Multi Antenna Techniques for Digital Video Broadcasting (DVB) Systems

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Abstract

In this paper we describe the potential of multi-antenna techniques (MIMO) in the context of digital video broadcasting (DVB) systems. DVB standards have been challenged by the increasing demand of high data rate applications and larger indoor coverage area. MIMO is a key technology to increase the system capacity and link reliability without any additional bandwidth or transmit signal power. The Mobile Communications Group of iTEAM research institute has been actively participating in the standardization process of the next generation of mobile TV broadcasting DVB-NGH (digital video broadcasting – next generation handheld) for the validation of the various MIMO signaling techniques. In this paper, we describe the benefits in the utilization of MIMO and its application to DVB standards, i.e. DVB-NGH and DVB-T2 (Terrestrial 2nd generation). Following a description of the transmission techniques adopted for the DVB-NGH specification, we furthermore provide theoretical and physical layer simulation results to illustrate the performance gains of MIMO in various channel models.

Keywords: Digital Video Broadcasting, MIMO, mobile TV.

1. Introduction

Broadcasting as well as telecommunication systems have been challenged by the demanding throughput increase for high bit-rate services like ultra-high definition TV (UHDTV) or mobile video/internet and increased indoor coverage. The most promising way to achieve more spectral efficiency and a more reliable transmission link is by means of MIMO (multiple input multiple output) technology without any additional bandwidth or transmit signal power.

The first broadcast system to include MIMO is DVB-NGH (Next Generation Handheld) the mobile evolution of the second generation digital terrestrial TV broadcasting technology, DVB-T2 (Terrestrial 2nd Generation) [1]. Its development has been motivated by the continuous growth of mobile multimedia services for handheld devices such as tablet computers and smart phones. Its main objective is to provide superior performance, robustness and increased indoor coverage compared to other existing DVB standards. DVB-NGH is based on the physical layer of DVB-T2 and has been designed such that it can be incorporated in existing DVB-T2 deployments, allowing the re-use of spectrum and infrastructure. The main technical enhancements of DVB-NGH are:

- Multiple-input multiple-output (MIMO) for increased spatial diversity and spectral efficiency.
- 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 for better indoor penetration.
- 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 content) with MPLPs (multiple physical layer pipes) for graceful service degradation.
- Efficient transmission of local services within SFN (single frequency networks).

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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 the need of additional bandwidth or increased transmission power. Because of its potential, MIMO has become an integral part of wireless standards such as IEEE 802.11n for wireless local area networks, WiMAX for broadband wireless access area systems, and the incoming 3GGP Long-Term Evolution (LTE) for cellular networks amongst others. In the broadcast world, DVB-NGH is the first system to include MIMO as key technology.

At the time of writing this paper, a potential addition to the DVB-T2 standard in the form of a MIMO profile is under discussion by the DVB forum. The capacity increase expected for rooftop reception where high CNR values are sensible could increase considerably the system spectral efficiency.

The rest of the paper is structured as follows: Section 2 describes the benefits that can be extracted from the MIMO channel. In section 3 theoretical results based on the channel model developed during the standardization process are presented, followed by a brief discussion on MIMO implementation aspects in Section 4. Then, in Section 5 the adopted schemes for DVB-NGH are detailed, while Section 6 illustrates performance simulation results in mobile scenarios. Finally, Section 7 gives a first view of a T2-MIMO based profile, and Section 8 contains the conclusions and futures lines of research.

2. MIMO benefits

Multi antenna techniques provide a more reliable transmission link and increase the capacity of the system without any additional bandwidth or transmit power.

Multi antenna techniques are commonly known by multiple-input multiple-output (MIMO) and it stands for a wireless link with various antennas at both sides of the transmission link. While implementing multiple antennas just at the receive side is known as single-input multiple-output (SIMO), the utilization of multiple antennas just at the transmitter side is referred as multiple-input single-output (MISO). Employing MIMO provides three kinds of gains, i.e. array gain, diversity gain and multiplexing gain, which are illustrated in Fig. 1 and explained next.

2.1. Array gain

Array gain increases the received carrier-to-noise-ratio (CNR) with coherent combination at the receive side (signal co-phasing and weighting for constructive addition). Coherent combination of received signals requires channel state information (CSI) that is commonly obtained by tracking the channel variations with the transmission of pilot signals. While SIMO coherently combines the signals at each of the receive antennas, array gain is also available at the transmitter side; however, it requires transmit-side knowledge by a feedback channel which is not available in broadcasting systems. Using antennas with the same polarization (co-polar), the gain is equal to 3 dB every time the number of receive antennas is doubled.

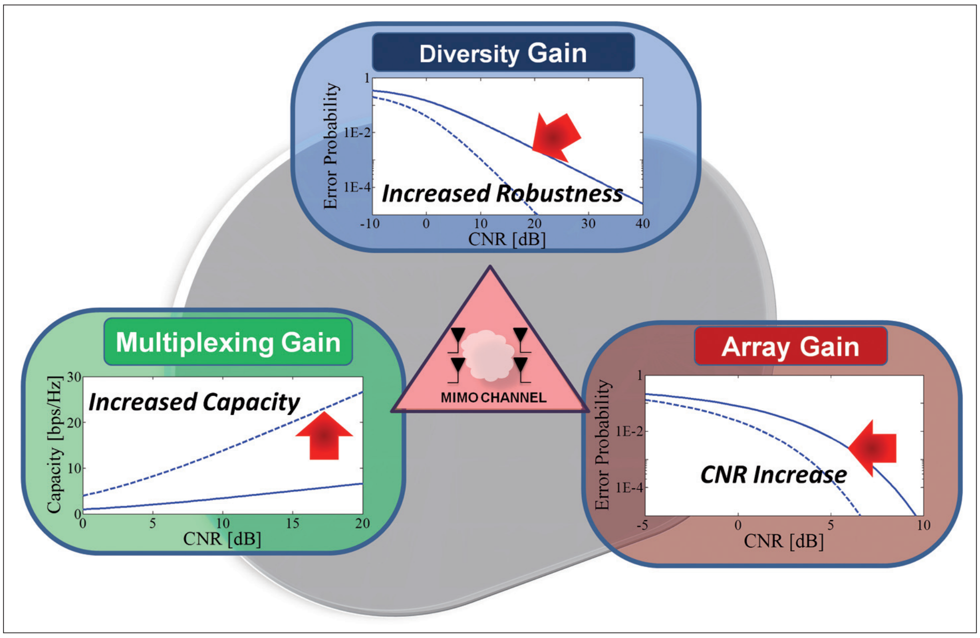

Figure 1. *MIMO benefits.*

For antennas with different polarization (cross-polar), the gain depends on the XPD (cross polarization discrimination), the presence of polarization mismatch at the receiver, and the power asymmetry between transmit antennas.

2.2. Diversity gain

The signal fading produced in the multipath channel can significantly reduce the received quality-of-service (QoS) in SISO systems. Transmitting the same information through independently faded spatial branches reduces the probability that all channels are in a deep fade, improving the reliability of the transmission. This is known as diversity gain. The correlation between fading channels determines the maximum diversity gain that can be extracted. While independent fading channels provide the maximum diversity gain, highly correlated fading channels, e.g. strong line-of-sight (LoS) conditions, reduce the achievable diversity gain.

2.3. Multiplexing gain

In addition to array gain and diversity gains, the MIMO channel can increase the system capacity by transmitting independent data streams across the transmit antennas. This is known as multiplexing gain and is strongly dependent on the channel statistics. On the one corner, fading independent spatial paths allow the separation of the mixed data streams at the receiver side and provide the maximum spatial multiplexing gain. On the other extreme, with complete correlation between spatial paths (complete LoS condition) only array gain can be extracted from the MIMO channel, i.e. there is neither multiplexing gain nor diversity gain.

Spatial multiplexing architectures exploit all the benefits of the MIMO channel because they use all the available degrees-of-freedom. Degree-of-freedom of a channel is defined as the dimension of the received signal space [2]. As well as dependent on the channel characteristics, the MIMO gain has different behavior depending on the operating CNR range. Assuming an NxM i.i.d. Rayleigh fading MIMO channel being N and M the number of transmit and receive antennas respectively, the MIMO capacity in the high CNR range was demonstrated by Foschini [3] to be approximately

$$C_{NM} \approx \min\{M,N\} \cdot \log_2(\mathrm{CNR}) \text{ (bits/s/Hz)}, \qquad [1]$$

where the capacity increases by a factor determined by the minimum number of transmit or receive antennas [2]. This channel is said to provide a min $\{M,N\}$ degrees-of-freedom and stands for the number of independents spatial paths that can be opened through the MIMO channel to transmit independent streams and to increase the spectrum efficiency. On the other hand, in the low CNR regime the MIMO capacity approximately is given by

$$C_{NM} \approx M \cdot \mathrm{CNR} \cdot \log_2(e) \text{ (bits/s/Hz)}, \qquad [2]$$

where the capacity is proportional to the number of receive antennas. Moreover, for the entire CNR range the capacity increases linearly with N for a NxN MIMO system [2]. We note that total transmit power is uniformly distributed across the N transmit antennas.

In Fig. 2 we illustrate the capacity of an i.i.d. Rayleigh fading MIMO channel with two different terms widely used in the literature. The first term presented at the bottom of Fig. 2 is the so-called ergodic capacity and it refers to the case where the transmission interval is long enough to observe the full channel statistics, i.e. a codeword spans many fading realizations as fast fading and the capacity can be found by averaging over the MIMO channel transfer distribution [4]. The second term the top of Fig. 2 is the outage capacity with a target outage probability of 1%. In this case the fading is quasi-static or slow, that the channel fading is random but constant along an entire codeword [2]. The definition of outage gives more insights about the solely gain provided by MIMO signaling since no frequency or time variation is accounted within one codeword.

At the top of Fig. 2 we can see the outage capacity of the i.i.d. Rayleigh channel. As can be seen in the figure, the additional diversity achieved by SIMO, MISO and diversity MIMO results in an offset of the capacity curves that does not affect its slope. We can also see the 3 dB advantage of

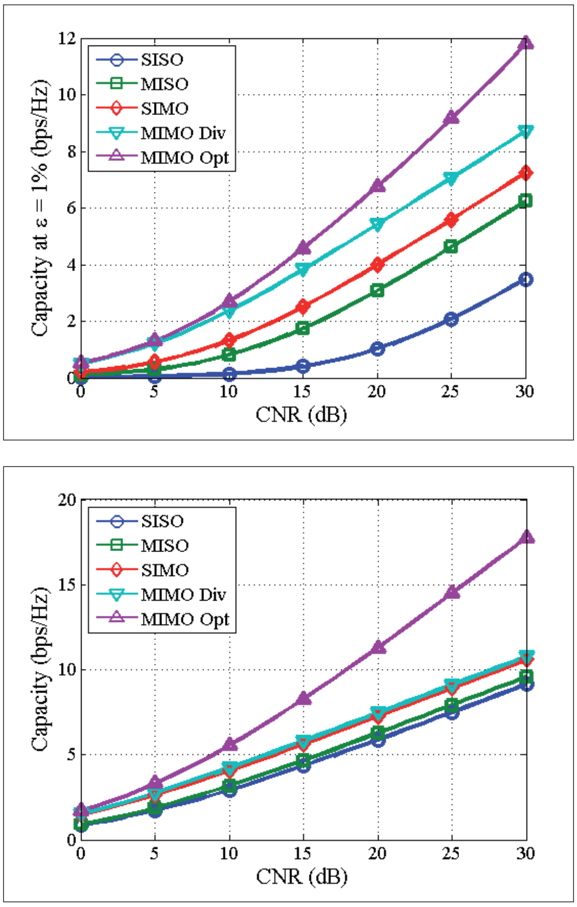

Figure 2. *Capacity (bps/Hz) of the Rayleigh channel. Outage capacity for a target outage probability of 1% on the top and ergodic capacity on the bottom.*

SIMO over MISO due to the array gain. On the other hand, the multiplexing gain achieved by optimal MIMO modifies the rate of growth of the capacity with the CNR, achieving a larger improvement at higher capacities.

At the bottom of Fig. 2 the ergodic capacity is presented where the use of SIMO, MISO and diversity MIMO does not result in a significant gain due to the large diversity already obtained by the fast fading occurred within a codeword. However, we see that for optimal MIMO, while having similar performance to diversity MIMO in the low CNR regime, we realize a significant capacity increase with increasing CNR.

During the standardization process of DVB-NGH, two types of MIMO techniques were distinguished according to their multiplexing capabilities and compatibility with single antenna receivers.

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 also be applied in a distributed manner across the transmitters of SFNs to reuse the existing network infrastructure (i.e. DVB-T and DVB-T2).

The second type of techniques is known as MIMO rate 2 codes, which exploit the diversity and multiplexing capabilities of the MIMO channel. As we have seen, spatial multiplexing techniques obtain very attractive capacity gains in favorable reception conditions (e.g. outdoor vehicular reception) for the provisioning of high data bit rate applications. Detailed description of MIMO rate 1 and rate 2 codes are presented in Section 5.

3. MIMO NGH Channel Model

Typical circumstances where the MIMO channel may approximate independent Rayleigh fading are a combination of co-polarised transmit and receive antennas and a 'rich-scattering' environment where many multipath components may be identified. A practical example might be indoors in a laboratory or office with many physical 'scatterers'. Although tending to maximize diversity in a cluttered environment, a disadvantage of such a co-polar antenna configuration is the performance degradation in predominantly LoS propagation conditions. Moreover, in the UHF frequency range, the antenna separation required in the co-polar case to provide sufficiently independent fading signal may exceed typical handheld devices sizes. For these reasons DVB-NGH employs instead a cross-polar 2x2 configuration replacing two spatially separated uni-polarized antennas by a space-effective single structure with two antennas orthogonally polarized, that furthermore improves reception in LoS condition.

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 [5]. The main objective was to obtain a channel model representative of cross-polar MIMO propagation at UHF frequencies in order to evaluate the performance obtained by multiple antenna techniques in realistic scenarios. This measurement campaign was the first one with a cross-polar antenna configuration in the UHF frequency range. In particular, an outdoor mobile, an outdoor portable and an indoor portable model were proposed. 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 of 8 taps with different values of delay, and power gain. For each channel, the XPD factor describes the energy coupling between cross-polarized paths, the K factor describes the power ratio between LoS and nLoS (non-Line-of-Sight) components, and the covariance matrix describes the spatial correlation between antennas. 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.

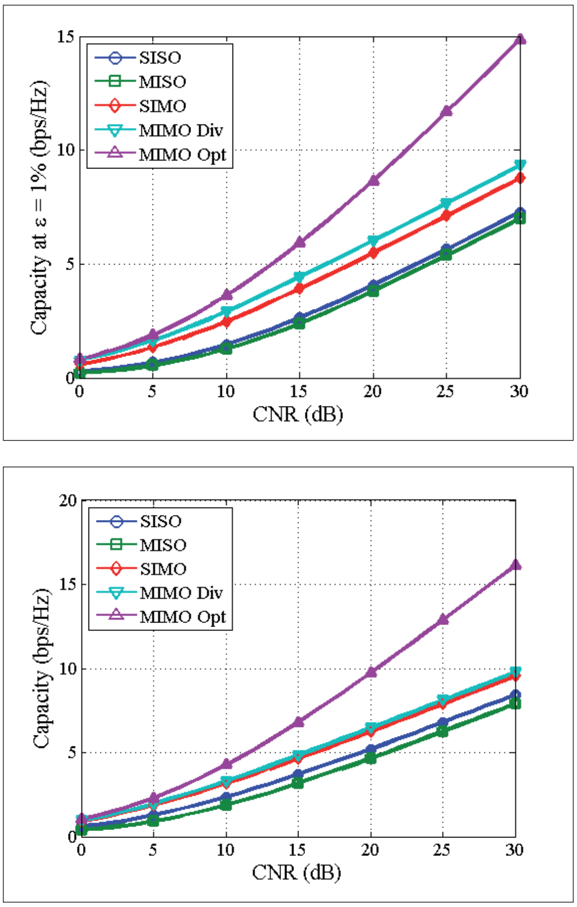

Figure 3. *Capacity (bps/Hz) of the NGH outdoor MIMO channel with 60 km/h speed. Outage capacity for a target outage probability of 1% on the top and ergodic capacity on the bottom.*

Fig. 3 presents capacity in bps/Hz vs. the CNR in the NGH outdoor MIMO channel model with 60 km/h speed. For the ergodic capacity illustrated at the bottom, we realize a similar behavior than for the i.i.d. Rayleigh channel of Fig. 2; however in this case MISO is outperformed by SISO. As for the outage capacity with a target outage probability of 1% at the top of Fig. 3, SISO also outperforms MISO, but moreover, we observe that MIMO diversity performs closer to SIMO. On the other hand, optimal MIMO provides a significant capacity increase also in this channel model. In general terms, the utilization of cross-polar antenna configuration, although dependent on the XPD factor, is generally detrimental for transmit diversity techniques while beneficial for spatial multiplexing schemes [6].

4. Aspects on MIMO implementation

MIMO technology is the only method to overcome the information-theoretic limits of SISO systems without any additional bandwidth or increased transmit power. However, its implementation requires a more sophisticated signal processing, i.e. with higher computational complexity, and it may furthermore require upgrading the existing network infrastructure.

4.1. MIMO demodulation

The receiver has to demodulate the received signal to provide soft information to the channel decoder. This task is performed by the demapper and to exploit the gains offered by MIMO technology, it is essential to employ high-performance MIMO demodulation algorithms. However, such algorithms often entail high computational complexity. Therefore, an important aspect in designing MIMO systems is the complexity-performance tradeoff.

The optimal maximum a-posteriori (MAP) demapper minimizes the bit error probability, but its complexity increases exponentially with the number of transmit antennas. To reduce the complexity of the MAP demapper, the max-log approximation replaces the logarithm of a sum of exponentials by a minimum distance calculation. While the performance impact of this approximation is usually small, the complexity still scales exponentially with the number of transmit antennas.

Linear receivers like zero-forcing (ZF) and minimum-mean-squared-error (MMSE) provide significant complexity reductions. They apply a linear equalizer to the received signal which cancels the multi-stream interference, thereby transforming the MIMO detection problem into independent SISO problems. The ZF receiver eliminates the multi-stream interference at the cost of noise enhancement, while the MMSE receiver yields a trade-off between interference cancellation and noise enhancement. The complexity of these demappers scales polynomially with the number of transmit antennas, i.e. a significant complexity reduction can be achieved compared to optimal demapping.

The implementation of multiple antennas at the transmitter and the receiver side (MIMO) allows overcoming the Shannon limit of single antenna communications without the need of additional ban-dwidth or increased transmission power.

In MIMO-BICM with iterative decoding, the output of the channel decoder is fed back to the MIMO demapper in order to improve the detection [7]. We note that iterative decoding only affects the receiver side and therefore no modification is required in standards and transmitters. However, the complexity of optimal MIMO demapping together with iterative decoding is too high for many practical applications.

4.2. Network deployment aspects

In addition, the exploitation of MIMO may demand an upgrade into the current network infrastructures formed by single antenna transmitters and receivers. While MIMO rate 1 can be applied across the transmitters of SFNs to reuse the existing network infrastructure with a single receive antenna, the use of MIMO rate 2 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.

Furthermore, DVB-NGH specification defines the implementation of MIMO techniques as an optional profile; therefore, it is not mandatory for all DVB-NGH transmissions. The standard profile utilizes single antenna transmissions, allowing for a progressive deployment of MIMO networks depending on the market demands. For easy migration from legacy SISO-based broadcasting network to new MIMO transmission which requires two antennas for both transmitter and receiver side, it is helpful to support lowering the existing transmit antenna power slightly and adding a second transmit antenna with minimum power not to affect any performance degradation of legacy receiver. With this special care and if this scheme still maintains the MIMO gains, both legacy and new receiver can benefit from introducing new schemes (DVB-NGH) to existing network (DVB-T2 in this case). With this situation, MIMO rate 2 schemes are designed to take into account power imbalance situations to reduce performance degradation.

5. MIMO techniques in DVB-NGH

5.1. MIMO rate 1 schemes for DVB-NGH

For rate 1 MIMO, DVB-NGH has adopted the Alamouti code [8] already featured in DVB-T2, together with a novel scheme known as eSFN (enhanced Single Frequency Networks). The Alamouti code is a MIMO scheme

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designed for increasing the diversity in systems with two transmit antennas. In OFDM systems, it operates by encoding in pairs the information symbols of adjacent subcarriers. The Alamouti code is well-known for achieving full diversity with reduced (linear) complexity required at the receiver side. In order to use the Alamouti code, it is necessary to employ alternate or orthogonal pilot patterns between antennas, so that the receiver can estimate the channel response from each transmit antenna. This also means that the number of pilots that is transmitted must be doubled for the same resolution of channel estimation. The utilization of additional pilots decreases the amount of carriers that can be used for carrying information and thus, it reduces the overall system capacity. 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. These notches can erase a significant percentage of subcarriers and degrade the QoS in an important manner. By using the Alamouti code in a distributed manner it is possible to combine the signals from different transmitters in an optimum way and remove the presence of notches from the channel.

The main idea of eSFN is to apply a linear pre-distorsion function to each antenna in such a way that it remains invisible for 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-distorsion 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. 4 illustrates the combination of MISO Alamouti and eSFN in the same transmission chain. 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.

5.2. MIMO rate 2 schemes for DVB-NGH

For rate 2 MIMO, DVB-NGH has adopted a novel scheme known as eSM (enhanced Spatial Multiplexing) in combination with PH (Phase Hopping), that we refer as eSM-PH. Its structure is presented in Fig. 5. The most simple way of increasing the multiplexing rate of information consists on simply dividing the information symbols between the transmit antennas. This is referred to as SM [9]. The incoming stream is divided in multiple independent streams which are modulated and directly fed to the different transmit antennas, as it is shown in the left part of Fig. 5.

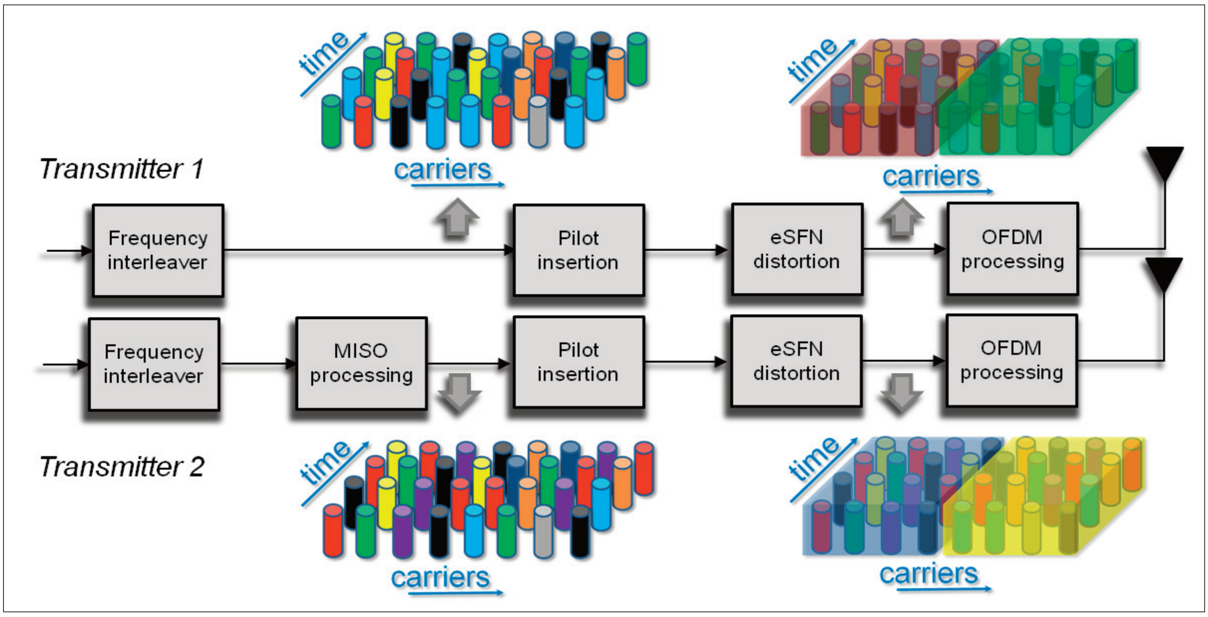

Figure 4. *MIMO rate 1 signal processing with a combination of distributed MISO Alamouti and eSFN.*

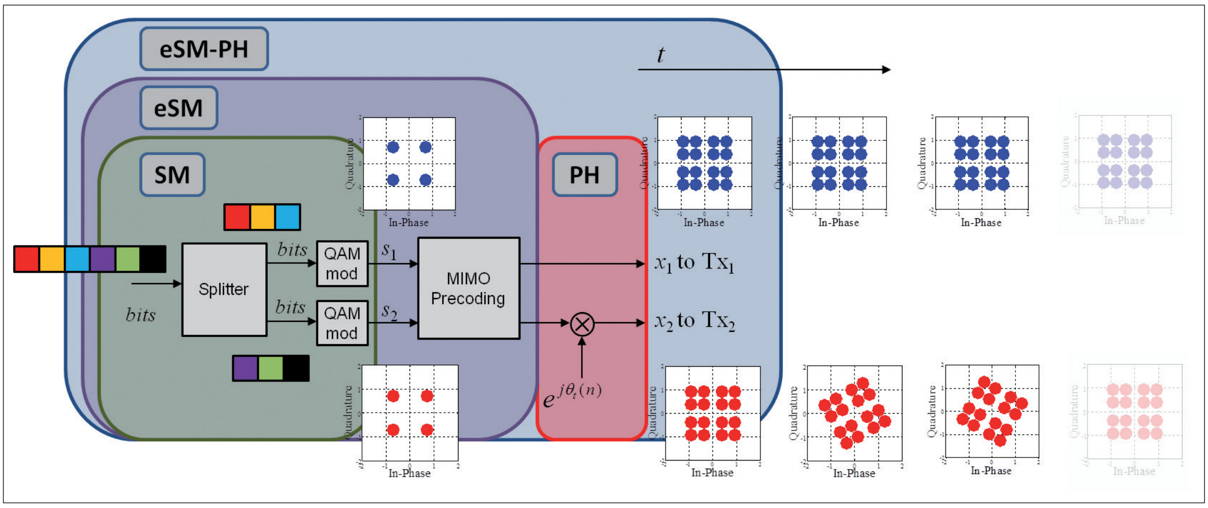

Figure 5. *Diagram multiplexing techniques: SM (Spatial Multiplexing), eSM (enhanced Spatial Multiplexing) and PH (Phase Hopping), and the combination of them, eSM-PH (enhanced-Spatial Multiplexing – Phase Hopping).*

The presence of correlation in the MIMO channel due to the lack of scattering (LoS condition) is especially detrimental for SM. To improve that, eSM-PH retains the multiplexing capabilities of SM, and at the same time, increases the robustness against spatial correlation. To do so, the information symbols are weighted and combined before their transmission across the antennas. The weighting of the information symbols depends on a rotation angle, which has been specifically tuned for every combination of constellation order and deliberated transmit power imbalance. 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.

The three constellation orders defined for eSM-PH are: 6 bpc (bits per cell, as the number of bits assigned per subcarrier), 8 bpc and 10 bpc. 6 bpc transmits a QPSK constellation in the first antenna and transmits a 16-QAM constellation in the second one. 8 bpc transmits a 16-QAM constellation in the first and second antenna. Finally, 10 bpcu transmits a 16-QAM constellation in the first antenna and transmits a 64-QAM constellation in the second one.

In addition, eSM-PH can be transmitted with power imbalance between the antennas to ease the introduction of dual polar operation. However, this imbalance degrades the performance. eSM-PH is optimized with a different rotation angle, for every combination of constellation order and power imbalance, to minimize the performance loss. The available power imbalances are 0 dB, 3 dB and 6 dB.

With eSM-PH, the receiver needs to estimate all the antenna paths in order to decode the signal. This means that, as with the Alamouti code, the number of pilots that must be transmitted for channel estimation purposes is doubled compared with SISO transmissions.

6. Performance simulation results in mobile environments of DVB-NGH MIMO schemes

In this section we provide physical layer simulation results to illustrate the performance of MIMO schemes for DVB-NGH. The simulated scenarios are NGH outdoor, and NGH indoor MIMO channel models with 60 km/h and 3 km/h speed, respectively. The simulations include LDPC codes with a word length size of 16200 bits.

Fig. 6 and 7 present 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 with the following values used during the NGH standardization process. 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. 6, 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 provides a 44.7% of capacity increase or equivalently 4.5 dB of CNR gain at 3.2 bpc, eSFN provides 57% of capacity increase (5.8 dB of CNR gain at 3.45 bpc), and eSM-PH provides 81.5 % of capacity increase (7.8 dB of CNR gain at 4 bpc).

For the indoor scenario illustrated in Fig. 7, the overall required CNR to achieve the QoS is higher. In this case, the gains achieved by the MIMO schemes compared with SISO for the indoor environment are higher than those for the outdoor environment. Here, compared with SISO and with 17.5 dB of average CNR, SIMO provides 83.3% of capacity increase (6.8 dB of CNR gain at 3.28 bpc), eSFN provides 100% capacity increase (8.2 dB of CNR gain at 3.65 bpc), and eSM-PH provides 122% capacity increase (9.4 dB of CNR gain at 3.95 bpc).

In both scenarios, the performance of MIMO Alamouti lies between SIMO and eSFN due to the effect of increased pilot overhead.

Now, we present eSM-PH performance results with iterative decoding (cf. FER curves labelled with "ID"). Fig. 8 shows the FER vs. CNR for code rates 1/3, 8/15 and 11/15, i.e. the lowest, medium and highest available code rate for rate 2 MIMO transmissions. Here, the selected QoS for the comparisons is a FER of 10^{-2}. For the max-log demapper the gain due to iterative decoding increases with the code rate, i.e. 1 dB, 1.1 dB and 1.8 dB for code rate 1/3, 8/15 and 11/15 respectively. Furthermore, we present results with MMSE demodulator that is able to exploit the benefits of iterative decoding while keeping computational complexity low [10]. In this case, MMSE demodulator gains around 0.7 dB (1/3), 0.9 dB (8/15) and 1.1 dB (11/15) by iterative decoding. However,

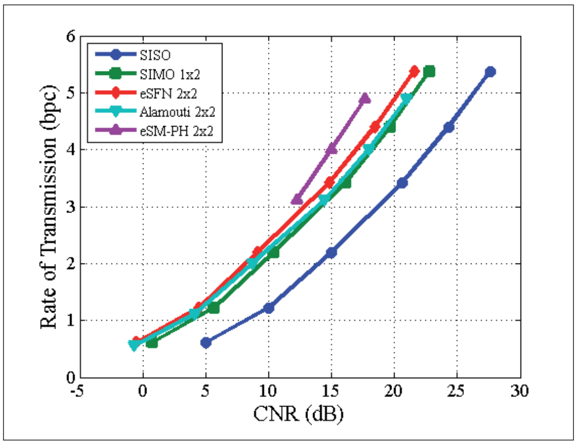

Figure 6. *Rate of transmission for the different NGH MIMO schemes in the NGH outdoor MIMO channel with 60 km/h speed including pilot overhead.*

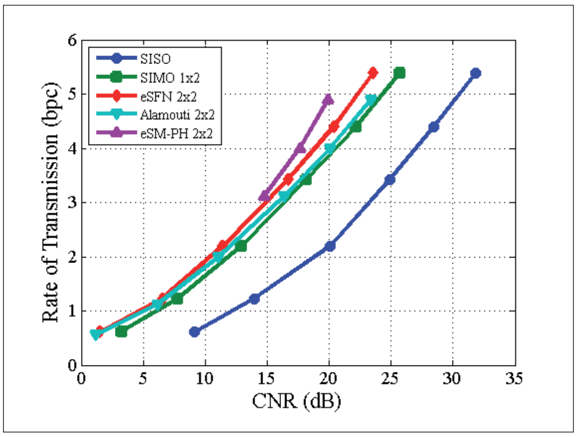

Figure 7. *Rate of transmission for the different NGH MIMO schemes in the NGH indoor MIMO channel with 3 km/h speed including pilot overhead.*

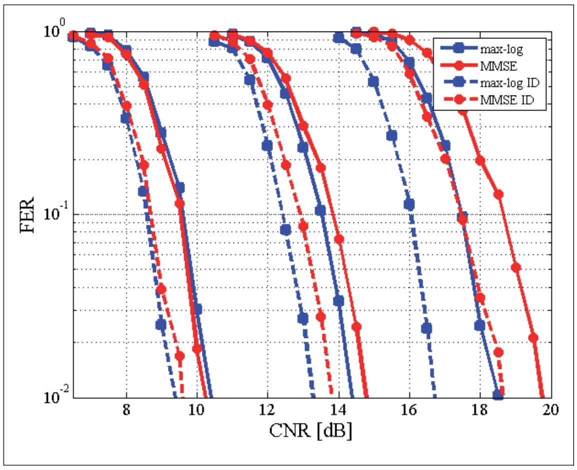

Figure 8. *FER vs. CNR of iterative decoding with 8 bpc and code rates 1/3, 8/15 and 11/15 in the NGH Outdoor MIMO channel with 60 km/h speed.*

we observe performance degradation of MMSE demapper compared with the max-log demodulator with the increasing rate. The max-log demapper outperforms the MMSE demapper by about -0.15 dB (0.2 dB), 0.4 dB (0.5 dB) and 1.2 dB (1.9 dB) for (non-)iterative decoding. We note that for all simulated code rates, the MMSE receiver with iterative decoding does not perform worse that the non-iterative max-log receiver.

7. A new T2-MIMO profile?

At the time of writing this paper, a potential addition to the DVB-T2 standard in the form of a MIMO profile is under discussion, justified by the ever-increasing demands on broadcast spectrum by new high data rate applications, e.g. HDTV, 3DTV and future services of UHDTV amongst others, and other standard technologies, e.g. LTE. Furthermore, other standardization bodies are considering next generation broadcast systems and they will likely provide higher capacity than the current DVB-T2. The MIMO techniques developed within DVB-NGH provide a possible starting point for the possible use of MIMO in the context of fixed rooftop reception.

As we discussed in Eq. 1, in the high CNR regime, the multiplexing gain is significant and proportional with the minimum number of transmit and receive antennas. For the target rooftop reception in DVB-T2 CNR figures of 20 dB are sensible and high data rate services can be transmitted. Despite the time-static channel and the strong LoS component for rooftop reception, the antenna cross-polar configuration provides an inherently well-conditioned channel transfer matrix, although dependent on the XPD factor, with high multiplexing gain. Fig. 9 presents the capacity derived from the BBC Guildford channel model [11], where only the LoS component is used for the calculation. We observe a 69% of capacity increase for MIMO compared with SISO for 20 dB of CNR.

Additional technologies are also considered to boost the capacity of a DVB-T2 MIMO based profile: higher order constellations, e.g. 1024-QAM, time frequency slicing, non-uniform constellation, channel bundling and higher LDPC word sizes, amongst others.

8. Conclusions

In this paper we introduced the utilization of multi antenna techniques for DVB systems. We first reviewed the benefits that can be exploiting by the utilization of MIMO techniques and provided capacity results that showed a potential gain in spectral efficiency compared to single antenna communications. Furthermore, we briefly described some implementation aspects when employing MIMO. After the description of the selected MIMO signaling schemes for the DVB-NGH specification, we provided physical layer simulation results under the NGH channel model in mobile environments to prove the performance gains predicted by the theoretical results. The gains provided by MIMO can significantly enhance the spectral efficiency of the system. Furthermore, we discussed and gave initial capacity results for a T2-MIMO based profile.

Future work will embrace topics on receiver implementation aspects such as suboptimal demodulators and finite resolution (quantization) and the evaluation of their performance impact. During the DVB-NGH standardization process, the performance of the different transmission techniques (such as MIMO spatial multiplexing) has been evaluated under ideal conditions, e.g., optimal demodulators, infinite resolution in computations, and perfect channel state information (CSI). However, due to the severe complexity and memory constraints of mobile battery-powered devices, it is crucial for the overall system performance to carefully design the receiver algorithms.

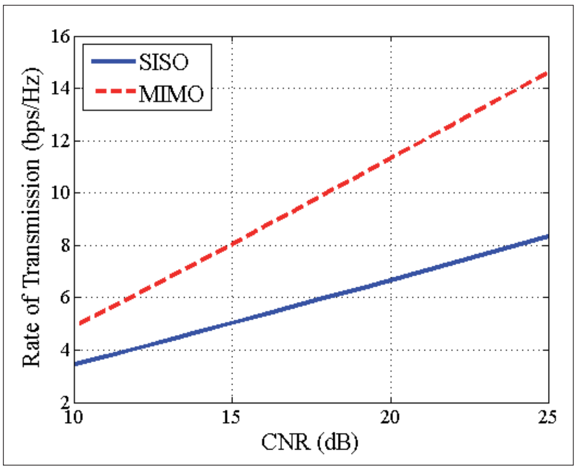

Figure 9. *MIMO vs. SISO ergodic capacity with BBC Guildford channel model with only LoS component.*

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Biographies

David Vargas received his M.Sc. degree in Telecommunication engineering from Universidad Politécnica de Valencia (UPV), Spain in 2009. During his studies he spent one year at the University of Turku (UTU), Finland and carried out his M.Sc. Thesis which was awarded with the ONO prize of the Official College of Telecommunication Engineers of Spain. In December 2009 he joined the Mobile Communications Group at the Institute of Telecommunications and Multimedia Applications (iTEAM), UPV as research engineer. In the summer of 2011 was 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 main research interests are in the area of implementation aspects for MIMO receivers in the context of DVB physical layer standards.

David Gómez-Barquero received a double M.Sc. degree in Telecommunications engineering from the Universidad Politecnica de Valencia (UPV), Spain, and the University of Gavle, Sweden, in 2004; and a Ph.D. in Telecommunications from UPV in 2009. During his doctoral studies, he was a guest researcher at the Royal Institute of Technology, Sweden, the University of Turku, Finland, and the Technical University of Braunschweig, Germany. He also did an internship at Ericsson Eurolab, Aachen, Germany. During 2010 and 2011, he was a postdoc guest researcher at the Fraunhofer Heinrich Hertz Institute (HHI) in Berlin, Germany, 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 general, and in particular in the optimization of DVB (Digital Video Broadcasting) and 3GPP MBMS (Multimedia Broadcast Multicast Services) systems. Since 2008, he is actively participating in the technical module of the digital TV standardization forum DVB. He co-edited the DVB bluebook on upper layer forward error correction as an invited expert, participated in the standardization process of the next generation mobile broadcasting standard DVB-NGH, and the mobile profile of the second generation digital terrestrial TV system DVB-T2, known as T2-Lite, and also and contributed to the DVB-T2 implementation guidelines.

David Gozálvez Serrano received his M.S. degree in electrical engineering from the Universidad Politécnica de Valencia (UPV) in 2007. He was the recipient of the Cátedra Telefónica prize for his Master Thesis in the same year. Currently he holds a PhD student Grant from the Spanish Government to research on transmission optimization of DVB broadcasting systems. 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 has contributed to the DVB-T2 implementation guidelines.

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