MIMO FOR DVB-NGH, THE NEXT GENERATION MOBILE TV BROADCASTING

Abstract

DVB-NGH (*Digital Video Broadcasting – Next Generation Handheld*) is the next generation technology for mobile TV broadcasting, which has been developed by the DVB project with the most advanced transmission technologies. DVB-NGH is the first broadcasting standard to incorporate multiple-input multiple-output (MIMO) as the key technology to overcome the Shannon limit of single antenna communications. MIMO techniques can be used to improve the robustness of the transmitted signal by exploiting the spatial diversity of the MIMO channel, but also to achieve increased data rates through spatial multiplexing. This paper describes the benefits of MIMO that motivated its incorporation in DVB-NGH, reviews the MIMO schemes adopted and discusses some aspects related to the deployment of MIMO networks in DVB-NGH. The paper also provides a feature comparison with the multi-antenna techniques for 3GGP´s LTE/LTE-Advanced for cellular networks. Finally, physical layer simulation results calibrated within the DVB-NGH standardization process are provided to illustrate the gain of MIMO for the next generation of mobile TV broadcasting.

1 Introduction and Background

DVB-NGH (*Next Generation Handheld*) is the mobile evolution of the second generation digital terrestrial TV broadcasting technology, DVB-T2 (*Terrestrial 2nd Generation*) [1]. Its deployment is motivated by the continuous growth of mobile multimedia services to handheld devices such as tablet computers and smart-phones. Its main objective is to provide superior performance, robustness and increased indoor coverage than other existing DVB standards, including DVB-H (*Handheld*) and DVB-SH (*Satellite services to Handheld devices*). DVB-NGH is based on the physical layer of DVB-T2 and has been designed so that it can be incorporated in DVB-T2 transmissions, allowing the re-use of spectrum and infrastructure. Its standardization started in March 2010 and it is expected to be completed in September 2012. The main technical solutions of the new mobile TV broadcasting standard are:

- Multiple-input multiple-output (MIMO) for increased spatial diversity and transmission rate.
- TFS (*Time Frequency Slicing*) for increased frequency diversity and more efficient statistical multiplexing.
- Convolutional time interleaving for increased time diversity.
- Improved LDPC codes and lower code rates.
- Improved signalling robustness compared to DVB-T2.
- RoHC (*Robust Header Compression*) to reduce the overhead due to IP encapsulation.
- Additional satellite component for a hybrid profile (terrestrial + satellite).
- SVC (*Scalable Video Coding*) with MPLPs (*Multiple Physical Layer Pipes*) for graceful service degradation.
- Efficient transmission of local services within SFN (*Single Frequency Network*).

The utilization of LDPC codes, as forward error correction (FEC) in wireless systems, achieves a performance that is close to the theoretical limits in AWGN for a system that uses a single transmit-to-receive antenna architecture known as SISO (*Single-Input Single-Output*). The implementation of multiple antennas at the transmitter and the receiver side (MIMO) allows overcoming the Shannon limit of single antenna communications without any additional bandwidth or increased transmission power. Because of its potential, MIMO has become part of wireless standards such as IEEE 802.11n for wireless local area networks, WiMAX for broadband wireless access area systems, and the upcoming 3GGP´s Long-Term

Evolution (LTE) for cellular networks amongst others. First multi-antenna transmissions for broadcasting systems were adopted for the digital terrestrial TV standard DVB-T2. However, in this case a transmitter site distributed configuration was defined to exploit only diversity gain. Hence, DVB-NGH is the first broadcast system to employ pure MIMO as key technology exploiting all the benefits of the MIMO channel.

DVB-NGH introduces new key features for terrestrial broadcast MIMO. For transmit diversity DVB-NGH has specified a novel scheme known as enhanced single frequency network (eSFN) that is transparent to receiver terminals. To increase the system capacity, DVB-NGH has adopted (as an optional MIMO profile) a new technique known as enhanced spatial multiplexing with phase hopping (eSM-PH) that improves robustness in presence of spatial correlation. Additionally, the MIMO profile has adopted a new bit interleaver that eases the implementation of iterative structures which can provide significant gains on the top of the MIMO gain. The eSM-PH code and the bit interleaver have been optimized for the case of deliberated power imbalance between the transmit antennas, which may be useful in some deployment scenarios where not all the receiver population supports MIMO. Dual polar MIMO transmissions in DVB-NGH can be introduced and co-exist with existing SISO transmissions. Moreover, during the DVB-NGH standardization process a new simple channel model was created based on measurement campaign carried out at a frequency near 500 MHz and including the effects of a 'typical' handset/portable device antenna placed in both indoor and outdoor scenarios.

MIMO Benefits

The implementation of MIMO provides three benefits, i.e. array gain, diversity gain and multiplexing gain, which are described next and illustrated in Fig. 1.

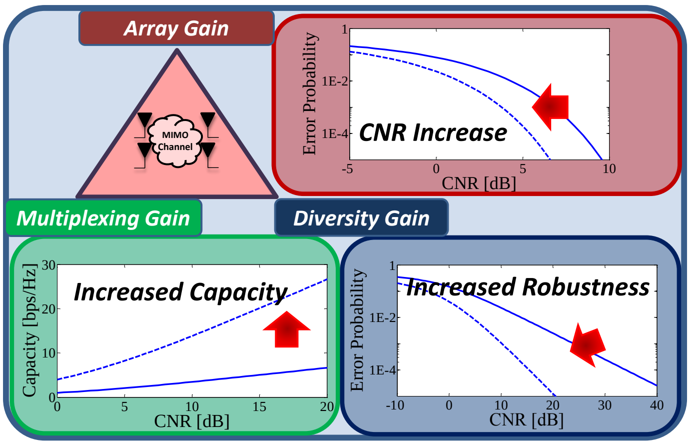

Figure 1: MIMO gains. Array gain produces an average increase in the received CNR, diversity gain increases the resilience against fading, and multiplexing gain increases the capacity of the system.

Array gains are achieved by having the received signals coherently added. This results in a constant increase in terms of CNR (*Carrier-to-Noise-Ratio*) that does not depend on the channel properties and that is only determined by antenna characteristics. Using antennas with the same polarization (co-polar), the gain is equal to 3 dB every time the number of receive antennas is doubled. For antennas with different polarization (cross-polar) the gain depends on: the XPD (*Cross Polarization Discrimination*) factor which describes the energy coupling between cross-polarized paths, and the power asymmetry between transmit antennas.

Diversity gain improves the system performance by averaging the uncorrelated fading experienced by multiple spatial branches. The effective number of spatial branches (with low degree of correlation) employed to average the fading is commonly referred as diversity order and it changes the slope of the error probability curve against CNR. To ensure independent fading with co-polar antennas, it is necessary that the spatial separation is larger than the coherence distance of the channel, i.e. maximum spatial separation over which the channel can be assumed constant. Cross-polar antennas, on the other hand, rely on the fact that the fading experimented by each polarization path possess a low degree of correlation. The diversity gain in this kind of system depends not only on the correlation between polarization paths, but also on additional factors such as the XPD. In particular, high XPD values (i.e. less coupling) have been shown to be detrimental for transmit diversity [2].

The simultaneous utilization of multiple antennas at the transmitter and receiver side permits the opening of multiple spatial pipes across the wireless channel providing *multiplexing gain*. In the case of co-polar antennas, spatial multiplexing relies on independent fading between antennas to separate the multiple data streams at the receiver side. The presence of correlation, especially at the transmitter side, is very detrimental for spatial multiplexing techniques. In this case, the utilization of cross-polar antennas, which rely on the decoupling between polarizations to separate the data streams, generally improves the performance.

The utilization of multiple antennas can be categorized into SIMO (*Single-Input Multiple-Output*), MISO (*Multiple-Input Single-Output*) and MIMO (*Multiple-Input Multiple-Output*), depending on whether multiple antennas are used at the receiver side, at the transmitter side, or at both sides. SIMO systems can achieve diversity and array gains without the need of any modification in standards or transmitters. MISO systems due to the lack of an uplink channel cannot provide array gains in mobile broadcasting systems and only improve the performance by diversity. MIMO systems, on the other hand, allow for increased data rates through spatial multiplexing.

MIMO Codes for NGH

The first type of techniques is known as MIMO rate 1 codes, which exploit the spatial diversity of the MIMO channel without the need of multiple antennas at the receiver side. They can be applied across the transmitter sites of SFNs to reuse the existing network infrastructure (i.e. DVB-T and DVB-T2[1]), as well as to an individual multiple-antenna transmitter site. These codes are specified as part of the base (sheer-terrestrial) profile.

The second type of techniques is known as MIMO rate 2 codes, which exploit the diversity and multiplexing capabilities of the MIMO channel. However, they require additional investment at both sides of the transmission link. At the receiver side, it is mandatory the integration of two antennas to demodulate the signal. At the transmitter side, the current transmitter network infrastructure requires extra elements like: an additional second cross-polar antenna, cooling systems, RF feedings, power combiners and amplifiers amongst others. These codes are specified as an optional profile to allow for a progressive deployment of MIMO networks depending on the market demands.

Feature Comparison with Long Term Evolution (LTE) Multi-Antenna Techniques

LTE/LTE-Advanced is a wireless standard for cellular networks with multi-antenna technology [3]. The main physical difference with broadcasting systems is the feedback channel from the receiver to the transmitter that allows for link adaptation techniques in LTE/LTE-Advanced. Link adaptation techniques improve the communication from the transmitter to the receiver by dynamically adapting key transmission parameters (e.g. modulation, coding rate, antenna weight vector for transmit beamforming) to the channel variations occurred in time, frequency and/or space.

Note that LTE/LTE-Advanced does not include MIMO for its multicast/broadcast extension known as E-MBMS (*Enhanced – Multimedia Broadcast Multicast Services*). However, the MIMO schemes adopted for

[1] Commercial requirements of DVB-T2 mandated the reuse of existing domestic receiving antenna installations and of existing transmitter infrastructures.

DVB-NGH share similar technologies with LTE/LTE-Advanced open loop single user downlink schemes as the way to exploit the benefits of the MIMO channel. Regarding the number of transmitting elements, DVB-NGH defines a maximum of two transmit antennas, while for LTE the maximum number is four, and eight for LTE-Advanced. Increasing the number of transmit antennas generally improves the system performance at expense of higher system complexity.

MIMO NGH Channel Models

The MIMO channel model used during the standardization process of DVB-NGH was developed from a sounding campaign that took place in Helsinki in June 2010 [4]. The objective was to obtain a channel model representative of cross-polar MIMO propagation at UHF frequencies ($f_c \approx 600$ MHz) in order to evaluate the performance obtained by multiple antenna techniques in realistic scenarios. In particular, an outdoor mobile model, an outdoor portable model and an indoor portable model are defined. For the mobile case, a user velocity of 350 km/h or 60 km/h is considered, whereas for the portable case, the velocity is 3 km/h or 0 km/h. The channels are made up of 8 taps with different values of delay, power gain, and Rice distributed. For each channel, the XPD factor describes the energy coupling between cross-polarized paths, the K factor describes the power ratio between LoS (*Line-of-Sight*) and nLoS (*non-Line-of-Sight*) components, and the covariance matrix describes the spatial correlation between antennas. The nLoS components are time-variant taps with shifted versions of a reduced-width Jakes spectrum. Additional terms for antenna rotation and asymmetry are also included for both outdoor and indoor models. In particular, a rotation matrix describes the presence of polarization mismatch between the transmit and the receive antennas, whereas an asymmetry matrix describes the presence of power imbalance between different polarizations at the transmitter side.

Fig. 2 shows the ergodic capacity in bps/Hz vs. the CNR in the NGH outdoor MIMO channel model with 60 km/h speed. Diversity MIMO refers to MIMO schemes that only exploit spatial diversity (i.e. MIMO rate 1), whereas optimal MIMO refers to MIMO schemes with additional multiplexing capabilities (i.e. MIMO rate 2). SIMO clearly outperforms SISO due to the array gain and the diversity gain whereas diversity MIMO provides better performance than SIMO due to the increased number of spatial paths that improves the diversity gain. However, both perform very similarly in the NGH outdoor channel model. Compared with diversity MIMO, optimal MIMO provides better performance due to multiplexing capabilities. The difference between optimal MIMO and the rest of the MIMO schemes increases with the CNR.

Note that the utilization of multiple receive antennas provides significant gains in the NGH channel model. This is due to the combination of array and diversity gains, and also due to the inclusion of antenna rotation and asymmetry in the channel.

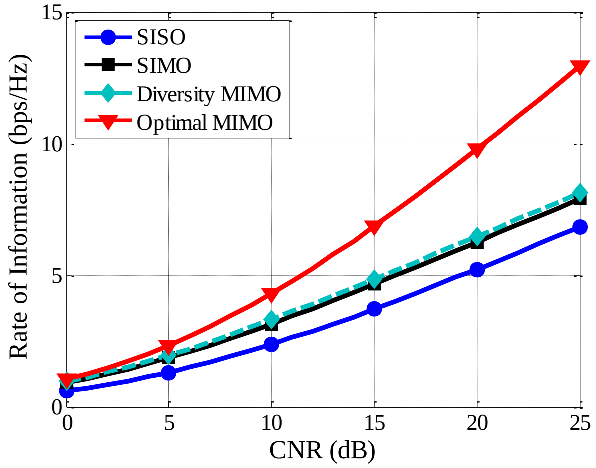

Figure 2: Ergodic capacity (bps/Hz) for different MIMO schemes in the NGH outdoor MIMO channel with 60 km/h speed.

The rest of the paper is structured as follows: Section 2 and 3 describe the MIMO schemes included in DVB-NGH. Section 4 discusses network deployment issues of MIMO networks. Section 5 presents performance simulation results in mobile scenarios with the NGH MIMO channel model. Finally, Section 6 draws conclusions and comments.

2 MIMO Rate 1 Schemes for NGH

For rate 1 MIMO, DVB-NGH has adopted the Alamouti code [5] already featured in DVB-T2, together with a novel scheme known as eSFN (*enhanced Single Frequency Network*). The Alamouti code is a SFBC (*Space-Frequency Block Code*) scheme designed for increasing the diversity in systems with two transmit antennas. The Alamouti code is well-known for achieving full diversity with reduced (linear) complexity at the receiver side. In order to use the Alamouti code, it is necessary to employ orthogonal pilot patterns between antennas, so that the receiver can estimate the channel response from each transmit antenna. This means that the required number of transmitted pilots must be doubled compared with single antenna transmissions for the same resolution of channel estimation. The Alamouti code can also be used in a distributed manner across pairs of transmitters in order to improve the reception in SFNs. The arrival of similar-strength signals from different transmitters in LoS scenarios can cause deep notches in the frequency response of the channel degrading the QoS (*Quality of Service*) in an important manner. By using the Alamouti code in a distributed manner it is possible to improve the performance in SFN transmission.

The main idea of eSFN is to apply a linear pre-distortion function to each antenna in such a way that it does not impact the channel estimation. This technique increases the frequency diversity of the channel without the need of specific pilot patterns or signal processing to demodulate the signal. eSFN is also well suited for its utilization in a distributed manner, as the randomization performed in each transmitter can avoid the negative effects cause by LoS components in this kind of networks. In addition, by using a different pre-distortion function in each transmitter, it is possible to allow for unique transmitter identification within the network, which can be used e.g. for monitoring applications.

Fig. 3 illustrates the combination of distributed MISO Alamouti and eSFN. The first transmit antenna applies only linear eSFN distortion (different phase modulation along frequency bins) whereas the second transmit antenna applies both MISO processing (Alamouti coding in frequency direction) and eSFN. The colored boxes after eSFN processing illustrate the different phase modulation applied along transmitters (different for each transmit antenna in the network). The combination of both techniques increases the frequency diversity of the received signal under low-diversity channels due to eSFN, and the combination keeps the spatial diversity from the Alamouti coding under high-diversity channels.

LTE/LTE-Advanced Downlink MIMO Techniques for Open-Loop Transmit Diversity

LTE defines the same SFBC as defined for MIMO rate 1 in DVB-NGH for two transmit antennas based on Alamouti coding. Additionally, for four transmit antennas, LTE specifies a combination of SFBC and FSTD (*Frequency Switched Transmit Diversity*). For LTE-Advanced no new transmit diversity schemes are standardized. If more than four antennas are employed, a suitable pre-coding makes transparent the processing to the receiver.

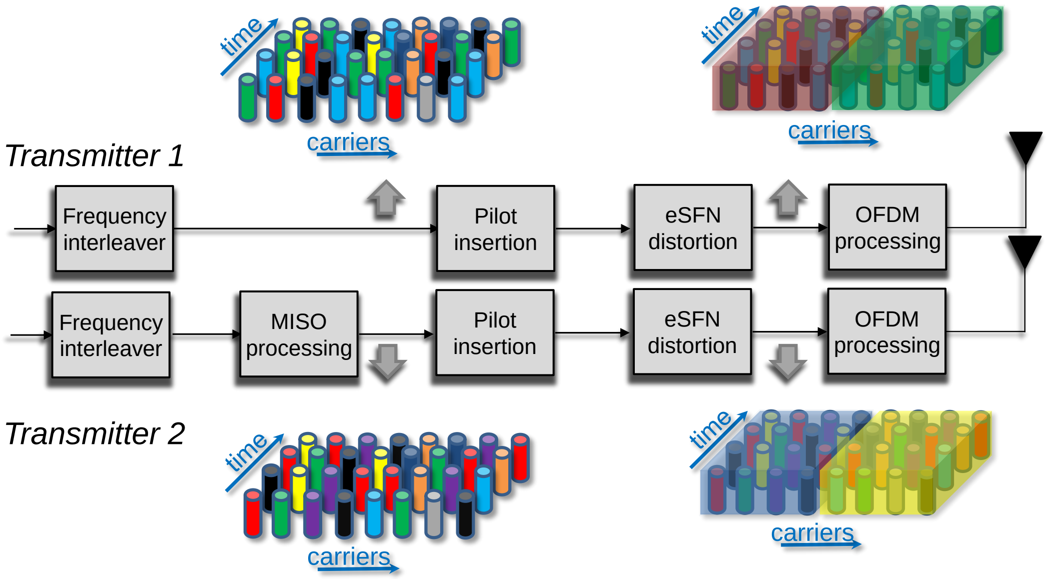

Figure 3: MIMO rate 1 signal processing with a combination of distributed MISO Alamouti and eSFN.

3 MIMO Rate 2 Schemes for NGH

For rate 2 MIMO, DVB-NGH has adopted a novel scheme known as eSM-PH (*enhanced Spatial Multiplexing – Phase Hopping*) and presented in Fig. 4. The most simple way of increasing the multiplexing rate of information consists on dividing the information symbols between the transmit antennas. This is referred to as MIMO SM (*Spatial Multiplexing*).

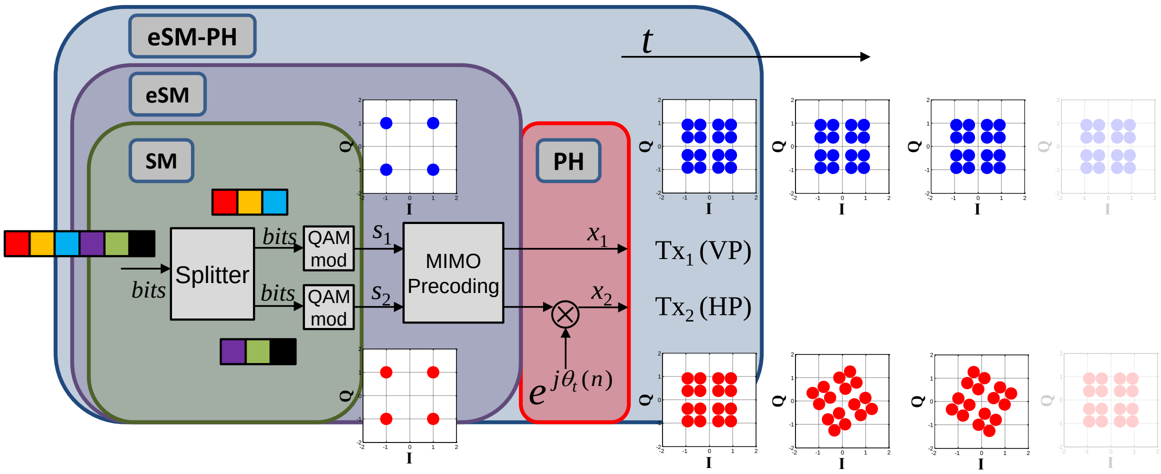

Figure 4: Multiplexing techniques: SM (*Spatial Multiplexing*), eSM (*enhanced Spatial Multiplexing*) and PH (*Phase Hopping*), and the combination of them, eSM-PH (*enhanced-Spatial Multiplexing – Phase Hopping*).

The presence of correlation in the MIMO channel due to LoS channel condition, which frequency happens in terrestrial broadcast transmissions, is especially detrimental for MIMO SM. eSM-PH overcomes this situation retaining the multiplexing capabilities of MIMO SM, and at the same time, increasing the robustness against spatial correlation. The information symbols are weighted and combined before their transmission across the antennas according to a specified rotation angle. This rotation angle has been tuned for every combination of constellation order and deliberated transmit power imbalance. To ease dual polar operation, MIMO rate 2 codes can be transmitted with deliberated power imbalance between the transmit antennas with values of 0 dB, 3 dB and 6 dB. In addition, a periodical phase hopping term is added to the second antenna in order to randomize the code structure and avoid the negative effect of certain channel realizations.

Three steps of spectral efficiency are defined for eSM-PH with 6 bpc (bits per cell, as the number of bits assigned per subcarrier), 8 bpc and 10 bpc. Asymmetric constellations are employed for each transmit antenna to provide higher granularity. The defined constellation for the first/second antenna are QPSK/16QAM for the case of 6 bpc, 16QAM/16QAM for the case of 8 bpc, and 16QAM/64QAM for the case of 10 bpc.

To demodulate an eSM-PH signal it is necessary to employ orthogonal pilot patterns (as for the Alamouti code) between antennas, so that each receive antenna can estimate the channel response from each transmit antenna. Compared with single antenna transmissions, the required number of transmitted pilots must be doubled for the same resolution of channel estimation, hence reducing the overall spectral efficiency.

In a MIMO system, performance can be further improved by employing *iterative decoding* [6]. Here, the MIMO demapper and the channel decoder exchange extrinsic information in an iterative fashion. However, iterative decoding significantly increases the receiver complexity, making it less suited for mobile devices. We note that iterative decoding only affects the receiver side and therefore no modification is required in standards and transmitters. DVB-NGH includes in its specification a novel bit interleaver with reduced hardware complexity and low latency. It encourages the use of iterative structures, and it has been optimized for iterative reception.

LTE/LTE-Advanced Downlink MIMO Techniques for Open-Loop Spatial multiplexing

LTE downlink open loop spatial multiplexing and MIMO rate 2 for DVB-NGH have similar signal processing. In LTE a precoding matrix similar to eSM in DVB-NGH is used. Additionally, CDD (*Cyclic Delay Diversity*) in LTE changes the symbol phase of one of the transmit antennas as with PH for DVB-NGH. Additionally, for LTE, in the case of four transmit antennas, the precoders are cyclically switched. LTE-Advanced supports the transmission of eight independent streams. However, the demodulation complexity increases substantially with the number of transmit antennas.

4 Deployment Aspects of MIMO

Deployment Aspects of MIMO Networks

DVB-NGH is designed such that it can be incorporated in existing DVB-T2 deployments, allowing the re-use of spectrum and infrastructure by multiplexing both technologies in time. However, if network operators update the transmitter infrastructure with an additional cross-polar antenna to implement MIMO techniques, the transmission mode has to switch from single polar (SISO) to dual polar (MIMO) operation over time.

The first (and more intuitive) operation mode is to switch from single polar operation (i.e. during SISO transmissions) to dual polar operation (during MIMO transmissions). However, this operation mode produces power envelope fluctuations for both polarizations during the switch from SISO to MIMO operation. This fluctuation may have undesired effects in the AGC (*Automatic Gain Control*), synchronization as well as a higher interference to the adjacent channel due to the pulsed nature of the signal. Furthermore, dual polar operation may need to be revised by international regulatory bodies and broadcasters.

To reduce power fluctuations one possible deployment scenario would be to transmit the same power at each antenna element at all times but lowering the power accommodated to the cross-polarized antenna. This deliberated transmitted power imbalance provides a reasonable coverage reduction for SISO/SIMO terminals while MIMO rate 2 codes are optimized to maintain good performance in this situation. Additionally, the bit interleaver between the LDPC code and the symbols mapper is optimized for all the combinations of constellation orders, transmitted power imbalances and LDPC code rates.

Scalable Video Coding (SVC) with MIMO

The extensive utilization of SVC [7] is expected to play a significant role in DVB-NGH, allowing for a better utilization of the available capacity. The SVC extension of H.264/AVC allows for extracting different video representations from a single bitstream, where the different substreams are referred to as layers. The base layer provides the lowest level of quality and ensures backwards compatibility with H.264/AVC compliant receivers. Additional enhancement layers improve the video quality of the base layer in the temporal, spatial or quality dimension. The base layer is transmitted in a way to ensure reception in the entire coverage area and for all receivers. Therefore, the transmitted signal is modulated with low order constellations, robust coding rate, and MIMO rate 1 schemes that allow for compatibility with single antenna receivers. The enhancement layers target users in good reception conditions (e.g. outdoor scenarios) or with better equipment (e.g. multiple antennas), which can enjoy a better video quality. Here, the signal is transmitted with more relaxed parameters and MIMO rate 2 schemes, which provide significant multiplexing gains in the medium/high CNR range.

5 Performance of NGH MIMO Schemes in Mobile Environments

In this section we provide physical layer simulation results to illustrate the performance of the reviewed MIMO rate 1 and MIMO rate 2 schemes. The simulated scenario is NGH outdoor MIMO channel model with 30 km/h. The simulations include inner LDPC codes with a word length size of 16200 bits and outer BCH.

Fig. 5 presents the system capacity for a frame error rate (FER) 1% after BCH. The analyzed schemes are SISO, SIMO with two receive antennas; and eSFN, MIMO Alamouti and eSM-PH with two transmit and two receive antennas. The capacity results include the effect of pilot overhead. While a pilot density of 1/12 is assumed for SISO, SIMO and eSFN, a pilot density of 1/6 is assumed for MIMO Alamouti and eSM-PH.

For the outdoor scenario illustrated in Fig. 5, the results highlight the significant gains achieved by the different DVB-NGH MIMO schemes over SISO. Compared with SISO and with 15 dB of average CNR, SIMO, eSFN and eSM-PH provide a capacity increase of 45%, 56% and 81%, respectively. And for the same schemes, the gain in terms of CNR for 4 bpc is 4.6 dB, 5.7 dB and 7.7 dB. However if the performance of eSM-PH is compared with SIMO, the gain is reduced to 25% of capacity increase and to 3.1 dB of CNR gain. The performance of MIMO Alamouti lies between SIMO and eSFN due to the effect of increased pilot overhead. We note, that such a high field strength levels are unlikely in practice for indoor environments, restricting the utilization of eSM-PH for portable outdoor or vehicular reception.

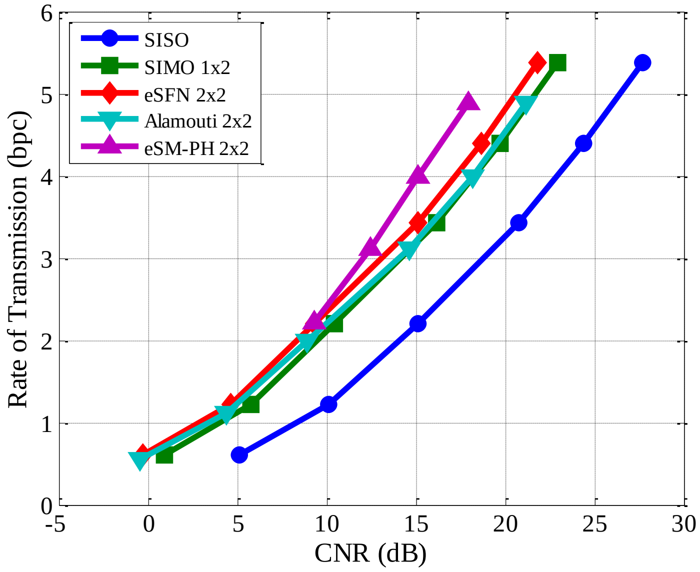

Figure 5: Rate of transmission for the different NGH MIMO schemes in the NGH outdoor MIMO channel with 30 km/h speed including pilot overhead.

Fig. 6 (left part) presents FER after BCH vs. CNR for eSM-PH with iterative decoding. We use 8 bpc and three code rates (1/3, 8/15 and 11/15). In the case of non-iterative decoding (solid lines), there are zero outer iterations and the LDPC decoder performs 50 inner iterations. With iterative decoding (dashed lines) the number of outer iterations is limited to 25. In each outer iteration, the LDPC decoder performs 2 inner iterations. The gains achieved with iterative decoding increase with the code rate, i.e. 1 dB (1/3), 1.1 dB (8/15) and 1.8 dB (11/15) gain at FER 10^{-2}.

Fig. 6 (right part) presents the system capacity in bpc vs. the CNR that is required to achieve the selected QoS criterion of FER after BCH of 10^{-2}. We study all combinations of constellation orders (i.e. 6 bpc, 8 bpc and 10 bpc), and transmitted power imbalances (i.e. 0 dB, 3 dB and 6 dB). The channel model used for this analysis has a Rice distribution with spatial correlation between the antennas. The results illustrate a performance loss compared with 0 dB of imbalance up to 0.3 dB (3 dB of imbalance) and 0.65 dB (6 dB of imbalance).

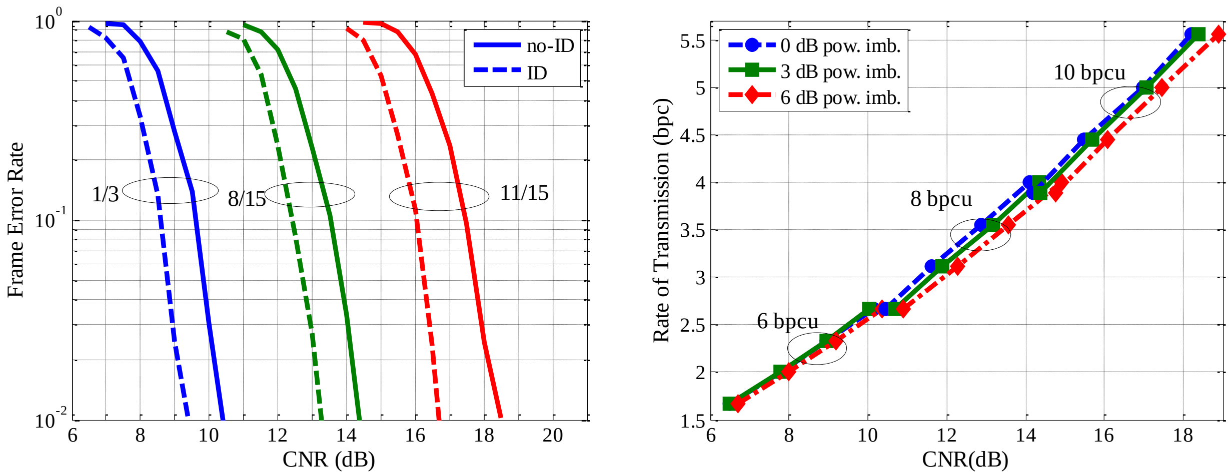

Figure 6: Frame Error Rate of iterative decoding with 8 bpc and 3 different code rates (i.e. 1/3, 8/15 and 11/15) under NGH outdoor scenario with 60 km/h speed (left). Rate of transmission for eSM-PH with different deliberated transmitted power imbalances of 0 dB, 3 dB and 6 dB under correlated Rice channel model (right).

6 Conclusions

DVB-NGH includes multi-antenna techniques as key technology to cope with the increasing demand for data rate and transmission reliability in broadcasting systems. In DVB-NGH the system coverage area can be extended with a high-robustness transmission through MIMO rate 1 codes reusing the current transmitter infrastructure and keeping compatibility with single antenna receivers. If delivery of high data rate services is the primary goal, MIMO rate 2 codes allow for increased data rates through spatial multiplexing. DVB-NGH MIMO rate 2 schemes are best suited for outdoor medium/high signal use cases such as tablet PCs and automotive reception as the generally lower signal-to-noise ratios of portable/indoor reception substantially reduces the available multiplexing gain which may be exploited. In addition, dual polar MIMO transmissions in DVB-NGH can be introduced and co-exist with existing SISO transmissions and to this end optimized codes for deliberated transmit power imbalance are specified. Of special interest is the combination of MIMO with SVC for the efficient delivery of video broadcast. While the SVC base layer aim to increase the spatial diversity for improved coverage through MIMO rate 1 schemes, MIMO rate 2 schemes for the SVC enhancement layers aim to increase the capacity through spatial multiplexing gain.

7 Acknowledgment

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8 References

[1] ETSI EN 302 755, "*Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2),*" v. 1.3.1, April 2012.

[2] R. U. Nabar, H. Bolcskei, V. Erceg, D. Gesbert, and A. J. Paulraj, "Performance of multiantenna signaling techniques in the presence of polarization diversity," *IEEE Transactions on Signal Processing*, vol.50, no.10, pp. 2553- 2562, Oct 2002.

[3] S. Sesia, I. Toufik, and M. Baker, *LTE - The UMTS Long Term Evolution: From Theory to Practice*, 2nd ed. John Wiley and Sons, Ltd: Chichester, UK, 2011.

[4] P. Moss, T. Y. Poon, and J. Boye, "A simple model of the UHF cross-polar terrestrial channel for DVB-NGH," *White Paper, BBC*, 2011.

[5] S. M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications," *IEEE JSAC*, vol. 16, no. 8, pp. 1451–1458, Oct. 1998.

[6] B. M. Hochwald and S. ten Brink, "Achieving near-capacity on a multiple-antenna channel, " *IEEE Transactions on Information Theory*, vol. 51, no. 3, pp. 389–399, March 2003.

[7] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the Scalable Video Coding Extension of the H.264/AVC Standard, " *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 17, no. 9, pp. 1103–1120, September 2007.

9 Biographies

David Vargas (davarpa@iteam.upv.es) received his M.Sc. degree in Telecommunication engineering from Universitat Politècnica de València (UPV), Spain in 2009. During his studies he spent one year at the University of Turku (UTU), Finland. Currently he is pursuing a Ph.D. degree at the Mobile Communications Group at the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV. In the summer of 2011 he was a guest researcher at the Vienna University of Technology, Austria. He has participated in the standardization process of the next generation mobile broadcasting standard DVB-NGH inside the MIMO working group. His research interests include iterative MIMO decoding, channel estimation techniques, and mutual-information-based quantizer design with application to DVB physical layer standards.

David Gozálvez (dagoser@ieee.org) received his M.S. degree and Ph.D. in electrical engineering from the Universitat Politècnica de València (UPV) in 2007 and 2012, respectively. In 2008 he undertook an internship in NOMOR research (Munich, Germany) and in 2009 and 2010 he was a guest researcher in the University of Turku. David Gozálvez has been an active participant in the standardization process of DVB-NGH inside the CCI (Constellation, coding and interleaving) and MIMO working groups, and a contributor to the implementation guidelines of DVB-T2. His main research activities are in the area of mobile communications.

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Dr. Gómez-Barquero is a senior researcher at the Institute of Telecommunications and Multimedia Applications (iTEAM) of UPV, where he leads a research group working on multimedia broadcasting, in particular in the optimization of DVB (Digital Video Broadcasting) systems. Since 2008, he has been actively participating in the digital television standardization forum DVB. He participated in the validation of the second generation digital terrestrial TV technology DVB-T2, and in the standardization processes of its mobile profile, known as T2-Lite, and its handheld evolution, known as DVB-NGH.

Narcís Cardona (ncardona@iteam.upv.es) received the M.Sc. degree in telecommunications engineering from the Universitat Politècnica de Catalunya, Barcelona, Spain, in 1990 and the Ph.D. degree in telecommunications from the Universitat Politècnica de València (UPV), Spain, in 1995. Since 1990, he has been with UPV, where he is currently a Full Professor and Head of the Mobile Communications Group. In addition, he is the Director of the Mobile Communications Master Degree program and the Assistant Director of the Research Institute on Telecommunications and Multimedia Applications. His current research interests include mobile channel characterization, planning and optimization tools for cellular systems, radio resource management techniques applied to personal communications, and broadcast cellular hybrid networks. He has led several national research projects and has participated in the mobile communications aspect of some European projects, Networks of Excellence, and other research forums. At the European level, he has been Vice- Chairman of the COST273 Action, and he is currently in charge of the WG3 of COST2100 in the area of radio access networks. He also chaired the Third International Conference on Wireless Communications Systems.

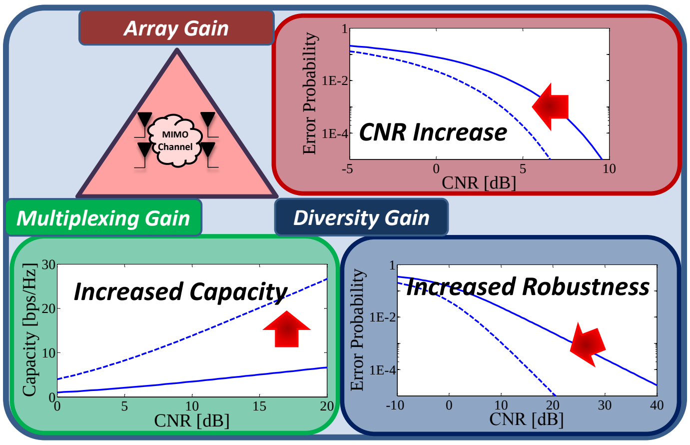

Figure 1: MIMO gains. Array gain produces an average increase in the received CNR, diversity gain increases the resilience against fading, and multiplexing gain increases the capacity of the system.

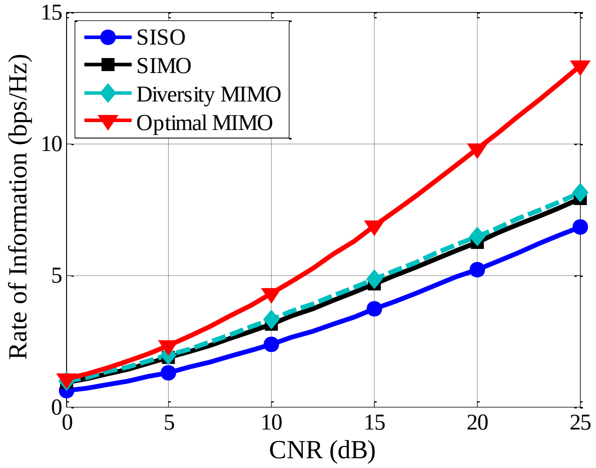

Figure 2: Ergodic capacity (bps/Hz) for different MIMO schemes in the NGH outdoor MIMO channel with 60 km/h speed.

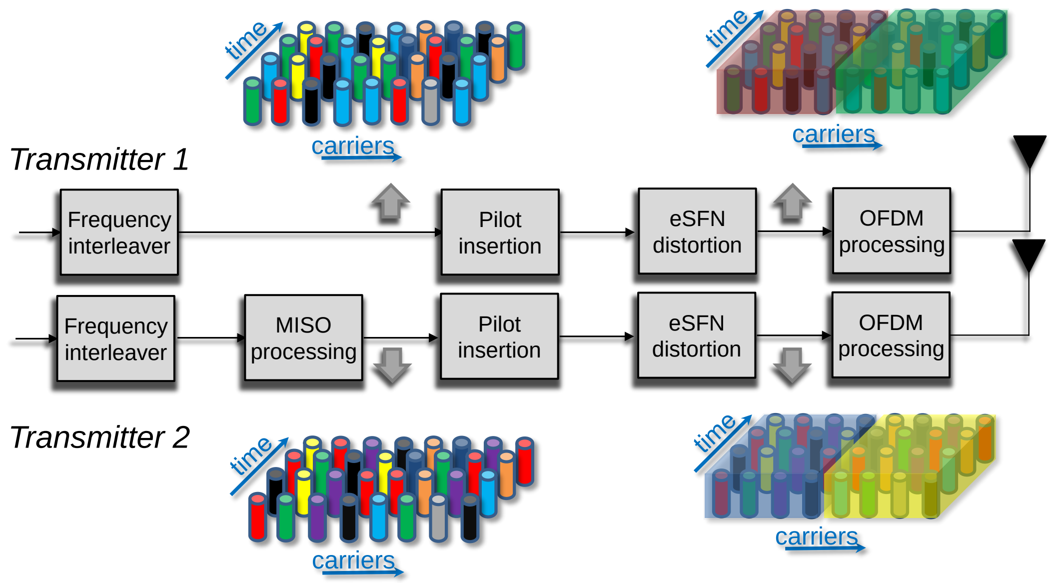

Figure 3: MIMO rate 1 signal processing with a combination of distributed MISO Alamouti and eSFN.

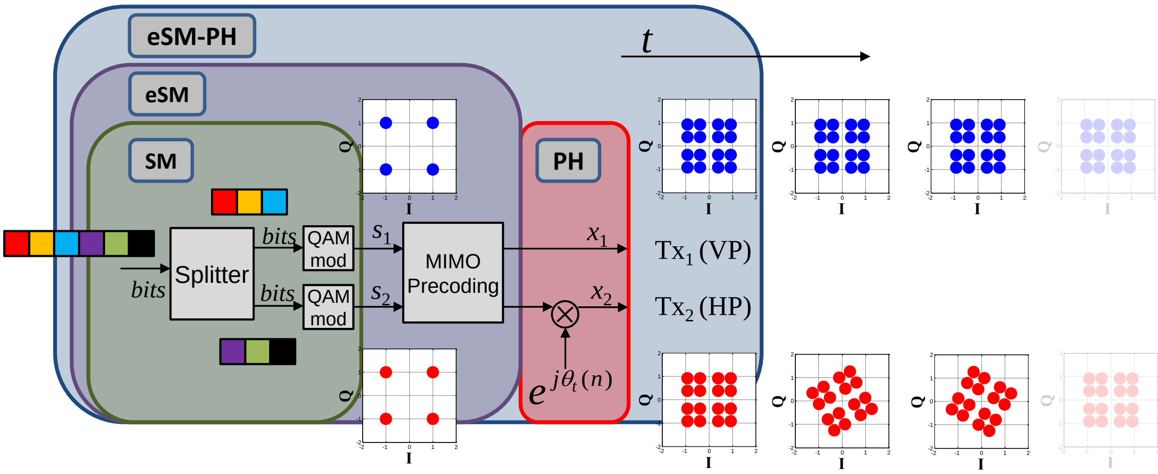

Figure 4: Multiplexing techniques: SM (*Spatial Multiplexing*), eSM (*enhanced Spatial Multiplexing*) and PH (*Phase Hopping*), and the combination of them, eSM-PH (*enhanced-Spatial Multiplexing – Phase Hopping*).

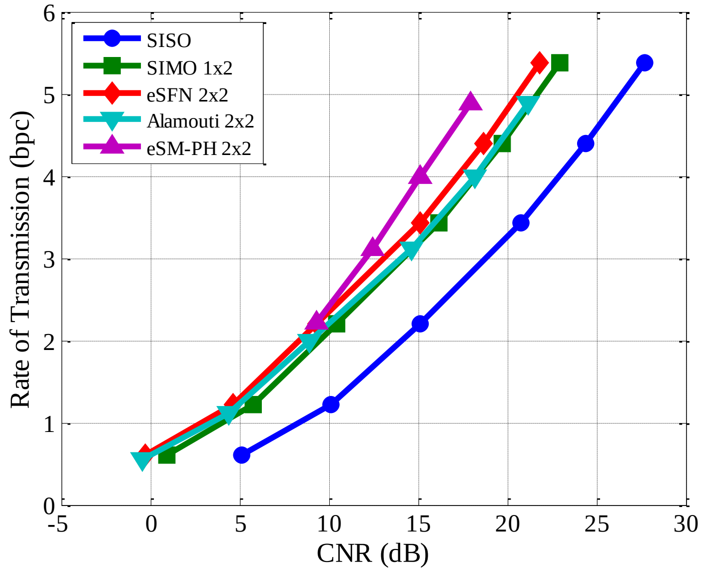

Figure 5: Rate of transmission for the different NGH MIMO schemes in the NGH outdoor MIMO channel with 30 km/h speed including pilot overhead.

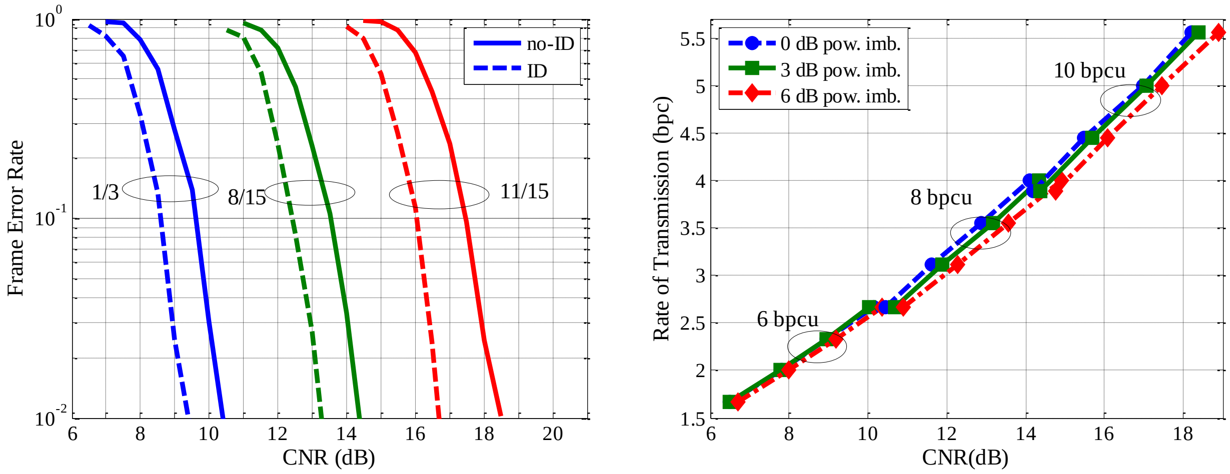

Figure 6: Frame Error Rate of iterative decoding with 8 bpc and 3 different code rates (i.e. 1/3, 8/15 and 11/15) under NGH outdoor scenario with 60 km/h speed (left). Rate of transmission for eSM-PH with different deliberated transmitted power imbalances of 0 dB, 3 dB and 6 dB under correlated Rice channel model (right).