Roads to Multimedia Broadcast Multicast Services in 5G New Radio

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Abstract—**Broadcast and multicast represent a key opportunity in 5G for the massive consumption of multimedia services in the near future. These technologies permit to offload an important portion of this traffic in peak demand scenarios where users are consuming parallel content. An initial specification of 5G New Radio (NR) Rel15 was delivered in December 2017 and the final version will be published in June this year. However, 3GPP has not yet defined any broadcast/multicast solution for Rel15 NR, although some proposals will be revisited as soon as time units in Rel16 become available. In this work, we analyse the use of a mixed mode that shares multicast, broadcast and unicast resources via the same physical channel. This technology, as well as its LTE counterpart, is evaluated through link level air interface and subsequently system level simulations, providing an objective insight roads to MBMS provision in 5G NR.**

Index Terms—**Multimedia, Broadcast, 5G, New Radio, MBMS, mobile networks.**

I. INTRODUCTION

MULTIMEDIA consumption will constitute 78% of all mobile network traffic by 2021 [1]. Broadcast is the only technology able to offload a significant portion of this traffic in peak demand scenarios where users are consuming parallel content. Over the years, the use of broadcast in order to address video delivery to mobile devices was specified by different standardization forums. The Digital Video Broadcasting (DVB) consortium specified first the digital terrestrial television (DTT) system DVB-Handheld (DVB-H) [2] and later DVB - Next Generation Handheld (DVB-NGH) [3]. However, the demand of most of these technologies was not sufficiently high to offset the costs associated. The Integrated Services Digital Broadcasting - Terrestrial (ISDB-T) systems also permits to transmit data to mobile devices by using the one-seg technology [4], but with a resolution that does not satisfy the current user demands.

The 3rd Generation Partnership Project (3GPP) standardisation forum has also adopted the use of broadcast in 4G (the 4th Generation) LTE (Long Term Evolution) with the inclusion of evolved Multimedia Broadcast Multicast Services (eMBMS) [5]. This technology allows a potential infinite number of mobile users to consume the same content at once, using just a fixed amount of network resources. Today, the state-of-the-art specification for broadcast and multicast is LTE-Advanced Pro Release 14 (Rel'14) eMBMS, which has included specific requirements to deliver linear services to both mobiles and fixed rooftop receivers. From its specification in Rel'9, eMBMS has gone through a very significant set of enhancements, which are identified and studied in [6]. One of the highest improvements was the use of MBMS over Single Frequency Networks (MBSFN) by introducing new physical, transport and logical channels into the specification. Another main novelty is the use of Single Cell PTM (SC-PTM), introduced in Rel'13 to increase the resource allocation flexibility by multiplexing broadcast and unicast data on the same physical channel.

The consumption of media on the go and its subsequent demand on mobile networks has placed mounting pressure on the spectrum resources assigned to DTT services. This has already resulted in the auctioning of 800 MHz band (first digital dividend) and now 700 MHz band (second digital dividend) over to mobile networking technology. Given the scarcity of spectrum in this band, guard bands between the technologies were left minimal [7]. Taken together, these trends coupled with prior experience logically lead to a convergence of technologies. In this sense, 5G (the 5th Generation) New Radio (NR) which will employ frequency bands above 6 GHz arises as an unprecedented opportunity not only for this convergence but also for the simultaneous transmissions of unicast, multicast and broadcast services.

3GPP has planned the 5G standardisation into two phases: Phase 1 to finalise Rel'15 by the 2nd half of 2018; Phase 2 to finalise Rel'16 by the end of 2020. An initial 3GPP Rel'15 NR was delivered in December 2017 and the final version is expected to be published in June 2018. This work extrapolates the features and technologies most likely to be available and implemented for NR broadcast, such as Media and Entertainment (M&E), Public Warning Systems (PWS), automotive and Internet of Things (IoT) [8], from the state of the art of NR unicast technology and standardisation [9]. These technologies, as well as their LTE counterparts, are evaluated through link level air interface and subsequently system level simulations, providing an objective preliminary insight roads to MBMS provision in 5G NR.

The rest of this paper is structured as follows. Section II explains the technical specifications in 3GPP, including both 4G LTE and 5G NR. In Section III, the air interface solution is evaluated. Section IV presents the system-level evaluation, based on results previously obtained in Section III. Finally, the main findings of the work are summarized in Section V.

TABLE I
MBSFN AND SC-PTM PARAMETERS COMPARISON

	MBSFN	**SC-PTM**
Data channel	PMCH	PDSCH
Subcarrier spacing (kHz)	15, 7.5, 1.25	15
Cyclic prefix	Extended	Normal / Extended
Control channel OFDM symbols	1 or 2 @ 15 kHz	3 if $BW \leq 5$ MHz
	0 otherwise	2 if $BW \geq 10$ MHz
Resource allocation	Static	Dynamic

II. TECHNICAL SPECIFICATION FOR CELLULAR BROADCAST TECHNOLOGY IN 3GPP

A. Evolved Multimedia Broadcast Multicast Services

eMBMS Rel'14 is the latest fully standardised 3GPP LTE PTM technology. The eMBMS standard can be predominantly described by two deployment methodologies, i.e. MBSFN and SC-PTM.

MBSFN deployments consist of a group of cells which perform completely synchronized transmission, eliminating inter-cell interference for the broadcast service within the given area. The trade-off here comes in flexibility, particularly with regard to resource scheduling, which is rigid and largely fixed for the duration of the service. With MBSFN, broadcast and multicast use the Physical Multicast Channel (PMCH) for an independent transmission that permits SFN synchronisation. A different physical channel allows using configurations that are not permitted with unicast. As Table I shows, MBSFN employs three values for subcarrier spacing (15, 7.5 and 1.25 kHz) that in turn provide extended cyclic prefix (CP) lengths of 16.6, 33.3 and 200 μs. Due to the SFN transmission, MBSFN uses a more dense reference signal pattern than the one used for unicast. As a main drawback, the use of Multiple-Input Multiple-Output (MIMO) techniques that provide spatial multiplexing gain is not defined for MBSFN, which reduces the peak spectral efficiency drastically compared with SC-PTM used in 5G NR technologies.

The SC-PTM method was first introduced in Rel'13 with the aim of increasing the resource allocation flexibility for PTM deployments. Since then it has evolved to the 5G stage in Rel'15 [10]. At the Medium Access Control layer (MAC), apart from the Multicast Traffic Channel (MTCH), the Single-Cell Multicast Traffic Channel (SC-MTCH) is defined to transmit traffic data from the network to the UE using SC-PTM. At the physical layer (PHY), SC-PTM allows a single cell to broadcast to a group of users over the Physical Downlink Shared Channel (PDSCH), used by unicast transmission. Sharing a physical channel also implies to use the same carrier spacing of 15 kHz. With SC-PTM, both normal CP (5.2 μs first symbol and 4.7 μs the rest) and extended CP (16.7 μs) are available to use. The use of MIMO with up to four transmitter and receiver antennas is permitted in this case. Further technical distinctions of note are shown in Table I.

B. 5G New Radio

Evolving from 4G LTE, 5G NR is the next generation of mobile telecommunication networks. Besides looking towards employing new higher frequency bands normally above 6 GHz, NR includes new techniques to improve the system performance in terms of data rate, coverage, reliability, latency and mobility [11]. Some of the most crucial technologies adopted are:

- Scalable OFDM numerology. Unlike 4G LTE which operates on carrier bandwidth up to 20 MHz with fixed OFDM numerology, 5G NR will be able to operate on millimetre wave (mmWave) of 100s of MHz bandwidth, with scalable sub-carrier spacing.
- Flexible framework with scalable Transmission Time Interval (TTI). Instead of a fixed TTI of 1 ms supported by LTE, 5G NR will provide a framework supporting scalable TTI in the range of 100s of μs and TTI multiplexing, tailored to accommodate differentiated service requirements.
- New channel coding and rate matching. 5G NR may use various codes such as LDPC (Low Density Parity Check) and Polar code amongst the options, which offer great gains in performance compared with the Turbo code used for LTE.
- Massive MIMO and beamforming. Evolving from up to 4x4 MIMO used by current LTE, 5G NR may support Massive MIMO with up to 256 antenna elements. The smart beamforming can extend the coverage of a base station by focusing the emission power directionally.

At the time of this paper being written, 3GPP has not yet defined any broadcast solution for Rel'15 NR, and it is expected to revisit some proposals as soon as time units in Rel'16 become available. In this work, we consider the use of a mixed mode where available resources are shared by unicast, multicast and broadcast services by using the same physical channel. This resource sharing can be performed in the same subframe (same concept as SC-PTM in LTE) or in different subframes that permit the use of small-scale SFN deployments (MBSFN-like). This is aligned with the 3GPP vision for future 5G releases and the proposal in [12]. The mixed mode facilitates a seamless transition between services but as main disadvantage the broadcast part keeps the unicast parameters, which may hamper some potential use cases.

Note that the use of a 5G NR broadcast solution that uses an independent physical channel and therefore could implement additional techniques such as Non-Uniform Constellations (NUC) [13] or time/frequency interleaving is not considered in this paper.

III. AIR INTERFACE TECHNOLOGY EVALUATION

Fig. 1 depicts signal-to-noise ratio (SNR) vs. BLER for 5G NR mixed UC/BC mode and AWGN channel, for a whole range of Modulation and Coding Schemes (MCS) defined in [14] (Tables 5.1.3.1-1 and 5.1.3.1-2). Fig. 2 also shows the data spectral efficiency as a function of the required SNR

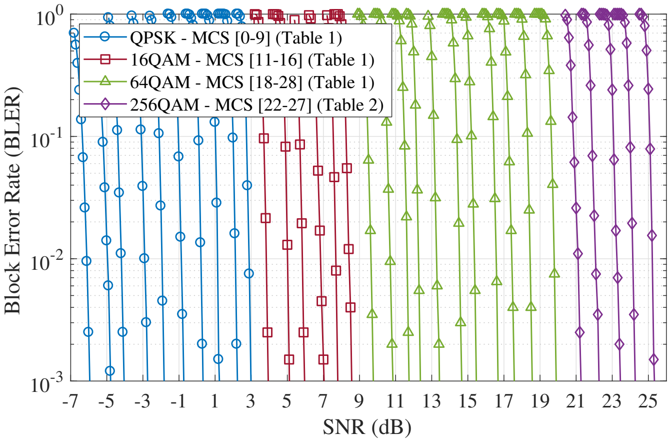

Fig. 1. SNR waterfall for 5G NR mixed UC/BC mode and AWGN channel.

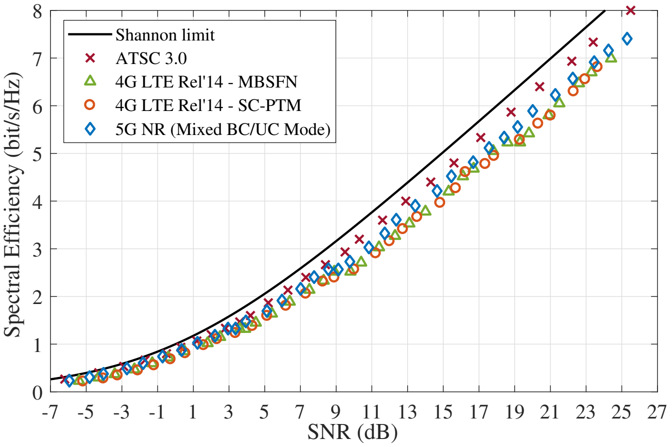

Fig. 2. Air interface performance of eMBMS and 5G NR broadcast proposed for AWGN channel.

for this technology, compared to eMBMS Rel'14 and the current state-of-the-art DTT specification, i.e. ATSC 3.0. An optimum Maximum Likelihood (ML) demapper with ideal channel estimation is considered in all cases. In this case, only one transmitting/receiving antenna is selected. The quality of service is a block error rate (BLER) lower than 0.1%.

Observing Fig. 2, it is possible to affirm that the use in 5G NR of a more efficient channel coding such as Low-Density Parity Check (LDPC) codes provides a significant performance improvement compared to 4G. SNR gains of up to 1 dB are obtained, regardless of the eMBMS technology employed, that is, MBSFN or SC-PTM. Note that neither frequency nor time interleaving affects the results for this channel model.

Although the 5G performance is better compared to its prior generation, there is still room for improvement. For instance, ATSC 3.0 achieves higher capacities in similar SNR conditions due to the use of NUCs for modulation and longer LDPC code lenghts. On the one hand, NUCs provide an important improvement due to the geometrical signal shaping, whereas longer LDPC codes achieve higher gains because of the higher correcting capabilities. This gain also depends on the CR, achieving from 0.2 dB (high CR) to 0.7 dB (robust CR), regardless of the modulation order.

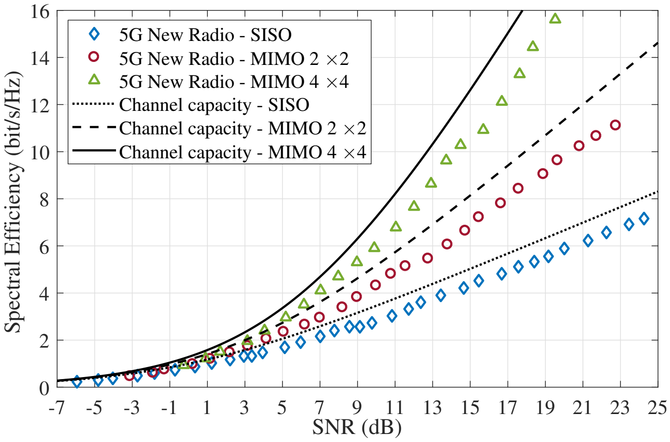

Fig. 3. Air interface performance of eMBMS and 5G NR broadcast proposed for AWGN channel.

Fig. 3 also shows the 5G NR mixed BC/UC mode performance shown in Fig. 2 against different MIMO configurations, for a whole range of MCS indexes. In particular, configurations with a 2 and 4 transmitter/receiver antennas as well as 2 and 4 layers respectively are used. The use of MIMO permits to increase the capacity thanks to the spatial multiplexing, while maintaining the minimum SNR required to receive the signal correctly. For instance, the capacity achieved with one layer for an SNR of 20 dB is 6 bit/s/Hz, which can be increased to 10 and 16 bit/s/Hz when 2 and 4 layers are used respectively.

IV. SYSTEM-LEVEL EVALUATION

A. Simulation Platform

Samsung R&D Institute UK has developed an in-house abstract system level simulator called 5G-PySim, written in Python. The simulator focuses on the physical layer and reasonably simplifies higher layers implementation. The data used in link level parameter settings can be imported from the results presented in Section III, and the system level simulation (SLS) results can be represented in IPython with any available tool, such as Jupyter. It allows us to carry out the simulations intended to investigate the performance of 4G LTE and 5G NR with comparable settings.

B. Results

To characterise the performance of the proposed NR broadcast solution in a full deployment scenario, system level simulations are conducted using the latest 3GPP Channel Model [15] and following the UMi Street Canyon scenario parameters presented therein. Key parameters used are shown in Table II with any omitted parameters remaining identical to the calibration definitions in [15]. The MCS and CQI (Channel Quality Indicator) tables are set as specified in [14]. The cellular network layout is shown as in Fig.4, where the 285 UEs are randomly scattered around the configured 19 base stations. The simulations are conducted utilising performance

TABLE II
SYSTEM LEVEL SIMULATION PARAMETERS

Parameter	**Value**
Cell layout	Hexagonal grid, 19 micro sites 3 sectors per site, full wraparound
User deployment	Random deployment, 5 users per sector, 285 users in total
Inter-site distance	200m
Indoor user ratio	80% indoor
Antenna	TR 36.897 [16] (12° downtilt)
BW @ frequency	20MHz @ 2GHz
BS transmission power	44dBm
PTM resource allocation	Fixed frame allocation, period = 1, subframe map = 0111101111 (80%)

curves for BLER and SINR mapping obtained during link level simulations in Section III. Fig. 5 presents the error rate alongside the mean, minimum and maximum user throughput with increasing CQI for SC-PTM broadcast transmission.

From Fig. 5 it can be seen that 5G NR outperforms 4G LTE even in very limited 5G settings (SISO only, same bandwidth as for 4G LTE, etc.), thanks to the bigger Transport Block Size (TBS) used in 5G, increased spectral efficiency, and also a new MCS table defined in 5G NR. It can be safely predicted that much more gain would be seen if using massive MIMO, wider bandwidth on a higher frequency mmWave band with scalable numerology, and other 5G characteristics.

It is clear that for both 4G LTE and 5G NR there is a decisive cut off in CQI. For 4G LTE, between a CQI of 4 and 5 the error rate rises from 0% to over 15%. By a CQI of 6, the packet loss has climbed to over 60%. While in the case of 5G NR, the error rate rises to 8% and further to 50% at the CQI of 6. That means a drawback of the unified transmission against diversified channel quality of the all the broadcast receiver UEs, and would be considered unacceptable coverage in most cases. It is observed that for the same CQI values the throughput curves present a different story. Here for 4G LTE, the mean throughput for a CQI of 5 is 9.6 Mbps, a 1 Mbps improvement over a CQI of 4, while drops to 4.8 Mbps at the CQI of 6. Similarly on the side of 5G NR, the mean throughput for a CQI of 5 is 10.6 Mbps, a 3.3 Mbps improvement over the CQI of 4, and drops to 7 Mbps at the CQI of 6. This does imply that the granularity of CQI or MCS in broadcast is too limited.

V. CONCLUSION

Broadcast in 5G New Radio represents an unprecedented opportunity for the delivery of mobile video services to massive audiences. Compared to eMBMS, NR extends signal coverage to cell-edge users and is able to cope with higher traffic demands in mobile scenarios. SNR gains up to 1 dB are obtained when transmitting at high MCS indexes. Whilst the flexibility in scheduling provided is useful, if this additional degree of freedom is not fully exploited it remains highly prone to interference. Both SC-PTM and 5G broadcast are most powerful where a cluster of users all happen to have a high SINR; in this case it can be considerably more spectrally efficient than MBSFN. It has been observed that 5G NR outperforms 4G LTE even in very limited settings, thanks to the bigger transport block size used, increased spectral efficiency and also a new MCS table defined in 5G NR.

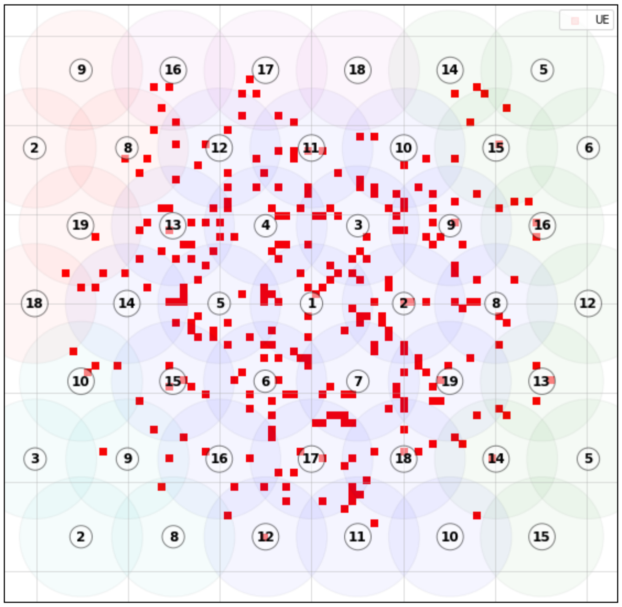

Fig. 4. User distribution for system-level simulations. 19 cells and 285 randomly distributed users.

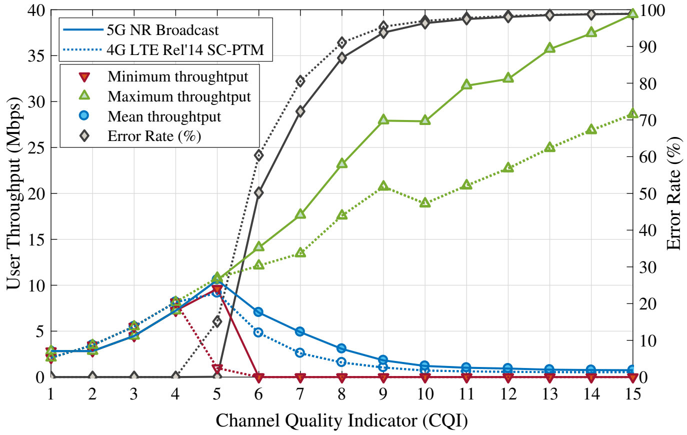

Fig. 5. User throughput in Mbps (left y-axis) and error rate (right y-axis) per CQI transmitted with eMBMS and 5G NR Broadcast.

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