Enhancements on Coding and Modulation Schemes for LTE-Based 5G Terrestrial Broadcast System

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***Abstract*—Broadcasting and broadband network is moving towards integration and LTE-based 5G terrestrial broadcast is now researched in Release 16 in Third Generation Partnership Project (3GPP) standardization meetings. However, the work scope of LTE-based 5G terrestrial broadcast focuses on specifying new numerologies and some minor improvement on cell acquisition subframe, which is insufficient. In this paper, limitations in coding and modulation schemes of LTE-based 5G terrestrial broadcast system, e.g., Turbo codes and Quadrature Amplitude Modulation (QAM), are detailedly analyzed. To further enhance the spectrum efficiency of LTE-based 5G terrestrial broadcast system, LDPC (Low Density Parity Check) codes from 5G new radio (NR) standard and newly designed non-uniform constellations (NUCs) are adopted in this paper to replace Turbo codes and QAM respectively. Extensive simulations and complexity analysis show that the proposed LDPC coding and NUC modulation scheme, either standalone or combined, can provide significant performance gain over Additive White Gaussian Noise (AWGN) and Tapped Delayline (TDL) channels, without additional complexity. To summarize, this paper investigates the weakness of the coding and modulation schemes in current systems and provides potential alternatives for the enhanced future broadcast in 3GPP standard.**

***Index Terms*—LTE-based 5G terrestrial broadcast system, 3GPP, coding modulation schemes, NUC, LDPC codes.**

I. INTRODUCTION

MOBILE wireless services grew rapidly in recent years. There has been tremendous growth in data traffic. According to Cisco, global IP traffic will increase threefold by 2022 and smartphone traffic will exceed personal computer (PC) traffic. Furthermore, 82% of the IP traffic is expected to be video traffic by 2022. These increasing demands indicate great challenges and opportunities which could not be fulfilled by mobile network based on unicasting [1]. For this reason, communication network structure is moving into the direction of heterogeneous and ubiquitous integration [2]. Researchers both in broadcast and mobile broadband society are seeking for convergence and development in their own perspective.

From the perspective of broadcast, there are some efforts starting to focus on integrating traditional High-Power-High-Tower (HTHP) broadcast network into Low-Power-Low-Tower (LPLT) broadband network for the purpose of offloading data traffic. The latest IP-based ATSC 3.0 brings inherent flexibility and lays strong foundation for the convergence of broadcast network toward mobile broadband network. In September 2018, China SARFT sets up a working group on Advanced Interactive Broadcasting (AIB) to study the integration of broadcast and mobile broadband. The goal of the AIB group is to invent a new generation broadcasting standard with better spectrum efficiency, flexibility and interactivity. In a conference cohosted in November 2018 by Telecommunications Standards Development Society India (TSDSI) and ATSC, a convergence plan to explore the capabilities of broadcast to offload traffic for broadband was proposed [3].

Meanwhile, from the perspective of mobile broadband, the 3GPP standardization participants also paid attention to the broadcast service, and the focuses shifted from adding the LPLT broadcast services in Release 6 (Rel-6) to adding HPHT and middle power middle tower (MPMT) broadcast services nowadays [4]. In specific, multimedia broadcast multicast system (MBMS) was first defined in Rel-6 and in Release 9 (Rel-9), MBMS was updated to include Long Term Evolution (LTE), which was named as evolved MBMS (eMBMS). LTE-based eMBMS (also called "eMBMS-enhancement" [5]) was further proposed and frozen in Release 14 (Rel-14) [6]. This LTE-based eMBMS service enabled numerous users to receive the same content simultaneously. Among others, LTE supported dedicated eMBMS, deployments with larger inter-site distance (ISD) and other functions such as network sharing and receive-only mode. Considering the requirements [7] for broadcasting services in 5G might not be met by LTE-based eMBMS, a study item (SI) was approved to carry out the gap analysis in Release 16 [8], [9]. Gaps are found in the SI, and then in [10], a work item (WI) of LTE-based 5G terrestrial broadcast is approved aiming to specify new numerologies for support of rooftop o reception with 200km coverage and mobile reception with mobility of up to 250 km/h, as well as to make some minor improvement on cell

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acquisition subframe [11], [12]. In addition, in this meeting agreement was reached on way forward towards future broadcast system in which further enhancement for LTE-based 5G terrestrial broadcast is likely to be specified in future Release (after Rel-17) in 3GPP [13]. For future broadcast in 3GPP, optimization in coding and modulation are among the key aspects that can lead to a better spectrum efficiency.

In LTE-based 5G terrestrial broadcast system, turbo codes and QAM are currently adopted. However, turbo codes are subject to low throughout and long latency time because of their serial nature [16]. And these restrictions can be improved by the adoption of Quasi-Cyclic Low Density Parity Check codes (QC-LDPC) [15], whose structure facilitates high parallelism and low decoding latency. QC-LDPC codes have already replaced Turbo codes due to the high throughput requirement [14] in 5G NR and some papers show that 5G NR LDPC codes have better performance compared with Turbo codes in LTE [16]. Thus, LDPC codes can be a potentially advanced technology for future broadcast in 3GPP. Meanwhile, a great gap between the BICM [17] capacity of QAM and Shannon limitation exists in LTE-based 5G terrestrial broadcast. The gap can be reduced by non-uniform constellations since NUCs can provide more shaping gains [18]. NUCs have been well adopted in traditional broadcast system (such as ATSC 3.0 [19] and DVB-NGH [20]), but have not yet been accepted in 3GPP due to the high demapping complexity at user equipment (UE). Towards this issue, in recent years, many efficient simplified demapping algorithms have been proposed [21], [22], [23] to reduce the complexity while maintaining good performance. Some researchers also focused on the advantages and designing processes of NUCs to be adopted in 5G network or converged network [24], [25]. Thus, NUCs possess significant potential to be considered as a key technology in future broadcast system in 3GPP.

In this paper, applicability and potential of LDPC coding and NUC modulation are explored. Considering the compatibility, LDPC codes adopted in 5G NR can be customized to fit the future broadcast system. Moreover, the design process of NUC is briefly introduced, based on which a set of NUCs is designed for future broadcast system. Extensive simulations are conducted based on the latest LTE-based 5G terrestrial broadcast system with replacement of Turbo and QAM by LDPC and NUCs. From the simulation results, it can be figured out that with proposed LDPC coding and NUC modulation scheme, the performance gain can be significantly improved by 0.1 $\sim$ 1.2 dB over AWGN channel and 0.3 $\sim$ 1.3 dB over TDL-B channel compared with current Turbo codes and uniform QAM modulation scheme.

The rest of this paper is structured as follows. In Section II limitations of coding and modulations schemes are analyzed based on LTE-based 5G terrestrial broadcast. Section III describes the proposed enhancement on coding and modulation schemes, including the customized LDPC coding schemes from 5G NR and the design of NUCs for future broadcast. Section IV presents simulation results over AWGN and TDL channels. Finally, Section V concludes this paper.

II. LIMITATIONS OF CODING AND MODULATIONS SCHEMES

Whole Channel coding scheme in either LTE or NR is a combination of transport block Cyclic Redundancy Check (CRC) attachment, code segmentation, code block CRC attachment, channel encoding, rate matching and code block concatenation procedures [5], [6]. Among them, channel coding are of great significance. In LTE-based 5G terrestrial broadcast, Turbo codes are used for Physical Multicast Channel (PMCH) coding. However, Turbo codes designed for W-CDMA (Wideband Code Division Multiple Access), which supports a peak UE data rate of 384 Kbps [14], are not efficient enough for the requirements [7] of 5G. In details, firstly, LTE Turbo codes are subject to high error floors and not suitable for higher reliabilities required by 5G. Secondly, in terms of high throughput and low latency requirements, Turbo codes suffer from their own serial nature [16].

Because of the limitations of Turbo codes, in 5G NR, LDPC codes are adopted to replace Turbo codes in Physical Downlink/Uplink Shared Channel (PDSCH/PUSCH). As shown in [16], LDPC codes (QPSK, the length of information bits $K = 6000$) in 5G NR perform better than Turbo codes in waterfall region as well as error floor region over AWGN channel [29]. On the other hand, LDPC codes have relatively simple and practical decoding algorithms and this property exactly satisfies high throughput and low latency requirements. It is worth mentioning that transformation from Turbo codes into LDPC codes has changed the corresponding whole channel coding scheme. Take rate matching as an example. The rate matching for Turbo codes consists of three parts: subblock interleaver, bit collection and bit selection. While there are only two parts, i.e., bit selection and bit interleaver for LDPC codes. Thus, 5G NR LDPC codes and the corresponding channel coding scheme can be applied in future broadcast system in 3GPP and the improvement is analyzed in this paper.

In LTE-based 5G terrestrial broadcast, uniform modulation scheme (QAM) is currently used. The modulation order is from 4 to 256. The rectangular distribution constellation symbols in uniform QAM implies a great gap between BICM capacity and Shannon limitation. NUC is widely known as a key technology to provide shaping gain and reduce this gap. Looking back on the study of modulation scheme in 3GPP, some researchers proposed that high order modulation and non-uniform constellations should be considered to improve the performance in 3GPP meetings [26], [27], [34]. Given the complexity issue for UE, the technology of NUC failed to attract enough interests in previous 3GPP meetings. However, with the numerous simplified demapping algorithms coming out, UE complexity regarding NUC can be reduced to acceptable range and the shaping gain of NUC is still outstanding. It can be predicted that NUC will be applied in future broadcast system in 3GPP and the improvement is analyzed in this paper.

III. ENHANCEMENTS ON CODING AND MODULATION SCHEMES

A. Channel Coding

5G NR LDPC codes are designed to support different services, such as enhanced mobile broadband (eMBB),

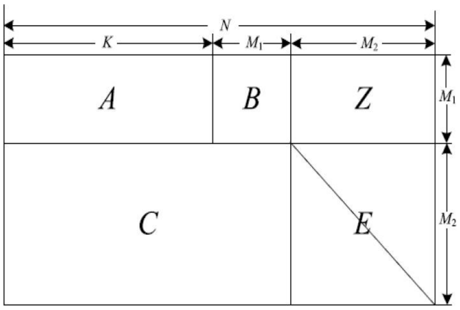


Fig. 1. MET base matrix.

ultra-reliable and low latency (URLLC), and massive machine type communications (mMTC) [7]. In order to meet the key performance indicators (KPI) [7] of services mentioned above, quasi-cyclic rate-compatible (QC-RC) LDPC codes and their corresponding procedures, for example, CRC attachment, code segmentation, rate matching and code block concatenation, are selected as the 5G NR channel coding scheme.

In this part, we firstly review the main characteristics of 5G NR channel codes. Then the requirements and enhancement of coding scheme for further terrestrial broadcast are analyzed.

QC-structured LDPC codes are used in the design of 5G NR codes whose structure is imposed to facilitate parallelism and organize the message passing process. In contrast to the fixed lifting size Z_c of LDPC codes in conventional standards such as 802.16e [28], DVB-T2 [29], [30] and ATSC 3.0 [31], [32], [33], the lifting sizes Z_c of 5G NR LDPC codes are variant as described in (1).

$$Z_c = A \times 2^j \tag{1}$$

in which, $A \in \{2, 3, 5, 7, 9, 11, 13, 15\}$, $j = 0, 1, 2, 3, \ldots$ and $2 \leq Z_c \leq 384$. The set of optional lifting sizes can support different throughput requirements [7] in 5G NR by using variable size to adapt the PCM to the needs of each specific coding rate and code length.

In addition, the flexible rates and block lengths are key features for 5G NR LDPC codes. In 5G NR, not only high code rate and long block length are needed to support the peak throughput, but low code rate and short block length are also required to achieve extended coverage and meet the 100 Mbps edge-cell throughput target. Considering the low power consumption of UE, 5G NR LDPC codes are based on two rate-compatible mother base matrices. These two mother base matrices have the multi-edge (MET) structure as shown in Fig. 1, where $[A, B]$ is the core base submatrix and is irregular-repeat-accumulate (IRA) structured. Z is an $M_1 \times M_2$ zero matrix and E is an $M_2 \times M_2$ identity matrix. The base matrix for different rate/length LDPC codes in 5G NR is either Fig. 1-like or a punctured/shortened version of Fig. 1.

Last but not least, the submatrix C in 5G base matrix is row-orthogonal (RO), which means the inner product between any two consecutive rows in C is zero. It can be seen as an important and necessary characteristic to support higher parallelism which equals to higher data throughput [14], [16]

In fact, each LDPC code (with certain rate and certain length) in 5G NR is not best optimized due to it is not designed standalone but based on same base matrix with consideration of being compatible with other codes of different rates and length. Even though, the LDPC codes are able to address the requirements of good performance, high throughput, high parallelism, flexible rates/lengths and low UE complexity. Taking the compatibility issue of future broadcast systems and 5G NR into consideration, this LDPC codes and their corresponding channel coding scheme can be applied to replace the turbo codes in LTE-based 5G terrestrial broadcast.

B. Modulation

LTE-based 5G terrestrial broadcast still uses uniform QAM constellations. According to theoretical analysis, a Gaussian-like distribution of constellation symbols (like in NUC) can help achieve the promotion in channel capacity. NUC modulation scheme is to adapt the distribution of constellation symbols to the channel and maximize the BICM capacity. To enhance physical layer of future broadcast by replacing QAM with NUC, a set of NUCs must be designed.

NUCs can be divided into two different kinds: one-dimensional non-uniform constellation (1D-NUC) and two-dimensional non-uniform constellation (2D-NUC). 1D-NUC has non-uniform distance between constellation symbols but keeps uniform square shape to maintain low demapping complexity. 2D-NUC provides more shaping gain by relaxing the uniform shape constraint, which costs higher demapping complexity. Because of low-complexity, 1D-NUC is well suited for constellations of higher order, such as 1024-NUC (also called 1k NUC) and above. Since the highest modulation order in LTE-based 5G terrestrial broadcast is 256, only 2D-NUCs are considered in this paper.

BICM system can be modelled as a set of m parallel independent channels, so the BICM capacity can be calculated as follows [35]:

$$C = m - \sum_{i=1}^{m} E_{b,\boldsymbol{y},\boldsymbol{\theta}} \left[\log_2 \frac{\sum_{z \in \chi} p_{\boldsymbol{\theta}}(\boldsymbol{y}|z)}{\sum_{z \in \chi_b^i} p_{\boldsymbol{\theta}}(\boldsymbol{y}|z)} \right], \tag{2}$$

where $\boldsymbol{\theta}$ is the sequence of channel state parameters. The channel is assumed to be a memoryless discrete-input, continuous-output channel with input $\boldsymbol{x}$, output $\boldsymbol{y}$ and transition distribution $p_{\boldsymbol{\theta}}(\boldsymbol{y}|\boldsymbol{x})$. All the NUCs to memoryless channels, such as AWGN, Rice or Rayleigh, are optimized based on BICM capacity formula (2). Previous work [36], [37], [38] have put forward complete designing process for NUCs to memoryless channels. However, TDL channels for LTE-based 5G terrestrial broadcast or future broadcast are memory channels, the BICM capacity of which is not easy to calculate. It means NUCs designing process for future broadcast needs appropriate adjustments.

In this paper, designing process of 2D-NUCs are mainly focused for future broadcast. The optimization procedure is mainly based on Particle Swarm Optimization (PSO) designing approach (which was first proposed in [36]) over AWGN channel. Then a set of optimized NUCs will be selected over TDL channel.

In specific, the designing process is composed of the following four main steps. First of all, find the SNR value SNR_{AWGN}

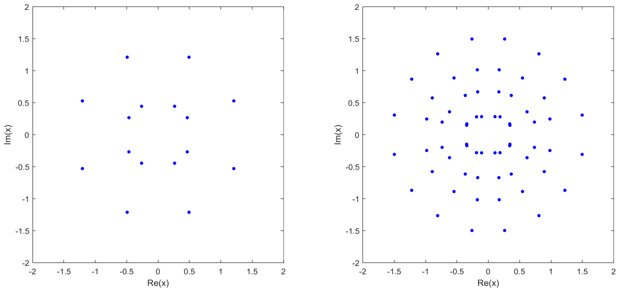


Fig. 2. Left: degisned 16NUC for simulation Case 4, right: designed 64NUC for simulation Case 7.

at which NUC is optimized. This SNR value is set to the threshold SNR of link-level simulation with M-ary ASPK as modulation scheme over AWGN channel. M-ary ASPK is used as initial constellation of optimization since its Gaussian-like shape can reduce the number of iteration times in the optimization [37]. Secondly, the SNR value SNR_{AWGN} and cognitive factors [36] p_k ($1 \leq k \leq N$, where N is defined as the total number of designed NUCs over AWGN channel) of PSO approach is introduced into the designing optimization and the optimized NUC $OptNUC_k$ is obtained. In this step, different PSO cognitive factors p_k are used to obtain N optimized NUCs in total.

During the designing process in this paper, cognitive acceleration factor v_k in PSO algorithm is adjusted as different cognitive factor p_k and optimized NUC $OptNUC_k$ are updated in cyclic iteration of PSO algorithm. In the third step, link-level simulation is conducted again with the optimized NUC $OptNUC_k$ over TDL channel to get the threshold SNR $SNR_{TDL,k}$. Finally, comparing the threshold SNR $SNR_{TDL,k}$, the designed NUC with lowest threshold SNR is selected among the optimized NUCs $OptNUC_k$.

By this designing process, 12 different NUCs with modulation order from 16 to 256 have been designed in this paper for different modulation and coding schemes provided by the Vienna 5G link-level simulator [39]. Fig. 2 shows the designed NUCs with order of 16 and 64. The overall performance can be improved by using the designed NUCs for future broadcast of 3GPP. Specific performance gain will be analyzed in next section.

C. Complexity Issues

As discussed detailedly in [16], LDPC codes have lower computational complexity than Turbo codes, i.e., require fewer operations to achieve the same frame error rate (FER) at a given energy per symbol. Besides, the proposed LDPC channel coding scheme for future broadcast in this paper is compatible with LDPC codes in 5G NR, which will benefit the equipment complexity considering the compatibility of UE.

Meanwhile, non-uniform constellations have been proposed in 3GPP more than once [26], [27], [34]. Future broadcast after Rel-17 will focus on the enhancements for physical layer, which brings a good chance for NUC to be adopted. For the base stations (BS), replacement of QAMs by NUCs only needs to change the modulation constellation table. This adjustment will not cause any difference on complexity. However, at UE, this replacement may lead to a little difference on complexity during demapping process. In specific, for M-ary QAM, only $\sqrt{M}$ Euclidean distance needs to be calculated in log-likelihood ratio (LLR) computation. But for NUCs, all the M Euclidean distance needs to be calculated. Regarding this issue, many simplified demapping algorithms are proposed [21], [22], [23] to reduce the demapping complexity. For instance, by using QCSR simplified demapping algorithm in [21] the required Euclidean distance calculation can be reduced up to 93% while demapping 256-ary 2D-NUCs with the performance loses less than 0.1 dB (which is negligible compared with the performance gain). This reduction ensures the demapping complexity of NUC is almost equal to QAM, but the performance gain of NUC is remarkable.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Carrier Frequency	700MHz
System BW	10MHz
Doppler frequency	77.78Hz
Speed	120km/h
Channel estimation	Perfect channel knowledge
Channel model	AWGN TDL-B (with DS =1us)
Number of Rx	AWGN:1 TDL-B:2
FEC	Turbo/LDPC
Modulation Scheme	QPSK 16QAM/16NUC 64QAM/64NUC 256QAM/256NUC

IV. EVALUATION

In this section, we conducted link-level simulations over AWGN and TDL-B channels to evaluate the performances of LTE-based 5G broadcast systems under different modulation and coding choices [39] based on Turbo codes and QAM. In mobile reception scenarios, TDL channel models [40] are more practical to be used to evaluate the link-level performance in LTE-based 5G terrestrial broadcast. Among different TDL channels, TDL-B is one of the most common choices in link-level simulation [34], [40], which is used in study item (in 3GPP meetings) of LTE-based 5G terrestrial broadcast. Thus, in our simulation, TDL-B is used.

Then the performance of enhancements via replacing Turbo by LDPC coding scheme and replacing QAM by designed NUC modulations are evaluated. In addition, the combined gain of LDPC and NUC scheme is explored in our overall evaluation. The simulation is based on the Vienna 5G link-level simulator [39]. The simulation parameters are shown in Table I [41]. LDPC codes and Turbo codes with same code rate and same code length are used in the simulation.

TABLE II
REQUIRED SNRS OF LDPC AND TURBO CODES IN DIFFERENT CASES OVER QAM AND AWGN CHANNEL

Case No.	Modulation	Code Rate	SNR of Turbo [dB]	SNR of LDPC [dB]	Gain [dB]
1	QPSK	0.076	-5.59	-6.38	0.79
2	QPSK	0.188	-2.42	-3.24	0.82
3	QPSK	0.438	1.18	0.90	0.28
4	16QAM	0.369	5.02	5.50	-0.48
5	16QAM	0.479	6.80	6.52	0.28
6	16QAM	0.602	8.68	8.25	0.43
7	64QAM	0.455	10.64	10.53	0.11
8	64QAM	0.554	12.50	12.05	0.45
9	64QAM	0.650	14.43	14.01	0.42
10	64QAM	0.754	16.02	15.79	0.23
11	64QAM	0.853	17.93	17.70	0.23
12	256QAM	0.694	19.99	19.71	0.28
13	256QAM	0.778	22.19	21.41	0.78
14	256QAM	0.864	24.07	23.35	0.72
15	256QAM	0.926	25.90	25.22	0.68

TABLE III
REQUIRED SNRS OF LDPC AND TURBO CODES IN DIFFERENT CASES OVER QAM AND TDL-B CHANNEL

Case No.	Modulation	Code Rate	SNR of Turbo [dB]	SNR of LDPC [dB]	Gain [dB]
1	QPSK	0.076	-3.61	-4.64	1.03
2	QPSK	0.188	0.14	-0.89	1.03
3	QPSK	0.438	4.50	3.72	0.78
4	16QAM	0.369	8.15	8.83	-0.68
5	16QAM	0.479	10.62	10.09	0.53
6	16QAM	0.602	12.73	11.78	0.95
7	64QAM	0.455	14.69	14.42	0.27
8	64QAM	0.554	16.87	16.00	0.87
9	64QAM	0.650	18.28	17.99	0.29
10	64QAM	0.754	20.30	19.66	0.64
11	64QAM	0.853	22.71	22.34	0.37
12	256QAM	0.694	23.99	23.52	0.47
13	256QAM	0.778	26.12	25.47	0.65
14	256QAM	0.864	28.58	27.74	0.84
15	256QAM	0.926	32.11	30.89	1.22

Note: In Table II and Table III, the column "SNR of LDPC" means the required SNR of BER=10^{-4} with LDPC codes. Similarly, the column "SNR of Turbo" means the required SNR of BER=10^{-4} with Turbo codes.

A. Channel Coding

The required SNRs to achieve BER $= 10^{-4}$ for LDPC and Turbo coding scheme based on AWGN channel are shown in Table II. Also, the required SNRs to achieve BER $= 10^{-4}$ for both two codes based on TDL-B channel are shown in Table III. In addition, the type of modulation is set to QAM of different orders for both coding schemes. In order to compare the BER performances of LDPC coding scheme and Turbo coding scheme, we list the gain between the required SNRs of these two codes in the table.

As shown in Tables II and III for 15 simulation cases of different code rates and modulation orders, the required SNRs to achieve BER $= 10^{-4}$ for LDPC coding scheme are mostly superior to those for Turbo coding scheme over both AWGN and TDL-B channels. Specifically, the maximum gain achieved for AWGN channel is 0.82 dB in Case 2. And for TDL-B channel, the maximum gain is 1.22 dB in Case 15. However, in Case 4 (for case of code rate equal to 0.3691 and the modulation order equal to 16), the required SNRs for LDPC coding scheme are worse compared to those for Turbo codes based on both two channels. This is because that the code rate is near 1/3 which is the base code rate of Turbo codes [42]. This gap can be compensated by NUC as shown in Tables VI and VII. In short, it can be concluded that, in most cases, LDPC coding scheme has better performance in terms of the BER for the considered scenarios.

TABLE IV
REQUIRED SNRS OF QAM AND NUC MODULATIONS IN DIFFERENT CASES OVER TURBO CODES AND AWGN CHANNEL

Case No.	Modulation Orders	Code Rate	SNR of QAM [dB]	SNR of NUC [dB]	Gain [dB]
4	16	0.369	5.02	4.87	0.15
5	16	0.479	6.80	6.67	0.13
6	16	0.602	8.68	8.52	0.16
7	64	0.455	10.64	10.14	0.50
8	64	0.554	12.50	12.01	0.49
9	64	0.650	14.43	13.84	0.59
10	64	0.754	16.02	15.81	0.21
11	64	0.853	17.93	17.85	0.08
12	256	0.694	19.99	19.37	0.62
13	256	0.778	22.19	21.83	0.36
14	256	0.864	24.07	23.62	0.45
15	256	0.926	25.90	25.70	0.20

TABLE V
REQUIRED SNRS OF QAM AND NUC MODULATIONS IN DIFFERENT CASES OVER TURBO CODES AND TDL-B CHANNEL

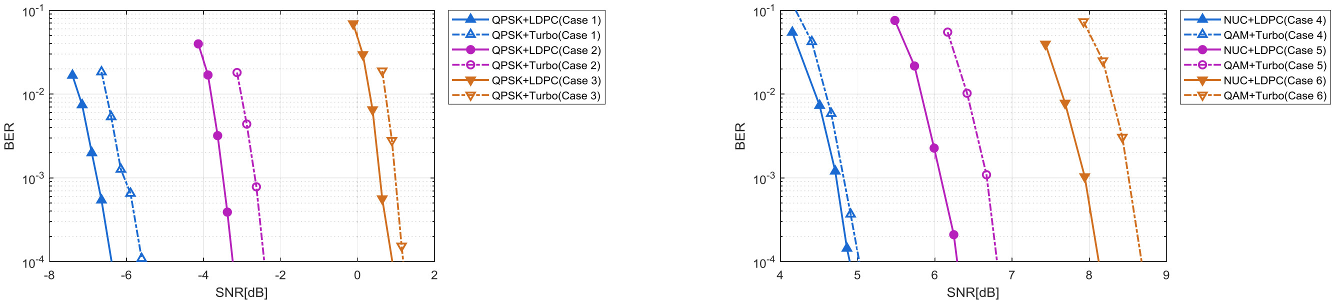
Case No.	Modulation Orders	Code Rate	SNR of QAM [dB]	SNR of NUC [dB]	Gain [dB]
4	16	0.369	8.15	8.10	0.05
5	16	0.479	10.62	9.92	0.70
6	16	0.602	12.73	12.49	0.24
7	64	0.455	14.69	14.08	0.61
8	64	0.554	16.87	15.72	1.15
9	64	0.650	18.28	17.74	0.54
10	64	0.754	20.30	20.05	0.25
11	64	0.853	22.71	22.63	0.08
12	256	0.694	23.99	23.34	0.65
13	256	0.778	26.12	25.63	0.49
14	256	0.864	28.58	27.86	0.72
15	256	0.926	32.11	31.57	0.54

Note: In Table IV and Table V, the column "SNR of QAM" means the required SNR of BER=10^{-4} with QAM. Similarly, the column "SNR of NUC" means the required SNR of BER=10^{-4} with NUCs.

B. Modulation

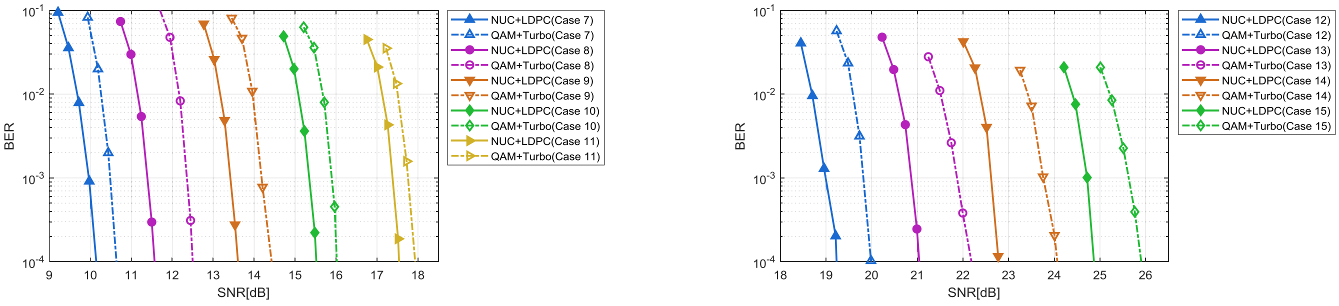
The required SNRs to achieve BER $= 10^{-4}$ for QAM and NUC modulations in different simulation cases based on turbo codes and AWGN channel are shown in Table IV. Considering NUC with quadrant symmetry is exactly same as QAM (QPSK)in the order of 4, Case 1, 2 and 3 are skipped in this section. Also, the required SNRs to achieve BER $= 10^{-4}$ for both two kinds of modulations based on turbo codes and TDL-B channel are shown in Table V. In addition, the type of coding is set to Turbo for both modulation schemes. Similarly, in order to compare the BER performances of QAM and NUC modulations, we list the gains between the required SNRs of these two kinds of modulations in the table.

As shown in Tables IV and V for all the 12 cases of different code rates and modulation types, the required SNRs to achieve BER $= 10^{-4}$ for NUC modulations are superior to those for QAM based on both AWGN and TDL-B channels.



(a) Modulation Order = 4

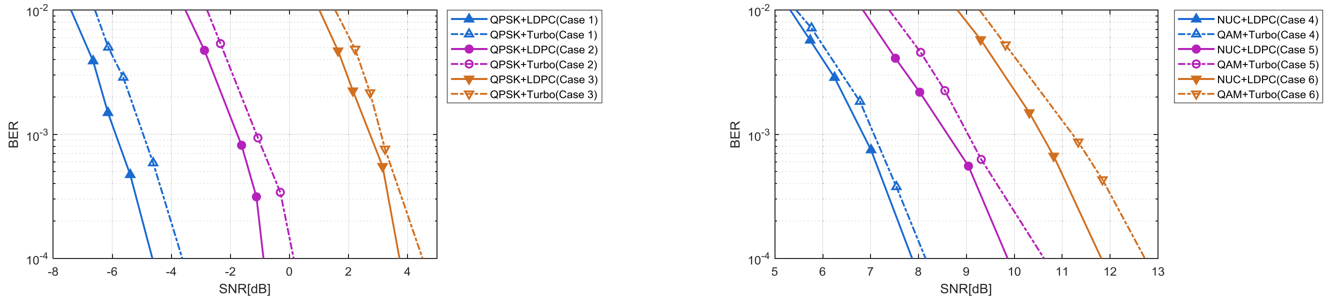
(b) Modulation Order = 16



(c) Modulation Order = 64

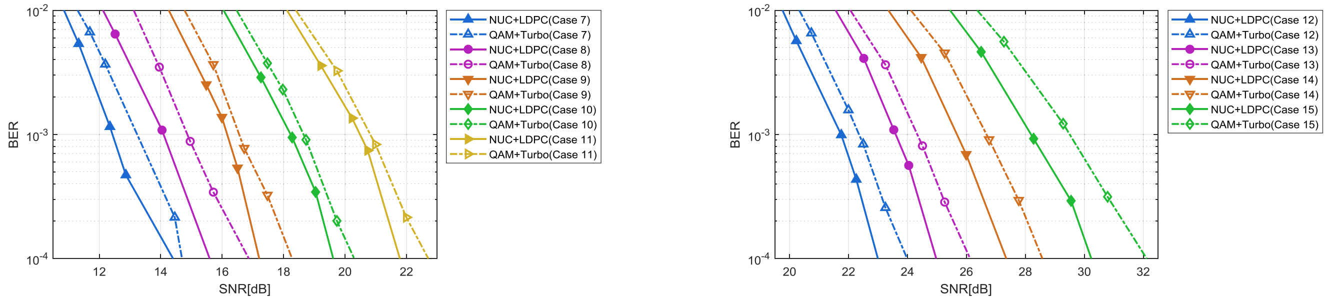
(d) Modulation Order = 256

Fig. 3. BER performance of proposed coding modulation scheme (NUC+LDPC) vs. current accepted one (QAM+Turbo) over AWGN channel.



(a) Modulation Order = 4

(b) Modulation Order = 16



(c) Modulation Order = 64

(d) Modulation Order = 256

Fig. 4. Performance of proposed coding modulation scheme (NUC+LDPC) vs. current accepted one (QAM+Turbo) over TDL-B channel.

Specifically, the maximum gain achieved for AWGN channel is 0.62dB in Case 12. And for TDL-B channel, the maximum gain is 1.15dB in Case 8. According to the simulation results, NUC modulations can provide more shaping gain and have better performance than QAM in terms of the BER for the considered scenarios.

C. Overall Evaluation

Sections IV-A and IV-B presents standalone, the gain of LDPC over Turbo and the gain of NUCs over QAM, respectively. While the whole proposal in this paper includes the LDPC codes replacing turbo and designed NUC modulations replacing QAM. Except in Case 1, 2 and 3, only codes are replaced since NUC with constellation order of 4 cannot be well designed based on quadrant symmetry.

In this part, LDPC and NUC are combined and evaluated. As shown in Fig. 3, BER performances of our LDPC plus NUCs scheme is remarkably better than the traditional Turbo codes with uniform QAMs schemes based on AWGN channel. According to Table VI, we can find out that the performance

TABLE VI
REQUIRED SNRS OF PROPOSED CODING MODULATION SCHEME AND CURRENT ACCEPTED ONE IN DIFFERENT CASES OVER AWGN CHANNEL

Case No.	Modulation Orders	Code Rate	Current Scheme [dB]	New Scheme [dB]	Gain [dB]
1	4	0.076	-5.59	-6.38	0.79
2	4	0.188	-2.42	-3.24	0.82
3	4	0.438	1.18	0.90	0.28
4	16	0.369	5.02	4.90	0.12
5	16	0.479	6.80	6.29	0.51
6	16	0.602	8.68	8.12	0.56
7	64	0.455	10.64	10.14	0.50
8	64	0.554	12.50	11.57	0.93
9	64	0.650	14.43	13.61	0.82
10	64	0.754	16.02	15.52	0.50
11	64	0.853	17.93	17.54	0.39
12	256	0.694	19.99	19.23	0.76
13	256	0.778	22.19	21.04	1.15
14	256	0.864	24.07	22.78	1.29
15	256	0.926	25.90	24.87	1.03

TABLE VII
REQUIRED SNRS OF PROPOSED CODING MODULATION SCHEME AND CURRENT ACCEPTED ONE IN DIFFERENT CASES OVER TDL-B CHANNEL

Case No.	Modulation Orders	Code Rate	Current Scheme [dB]	New Scheme [dB]	Gain [dB]
1	4	0.076	-3.61	-4.64	1.03
2	4	0.188	0.14	-0.88	1.02
3	4	0.438	4.50	3.72	0.78
4	16	0.369	8.15	7.86	0.29
5	16	0.479	10.62	9.86	0.76
6	16	0.602	12.73	11.81	0.92
7	64	0.455	14.69	14.40	0.29
8	64	0.554	16.87	15.59	1.28
9	64	0.650	18.28	17.20	1.08
10	64	0.754	20.30	19.61	0.69
11	64	0.853	22.71	21.78	0.93
12	256	0.694	23.99	22.99	1.00
13	256	0.778	26.12	24.97	1.15
14	256	0.864	28.58	27.35	1.23
15	256	0.926	32.11	30.23	1.88

Note: In Table VI and Table VII, the column "Current Scheme" means the required SNR of BER=10^{-4} with current accepted scheme. Similarly, the column "New Scheme" means the required SNR of BER=10^{-4} with our proposed coding modulation scheme.

gain of proposed LDPC plus NUCs scheme over AWGN channel can be 0.12 ∼ 1.29 dB. Fig. 4 shows the advantage of our scheme based on TDL-B channel. As shown in Table VII, the detailed performance gain of proposed scheme over TDL-B channel is 0.29 ∼ 1.88 dB.

From the performance gain over both AWGN channel and TDL-B channel, it can be figured out that as modulation order increases, the performance gain increases in general. For instance, while the modulation order is 16 in Case 4, the performance gain is only 0.12dB; but the performance gain is 0.76 ∼ 1.29dB in the cases of modulation order equal to 256 over AWGN channel. The maximum performance gain always achieves in the cases of modulation order equal to 256.

In conclusion, the performance evaluation verifies that proposed LDPC coding and NUC modulation scheme will provide significant performance gains in most of the combinations of modulation and coding schemes, which means LDPC codes and NUC modulation should be considered in future broadcast system.

V. CONCLUSION

This paper mainly investigates the possible enhancements in coding and modulation schemes for future broadcast systems in 3GPP. Limitations of Turbo codes and QAM modulation in latest LTE-based 5G Terrestrial Broadcast System are evaluated through analysis and link-level simulations. Furthermore, customized LDPC codes with backward compatibility and well-designed NUCs are proposed to replace Turbo codes and QAM. Extensive simulations show that the proposed LDPC coding and NUC modulation scheme will provide significant performance gain. The performance gain of LDPC codes is up to 0.82dB over AWGN channel and up to 1.22 dB over TDL-B channel, compared with Turbo codes. Moreover, the performance gain of NUCs is up to 0.62 dB over AWGN channel and up to 1.15 dB over TDL-B channel, compared with QAM based on Turbo codes. The overall performance gain of LDPC codes and NUCs is 0.12 ∼ 1.29 dB over AWGN channel and 0.29 ∼ 1.88 dB over TDL-B channel. Furthermore, the complexity issue is also analyzed in the paper to proofs that significant performance gain can be reached without complexity problem. Therefore the proposed LDPC and NUC is a good choice for future broadcast system of 3GPP.

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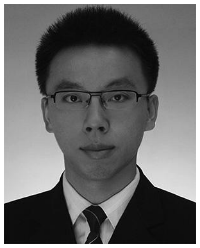

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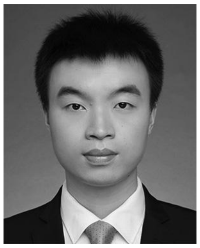

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