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BICM Module of Next Generation Handheld Broadcasting for System Diversity Development in Multipath Fading Channels

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Abstract — *One of the main modifications introduced by Digital Video Broadcasting Next Generation Handheld (DVB-NGH) is the advanced module of Bit-interleaved coded and modulation (BICM). This module is derived from a sub-set of Digital Video Broadcasting Terrestrial Second Generation (DVB-T2) BICM components with supplementary features purposed to minimize the receiver decoding complexity, power consumption and improve system robustness over mobile reception. This paper investigates the diversity gain achieved from the new components introduced in the DVB-NGH BICM module. Two types of rotation techniques have been used with this module, two dimensions and four dimensions rotated constellations (2D, 4D-RC), based on the selected code rate. The obtained gain is also compared to the gain achieved from the T2-Lite system with its original BICM module and rotated constellations scheme. The simulation results have been performed under various fading channels such as Ricean F1, Rayleigh P1, and 0 dB Echo to illustrate the effectiveness of the developed module. Finally, obtained results offer an outstanding improvement in system robustness when employing the DVB-NGH BICM module compared to the original T2-Lite BICM module. The highest gains achieved with the QPSK constellation and 11/15 code rates are 3.5 and 3.1 dB for 0 dB Echo and Rayleigh channels, respectively.*

Keywords — *DVB-NGH, T2-Lite System, BICM Module, 2D and 4D Rotated Constellations, Diversity Gain.*

I. INTRODUCTION

With the development of smartphones and tablets, interest in mobile multimedia broadcasting has resurfaced. Several mobile broadcast technologies, including DVB-H (Digital Video Broadcasting – Handheld) and DVB-SH (Satellite to Handheld), were created over the last decade to the widespread consumption of multimedia services like portable television (TV) [1]. However, due to the absence of a viable business strategy and the related substantial costs with the introduction of modern mobile television networks, the penetration of mobile TV services has fallen short of expectations. Due to both consumer's and operators' ever-increasing demands and desires, the development of a new mobile generation broadcasting technology became necessary [2]. This generation should employ the most recent advancements in wireless communications to offer substantial capacity and coverage efficiency enhancements over first-generation portable broadcasting standards [3].

Digital Video Broadcasting Next-Generation Handheld is the mobile development of the DVB-T2 [4]. Where the second-generation standard is the most sophisticated Digital Terrestrial Transmission (DTT) system globally, allowing efficiency and high robustness for the terrestrial environment and supporting high-quality television services, particularly (HDTV) [5]–[6]. DVB-T2 achieves a 50 to 70 present capacity improvement over its predecessor Digital Terrestrial First Generation DVB-T [7].

DVB-NGH was developed to be the reference industry standard for mobile multimedia broadcasting. DVB-NGH significantly outperforms the current mobile broadcasting standards from where coverage, capacity, and more spectrum efficiency [2]. Also, DVB-NGH is optimizing the DVB-T2 system in several features [8]. In terms of performance, DVB-NGH is considered the first broadcasting scheme that utilizes the full benefits of the Multiple-Input Multiple-Output (MIMO) system [9]–[10]. MIMO is the key technology to get through the Shannon limit of the SISO transmission scheme by employing spatial multiplexing without any further transmit power or bandwidth [11]–[12].

There are four broadcasting profiles defined by The DVB-NGH specification known as the sheer-terrestrial, MIMO-terrestrial, hybrid terrestrial–satellite, and hybrid-MIMO profiles [10]. DVB-NGH specification state that the sheer-terrestrial profile is compulsory, while the others are optional [13]. The sheer-terrestrial profile, which is also called base profile, depended on the features of DVB-T2 and DVBT2-lite standards [14]–[15]. DVB-NGH system employs several developed physical-layer techniques to enhance robustness and reliability over different fading conditions. These techniques are BICM, new LDPC coding rate, and signal space diversity (SSD), and enhanced spatial multiplexing multiple-input multiple-output (ESM-MIMO) [16].

The BICM of DVB-NGH depends on the DVB-T2 standard with specific improvements to minimize the receiver decoding complexity, extend the coverage area, and optimize spectral efficiency [3]. This BICM module is considered the most advanced in coding modulation technology. The DVB-NGH combines the most efficient BCIM module with orthogonal frequency division multiplexing (OFDM) that evaluated the favored choice of mobile broadcasting systems [17]–[19]. The BICM can separate the continuous bits error caused by symbol burst errors to boost system diversity in a fading environment. BICM supports DVB-NGH with diversity gains in frequency and time by efficiently combining forward error correction (FEC) codes and various interleaving schemes [2].

After presenting a brief introduction for the DVB-NGH system in section I, the remainder of the paper is structured as follows: Section II demonstrates a description of the overall structure for the DVB-NGH BICM module in terms of the developed features of FEC codes, bit interleaver, constellations rotation, time interleaver, and I/Q component interleaver. Moreover, this section presents the objective of the paper and how the diversity gain is obtained. Section III represents a characterization of the fading channels models and simulation system parameters. The discussion and simulation results indicate the enhancement achieved by applying the DVB-NGH BICM module to T2-Lite systems displayed in section IV. Finally, section V, offering some closing observations.

II. BICM MODULE FOR DVB-NGH

The DVB-NGH BICM module is built on a subset of modules from the DVB-T2 (T2-Lite) system, aiming to reduce complexity and power consumption in the receiver. This BICM has extra components to improve mobile receiving coverage and resilience [3]. DVB-NGH has the same receiver complexity limitations as T2-Lite, like allowing only 16k LDPC codewords, halving the space of the TI memory related to second-generation, and in 256QAM, preventing the usage of rotation scheme [13]. Furthermore, the greatest coded data bit rate in next-generation is restricted to 12 Mbps, covering both source and parity data. The source data for T2-Lite is constrained to 4 Mbps [1].

The following are the BICM improvements developed to achieve transmission robustness: Further robust inner coding rates as low as 1/5 were employed at the coding field. At the modulation level, non-uniform 64QAM and 256QAM modulation, as well as a four-dimensional rotational QPSK modulation, were included. At the interleaving level, the parity bit-interleaver is utilized [20]. The cyclic Q-delay of the DVB-T2 system is replaced with the I/Q component interleaving to take advantage of rotated constellations' signal-space diversity by dispersing each rotating symbol's parts with the most excellent possible time and frequency disjoining [1], [18].

DVB-NGH has improved the Time Interleaver (TI) belonging to DVB-T2 in pair waysFor frame interleaving, it incorporated a convolutional interleaver (i.e., interleaving over several frames) while retaining the same second-generation block interleaver is used to the CI is applied for interleaving over the frame[13]. The utilization of cell quantization in an adaptive manner with low constellations makes superior use of the TI memory. Compared to the Lite version of second-generation with the equivalent memory of time interleaved, using CI and adaptive quantization increases the overall interleaving period four times [2]. The CI's advantages include double the depth interleaving using the same memory and a 33 present reduction in total zapping duration for almost the identical depth of interleaving. These advantages are only available when the CI is used for inter-frame interleaving [21]–[22].

As in the T2-Lite system, DVB-NGH supports rotated constellations in two dimensions to provide diversity against fading environment, but this technique is not allowed with the 256-QAM constellation. In addition, the principle of 2D-RC is expanded to four dimensions rotated constellations to supply a higher diversity scheme. The 2D and 4D-RC accomplish by multiplying output vectors of cell interleaver by a rotation matrix have an orthogonal feature with size 2x2 or 4x4, respectively, as given in Eq. (1) and Eq. (2). DVB-NGH replaces the quadrature Q component in DVB-T2 with a cyclic Q delay with an extra sophisticated I/Q component interleaver. The I/Q interleaver supports preferable channel diversity and time separation for both diversity schemes when enabling multi-frame interleaving or time-frequency slicing (TFS). The overall BICM module of DVB-NGH applied in this work is shown in Fig. 1.

$$\begin{bmatrix} Y_I \\ Y_Q \end{bmatrix} = \begin{bmatrix} +a & -b \\ +b & +a \end{bmatrix} \begin{bmatrix} X_I \\ X_Q \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Y_{0I} \\ Y_{0Q} \\ Y_{1I} \\ Y_{1Q} \end{bmatrix} = \begin{bmatrix} +a & -b & -b & -b \\ +b & +a & -b & +a \\ +b & +b & +a & -b \\ +b & -b & +b & +a \end{bmatrix} \begin{bmatrix} X_{0I} \\ X_{0Q} \\ X_{1I} \\ X_{1Q} \end{bmatrix} \quad (2)$$

Where vectors x consist of the number of rotation dimensions N_D components of $N_D/2$ adjacent cells, the amount of parameter b as a function of each constellation size and code rates is proposed in ETSI EN 303 105 v1.1.1. The parameter a is derived from N_D components and parameter b as given in Eq. (3).

$$a = \sqrt{1 - (N_D - 1)b^2} \quad (3)$$

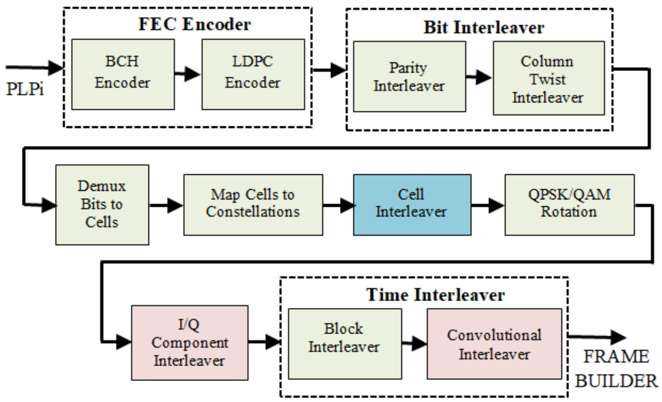


Fig. 1 Developed BICM module for DVB-NGH

The work presented in this paper aims to obtain the diversity gain associated with the developed DVB-NGH BICM module. To do this, the T2-Lite system is simulated, and the desired SNR to produce BER less than $1*10^{-7}$ after the inner decoder is obtained for no rotation case. Then, the 2D-RC and cyclic Q delay is applied in the T2-Lite original BICM module to obtain SNR with the exact requirement. In the second stage, the T2-Lite BICM is changed with the new DVB-NGH BICM module and displays diversity gain for 2D and 4D-RC schemes (with I/Q component interleaver). Moreover, this gain is compared to the T2-Lite system with its traditional BICM module and 2D-RC. Three types of fading channel profiles have been included in the simulation Ricean, Rayleigh, and 0 dB Echo channels. Furthermore, this research evaluates the parameters configuration that produces optimal performance suitable for each channel's conditions.

III. SIMULATION CHANNEL MODELS AND SYSTEM PARAMETERS

Three-channel fading models are used in this work for the simulation of the T2-Lite system with both BICM modules. Several conditions determine the fading channel models during the reception. According to ETSI EN 302 755 standards, each fading model has a different signal path, delay, attenuation, Doppler frequency, and phase shift. The first channel model considered in the simulation is the Ricean channel. This channel, also known as the F1 channel, represents a fixed outdoor model's receiving conditions. This model does not contain Doppler frequency impact. The model has one component in the direct path, and 21 other paths have a different delay, attenuation, and phase shift.

The second channel model is the Rayleigh channel, characterized by no direct path of the transmitted signal and heavy multipath. This model presents the portable outdoor or indoor channel conditions known as the P1 fading channel model. P1 channel has 20 taps of multipath components, and each scattered path comes with distinct time-delay and phase-shift. The last channel model considered in this simulation is the 0 dB Echo profile. It composes of two paths with identical amplitude. The directions are separated by a time equal to 0.9 from Guard Interval (GI), i.e., 90% GI. The second path of 0 dB comes with a 1 Hz frequency shift.

A specific parameter configuration is applied to simulate the behavior of the DVB-NGH BCIM module and T2-Lite system. The main configuration parameters for each test are 8K FFT, 1/8 guard interval, normal carrier mode, PP2 Scattered pattern, 8 MHz bandwidth, 16200 FEC Length, and 50 LDPC decoding Iterations. The constellations for this simulation are QPSK, 16-QAM, and 64-QAM with 1/3, 2/5, 3/5, 2/3, 11/15 selected code rates for both systems. The simulation of the T2-Lite system is done using MATLAB 2020b software based on ETSI EN 302 755 v1.4.1, while DVB-NGH BCIM is based on advanced features proposed in ETSI EN 303 105 v1.1.1.

IV. SIMULATION RESULTS AND DISCUSSION

The simulation demonstrates the T2-Lite system performance using the original BICM module presented in DVB-T2 standard with or without the 2D-RC technique. The second part introduces the DVB-NGH BCIM module in place of the original module to show diversity gain from employing its new features with 2D-RC and 4D-RC. Both simulated systems are employed the same three fading channel profiles that are mentioned previously.

This first step aims to find the resulting diversity gain from employing the 2D-RC and cyclic Q delay technique provided by the original BICM for the T2-Lite system. This gain depending on the minimum required SNR's numerical results based on Quasi Error Free reception (QEF) criteria. QEF is a minimal limit defined at a rate of error less than or equal to $1*10^{-7}$ after inner decoder LDPC, as specified in the DVB-T2 implementation guidelines. The considered BER is obtained after applying the LDPC inner decoder. Table I presents the results for all mentioned channels with the non-rotation case, and Table II displays the 2D-RC case.

I. TABLE
SNR for T2-Lite system with no constellations rotation

Constellation	CR	F1	P1	0 dB Echo
QPSK	1/3	-0.60	0.30	-0.20
QPSK	2/5	0.30	1.40	0.90
QPSK	3/5	3.10	5.10	4.50
QPSK	2/3	4.10	6.50	6.30
QPSK	11/15	5.10	8.30	8.20
16-QAM	1/3	3.50	4.80	4.50
16-QAM	2/5	4.80	6.20	6.00
16-QAM	3/5	8.40	10.30	10.00

16-QAM	2/3	9.70	11.90	11.70
16-QAM	11/15	11.10	13.80	13.70
64-QAM	1/3	6.30	8.00	7.80
64-QAM	2/5	8.10	9.90	9.90
64-QAM	3/5	12.70	14.80	14.70
64-QAM	2/3	14.30	16.40	16.30
64-QAM	11/15	16.00	18.50	18.50

II. TABLE
SNR for T2-Lite system with original BICM module

Constellation	CR	F1	P1	0 dB Echo
QPSK	1/3	-0.60	-0.30	-0.40
QPSK	2/5	0.20	0.90	0.60
QPSK	3/5	2.90	4.10	3.80
QPSK	2/3	3.90	5.30	4.80
QPSK	11/15	4.80	6.50	6.00
16-QAM	1/3	3.50	4.50	4.10
16-QAM	2/5	4.90	6.00	5.80
16-QAM	3/5	8.50	9.70	9.40
16-QAM	2/3	9.60	11.20	10.90
16-QAM	11/15	10.90	12.9	12.50
64-QAM	1/3	6.30	7.80	7.60
64-QAM	2/5	8.10	9.60	9.70
64-QAM	3/5	12.80	14.50	14.40
64-QAM	2/3	14.20	16.10	16.00
64-QAM	11/15	16.00	18.20	18.00

The second step aims to simulate the developed DVB-NGH BICM inside the T2-Lite system instead of the original BICM with 2D-RC and 4D-RC techniques. The configuration of rotated dimensions presented in DVB-NGH BICM based on the selected code rate, where 5/15 and 6/15, for 2D-RC and 9/15, 10/15, 11/15 with the 4D-RC scheme (QPSK only). The required SNRs with the new BCIM configuration are given in Table III with the same three-channel profiles.

III. TABLE
SNR for T2-Lite system with DVB-NGH BICM module

Constellation	CR	F1	P1	0 dB Echo
QPSK	5/15	-0.70	-0.50	-0.70
QPSK	6/15	0.10	0.70	0.50
QPSK	9/15	2.70	3.20	3.00
QPSK	10/15	3.60	4.40	3.80
QPSK	11/15	4.60	5.20	4.70
16-QAM	5/15	3.40	4.40	3.90
16-QAM	6/15	4.70	5.90	5.50
16-QAM	9/15	8.20	9.40	9.00
16-QAM	10/15	9.50	10.90	10.50
16-QAM	11/15	10.70	12.50	12.00
64-QAM	5/15	6.20	7.70	7.40
64-QAM	6/15	7.90	9.40	9.30
64-QAM	9/15	12.50	14.30	14.10
64-QAM	10/15	14.10	15.80	15.70
64-QAM	11/15	15.90	17.90	17.70

IV. TABLE
Diversity gain in dB for T2-Lite system with both BICM modules for (F1 and P1) channels

Constellation	CR	F1		P1	
		T2-Lite	DVB-NGH	T2-Lite	DVB-NGH
QPSK	1/3	0	0.1	0.6	0.8
QPSK	2/5	0.1	0.2	0.5	0.7
QPSK	3/5	0.2	0.4	1	1.9
QPSK	2/3	0.2	0.5	1.2	2.1
QPSK	11/15	0.3	0.5	1.8	3.1
16-QAM	1/3	0	0.1	0.3	0.4
16-QAM	2/5	-0.1	0.1	0.2	0.3
16-QAM	3/5	-0.1	0.2	0.6	0.9
16-QAM	2/3	0.1	0.2	0.7	1
16-QAM	11/15	0.2	0.4	0.9	1.3
64-QAM	1/3	0	0.1	0.2	0.3
64-QAM	2/5	0	0.2	0.3	0.5
64-QAM	3/5	-0.1	0.2	0.3	0.5
64-QAM	2/3	0.1	0.2	0.3	0.6
64-QAM	11/15	0	0.1	0.3	0.6

V. TABLE
Diversity gain in dB for T2-Lite system with both BICM modules for (0 dB Echo) channel

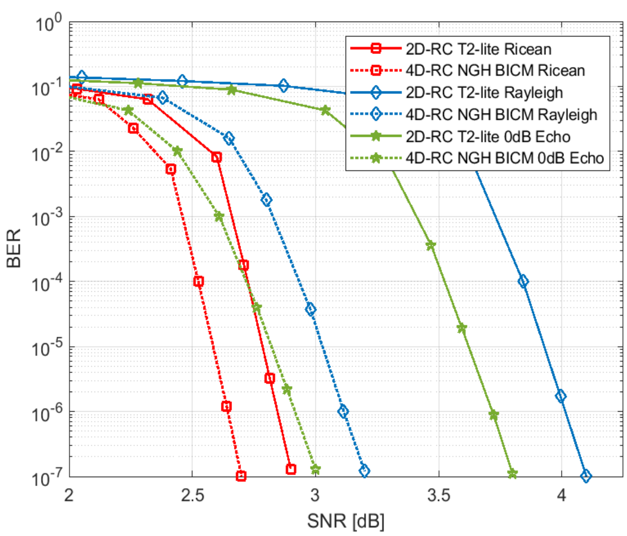
Constellation	CR	0 dB Echo	
		T2-Lite	DVB-NGH
QPSK	1/3	0.2	0.5
QPSK	2/5	0.3	0.4
QPSK	3/5	0.7	1.5
QPSK	2/3	1.5	2.5
QPSK	11/15	2.2	3.5
16-QAM	1/3	0.4	0.6
16-QAM	2/5	0.2	0.5
16-QAM	3/5	0.6	1

16-QAM	2/3	0.8	1.2
16-QAM	11/15	1.2	1.7
64-QAM	1/3	0.2	0.4
64-QAM	2/5	0.2	0.5
64-QAM	3/5	0.3	0.6
64-QAM	2/3	0.3	0.6
64-QAM	11/15	0.5	0.8

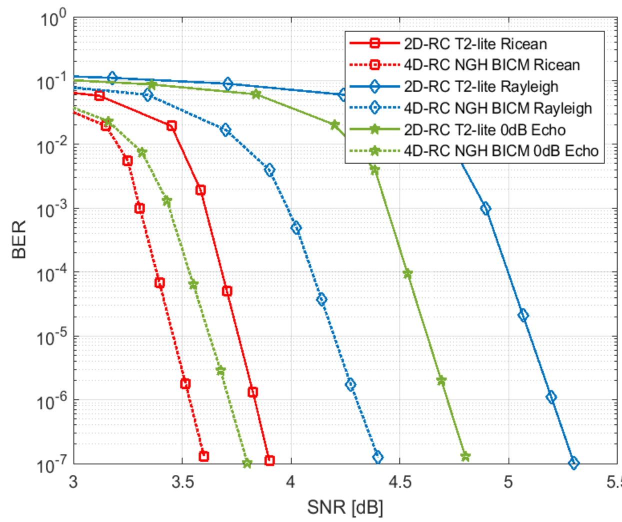
The diversity gain achieved using the T2-Lite system with 2D-RC is presented in Tables IV and V. The same Tables contain the diversity gain obtained after changing the original T2-Lite BICM by the next-generation BICM Module. The resulting gain of the new BICM module is associated with applying 2D and 4D-RC schemes according to the code rate and constellation sizes.

It must be emphasized that the highest gain can be accomplished by small constellation sizes like QPSK combined with higher code rates for both BICM modules. Because higher code rates have a lower ability to correct errors; therefore, the system's performance depends basically on the diversity presented by the BICM module. On the other side, the gain is significantly reduced due to high constellation and lower code rates.

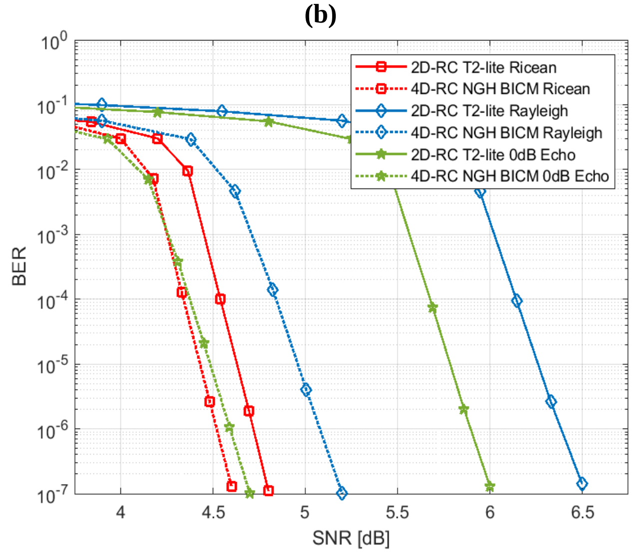
Therefore, the highest gain for T2-lite BICM is achieved for the QPSK constellation, and the 11/15 code rate is 2.2 and 1.8 dB for the 0 dB Echo and Rayleigh channels, respectively. When using the DVB-NGH BICM module inside T2-Lite, the gain is increased due to the diversity effect introduced by the developed BCIM elements. In this case, the obtained gain is 3.5 and 3.1 dB for the same T2-lite BICM configuration in terms of the constellation, code rate, and channel profiles.



(a)



(b)



(c)

Fig. 2 BER for T2-Lite with both BICM modules and QPSK constellation for code rate (a) 3/5, (b) 2/3, and (c) 11/15

The BER curves are simulated for the QPSK constellation with three selected code rates which are 3/5, 2/3, 11/15, as a graphical sample because these code rates show the maximum benefit of BICM diversity for both systems over simulated channels. The test has been accomplished with the same three-channel profiles discussed previously.

The simulation displays BER curves of T2-Lite with 2D-RC and DVB-NGH BICM with 4D-RC schemes. BER curves for all mentioned cases are shown in Fig. 2. All BER results indicate a significant reduction in SNR when applying DVB-NGH BICM instead of the original T2-Lite BICM module. The maximum SNR reduction is achieved with a code rate of 11/15 and 0 dB echo conditions followed by the Rayleigh channel at the same code rate.

VI. CONCLUSIONS

In this paper, diversity gain for T2-Lite BICM module with the 2D-RC technique was investigated and compared with the case of employing a non-rotated constellation. Diversity gain is also obtained for changing the BICM module of T2-Lite with the DVB-NGH BICM module, which is the core of this research. Two types of rotation techniques have been used, 2D and 4D-RC, based on the selected code rate. The BER curves are also taken into account to show the performance associated with the DVB-NGH BICM module, including 4D-RC schemes.

It has been shown that the T2-Lite BICM with 2D-RC features can supply a good diversity gain by 2.2 and 1.8 dB for the 0 dB Echo and Rayleigh channels, respectively, for the QPSK constellation and the 11/15 code rate. In contrast, employing the DVB-NGH BICM module with the T2-Lite system instead of the original module can provide an excellent diversity gain by 3.5 and 3.1 dB for the same T2-lite BICM configuration in terms of the constellation, code rate, and fading conditions.

The simulation results demonstrate that the diversity gain is high for small modulation schemes such as QPSK and a high coding rate (11/15) rather than large constellation sizes and low code rates for both BICM modules. Therefore, combining a high code rate and BICM module of DVB-NGH with 4D-RC offers additional robustness. This robustness improves the data rate while maintaining the same field strength, making DVB-NGH a promising technology for future terrestrial multimedia broadcasting systems over existing mobile broadcasting standards.

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