MIMO Extension to DVB-SH

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DVB-SH is a hybrid satellite-terrestrial system combining a satellite component and a complementary ground component to provide service in all types of environments, i.e., outdoor and indoor coverage in urban, sub-urban and rural. This paper reports the studies on multiple-input multiple-output (MIMO) extension to the existing DVB-SH standard. MIMO techniques are considered in this paper for achieving increased spectral efficiency and reliability in the challenging satellite and hybrid channel environments.

Nomenclature

APSK	=	Amplitude Phase Shift Keying
BER	=	Bit Error Rate
CGC	=	Complementary Ground Component
DVB-SH	=	Digital Video Broadcast-Satellite to Handheld
DVB-NGH	=	Digital Video Broadcast-Next Generation Handheld
ESR5(20)	=	Error Second Ratio at 5% in 20 Seconds

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FEC	=	Forward Error Correction
FFT	=	Fast Fourier Transform
ITU-R	=	International Telecommunications Union-Radiocommunication Sector
LHCP	=	Left Hand Circular Polarization
LMS	=	Land Mobile Satellite
LTE	=	Long Term Evolution
MFN	=	Multiple Frequency Network
MIMO	=	Multiple Input Multiple Output
MISO	=	Multiple Input Single Output
MSB	=	Mobile Satellite Broadcasting
OFDM	=	Orthogonal Frequency Division Multiplexing
PSK	=	Phase Shift Keying
QAM	=	Quadrature Amplitude Modulation
RHCP	=	Right Hand Circular Polarization
SC	=	Satellite Component
SFBC	=	Space Frequency Block Codes
SFN	=	Single Frequency Network
SISO	=	Single Input Single Output
SM	=	Spatial Multiplexing
STBC	=	Space Time Block Codes
STC	=	Space Time Coding
TDM	=	Time Division Multiplexing
UT	=	User Terminal
XPD	=	Cross Polarization Discrimination

I. Introduction

BROADCASTING services have traditionally been offered either by satellite or by terrestrial systems. Satellite broadcasting is an effective method for national connectivity to mobile terminals, but coverage in densely built environments is not possible due to shadowing of the signal. On the other hand, while terrestrial networks provide coverage to urban environments, their use for nationwide networks is far too expensive. Therefore, hybrid satellite-terrestrial networks, complementing the features of both networks, are being considered. Advances on this front include standardization through the DVB-SH drafting[1], efforts under ITU-R framework[2] as well as system implementation, for e.g. Sirius and S-DMB[3].

During the last decade and a half, research on multiple antenna systems, also known as MIMO systems, has predicted vast improvements in reliability and spectral efficiency of communication networks. These spectacular gains have motivated the inclusion of MIMO schemes in modern terrestrial communication standards, such as IEEE 802.11n, LTE, LTE-Advanced and WiMAX. With regards to terrestrial broadcasting *per-se*, multiple transmitter antennas have been considered in DVB-T2 (Digital Video Broadcasting – Terrestrial Second Generation). Higher spectral efficiency manifests in broadcasting systems being able to accommodate more services; increased reliability translates into higher robustness against the menacing channel fading.

Compared to the terrestrial domain, adoption of MIMO technology by the satellite community has been slow. A good review charting the progress of MIMO in satellites can be found in Ref 4. As highlighted in Ref 4, impediments in the adoption include negligible Non Line-of-Sight components (warranted by lower link budgets) and lack of scattering (arising due to absence of reflectors near the satellite) – the phenomena central to the gains accrued in the terrestrial systems. These impediments have rendered the use of point-to-point MIMO systems in fixed satellite systems infeasible. On the other hand, the channel for communicating to a mobile terminal using dual polarization is shown to be amenable for MIMO[4] and various techniques have been incorporated for such land-mobile systems[4]. Extending the scope, the use of MIMO techniques for hybrid terrestrial/ satellite systems have also been considered[5-8] and the gains have been shown to be promising. Some of these[7] are based on the architecture of DVB-SH, while some others[8] have been proposed (and subsequently included) for the next generation DVB standard – DVB-NGH.

The current work reports the results of the ESA activity[9] titled *MIMO Hardware Demonstrator* that aims to quantify the gains of using MIMO techniques in the ambit of the DVB-SH standard. The aim has been to select feasible MIMO techniques and study the interaction of various physical layer elements of the DVB-SH standard – particularly Turbo coding and interleaving – on these techniques based on realistic channels. This objective is being achieved in two stages: in the first stage a software simulator incorporating the entire DVB-SH chain is developed and this simulator is used to devise a hardware test bed with transceivers and channel emulators in the second phase. This paper represents the simulation results of phase 1.

The rest of the chapter is structured as follows: Section 2 describes hybrid MIMO architecture based on DVB-SH and, in particular, the various scenarios considered in the activity. Section 3 discusses MIMO techniques considered for the various scenarios described above taking into account the particularities of combining the terrestrial with satellite transmission. Performance of these techniques have been simulated and analyzed in Section 4 with the conclusions summarized in Section 5.

II. MIMO System based on DVB-SH

A. **Existing DVB-SH standard**

One of the first comprehensive standardization efforts in the area of hybrid satellite-terrestrial communications is the DVB-SH standard [1, 10, 11]. This standard aims at providing ubiquitous IP (Internet Protocol)-based multimedia services to a variety of mobile and fixed terminals having compact antennas with very limited directivity at frequencies below 3 GHz. The system coverage is obtained by combining the satellite and terrestrial signals and a typical DVB-SH system is reproduced in Figure 1. It is based on a hybrid architecture combining the SC and the CGC. The CGC consists of terrestrial repeaters fed by a broadcast distribution network. In DVB-SH the terrestrial repeaters provide local re-transmission, on-frequency (SFN) and/or with frequency conversion (MFN).

The salient physical layer elements of this standard are summarized below[12]:

- System components: SC is an OFDM waveform in the SH-A option or a TDM waveform in the SH-B option, whereas the CGC is always OFDM to cope with the terrestrial frequency selective channel. Thus SH-A can be employed both in SFN as well as MFN configurations while SH-B profile is used only in MFN configuration.
- Modulation formats: SH-B TDM supports QPSK, 8PSK and 16APSK, SH-A OFDM supports QPSK and 16QAM.
- For OFDM various FFT sizes (1k, 2k, 4k and 8k) are available. For TDM, various roll-off values (0.15, 0.25 and 0.35) are available.
- Physical layer coding: In all SH-A/B cases a turbo FEC scheme is adopted with a variety of coding rates spanning from 1/5 to 2/3.
- Receiver classes: Two receiver classes are possible. Class 1 has short physical layer time interleaver (200 ms), Class 2 time interleaver size can extend to 10 s. Class 1 is often combined with a link layer SH-specific FEC named iFEC, which can span over tens of seconds.

B. **MIMO Possibilities in DVB-SH**

Realizing MIMO functionality involves simultaneous utilization of, possibly related, multiple streams. Towards meeting this objective, additional resource and/ or processing is needed. The following set of scenarios describes the possibilities of extending current DVB-SH to support MIMO and is the basis for subsequent work.

1. *Scenario 1: Satellite only 2 x 2 MIMO*

In this scenario, a single geostationary (GEO) satellite is considered and dual polarized transmissions are employed for inducing MIMO. The satellite transmits using dual (circularly) polarized antennas (RHCP/LHCP) while the UT employs two co-located circularly polarized receiver antennas.

2. *Scenario 2: Hybrid satellite/terrestrial 2 x 1 / 2 x 2 MIMO*

This scenario involves a single satellite and a single terrestrial base station jointly transmitting data to an UT. One stream (polarization) is transmitted per link and a SFN configuration is considered. The UT is equipped with either a single polarization antenna or a dual polarized antenna, which may be either circular or linear. A single polarization antenna at UT leads to a 2 x 1 MISO system and is an extension of the existing DVB-SH architecture, in the sense of incorporating coding across the streams (distributed space-time coding). In this mode, no additional resources are used. Use of dual polarized antennas at UT leads to a 2 x 2 MIMO system. Note that only for a small percentage of the coverage both the SC and the CGC will be available.

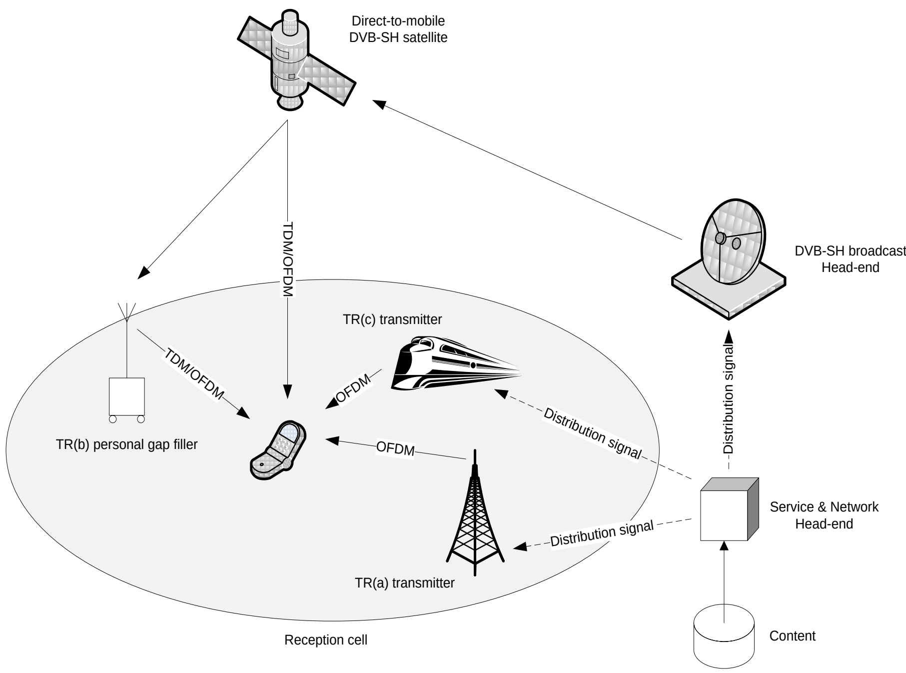

Figure 1. Overall DVB-SH transmission system reference architecture

3. Scenario 3: Hybrid satellite/terrestrial 4 x 2 MIMO

The transceiver configuration is similar to Scenario 2 except for the use of two streams (orthogonal polarizations) by each transmitter. The satellite uses LHCP/ RHCP while CGC uses two linear polarizations. Thus, polarization is used as the resource for inducing MIMO here. Since both SC and CGC use dual polarization, the UT also employs a dual polarized antenna, leading to a 4 x 2 MIMO configuration. Note that only for a small percentage of the coverage both the SC and the CGC will be available.

4. Scenario 4: Hybrid satellite/terrestrial 4 x 4 MIMO

This is quite similar to previous scenario except that it operates in a MFN mode. This translates into a dual polar satellite and CGC transmitting in S-band and UHF-band respectively. Since the transmissions are in different bands, this scenario comprises two independent 2 x 2 MIMO systems, leading to a 4x4 distributed MIMO architecture. Both polarization and frequency are used to induce MIMO. Note that only for a small percentage of the coverage both the SC and the CGC will be available.

5. Scenario 5: Dual satellite 2 x 1/ 2 x 2 MIMO

In this scenario, two satellites separated in their orbital position, transmit using a single, identical polarization resulting either in a distributed 2 x 1 MISO configuration for a single polarization UT or a distributed 2 x 2 MIMO configuration for a dual polarized UT. This scenario provides satellite or spatial diversity by exploiting the angular separation of the satellites. Note that due to the large delay differences between the signals arriving from two satellites, this scenario is less interesting for broadcasting services and more interesting for interactive services.

III. MIMO Techniques for DVB-SH Extension

The aim of this section is to select a few feasible techniques from the rich literature on MIMO systems. This section provides a consolidated list of techniques for each scenario to be further considered for performance analysis.

A. **MIMO Techniques Selection for Scenario 1**

This scenario constitutes the highest priority to the ESA activity and, therefore, the selection of appropriate MIMO techniques has been carried out taking relevant prior art into consideration to the maximum extent possible. In particular, the following sources are consulted

- *Literature on MIMO techniques for terrestrial channels*: A number of MIMO techniques have been developed in the terrestrial literature over the last 15 years for MIMO systems. This definitely provides for a first choice to look for, albeit fundamental differences between spatial multipath MIMO channels and the LMS channel for dual polarized transmissions.
- *Literature on MIMO techniques for LMS channels*: Due to the increased interest in a possible application of dual polarization MIMO to MSB systems, a number of publications have been recently produced concerning different aspects of a purely dual polarization MIMO LMS (consult Ref. 4 for details). These are extremely valuable to the current activity and will serve as a guide for the final choice of MIMO techniques.
- *Past MIMO related ESA activities*: ESA has expressed an interest in MIMO by initiating a number of activities implemented by different institutions including "Characterisation of the MIMO Channel for Mobile Systems," (2009). "MIMO Technology in Satellite Communications for Interference Exploitation and Capacity Enhancement" (2008), and "MIMO applicability to satellite networks," (2006).
- *Results on MIMO performance from applicable wireless standards, particularly DVB-NGH*: DVB-NGH[13] is the extension of the DVB-H standard concerning the broadcasting of TV to high speed terminals published in 2012. Multiple antenna techniques at both ends of the terrestrial link and the waveforms for the satellite component have been adopted in the frame of the DVB-NGH. Tracking this activity provides relevant topical information for this activity,

Based on these sources and additional investigation, Table 1 lists the set of chosen techniques, taking into account

- Practicality of the specific scenario in terms of near term application possibility from a space segment point of view
- Current technological level of the UT equipment
- Dimensions of the channel

Table 1. List of Consolidated MIMO Techniques for Scenario 1

Dual Stream Technique	Encoding	Decoding	Complexity
2xSISO[13]	Independent	Independent	Low (Single Symbol)
SM[4]	Independent	Joint	Medium (Dual Symbol)
Alamouti[4]	Joint	Joint	Low (Single Symbol)
Golden[4]	Joint	Joint	High (Quartets of Symbols)

B. **MIMO Techniques Selection for Scenario 2**

Scenario 2 of the activity exhibits proximity to the existing DVB-SH standard. From the description above, it becomes evident that only Scenario 2 *does not necessitate any additions to existing DVB-SH transmit equipment*, i.e. on the satellite and on the CGC. The same is true if a single polarization antenna is employed on the UT side. The following methodology (a literature review followed by insight from standardization) has been considered during the algorithm selection:

- *Literature on MIMO techniques for terrestrial channels* as in Scenario 1. However, additional system limitations to be considered are
  a. Ability of the UT to decode the transmission in case of a failure of either of the links
  b. Distributed nature of transmitters
  c. Differences in characteristics of the channel from the two transmitters.
- *Insights from Standardization Perspective:* A setting similar to Scenario 2 had generated interest in DVB-NGH[13] forum and a recent ITU-R Report[2] proposes certain techniques for use in hybrid/integrated systems operating in the 1-3 GHz band.

The wireless literature on distributed STC, recent MSB publications, but more importantly recent indications from standardization institutes such as DVB-NGH and ITU-R have demonstrated that an appropriate and practical choice is a distributed 2 x 2 Alamouti STBC.

C. MIMO Techniques Selection for Scenario 3

Scenario 3 is the MIMO extension of scenario 2. It is a hybrid system, where both the satellite and ground component transmit two streams to the user terminal and the system limitations for Scenario 2 are applicable here as well. While Scenario 3 is also SFN, the literature is richer compared to Scenario 2, with several 4 x 2 Space Time codes. Some of these were also considered for DVB-NGH[8].

Based on the system limitations, noting that the recent 4 x 2 codes are proposed for co-located transmitters[8] and that these codes are sensitive to power imbalances in the two links, the following techniques are considered:

- *Distributed 4x2 MIMO SM*: The simplest choice is to send the same spatially multiplexed streams from satellite and terrestrial base station and consider these signals as multipath components at the receiver.
- *Distributed 4x2 MIMO SM + Block Alamouti*: Another appropriate choice is SM between co-located antennas and Alamouti coding over satellite and terrestrial link.

D. MIMO Techniques Selection for Scenario 4

In this configuration, the satellite and terrestrial links operate at different frequencies. A trivial solution in this case, also pursued further in this activity, is to choose techniques from Scenario 1 for the SC and CGC transmissions and use one of the following combing techniques assuming the existence of two aerials (demodulators) in the UT[10]:

- Selective combining: The signal which provides better quality is chosen
- Maximum ratio combining: The signals are combined, weighted accordingly to its specific reception quality
- Complementary code combining: different code bits are combined, chosen accordingly to its occurrence in the puncturing pattern.

E. MIMO Techniques Selection for Scenario 5

Scenario 5 is conceived to cover the case of *satellite diversity*, that is two single polarization satellites with overlapping coverage regions operating at the same frequency band (S-band) and at appropriate angular separation in the GEO orbit (in this case, orbital slot allocation over Europe and Canada needs to be considered). The satellites transmit using circular orthogonal polarizations and the UT side employs a single/ dual polarization antenna. However, to decide on an appropriate orbital separation of the two GEO satellites, a trade-off comes into play taking into account:

a) The system limitation of achieving a high angular separation but, at the same time, ensuring European coverage for both satellites. Although it is not imperative to have both satellites covering the entire European continent or having exactly the same coverage area, there should be overlapping coverage areas at large, so that the production of dual polarization UT is justified.
b) The channel limitation of having a large orbital separation without penalizing the elevation angle towards any of the two satellites, since the lower the elevation is, the more the satellite path is masked from obstacles on ground.

While literature deals either with fixed satellites or dual polarized satellites for MSB, there exists no literature applicable to the present case (single polarization, MSB). Similarly, the standardization activities pertaining to this scenario seem to be marginal as well. The only relevant documentation comes from the documents submitted by CNES in DVB-NGH where the considered scenario matches Scenario 5. This specific NGH contribution is very much aligned with the selection of the Alamouti scheme, as carried out in the previous subsection.

Based on this investigation and similarly to Scenario 2, two variants are selected as candidate MIMO schemes for Scenario 5:

- *Distributed 2x1 MISO Alamouti* scheme for a single-polarization UT.
- *Distributed 2x2 MIMO Alamouti* scheme for a dual-polarization UT.

IV. Performance Analysis

A. Simulation Architecture

The transmitter supporting MIMO extension to DVB-SH implementing the typical OFDM physical layer elements is depicted in Figure 2, while Figure 3 represents the corresponding receiver. Note that, each stream represents a polarization in the dual polarization set-up and the per-stream processing (except for MIMO Encoding) mimics the DVB-SH/A chain. When using the same waveform, terrestrial and satellite transmissions employ the same transmitter architecture. The novel blocks in this representation *vis-a-vis* Ref 1 are the MIMO encoding and decoding and the reader is referred to the DVB-SH standard[1] for additional details on the other blocks. A similar chain with TDM physical layer elements[1, 10] is devised as well for corresponding simulations.

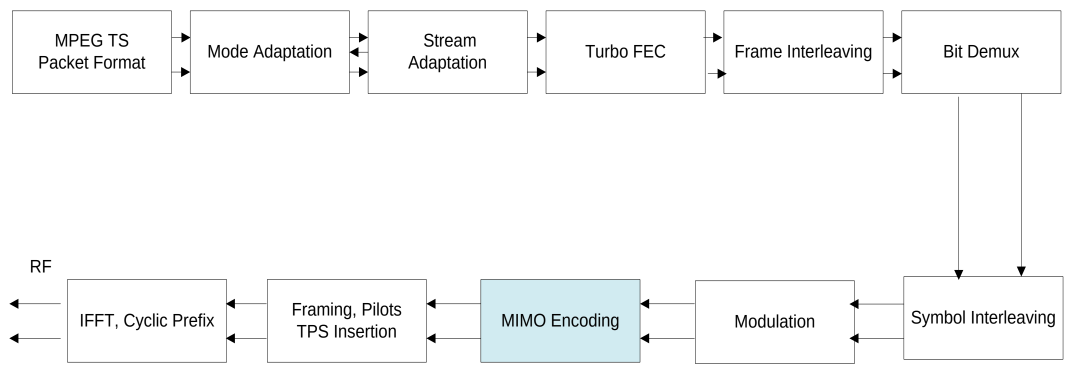

Figure 2. Block diagram of DVB-SH OFDM transmitter adapted to support MIMO extension

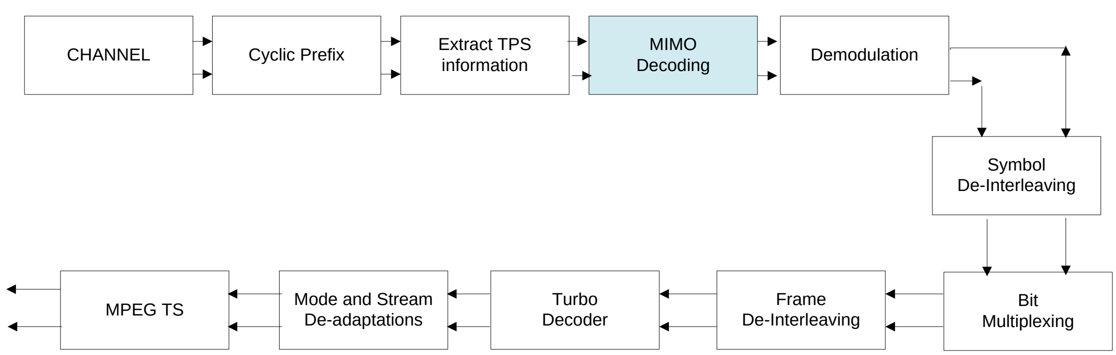

Figure 3. Block diagram of DVB-SH OFDM receiver adapted to support MIMO extension

B. Channel Models

In terms of channel modelling, a sophisticated model compared to DVB-NGH dual polarization MIMO channel model is employed: For the terrestrial dual polarization MIMO channel the Winner II model[17] is employed, whereas for the satellite dual polarization MIMO channel the model based on a first-order Markov chain[15] is employed. Additional details on the channel parameters used in these simulations are presented in Table 2 and Table 3.

C. Scenario 1 Simulation Results

The simulation results for Scenario 1 based on the DVB-SH A (OFDM) waveform are presented. Figure 4 illustrates the BER and ESR5(20)[10] metrics for the transmission schemes listed in Table 1 based on the channel parameters of Table 2. The best performing technique is SM. Its relative gains at the 90% ESR5(20) fulfilment level with respect to the rest of techniques are tabulated in Table 4. It should be noted that the Alamouti code is implemented as a SFBC instead of the traditional STBC[7] for the OFDM scenario. The results for TDM simulations are also presented in Figure 5 and show trends similar to OFDM.

Table 2. MIMO channel characteristics employed for the terrestrial component (WINNER II model for sub-urban area)

Parameter	Value Used	Parameter	Value Used
Carrier frequency	S-band (2.2 GHz)	**antenna patterns**	Ideal isotropic pattern with unit gain for co-polarization
Vehicle speed	60 km/h	**Rx-antenna XPD**	15 dB
Propagation Environment	Suburban macro cell	**Number of clusters**	LOS: 15 NLOS: 14
Large scale parameters update interval	3 m	**Number of rays per cluster**	20
Tx/Rx-antenna array	Two co-located elements with linear (H/V) elements		

Table 3. MIMO LMS channel characteristics

Parameter	Value Used	Parameter	Value Used
Reference	Ref. 15	**Large Scale Correlation**	~0.9
Simulation time	3600 s	**Antenna XPD**	15 dB
Carrier frequency	S-band (2.2 GHz)	**Environment XPD**	5.5 dB
Vehicle speed in km/h	60 km/h	**Very Large-Scale propagation model**	2-State First-Order Markov Model
Polarization	right hand/left hand CP	**Small Scale Correlation**	0.5
Propagation Environment	Tree-Shadowed	**Loo Distribution Triplet**	Ref. 16
Elevation angle	40	**Doppler Spectrum**	Low Pass Filter

Table 4. SM gains over the rest of SISO, 2xSISO and MIMO techniques

Gain of SM QPSK 1/3 @ 90% ESR5(20) fulfilment level					
	MIMO Golden QPSK 1/3	MIMO Alamouti 16QAM 1/3	MIMO Alamouti QPSK 2/3	SISO 16QAM 1/3	2xSISO QPSK 1/3
OFDM	0.5 dB	1.1 dB	2.8 dB	3.0 dB	3.3 dB
TDM	0.7 dB	0.85 dB	--	3.8 dB	3.8 dB

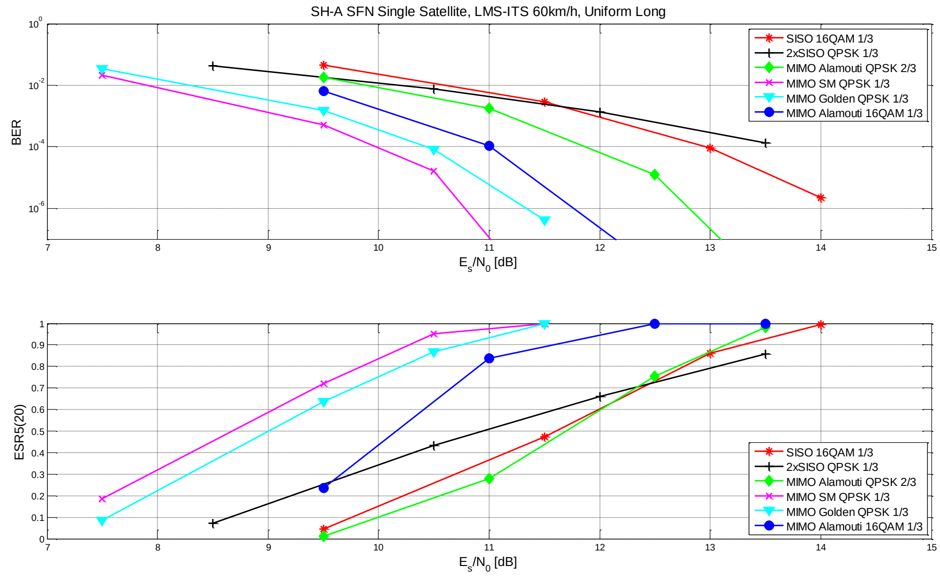

Figure 4: DVB-SH A (OFDM) BER and ESR5(20) SISO, 2xSISO and MIMO Results.

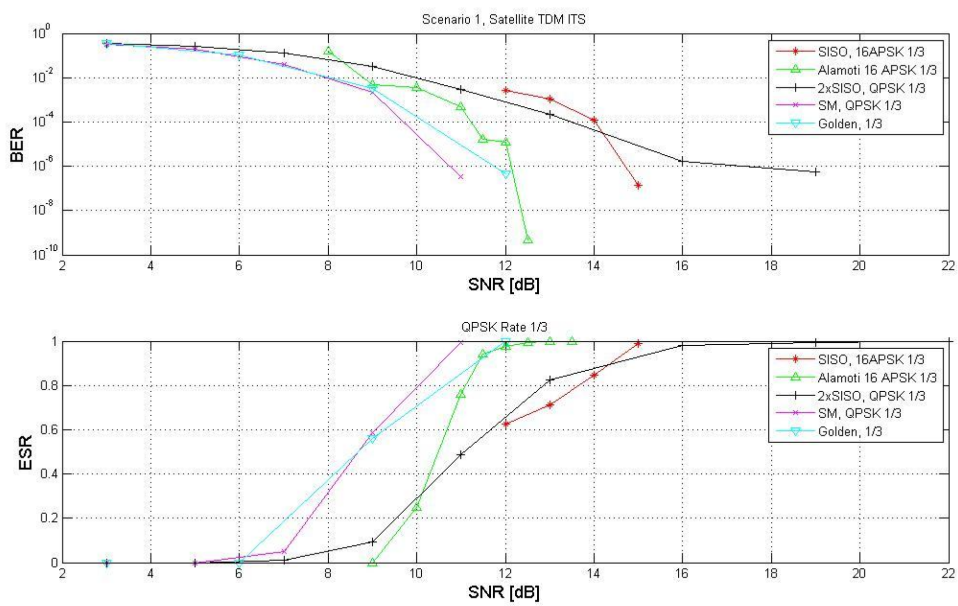

Figure 5. DVB-SH B (TDM) BER and ESR5(20) SISO, 2xSISO and MIMO Results

D. Scenario 2 Simulation Results

The simulation results that have been collected for Scenario 2 imply that adding the satellite reception to the terrestrial component produces a gain of 1.25 dB at 90% ESR5(20) fulfilment compared to terrestrial only transmission. If, on top of this benchmark scheme, the distributed 2x1 MIMO Alamouti is used, then an additional 0.25 dB become available to the system. When the UT is making use of both polarizations in a receive diversity scheme, the application of an advanced space-time coding scheme offers at the 90% ESR5(20) fulfilment level, a gain of about 1.9 dB.

E. Scenario 3 Simulation Results

Figure 6 presents the simulation results for the distributed 4x2 MIMO system of Scenario 3 in terms of BER and ESR5(20) employing the channel parameters presented in Table 2 and Table 3. The link budget parameters have been selected in a way that renders the receive power from the terrestrial site 4 dB stronger compared to the satellite reception. The two hybrid MIMO modes have been considered with two list sphere detector list sizes, i.e. 16 and 32. From Figure 6, one observes that the more sophisticated coding in the distributed 4x2 MIMO SM + Block Alamouti, only provides marginal gain with respect to the distributed 4x2 MIMO SM. And this happens exclusively when the higher list size is employed for the decoder. Therefore, it can be concluded that the strong FEC coding together with the long interleaving over this particular 4x2 hybrid MIMO setting renders the addition of the Alamouti coding over the pure SM not attractive.

F. Scenario 4 Simulation Results

Due to the similarity of this configuration with Scenario 3, the results are not presented in this case.

G. Scenario 5

Simulation results for the two satellite case demonstrated that, for a low shadowing correlation (equal to 0.3) corresponding to an orbital separation of 50° between the satellites, there is a negligible gain of employing a distributed space-time coding approach compared with the use of two satellites in diversity configuration.

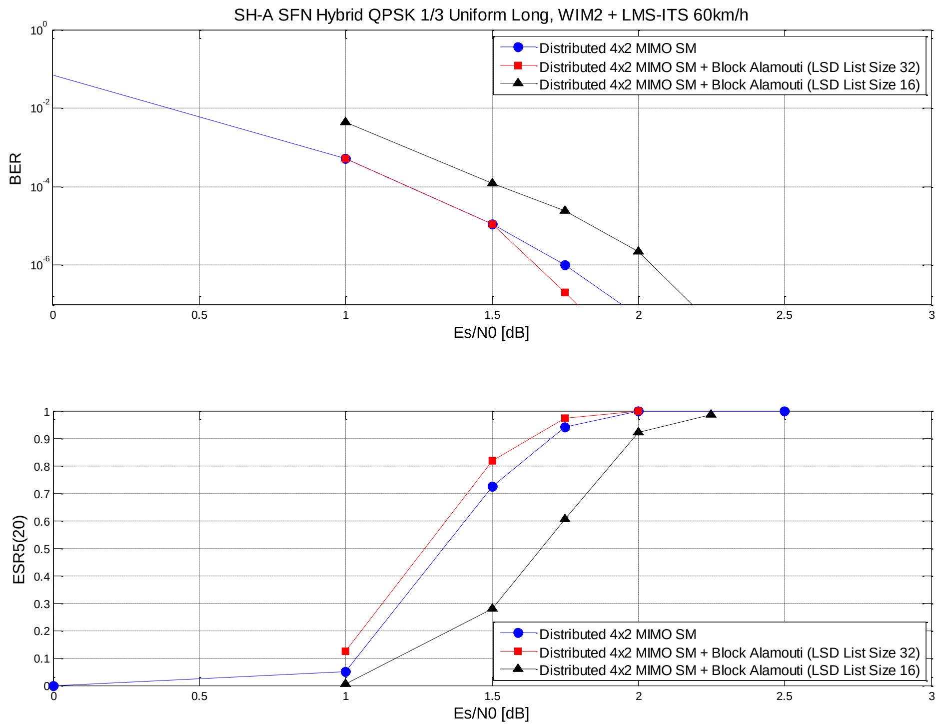

Figure 6. Simulation results for Scenario 3 assuming a SFN 4x2 MIMO channel with two hybrid modes available

V. Conclusion

After the detailed studies and simulations, some of which have been presented in this paper, a key finding is that MIMO offers significant gains for some cases/geometries of a hybrid DVB-SH system. SM, for example, is the best performing technique for satellite only reception involving two polarizations. Performance of SM is also favorable in the case of repeating a dual polarization stream from both the SC and the CGC in SFN mode. However, MIMO seems to be of less relevance for a single polarization hybrid DVB-SH system or a dual satellite configuration. The results are crucially determined by the fact that DVB-SH relies on low FEC coding rates and very long interleavers. Moreover, in the frame of the activity[9] the full set of physical layer impairments (HPA non-linearities, phase noise, channel estimation) have been considered, but presenting all the results is beyond the scope of this introductory paper. Thus, the ground work for introducing MIMO into DVB-SH has been laid for both SH-A and SH-B The final development of the MIMO HW Demonstrator for Satellite Communication, the first of its kind globally, will have concluded the technical work for a MIMO extension to DVB-SH.

Acknowledgments

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