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Broadcasting Scalable Video With Generalized Spatial Modulation in Cellular Networks

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ABSTRACT This paper considers the transmission of scalable video via broadcast and multicast to increase spectral and energy efficiency in cellular networks. To address this problem, we study the use of generalized spatial modulation (GSM) combined with non-orthogonal hierarchical M-QAM modulations due to the capability to exploit the potential gains of large scale antenna systems and achieve high spectral and energy efficiencies. We introduce the basic idea of broadcasting/multicasting scalable video associated to GSM, and discuss the key limitations. Non-uniform hierarchical QAM constellations are used for broadcasting/multicasting scalable video while user specific messages are carried implicitly on the indexes of the active transmit antennas combinations. To deal with multiple video and dedicated user streams multiplexed on the same transmission, an iterative receiver with reduced complexity is described. 5G New Radio (NR) based link and system level results are presented. Two different ways of quadruplicating the number of broadcasting programs are evaluated and compared. Performance results show that the proposed GSM scheme is capable of achieving flexibility and energy efficiency gain over conventional multiple input multiple output (MIMO) schemes.

INDEX TERMS Broadcasting, generalized spatial modulation, multiple input multiple output, scalable video coding.

I. INTRODUCTION

To meet the expected growth of mobile data traffic [1], 5G networks need to deliver a substantial capacity increase compared to the current 4G wireless networks. 5G technology will provide faster, reliable and almost instant connections to people and everything with many types of devices [2]. Streaming video will be experienced in real time while smart devices with artificial intelligence and machine learning will give customized and personalized services.

Spatial modulation (SM) and generalized spatial modulation (GSM) have been raising substantial research interest due their capability to exploit the potential gains of large scale or massive multiple input multiple output antenna (MIMO) systems, with lower implementation complexity and better energy efficiency than conventional MIMO [3], [4]. The use of only one active transmitting antenna at any given time of SM limits the spectral efficiency that can be achieved. However, SM can achieve good energy efficiency and reduced receiver implementation complexity. On the other hand, GSM transmits using a subset of the available antennas, which permits achieving a better tradeoff between the reduced complexity of SM and the high spectral efficiency of conventional MIMO.

In a broadcast cellular system, there may be a heterogeneous network with users requiring diverse bitrates using different terminals capabilities and connection speeds. Furthermore, there is also a substantial and variable decrease of the received power depending on the distance between the base station (BS) and each of the different receivers. For the

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particular case of video, there are several strategies presented in the literature to adapt its content within a heterogeneous communications environment [5]–[7].

Scalable Video Coding (SVC) provides a base layer for minimum requirements, and one or more enhancement layers to offer improved qualities at increasing bit/frame rates and resolutions. Common scalability options are: temporal scalability, spatial scalability and signal to noise ratio (SNR) scalability [8]. SNR scalability implies the creation of multi-rate bit streams. It allows for the recovery of the difference between an original picture and its reconstruction. A lot of research has been done on SVC transmission over wireless broadcast networks. In [9], [10], the topics addressed were mobile video delivery associated to rate scalable media and multi-resolution to provide graceful degradation of quality. In [11], the authors discussed the combination of layered media with the physical layer pipes feature of digital terrestrial TV standard DVB-T2, enabling flexible broadcast of services with differentiated protection of the quality layers. The DVB-NGH (Next Generation Handheld) is the handheld evolution of DVB-T2 [12]. The main new technical elements introduced with respect to DVB-T2 are: layered video coding with multiple physical layer pipes and time-frequency slicing. Another important standard system that is a reference of broadcasting is the Advanced Television Systems Committee (ATSC) 3.0, the next-generation digital terrestrial broadcasting standard [13], [14]. Other very important broadcasting/multicasting standards are Multimedia Broadcast/Multicast Service (MBMS) for UMTS and evolved MBMS (eMBMS) for LTE [15]–[17] that support downlink video streaming and other type of services to large groups of users over mobile networks. In this type of networks, channel quality indicators (CQIs) of individual users are available at the BS in the form of CQI feedbacks. In order to exploit the availability of CQIs, multicast/unicast resource allocation for OFDMA with CQI feedback was studied in [18], [19].

Motivated by the above, in this paper, we focus on broadcasting within mobile 5G cellular networks. Our proposed hierarchical layer system can be seen as a variant of layer division multiplexing (LDM) of ATSC 3.0 [20], [21], where several data streams are transmitted at different power levels. The topic of efficient transmission of multiple broadcasting services using LDM and SVC was addressed without MIMO in [21]. The DVB-NGH was the first broadcasting system that allowed for the possibility of using MIMO schemes [12]. ATSC 3.0 has also adopted an optional MIMO profile [20]. However, all of these works include only MIMO 2×2. In this paper, we introduce the novelty of considering a specific form of massive MIMO for broadcasting, namely, GSM combined with SVC, hierarchical modulation and unequal error protection for cellular networks.

Our system considers a GSM aided system which can simultaneously transmit dedicated user streams while also broadcasting multiple video channels using a reduced set of active antennas. The user specific messages are carried implicitly on the indexes of the active transmit antennas combinations, improving the spectral and power efficiency of the system. To cope with the multiple streams multiplexed on the same transmission we extend the low complexity detector that was proposed in [22] within the context of single user GSM-MIMO transmissions. Using the proposed system model and receiver, several link and system level results are presented considering parameters of 5G NR cellular networks showing the gains of the proposed approach.

The rest of the paper is organized as follows: in section II the model for the current multi-resolution broadcast system based on SM is introduced. Section III describes the proposed iterative receiver while Section IV presents discusses the simulation results. Conclusions are drawn in Section V.

Notation: Matrices and vectors are denoted by uppercase and lowercase boldface letters. The superscripts $(\cdot)^{\mathrm{T}}$ and $(\cdot)^{\mathrm{H}}$ denote the transpose and conjugate transpose of a matrix/vector, $||\cdot||_2$ is the 2-norm of a vector, $\mathrm{supp}(\mathbf{x})$ returns the set of indices of nonzero elements in $\mathbf{x}$ (i.e., the support of $\mathbf{x}$), $\binom{N}{k}$ is the number of combinations of N symbols taken k at a time and $\mathbf{I}_n$ is the $n \times n$ identity matrix.

II. SYSTEM MODEL

The system we consider here is multi-rate based, where we apply the stream splitting technique. This technique splits the high-rate content into multiple low-rate layers. We mainly consider a broadcast/multicast video service that is encoded into multiple layers using SVC, which enables delivering this service using different multicast multi-rate transmissions with varying degrees of quality. The use of GSM allows the introduction of an additional traffic (can be unicast) associated to the choice of the set of transmitting antenna groups. Later this is designated as the spatial component of the multi-layer stream scheme. Each multicast service is split into different subgroups in accordance to the video layers available to deliver the service. In this paper, we mainly evaluate a service with three video layers, the base layer and two additional enhancement layers, as shown in Figure 1.

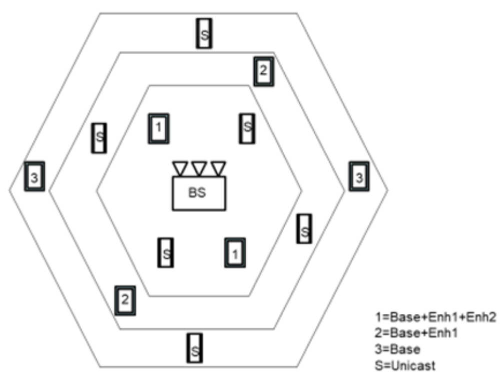

FIGURE 1. Cell with three different regions and different multi-rate transmissions.

The associated M-QAM hierarchical modulations (also known as embedded or multiresolution modulations) consist of constellations with nonuniformly spaced signal points that are transmitted in the OFDMA network (see Figure 2).

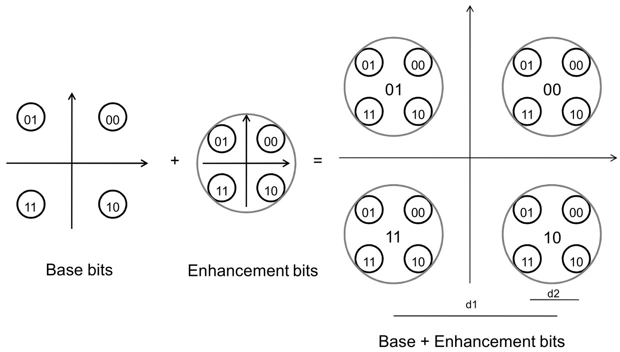

FIGURE 2. **Illustration of the hierarchical 16QAM constellation.**

The distances we use in this constellation are based in a hierarchy. Parameter d_1 represents the distance between the points in the quaternary-shift keying (QPSK) constellation (base bits). This is the first level of hierarchy. Parameter d_2 is the second level of hierarchy and represents the distance between the points in the 16QAM constellation (enhancement bits) centered around the QPSK points. A third level of hierarchy is defined through d_3 which is the distance between points of the corresponding 64QAM (second enhancement bits) constellation centered around 16QAM points (see [23]).

Based on the CQI reported by the worst user on the group and the average block error rate (BLER) constraint, the adequate k parameter is selected from ($k = d_2/d_1$ with $0<k\leq 0.5$) of the associated hierarchical M-QAM constellation [24] to transmit the video layers with good coverage within the cell area as illustrated in Figure 1.

We do not focus on a fair resource distribution between broadcast/multicast and additional traffic in this paper but it is easy to balance these two traffics on a GSM transmission by increasing or decreasing the number of transmitting antennas of the global set of transmitting antennas and changing the associated M-QAM in the constellation mapping block as shown in Figure 3.

While in this paper we do not consider the design of simple receivers that are only able to detect the active transmitting antennas, it is possible to implement such type of receivers. In this case, the receiver would be able to decode solely the dedicated spatial bits, sacrificing the multicast/broadcast streams. The receiver considered in this paper performs the decoding of spatial bits and multiple layers video bits at the same time. Note that to provide a reliable support for the dedicated streams mapped on the spatial bits it is essential that the coverage of spatial bits is high.

Let us consider a OFDM based system where the BS is equipped with N_u groups of N_t transmitter antennas serving users with N_r receiver antennas. Each of the N_u groups of transmitter antennas is able to transmit one GSM symbol using only N_a active antenna elements (AEs) at any given time. Each of these AEs sends a different hierarchical M-QAM symbol, which means that a GSM symbol carries $\left\lfloor \log_2 \binom{N_t}{N_a} \right\rfloor$ spatial bits and $N_a \log_2 M$ conventional modulated bits. The total number of bits transmitted simultaneously by the BS is then $N_u \left(\left\lfloor \log_2 \binom{N_t}{N_a} \right\rfloor + N_a \log_2 M \right)$. Assuming an OFDM system where the cyclic prefix (CP) is larger than the propagation delay spread then the channel is basically flat for each subcarrier. In this case, the baseband signal received by a user at each subcarrier can be represented in the frequency domain as

$$\mathbf{y} = \mathbf{H}\mathbf{s} + \mathbf{n} \tag{1}$$

where $\mathbf{y} \in \mathbb{C}^{N_r \times 1}$ is the received vector, $\mathbf{H} \in \mathbb{C}^{N_r \times N_u N_t}$ is the frequency domain channel matrix at that subcarrier and $\mathbf{n} \in \mathbb{C}^{N_r \times 1}$ is the vector containing independent zero-mean circularly symmetric Gaussian noise samples with covariance $2\sigma^2 \mathbf{I}_{N_r}$. Vector $\mathbf{s}$ comprises all the N_u GSM symbols transmitted simultaneously, i.e, $\mathbf{s} = \left[\mathbf{s}^{0^T} \ldots \mathbf{s}^{N_u - 1^T} \right]^T$ with

$$\mathbf{s}^u = \Bigg[\underbrace{\ldots, 0, s_0^u, 0, \ldots, 0, s_{N_a-1}^u, 0, \ldots}_{N_t} \Bigg]^T, \tag{2}$$

$s_j^u \in \mathcal{A}$ (j=0,..., N$_a$-1, u=0,..., N$_u$-1) and $\mathcal{A}$ denoting the M-sized complex valued constellation set. The configuration adopted for the system model allows the broadcast of N_u simultaneous video channels with multiple layers which are mapped on hierarchical constellations, and at the same time transmit N_u user specific messages which are carried implicitly on the indexes of the active transmit antennas combinations (TACs).

III. RECEIVER DESIGN

Taking into account the system model described in the previous section, the maximum likelihood detection (MLD) problem can be formulated as

$$\min_{\mathbf{s}} \|\mathbf{y} - \mathbf{H}\mathbf{s}\|_2^2 \tag{3}$$

$$\text{subject to } \mathbf{s} \in \mathcal{A}_0^{N_u N_t} \tag{4}$$

$$\operatorname{supp}\left(\mathbf{s}^u\right) \in \mathbb{S}, \quad u = 0, \ldots, N_u - 1, \tag{5}$$

where $\mathcal{A}_0 \overset{def}{=} \mathcal{A} \cup \{0\}$ and $\mathbb{S}$ denotes the set of valid TACs which has a size of $N_{comb} = 2^{\left\lfloor \log_2 \binom{N_t}{N_a} \right\rfloor}$. Due to the high complexity that is required in order to solve this nonconvex problem, we can adopt a heuristic based approach which can provide a solution faster even though it may not be the optimal one. Therefore, in the following we apply the same method that we used in [22] for a single user transmission and extend it to the scenario considered in this paper where N_u groups of spatial symbols are transmitted simultaneously with hierarchical M-QAM constellations carried on the active antennas. The approach is based on the alternating direction method of the multipliers (ADMM) [25]. In order to obtain an adequate formulation for applying ADMM, we first encode constraints (4) and (5) directly into the objective function (3), with the help of auxiliary variables, $\mathbf{z}$ and $\mathbf{x}^u$ (with

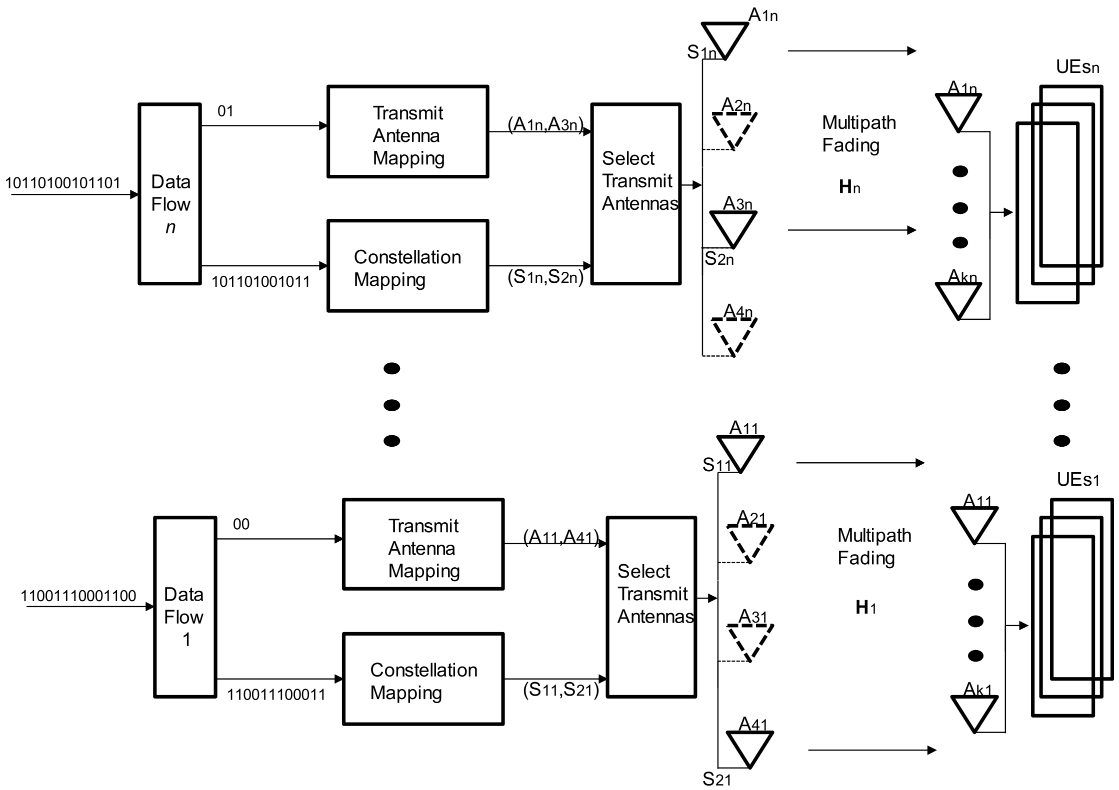

FIGURE 3. Illustration of the system model of the multiuser GSM assisted multi-antenna scheme for multi-rate broadcast.

$u = 0, \ldots, N_u - 1$), and rewrite the MLD problem as

$$\min_{\mathbf{s},\mathbf{x},\mathbf{z}} \|\mathbf{y} - \mathbf{H}\mathbf{s}\|_2^2 + \sum_{u=0}^{N_u-1} I_{\mathbb{S}}(\mathbf{x}^u) + I_{\mathcal{A}_0^{N_u N_t}}(\mathbf{z}) \tag{6}$$

$$\text{subject to } \mathbf{s} = \mathbf{z} \tag{7}$$

$$\mathbf{s}^u = \mathbf{x}^u, \quad u = 0, \ldots, N_u - 1 \tag{8}$$

where $I_{\mathcal{G}}(\mathbf{v})$ denotes the indicator function for a generic set $\mathcal{G}$ which is 0 if $\mathbf{v} \in \mathcal{G}$ and $+\infty$ otherwise. The corresponding augmented Lagrangian function (ALF) can be written as

$$L_{\rho_x,\rho_z}(\mathbf{s}, \mathbf{x}, \mathbf{z}, \mathbf{u}, \mathbf{w}) = \|\mathbf{y} - \mathbf{H}\mathbf{s}\|_2^2 + \sum_{u=0}^{N_u-1} I_{\mathbb{S}}(\mathbf{x}^u) + I_{\mathcal{A}_0^{N_u N_t}}(\mathbf{z}) + \rho_x\left(\|\mathbf{s}+\mathbf{u}-\mathbf{x}\|_2^2 - \|\mathbf{u}\|_2^2\right) + \rho_z\left(\|\mathbf{s}+\mathbf{w}-\mathbf{z}\|_2^2 - \|\mathbf{w}\|_2^2\right). \tag{9}$$

where $\mathbf{x} = \left[\mathbf{x}^{0^T} \ldots \mathbf{x}^{N_u-1^T}\right]^T$, $\mathbf{u}, \mathbf{w} \in \mathbb{C}^{N_u N_t \times 1}$ are scaled dual variables and ρ_x, ρ_z are the penalty parameters for constraints (7) and (8). An iterative detection algorithm can then be derived by minimizing the ALF independently over the primal variables $\mathbf{s}$, $\mathbf{x}^u$, $\mathbf{z}$, followed by the update of the dual variables $\mathbf{u}$, $\mathbf{w}$. Algorithm 1 summarizes the sequence of steps. In the algorithm, Q is the maximum number of iterations, $\prod_{\mathcal{D}}(\cdot)$ denotes the projection onto set $\mathcal{D} = \{\mathbf{s} : \sup p(\mathbf{s}) \in \mathbb{S}\}$ (accomplished by keeping the N_a largest magnitude elements whose indices also match a valid TAC) while $\prod_{\mathcal{A}_0^{N_u N_t}}(\cdot)$ is the projection over $\mathcal{A}_0^{N_u N_t}$ (implemented as a simple component-wise rounding to the closest element in $\mathcal{A}_0$). The initial values $\mathbf{u}^{(0)}$, $\mathbf{w}^{(0)}$, $\mathbf{x}^{u^{(0)}}$, $\mathbf{z}^{(0)}$ required by the algorithm can be obtained using the warm start or random start strategies described in [22]. To increase the chance of finding the optimal solution, the algorithm can be restarted multiple times, using different initializations. It is important to highlight that due to the adopted problem formulation, (6)-(8), it was possible to obtain a detector algorithm for multiuser/multigroup GSM transmissions that is very similar to the original single user detector [22]. The main differences lie on the operation with enlarged vectors, $\mathbf{s}$, $\mathbf{x}$, $\mathbf{z}$, $\mathbf{u}$ and $\mathbf{w}$, corresponding to the concatenation of the N_u groups/users, and on the projection $\prod_{\mathcal{D}}(\cdot)$ (line 6) which is performed individually for each group/user. Besides these differences, since our system is based on the use of hierarchical M-QAM modulations for supporting broadcast/multicast transmission with SVC, projection $\prod_{\mathcal{A}_0^{N_u N_t}}(\cdot)$ can be implemented according to construction procedure described in [24].

Looking at Algorithm 1, we can see that the heavier steps in terms of complexity correspond to line 3 (a $N_u N_t \times N_u N_t$ matrix inversion performed in the beginning of the algorithm) and line 6 (a search among all the N_{comb} possible TACs). For a fixed number of iterations, Q, the total complexity order is

Algorithm 1 GSM-MU Detector

Input: $\mathbf{u}^0$, $\mathbf{w}^0$, $\mathbf{x}^0$, $\mathbf{z}^0$, $\mathbf{H}$, $\mathbf{y}$, ρ_x, ρ_z, Q, P
$f_{best} = \infty$.
$\boldsymbol{\Phi} \leftarrow \left(\mathbf{H}^H\mathbf{H} + (\rho_x + \rho_z)\,\mathbf{I}_{N_uN_t}\right)^{-1}$.
For t =0,1,…Q-1 **do**
  $\mathbf{s}^{(t+1)} \leftarrow \boldsymbol{\Phi}\left(\mathbf{H}^H\mathbf{y}+\rho_x\left(\mathbf{x}^{(t)}-\mathbf{u}^{(t)}\right)+\rho_z\left(\mathbf{z}^{(t)}-\mathbf{w}^{(t)}\right)\right)$.
  $\mathbf{x}^{u^{(t+1)}} \leftarrow \prod_{\mathcal{D}}\left(\mathbf{s}^{u^{(t+1)}}\right)$, $u = 0, \ldots, N_u - 1$.
  $\mathbf{z}^{(t+1)} \leftarrow \prod_{\mathcal{A}_0^{N_uN_t}}\left(\mathbf{s}^{(t+1)} + \mathbf{w}^{(t)}\right)$.
  $I \leftarrow \sup p\left(\mathbf{x}^{(t+1)}\right)$.
  $\hat{s}_{\bar{I}}^{candidate} \leftarrow 0$, $\hat{s}_{I}^{candidate} \leftarrow \prod_{\mathcal{A}^{N_aN_u}}\left(\mathbf{s}_I^{(t+1)}\right)$.
  If $f\left(\hat{s}^{candidate}\right) < f_{best}$ **then**
    $\hat{s}_{\bar{I}} \leftarrow 0$, $\hat{s}_I \leftarrow \hat{s}_I^{candidate}$.
    $f_{best} = f\left(\hat{s}^{candidate}\right)$.
  end if
  $\mathbf{u}^{(t+1)} \leftarrow \mathbf{u}^{(t)} + \mathbf{s}^{(t+1)} - \mathbf{x}^{(t+1)}$.
  $\mathbf{w}^{(t+1)} \leftarrow \mathbf{w}^{(t)} + \mathbf{s}^{(t+1)} - \mathbf{u}^{(t+1)}$.
end for
Output: $\hat{s}$.

$O\left(N_{comb}N_a + N_u^3N_t^3\right)$, which can be reduced to $O\left(N_u^3N_t^3\right)$ if a simplified cardinality based projection is adopted instead (in this case $\prod_{\mathcal{D}}(\cdot)$ is implemented by zeroing the smallest magnitude elements of the argument vector). For comparison, solving the MLD problem exactly would involve evaluating all possible combinations of active antennas and M-QAM symbols resulting in a complexity order of $O\left(N_{comb}M^{N_uN_a}\right)$. This means that in practice the MLD is limited to very small problem sizes since its complexity quickly becomes unfeasible when the size grows. For example, in the case of $N_u = 1$, $N_t = 17$, $N_r = 17$, $N_a = 16$, which is one of the simplest scenarios considered in section IV, the complexity per subcarrier of MLD is 2e+33 real flops. On the other hand, the complexity of the proposed ADMM based GSM-MU detector with $Q = 100$ is only 3e+5 flops.

IV. NUMERICAL RESULTS

We present link and system level numerical simulations. The link level simulator evaluates the receiver BLER/BER performance, taking into account perfect channel estimation, interleaving, modulation, receiver structure and decoding.

The channel model used in the system level simulator considers three types of losses: distance loss, shadowing loss and multi-path fading loss. Channel state information is assumed to be known at the base station. Null correlation between antennas at transmission and at reception is also assumed. The model parameters depend on the environment. For the distance loss we considered that $L_{path} = 130.7 + 34.88 \cdot \log(r)$ dB where r is the distance in km. The multi-path fading in the link and system level simulators corresponds to the 3GPP Extended Typical Urban channel model [26]. Link performance results are used as input by the system level simulator where several estimates for coverage and throughput are made by populating uniformly the scenario topology with 19 base stations, each with three sectors, and giving pedestrians a random mobility. We assume adequate for the broadcasting of SVC around 2GHz in urban macro cells, the following two cases of 5G NR numerology and slot configuration parameters taken from [27]: the bandwidth of 20MHz for numerology 1 with normal CP where the subcarrier spacing is 30KHz and 28 OFDM symbols are transmitted in every subframe of 1ms; or the bandwidth of 40MHz for numerology 2 with extended CP where the subcarrier spacing is 60KHz and 24 OFDM symbols are transmitted in every subframe of 1ms.

According to the system model introduced in section II, we consider that there are three independent data streams: one for the base layer and two additional data streams for first and second enhancement layers. Each stream includes the same amount of data bits. We assume that the GSM assisted multi-antenna broadcasting system has equal power transmission policy. However, the transmission of hierarchical M-QAM constellations has inherent power differences between the internal constellations, such as LDM of ATSC 3.0. N_u denotes the number of simultaneous broadcasting transmissions. For $N_u = 1$, N_t is the total number of antennas available per user for transmission and N_a the number of active transmitting antennas per user. In general, there are N_uN_t antennas at the base station among which only N_uN_a are active at any given time. The number of receiving antennas will be $N_r = N_uN_t$. N_{sc} is the number of subcarriers per block. The size of the hierarchical M-QAM constellation M will be always 64 in the following results.

A. LINK LEVEL SIMULATIONS

All the simulation curves are generated by transmitting packets with more than 1000 bits per antenna over 1000 independent channel realizations. This corresponds to the transmission of more than 1 million bits to get any BLER simulation result.

In Figure 4 the BLER of a MIMO 16 × 16 is presented versus (E_s/N_0) in dB, which is defined as the ratio of symbol energy to noise spectral density for the hierarchical uniform 64QAM (H64QAM) constellation ($k_1 = k_2 = 0.5$). Note that there are no spatial bits due to $N_t = N_a = 16$ which means we are assuming a conventional MIMO system. The peak bit rate achieved assuming 5G NR numerology 1 with normal CP is 344.064Mbps and reaches 589.824Mbps for numerology 2 with extended CP. The spectral efficiency is 17 bps/Hz or almost 15bps/Hz for numerologies 1 and 2 respectively. For BLER=10^{-1} there is a difference of 0.5 dB between each of the three layer bits, namely, base, first and second enhancement.

Figure 5 depicts the BLER of GSM also with uniform 64QAM constellation, where spatial bits are transmitted due to $N_t = 17$ and $N_a = 16$. Terminals are able to decode the spatial bits by identifying what are the 16 active antennas from the total of 17 or, equivalently, detecting the inactive one. The peak bit rate based on numerology 1 is 358.4Mbps

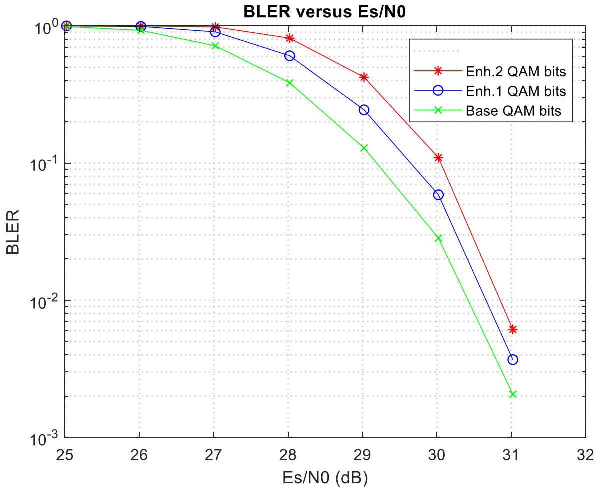

FIGURE 4. BLER of MIMO with Nu=1, Nt=16, Nr=16, Na=16, Nsc=128, H64QAM, $k_1 = k_2 = 0.5$.

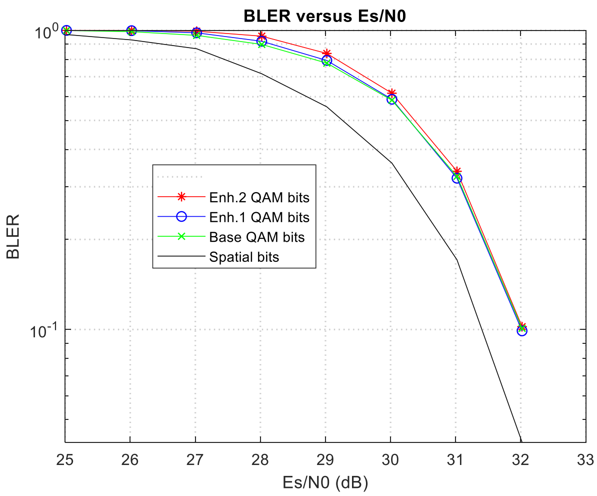

FIGURE 5. BLER of GSM with Nu=1, Nt=17, Nr=17, Na=16, Nsc=128, H64QAM, $k_1 = k_2 = 0.5$.

or 614.4Mbps for numerology 2. For BLER=10^{-1} there is a performance loss of GSM compared to the conventional MIMO of Figure 4 around 2dB. This is due to one additional antenna at transmitting (and receiving) side enabling that spatial bits are mapped at a rate of more than 14Mbps or 24Mbps, for numerology 1 or 2, respectively. Spatial bits perform better, with 0.7dB gain over the other bits for BLER=10^{-1}. The difference of E_s/N_0 between each of the three layer bits is very small due to the uniform constellation adopted. For broadcasting scalable video it is usually not necessary to transmit with such high peak bit rates. In addition, due to typical delay spread of the urban environment simulated, around 3μs, in order to avoid inter-symbol interference due to normal CP, we have chosen numerology 1 as reference, for the remaining numerical results.

For the next case we increased the number of antennas for transmission to $N_t = 32$ and decreased the number of active transmitting antennas to $N_a = 4$, instead of 16. As a result the expected peak bit rates will decrease by four.

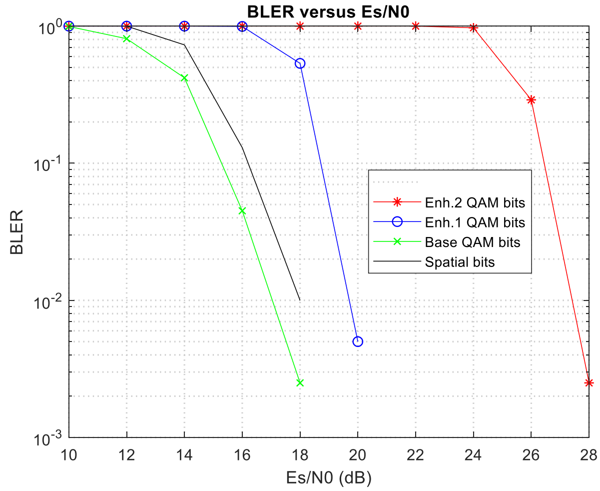

FIGURE 6. BLER of GSM with Nu=1, Nt=32, Nr=32, Na=4, Nsc=128, H64QAM, $k_1 = k_2 = 0.25$.

In Figure 6 we present the BLER performance of GSM for one typical non-uniform H64QAM constellation where $k_1 = k_2 = 0.25$. Different transmission power is assigned to the three nested 4-QAM bit constellations comprising the global H64QAM. The layer with 2nd enhancement QAM bits are transmitted with minimum power, the 1st enhancement QAM bits have intermediate power and base QAM bits get the maximum power. This H64QAM constellation is a typical non-uniform one, where the total transmitted power is the same as for the uniform case. We can see that the base QAM bits require $E_s/N_0 = 15.0$dB to achieve the BLER=10^{-1}. Next follows the 1st enhancement QAM bits with $E_s/N_0 = 18.6$dB and finally the 2nd enhancement QAM bits with $E_s/N_0 = 26.2$dB. Spatial bits require $E_s/N_0 = 16.0$dB, a value 1.0dB higher than base QAM bits but smaller than the 1st enhancement QAM bits.

1) SYSTEM LEVEL SIMULATIONS

The estimate for coverage purposes are based on an average of ten consecutive received packets. If the average received BLER of these packets is lower than 10% BLER the pedestrian is counted as being in coverage. For the throughput calculation the estimation is made based on each individual packet received with a BLER lower than 10%. For the computation of signal to noise ratio in dB used in the system level simulations we use the following formula $SNR = (E_s/N_0) + 10\log(Rs/B)$ dB, where Rs is the total symbol rate per antenna, B is the total bandwidth (20MHz). Values of (E_s/N_0) are obtained from the link level simulator results, like those presented on previous figures with BLER performance curves.

In Figure 7 is illustrated the average coverage of each four different blocks of bits that are transmitted corresponding to the BLER performance results of Figure 6. We can check in Figure 7 that only for 100% of transmitted carrier power, the coverage of 2nd enhancement QAM bits reaches 40% coverage of the cell.

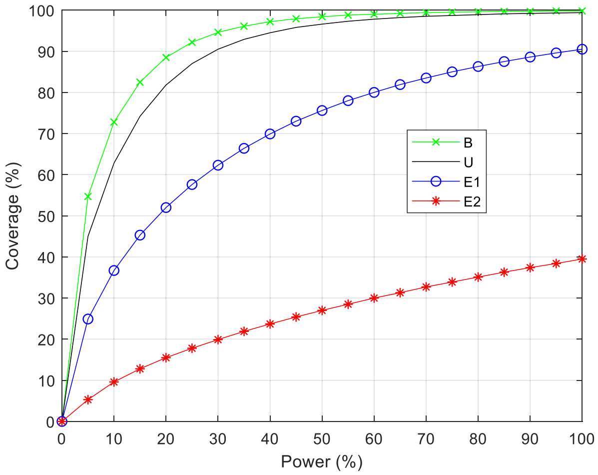

FIGURE 7. Coverage vs % of transmitted carrier power of GSM with Nu=1, Nt=32, Nr=32, Na=4, Nsc=128, H64QAM, $k_1 = k_2 = 0.25$.

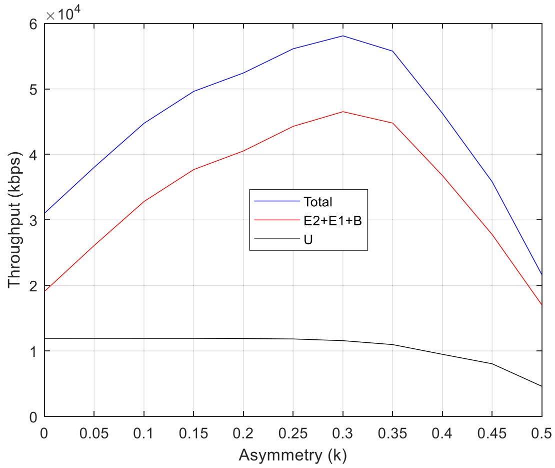

FIGURE 8. Throughput vs asymmetry for 100% of transmitted power of GSM with Nu=1, Nt=32, Nr=32, Na=4, Nsc=128, H64QAM.

This is due to the smaller transmission power of these bits compared to 1st and base bits. It is important to remind that users that decode successfully the 2nd enhancement QAM bits, have also decoded the 1st enhancement bits and the base bits. The coverage of spatial bits, label U in the figure, is quite close to the coverage of base bits and is clearly above the coverage of 1st enhancement bits.

In Figure 8 is presented the throughput averaged for all users uniformly distributed in the scenario. The aggregate throughput of the 2nd, 1st enhancement and base QAM bits ('E2+E1+B') is presented in addition to the throughput of spatial bits (U). The curve (Total), the sum of these two is also shown with the total average throughput in each cell. The interval $0.05 \leq k \leq 0.45$ indicates non-uniform H64QAM modulations where the three constituent constellations are transmitted with different power, however, the total transmitted power is always kept constant. *k=0* corresponds to a 4QAM constellation where only the base bits are transmitted with increased power, because there is no power transmitted for the other layer bits. The asymmetry interval enabling the highest values of throughput, around 58Mbps, is $0.30 \leq k \leq 0.35$. In this interval, the throughput gain compared to $k = 0.5$ is almost 2.7. Here, there is good coverage of the three QAM constellation bits, namely, base, 1st enhancement and 2nd enhancement. Remember that users that decode the 2nd enhancement bits get the triple bit rate compared to the base bits. The broadcasting system can transmit three different HDTV programs: users close to the base station decode the three programs (2nd enhancement), users in the middle of the cell decode two programs (1st enhancement) and users at the border only decode one program (base).

For spatial bits, from $k = 0.5$ up to $k = 0.30$ there is a substantial increase of the throughput (and coverage). Remember that spatial bits are not transmitted like the others. In every slot of 0.5ms, user specific messages are carried implicitly on the indexes of the active transmit antennas combinations. They are decoded at receivers by inferring what are the indexes of the active transmit antennas. The throughput of spatial bits is maximum when only the base layer bits ($k = 0$) are transmitted and is minimum for uniform H64QAM ($k = 0.5$).

There are different ways to quadruple the total transmitted bit rate. Firstly, we can keep constant the total transmitted power and the parameters $N_t = 32$, $N_a = 4$, and $N_u = 1$ while we quadruple N_{sc} to 4×128 (512). This provides the fourfold of HDTV programs to be broadcast by using a quarter of the subcarrier spacing while keeping the same total bandwidth, power and number of transmitting and receiving antennas. The second method to quadruple the bit rate relies on keeping the same $N_t = 32$, $N_a = 4$ parameters but doubling both N_{sc} and N_u. This quadruples the HDTV programs to broadcast by doubling both the number of broadcasting programs ($N_u = 2, N_r = 2 \times 32$,) and the number of symbols transmitted in every slot with 0.5ms, $N_{sc} = 2 \times 128(256)$.

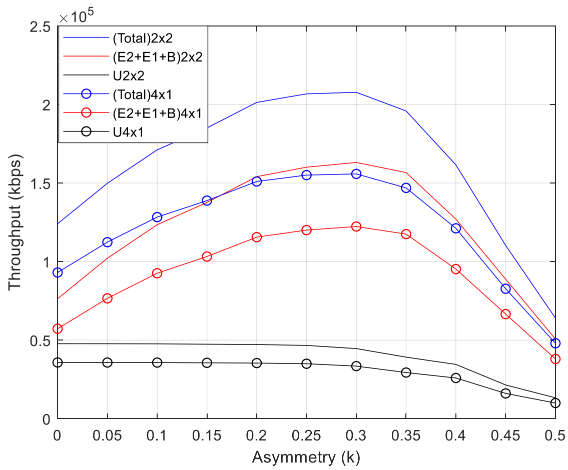

FIGURE 9. Throughput vs asymmetry for 100% of transmitted power, Nu=1, Nsc=4 × 128 plus Nu=2, Nsc=2 × 128 H64QAM.

Figure 9 presents the throughput for the two different methods to quadruple the total bit rate. The legend 4 × 1 corresponds to the first method and 2 × 2 refers to the second. The comparison between figures 9 and 8 indicates that the throughput gain is higher for the second method independently of k. Because we have $N_u = 2$, two simultaneous broadcasting programs that are transmitted and received by twice the number of antennas. The maximum throughput of almost 208Mbps is achieved for $k = 0.30$ and the gain compared to $k = 0.5$ is 3.25. The small shift to the left of all curves is a result of a reduction of $10 \log_{10}(4) = 6$dB in (E_s/N_0) of each H64QAM symbol as the symbol rate is quadruplicated while keeping the power constant. To achieve the same reference BLER, higher

signal to noise ratio is required. It is important to note that the number of spatial symbols U is also quadrupled. In spite of not requiring any additional transmitting power, spatial symbols depend on the signal to noise ratio of H64QAM symbols. For U symbols, we can see the same throughput behavior dependent of the asymmetry parameter that was observed previously.

V. CONCLUSION

In this paper, we addressed a specific broadcasting/multicasting system for cellular networks that integrates a massive multiple input multiple output antennas scheme based on generalized spatial modulation (GSM) combined with scalable video coding (SVC), hierarchical modulation and unequal error protection. We employed non-uniform hierarchical QAM constellations for broadcasting/multicasting SVC while user specific messages were carried implicitly on the indexes of the active transmit antennas combinations of GSM. We have presented a low complexity iterative receiver for GSM with HQAM modulations as a valid strategy for increasing both spectral and energy efficiencies. System level simulation results indicated that the best approach for the GSM scheme to quadruple the number of transmitted HDTV programs is doubling both the number of broadcasting programs (associated to a given number of transmitting and receiving antennas) and the number of symbols transmitted in every slot. This configuration achieves better results than by simply quadruplicating the number of symbols transmitted using a quarter of the subcarrier spacing. The adoption of non-uniform hierarchical QAM constellations instead of a uniform one, achieved the highest throughput gain above 3, by doubling both the number of GSM antennas employed and transmitted symbols.

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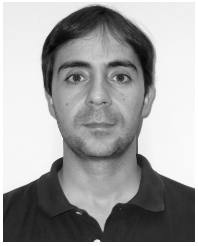

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