability of TFT-OFDM over harsh channels.

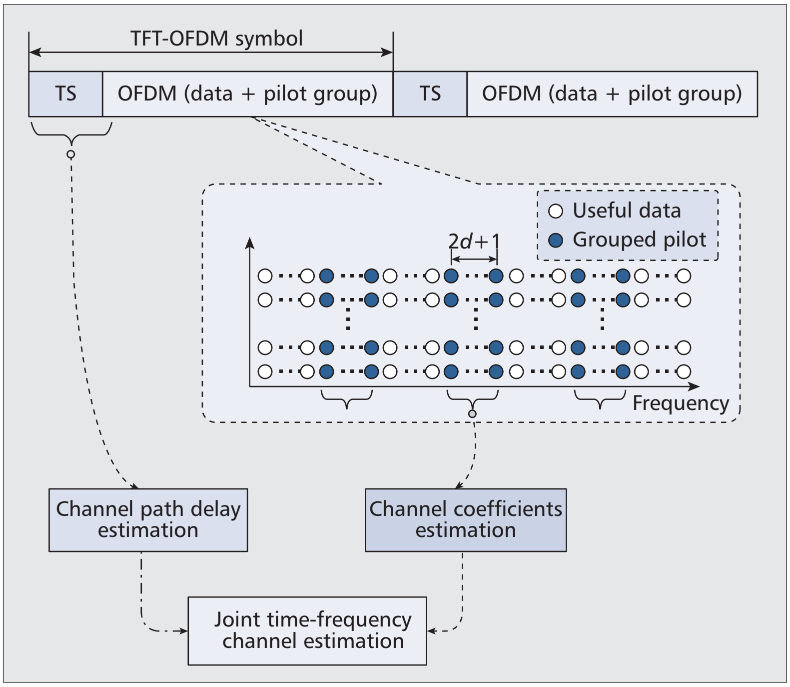

Figure 2. *Signal structure and the corresponding time-frequency joint channel estimation of the TFT-OFDM scheme.*

Future research topics about OFDM-based transmission may include flexible frame structure design with high efficiency, configurable OFDM design with variable guard interval length/IFFT size/subcarrier spacing, fast and reliable timing/frequency synchronization, high-performance channel estimation and equalization over doubly selective channels (CS theory can be exploited to substantially improve the performance), spectrum-efficient pilot pattern/training sequence design, PAPR reduction techniques, etc. When CS theory is used, how to design the TS under the new criterion required by the CS theory, and how to reduce the complexity of CS signal recovery algorithms for real-time implementation are open problems deserving extensive research efforts.

MODULATION AND CHANNEL CODING

The highest order of the modulation schemes supported by first-generation DTTB systems is 64 QAM, while higher-order modulation

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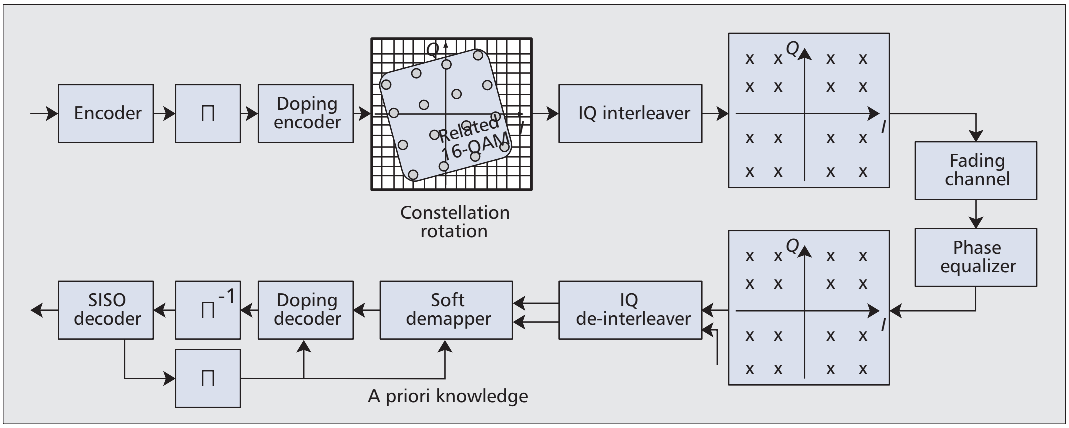

Figure 3. *Functional diagram of the BICM-ID-SSD technique.*

schemes like 256 QAM are expected for next-generation DTTB systems to improve the spectral efficiency. DVB-T2 with 256 QAM has been practically deployed in the United Kingdom [4]. For DTMB systems where TDS-OFDM is used, obvious performance loss for 256 QAM could be imagined because IBI cannot be completed removed, but this issue can be probably solved by the TFT-OFDM scheme derived from TDS-OFDM, especially when CS theory is utilized to further improve the performance. The capability of supporting higher order modulation schemes, e.g., 512 QAM, or even 1024 QAM, remains a challenging research topic.

Another exciting new technique for modulation is constellation rotation, whereby the standard constellation is rotated by a certain angle to correlated the originally independent I and Q components. Coordinate interleaving can be further used to make I and Q components subject to independent fadings, resulting in the so-called signal space diversity (SSD) technique used to achieve diversity gain without power or bandwidth penalty [9]. The challenging problem of how to determine the optimal rotation angle under different scenarios should be studied in the future.

In DTTB systems, the wireless channel is open to various interferences, and channel coding provides an efficient way to substantially improve the reliability. Channel coding is a everlasting hot research topic in information theory community, and numerous high-performance coding schemes have been studied and successfully used. Among them, due to its low complexity and excellent performance, LDPC code is widely recognized as the most promising candidate for next-generation DTTB systems and wireless communication systems. To ensure the rigid requirement of QEF for reliable HDTV services, BCH is usually cascaded with LDPC to eliminate the error floor of the standalone LDPC code. The first system adopting LDPC/BCH scheme maybe DVB-Satellite-Second Generation (DVB-S2), where 8PSK/16APSK/32APSK modulation schemes are used together with LDPC/BCH to provide the outstanding performance only 0.7 dB away from the Shannon limit [4]. DTMB and DVB-T2 also adopts LDPC as the inner code and BCH as the outer code to provide reliable performance over various channels [4, 5].

Conventionally, modulation and channel coding are separately studied and implemented. Nowadays, they are jointly optimized by the well-known coded modulation technology, and BICM-ID is an powerful coded modulation scheme, which is becoming the widely adopted technique over fading channels. For example, DVB-T and ISDB-T have adopted BICM-ID with the Gray mapped 64 QAM to improve the system reliability [1]. Moreover, extensive studies indicate that by combining BICM-ID and SSD, i.e., the BICM-ID-SSD technique as shown in Fig. 3, the system performance over various fading channels could be substantially improved [4]. BICM-ID-SSD was firstly adopted by DVB-Return Channel through Satellite (DVB-RCS), whereby Turbo code is used. DVB-T2 also recommends the LDPC-based BICM-ID-SSD scheme to achieve reliable performance [4]. One recent achievement of BICM-ID-SSD is that the constellation rotation angle can be optimized under the criterion of maximizing the average mutual information [9].

Future research trends for coded modulation lie in the optimal constellation mapping schemes (including APSK and QAM) to achieve the near-capacity performance, the low-complexity implementation strategies for practical applications, the error floor elimination methods like doping, and Turbo equalization over harsh channels. Moreover, BICM-ID could be combined with channel estimation in a turbo way to further improve the performance by jointly optimizing the inner and outer receivers.

Multiple-Input Multiple-Output

MIMO is widely recognized as an efficient way to increase the system capacity and improve the transmission reliability. Nowadays, MIMO and OFDM are becoming two indispensable physical layer technologies for most of emerging transmission systems [2, 4, 10].

When most of the first-generation DTTB standards were constituted in late 90s of the 20 century, MIMO was just an emerging technique at that time, so those standards did not consider MIMO. However, with the rapid development of MIMO technology, numerous research and experiments have been carried out for MIMO-based DTTB systems to improve the system performance. Field test results have

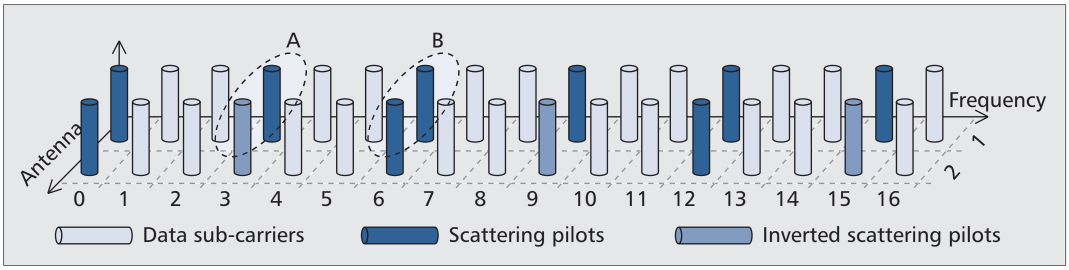

Figure 4. *Scattered pilot pattern for antennas 1 and 2.*

demonstrated that if four receive antennas are used, the signal-to-noise ratio (SNR) threshold at the receiver could be reduced by 6 dB when the mobile speed of 500 km/h is supported by DVB-T, and HDTV is feasible in mobile environments when 64 QAM is adopted by ISDB-T [2, 10].

Since receive diversity requires the replacement of the widely deployed fixed reception antennas, transmit diversity without changing the existing rooftop receive antennas is more attractive for DTTB systems, whereby several high-power transmit towers are serving hundreds of thousands of users. Therefore, to reuse existing reception antennas, only transmit diversity is recommended by DVB-T2 [4], whereby the Alamouti space-time block coding (STBC) scheme is adopted to enlarge the coverage area by about 30 percent. As shown in Fig. 4, the inverted scattering pilots are designed for channel identification when transmit diversity is adopted. Transmit diversity has also been extensively studied for DTMB, where multiple-antenna supporting is more challenging because of the complex interferences between PN sequences and unknown OFDM data blocks. The potential solution is to design the training sequences orthogonal in the time and/or frequency domains [10].

Due to the maturity of coding scheme design for MIMO systems, low-complexity implementation algorithms may be the future research focus. Moreover, transmit diversity has already been extensively studied for DTTB systems, which could be combined with receive diversity to improve the system reliability in more harsh scenarios like SFN. In addition, in contrast to a small number of antennas (e.g., 2, or 4) is mainly used to achieve the spectral efficiency of about 10 bps/Hz or less today, large-scale MIMO [11] with tens of antennas is an emerging technique to achieve the attractive spectral efficiency up to several tens of bps/Hz or even higher. The key challenges for large-scale MIMO systems include the proper antenna placement to ensure independent MIMO channels, low-complexity signal detection algorithms for practical implementation, and channel estimation of the large-size MIMO channel matrix, etc.

Return Channel for Interactive Services

Conventional DTTB systems could only provide unidirectional downlink broadcasting services to users. Nowadays, the booming need of interactive services like Video on Demand (VoD), remote voting, gaming, Web surfing, etc., requires the interaction between content providers and users. Interactive services have been recognized as the "killer application" for next-generation DTTB systems [12]. Real-time interactive services require a return channel to realize bidirectional interactivity.

One way to set up the return channel is to design a new uplink technology with multiple access capability. DVB-Return Channel through Terrestrial (DVB-RCT) with the coverage radius as large as 60 km is the typical standard for such solution [12]. Combined with traditional DTTB systems like DVB-T/ATSC, bidirectional and asymmetric links could be established [12]. The key component of return channel is the multiple access scheme, and DVB-RCT adopts orthogonal frequency division multiple access (OFDMA), which has also been successfully used in both downlink and uplink of IEEE 802.16e, as well as the downlink of Long-Term Evolution (LTE). However, high PAPR of OFDM/OFDMA signals imposes huge power consumption on user terminals, so single-carrier frequency-division multiple access (SC-FDMA) with low PAPR is adopted as the uplink multiple access scheme in LTE. Recently, a novel time-domain synchronous frequency division multiple access (TDS-FDMA) scheme has been proposed [13], whereby an unified frame structure for both single-carrier and multi-carrier transmissions is designed to improve the spectral efficiency and provide the simple selection between OFDMA and SC-FDMA according to the system requirements.

The alternative promising solution to the return channel is to exploit the existing communication networks like wireless local area network (WLAN) or 2G/3G cellular networks [14]. This solution has the advantages in coverage, charging, technical maturity, etc. One successful example is the joint European and Chinese project funded by the European Commission named MING-T (multi-standard integrated network convergence for global mobile and broadcast technologies), which focuses on the convergence of DTTB systems and mobile communication networks [14]. As illustrated in Fig. 5, the DTTB systems like ATSC/DVB-T/DTMB/DVB-Handhold (DVB-H) are used to provide high-speed downlink transmission, while the return channel is implemented by mature WLAN or 2G/3G wireless systems for handshaking and interaction. This project involves four universities and four international companies from both Europe and China, e.g., University of Hamburg, Tsinghua University, Nokia Siemens Networks, China Telecom, etc. This project has been successfully demonstrated in Beijing in March 2009.

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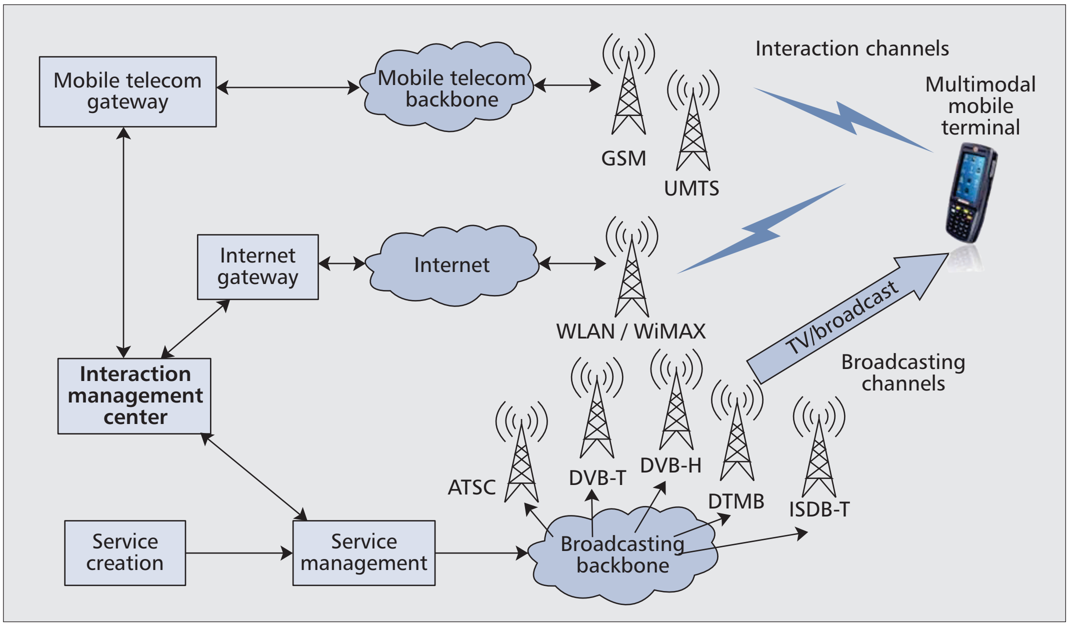

Figure 5. *The convergence between DTTB systems and wireless communications networks in MINT-T project.*

Wireless Localization

Location-based service (LBS) is deemed as one of the most promising applications for information technologies. Global Navigation Satellite System (GNSS), like the well-known Global Positioning System (GPS) governed by the U.S. military, is the most popular way for wireless localization, whereby dozens of satellites are used to determine the locations of users/vehicles/weapons with the accuracy of about 3–10 meters using the single-carrier orthogonal spread codes [15].

The pioneering work of professor Spilker, a famous architect of GPS from Stanford University, has initiated the new era of using DTTB signals for localization [15], whereby several DTTB transmit towers are equivalent to the satellites in GNSS. As shown in Fig. 6, the worldwide deployed DTTB systems provide a complementary solution to GNSS in indoor scenarios, dense urban areas, etc., where GNSS signal is unavailable or the signal power is very low. Due to the high radiated signal power (normally hundreds of Watts), short transmission distance, large signal bandwidth (several Megahertz), and the robustness to multipath fading channels, DTTB signals are proved to be able to achieve higher localization accuracy than common GNSS signals, especially when OFDM is used [16]. The localization accuracy of about one meter for ATSC-based localization systems has been demonstrated in [16]. Other DTTB-based localization schemes using ATSC-M/H, DVB-T, and DVB-H have also been studied. The American company Rosum announced the first commercial chip using DTTB signal for localization in March 2011.

For DTMB standard where TDS-OFDM signal is used, the time-frequency joint positioning method has been proposed [16], whereby the transmission parameter signaling (TPS) embedded in TDS-OFDM signals is time-division multiplexed as orthogonal frequency-domain pilots, and then the time-domain PN sequence and the frequency-domain TPS are jointly utilized for accurate time of arrival (TOA) estimation associated with each transmitter in SFN. It is shown that the positioning accuracy of less than one meter could be achieved [16].

The future research work about DTTB-based wireless localization lies in investigating the challenging problem in which the receiver is located near one particular transmitter and the signals received from all the other transmitters are extremely weak, as well as studying the well-known non-line-of-sight (NLOS) issue in the DTTB-based localization systems. The convergence of GNSS- and DTTB-based localization schemes is another promising direction to realize the real "global" positioning with improved accuracy.

Multi-Service Supporting

Nowadays, people are not satisfied with watching HDTV at home only, they also expect to enjoy reliable services using mobile handsets. Moreover, multiple services including news, real-time stock information, sports events, Web surfing, e-mail, etc., are highly expected, which make it an inevitable trend for DTTB systems to deliver multiple services with different quality of service (QoS) requirements [4]. When mobile handset is used, power consumption becomes essentially challenging.

In DVB-T, layered transmission technology is used to support multi-service with different priorities, but it is not suitable for mobile reception because of its high power consumption and low mobility. To address those issues, DVB-H is specially developed for mobile services, whereby time slicing technique is designed for power saving. DVB-T2 puts more emphasis on multi-service supporting by PLP technique, whereby time slicing, time-frequency slicing are jointly utilized to carry different types of services with variable modulation schemes/channel coding rates [4].

The BST-OFDM technology in ISDB-T divides the TV signal bandwidth into 13 segments, one of which is specially used for mobile services so that "one-segment" reception could be realized to reduce power consumption. Based on ISDB-T, ISDB-Tmm further divides the signal bandwidth with smaller granularity to achieve the segment with the bandwidth of 0.429 MHz [1]. In DTMB, the layered super-frame structure aligned with the natural time provides the fundamental mechanism for multi-service supporting and power saving, since different services could be carried by certain allocated signal frames. Furthermore, time-frequency slicing can be also used by DTMB to dynamically configure any part of time-frequency resources in a "gridless" fashion [2, 5].

Future research topics on this issue maybe the optimal strategy for dynamic resource allocation with the minimum latency, and how to guarantee the required QoS by optimized configuration of the modulation schemes/channel coding rates.

OTHER TECHNOLOGIES

Apart from those technologies discussed above, there are some other technologies should be paid attention to, e.g., the preamble design to reliably carry system signaling, the uniform framework for single-carrier and multi-carrier transmission, and so on. In addition, moving eyes from DTTB systems only, we can observe that other information infrastructure like Internet is also undergoing revolutionary change mainly due to the requirement of expanding data rate. Based on the social property of information that a large amount of people are interested in similar or even identical contents, e.g., popular videos and hot Web sites are repeatedly transmitted from the same server to hundreds of thousands of people all over the world, it would be preferred to deliver those common contents to local servers near the end users by broadcasting systems (notice that in one day, a 40 Mb/s DTTB system could deliver about 40 GB contents to unlimited number of local servers), and then people could access those materials just from nearby servers instead of from Internet. In this way, the throughput requirement of Internet is expected to be substantially reduced. Meanwhile, the potential value of DTTB systems beyond of just sending scheduled programs will be fully exploited in the future.

CONCLUSIONS

This article addresses the key technologies and research trends of next-generation DTTB systems. The first category of performance-oriented technologies are OFDM-based transmission, modulation and channel coding, and MIMO, while the second category of application-oriented technologies are return channel for interactive services, wireless localization, and multi-service supporting. Although great achievements have been gained, some challenging problems remain to be solved, and further improvements, especially in the aspect of the application-oriented technologies, are highly expected. We expect the bright future of next-generation DTTB systems not only to provide high quality services, but also to play a critical role in solving the crucial problem of information expansion by the convergence of Internet and broadcasting.

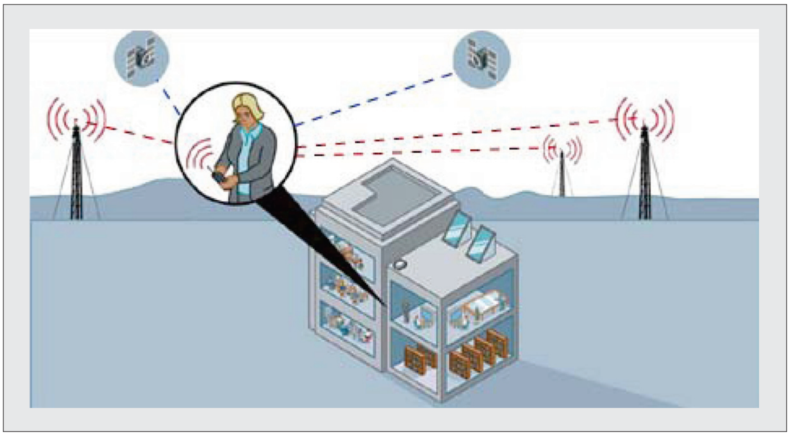

Figure 6. *DTTB-based wireless localization.*

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