Implementation issues and evaluated performance in local service insertion in DVB-NGH single frequency networks

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Abstract— *Current digital terrestrial television networks make use of either single frequency networks (SFN) or multi frequency networks (MFN). SFN is the network where several transmitters transmit the same signal over the same frequency channel. MFN is the frequency network where each transmitter transmits the signal over different frequency channels. Compared to MFN,SFN is the best approach because of the efficient utilization of the Radio spectrum, Low power operation and multi-channel capacity.*

On growing market demand, need to maintain the quality, flexibility, mobility and interactivity successfully without any overloading and overlapping issues. For this we introduce the following two techniques. One is Hierarchical Modulation (H-LSI) and another one is Orthogonal Frequency Division Multiplexing (O-LSI).In order to improve the performance of the SFN operation, DVB-NGH standard incorporates multiple input multiple output (MIMO) antenna diversity mechanisms. 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— DVB-NGH, Hierarchical Modulation, orthogonal Local Service Insertion, SFN, MIMO Technique

I. INTRODUCTION

DVB technology has become an integral part of global broadcasting, where it has a set of open standards to use like satellite, cable, terrestrial and IP-based services. TELEVISION (TV) services transmitted in a Digital Terrestrial Television (DTT) network can be classified depending on their target area. Global services target the services of the users throughout the network and local services are referred to the services which are relevant to users of certain sub- regions.

One of the main advantages of DTT networks is the possibility of deploying SFNs by the use of Orthogonal Frequency Division Multiplexing (OFDM) with a sufficiently long Cyclic Prefix (CP). The receiver usually receives multiple signals coming from different SFN transmitters with different channel attenuations and time delays, which exhibits a severe artificial multipath effect. All the signals from the different transmitters should arrive inside the CP interval in order to be considered constructive to the wanted signal. SFNs are ideally suited for global services because of the need of a single frequency channel and due to the mutual support of the signals from the different transmitters, the so-called SFN gain. However, if local services are transmitted, they have to be transmitted across the whole network, including regions where they are not required. This leads to a significant waste of capacity if the proportion of local content is large. On the other hand, using a MFN approach, the full channel capacity is available for the content transmitted within each cell. The main drawback is that more spectrum is required compared to the SFN approach. An ideal solution to transmit global and local content in SFN networks should retain all SFN advantages for global services. The transmission of local services should be spectrally efficient and using any subset of sites of the network, while their coverage area (Local Service Area, LSA) is restricted to the specific areas where local content is to be consumed. In order to achieve this, the SFN principle has to be violated partially, e.g., for a short period of time or a limited frequency range. The main problem is that different local services transmitted within single frequency cause interference. Thus, in areas where the signals of two or more sites transmitting different local services are strong, successful reception of local services may not be possible. However, for local services a reduced coverage area compared to global services may be acceptable for some use cases (e.g., urban areas), although for some uses cases the required coverage can be the same as for global services. The current state-of-the art DTT system, DVB-NGH (Digital Video Broadcasting – Next Generation Handheld), will allow exploring the viability of inserting local services in SFNs in a way that has not been possible before. DVB-NGH is the handheld evolution of the second generation digital terrestrial TV standard DVB-T2 (Terrestrial 2nd Generation), and one of the main technical innovations introduced with respect to DVB-T2 is the efficient provisioning of local content in SFNs. DVB-NGH has adopted two complementary techniques with small network overhead to transmit local content in SFNs, known as Hierarchical and Orthogonal Local Service Insertion (H-LSI and O-LSI, respectively). The first technique uses Hierarchical Modulation (HM), which generates each QAM symbol from two bit streams with different robustness levels (global content is transmitted within the so-called High Priority (HP) bit stream, whereas the local content is inserted into the Low Priority (LP) stream). HM was adopted for the first time for DVB-

T (Terrestrial), and it was also adopted for the mobile broadcasting system Media FLO and DVB-SH (Satellite to Handhelds), although it has never been commercially deployed yet. With O-LSI technique, a set of OFDM (Orthogonal Frequency Division Multiplexing) sub-carriers within the NGH frame structure are allocated to transmit local services. The transmitters of each LSA transmit local content using a subset of these sub-carriers. This concept is similar to the auxiliary stream insertion specified in the DVB-T2 transmitter signature standard. O-LSI is a novel technique for which no previous studies or performance results are available in the literature

The main contribution of this paper is the description of the basic concept of both H-LSI and O-LSI technical solutions adopted for DVB-NGH to insert local content in SFNs and description and implementing the MIMO technique to the DVB-NGH network.

In Section II describes the concept for H-LSI and O-LSI, MIMO Technique . In Section III the implementation of the MIMO technique and its equations. In Section IV describes its simulating results.

II. Complementary techniques for LSI in DVB-NGH and MIMO benefits

2.1. Concept of H-LSI techniques:

DVB-NGH supports hierarchical 16QAM and 64QAM modulation for the insertion of local services, where the global services employ a QPSK or 16QAM modulation, and the transmitters inserting local services add an additional QPSK constellation on top of the global QAM constellation, containing the local service. For the global service, the hierarchically modulated QAM symbols “look” like noise, requiring an increase in CNR (Carrier-to-Noise Ratio). This effect diminishes with distance from the local service inserting transmitter as shown in Fig. 1. Since the local service is mapped to the low priority bits of the constellation, the effective CNR of the local service is smaller compared to the global service. The required CNR for successful reception of the local stream can however be adapted by choosing a smaller code rate of the forward error correction (FEC) code for the local service compared to the global service.

The HM causes inter-layer interference, since the LP stream acts as noise to the HP stream (and vice versa), causing a coverage reduction of both the local and global services. The robustness of both LP and HP streams can be adjusted by means of the HM parameter (α) that describes the ratio of the smallest distance between the constellation points carrying different HP bits (b) to the distance between the LP bits (a), as shown in Fig. 1. In DVB-NGH, the allowed values for α are 1, 2 and 4 for 16QAM, and 1 and 3 for 64QAM. For high values of α, the degradation of the HP stream is practically negligible, but the robustness of the LP stream is significantly reduced. The selection of α is therefore a trade-off between the coverage reduction of the global services and the coverage achieved for the local services.

A second penalty for global services decoding arises from the violation of the SFN principle due to the symbols emitted from the all transmitters are not the same. Since the transmitters with global and local services transmit different complex values in all OFDM carriers that carry hierarchically modulated local services, compared with the transmitters with global services only. It effects the equalization at the receiver and it causes the performance penalty at both the services based on the characteristics of the channel at the receiver and it can be reduced with an iterative equalization and decoding scheme, called Iterative Sliced Decoding (ISD).

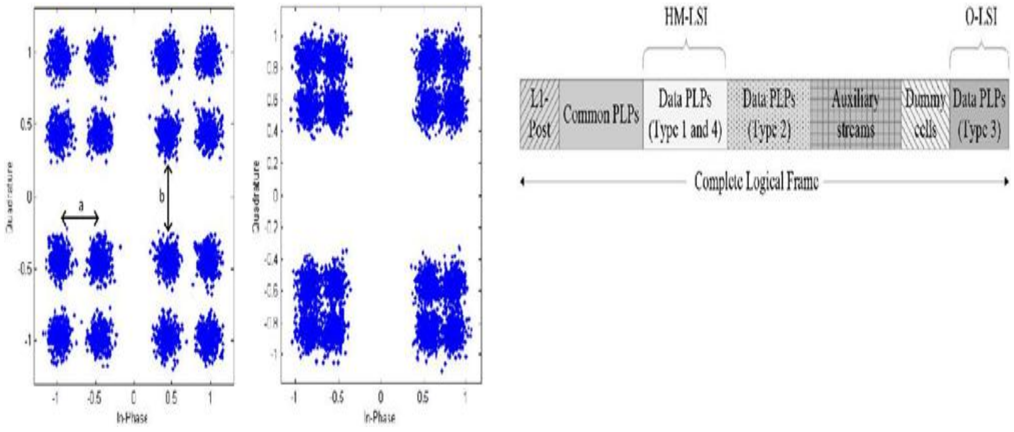

Fig.1. Received signal constellation in a network

2.2. O-LSI Technique:

With O-LSI a set of dedicated OFDM sub-carriers on dedicated OFDM symbols are reserved for the transmission of local services. Within the same OFDM symbol, the transmitters of different LSAs employ a different subset of subcarriers to broadcast local services, whereas the same OFDM sub-carriers used by the other transmitters are unused. The orthogonality obtained by using dedicated carriers for each local service ensures that no interference between adjacent transmitters occurs (Assuming correct frequency synchronization between SFN transmitters). Fig. 2 shows the general concept of the O-LSI technique for the insertion of local services in an SFN with three LSAs. For the sake of clarity, the picture shows the allocated data subcarriers in one OFDM symbol before frequency interleaving. After frequency interleaving, each set is spread across the complete bandwidth to achieve high frequency diversity, still avoiding interference between transmitters of different LSAs. However, similar to other OFDM systems, the frequency offsets such as Doppler Effect, can affect this orthogonality, resulting in inter-carrier interference (ICI) due to power leakage among subcarriers. In this case, the performance of global and local services in mobile reception is similar to the performance DVB-NGH in conventional SFN topology and depends on the velocity of the receiver and the robustness of the transmission mode.

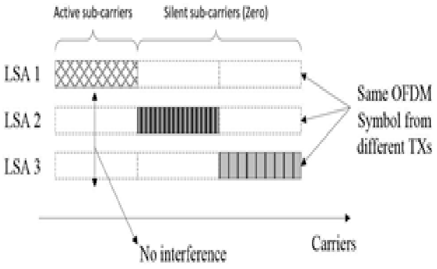

Fig.2. O-LSI technique Concept.

The main advantage of the O-LSI technique is that no interference between transmitters from different LSAs occurs, because the inserted local content is orthogonal to each other. Furthermore, LSAs separated by a long distance can reuse the same sub-carriers following a spatial reuse pattern. This way, local services can potentially have the same coverage area as global services, allowing receiving at least one local service at any point in the network. Furthermore, the insertion of local services does not affect the coverage area of the global services. The drawback is the reduction of the capacity available for global services, since the local services are not transmitted on top of the global services. With O-LSI, global and local services share all available OFDM data sub-carriers. O-LSI allows for a power boosting of the OFDM sub-carriers devoted to local services in order to compensate the unmodulated carriers of others LSAs keeping a constant OFDM symbol power over time. This power boosting can either be translated into a capacity increase using a transmission mode with higher spectral efficiency (higher code rate and/or higher modulation order) or can alternatively be used to improve the coverage area of the local services.

2.3. MIMO Technique:

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. 3 and explained next.

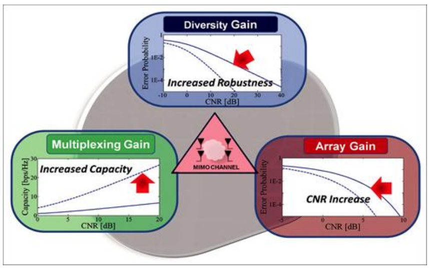

Figure 3. MIMO Technique

Array gain:

It increases the received carrier-to-noise-ratio (CNR) with coherent combination at the receive side 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.

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.

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 is called 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.

Multiplexing gain:

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 and is defined as the dimension of the received signal space. As well as dependent on the channel characteristics, the MIMO gain has different behavior depending on the operating CNR range. Assume 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 to be approximately

$$C_{NM}\ \min\{M,N\}\bullet \log_2(\mathrm{CNR})\ \text{(bits/s/Hz)},$$

where the capacity increases by a factor determined by the minimum number of transmit or receive antennas. 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

$C_{NM}\ M\bullet \mathrm{CNR}\bullet \log_2(e)$ (bits/s/Hz),

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. We note that total transmit power is uniformly distributed across the N transmit antennas.

In Fig. 4 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. 4 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. The second term the top of Fig. 4 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. 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. 5 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 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. 5 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 3.

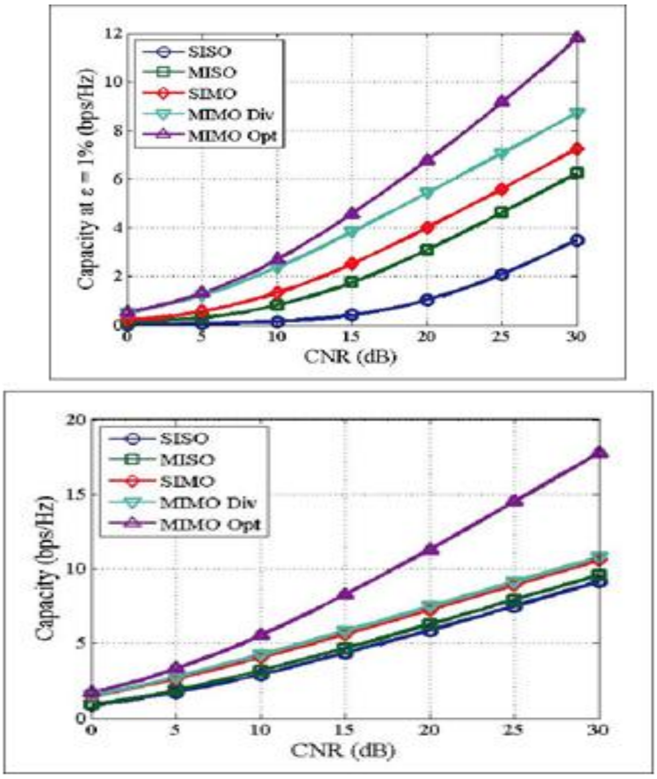

Figure 4. *Capacity (bps/Hz) of the Rayleigh channel. Ou-tage capacity for a target outage probability of 1% on the top and ergodic capacity on the bottom.*

III. Implementing Aspects of MIMO technique

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.

MIMO rate 1 scheme:

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

Fig. 5 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.

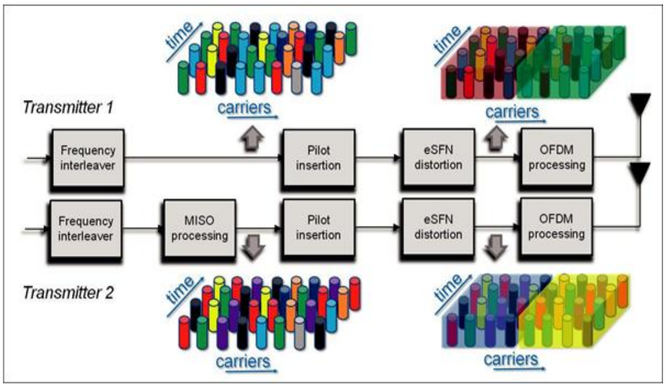

Figure 5. *MIMO rate 1 signal processing with a combination of distributed MISO Alamouti and eSFN.*

MIMO rate 2 scheme:

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 eSMPH. Its structure is presented in Fig. 6. 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 Spatial Multiplexing, SM. 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.

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.

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.

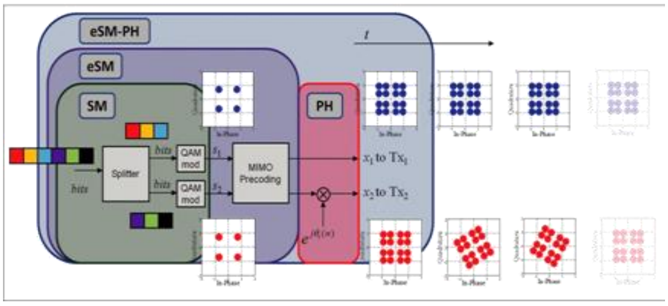

Figure 6. *Diagram multiplexing techniques: SM (Spatial Multiplexing), eSM (enhanced Spatial Multiplexing) and PH (Phase Hopping), and the combination of them, eSM-PH (enhanced-Spatial Multiplexing – Phase Hopping.*

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

Fig. 7 and 8 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. 7, 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. 9 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. 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 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.

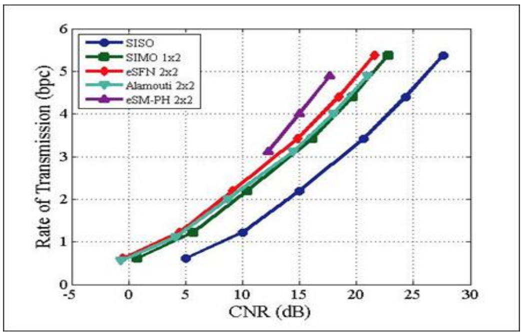

Figure 7. *Rate of transmission for the different NGH MIMO schemes in the NGH outdoor MIMO channel with 60 km/h speed including pilot overhead.*

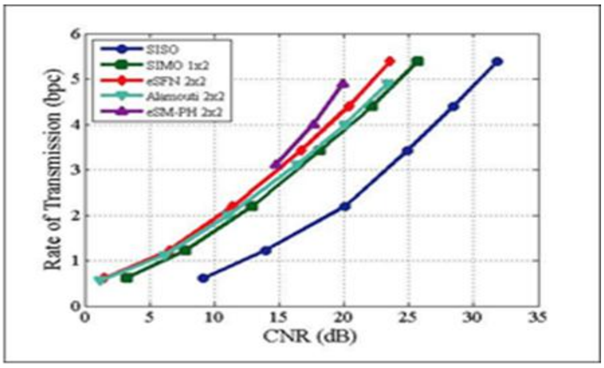

Figure 8. *Rate of transmission for the different NGH MIMO schemes in the NGH indoor MIMO channel with 3 km/h speed including pilot overhead.*

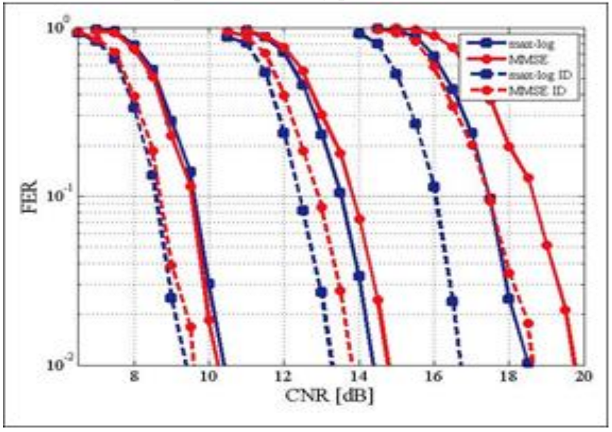

Figure 9. *FER vs. CNR of iterative decoding with 8 bpc and code rates 1/3, 8/15 and 11/15 in the NGH Outdoor MIMO channel with 60 km/h speed.*

V. Conclusion

The efficient provision of local services in SFNs with minimum increased overhead was one of the commercial requirements underlying DVB-NGH. This paper has analyzed the implementation issues and evaluated the performance in terms of minimum CNR required for successful decoding and capacity gain of the two complementary technical solutions adopted, known as H-LSI (based on hierarchical modulation) and O-LSI (using orthogonal transmission mode). 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

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