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Measurement Campaign on Transmit Delay Diversity for Mobile DVB-T/H Systems

R. Di Bari, M. Bard, A. Arrinda, P. Ditto, J. Cosmas, K.K. Loo, and R. Nilavalan

Abstract—This paper describes the work carried out by Brunel University and Broadreach Systems (UK) to quantify the advantages that can be achieved if Transmit Delay Diversity is applied to systems employing the DVB standard. The techniques investigated can be applied to standard receiver equipment without modification. An extensive and carefully planned field trial was performed during the winter of 2007/2008 in Uxbridge (UK) to validate predictions from theoretical modeling and laboratory simulations. The transmissions were performed in the 730 MHz frequency band with a DVB-T/H transmitter and a mean power of 18.4 dBW. The impact of the transmit antenna separation and the MPE-FEC was also investigated. It is shown that transmit delay diversity significantly improves the quality of reception in fast fading mobile broadcasting applications.

Index Terms— Broadcasting, MISO, Delay diversity (DD), DVB-T/H, Error Second Ratio (ESR), Field Trials.

I. INTRODUCTION

Current broadcast TV networks have been designed to enable reception by rooftop antennas, mainly in Line of Sight (LOS) conditions, while next generation digital TV service providers for mobile and fixed reception are finding that coverage indoors and areas of Non Line Of Sight (NLOS) is a fundamental requirement. It is essential that such networks are designed cost-effectively and with minimized environmental impact. Multipath can result in severe fading in Non Line of Sight reception situations. A radio network design must take this into account when predicting service availability. Traditionally broadcast reception in multipath situations is provided by increasing the density of transmitters and/or increasing the radiated power.

The use of transmit diversity techniques with multiple antennas have long been proposed to improve the performance and capacity of wireless systems [2][3]. Multiple Input Multiple Output (MIMO) systems use several antennas for

transmission and reception. Multiple Input Single Output (MISO) systems use several antennas for transmission and just one for reception. In Delay Diversity (DD) transmit systems, the same information is transmitted from both antennas simultaneously but with a delay to overcome the effects of flat fading by reducing the probability of observing deep fades at the receiver. Spatial transmit diversity can be implemented by transmitting identical signals from different transmit antennas, which are spatially separated from each other. This spatial separation of transmit antennas is required to achieve a sufficient decorrelation of the channels. Simulations carried out in [4] suggest that a minimum separation of approximately 10 times the carrier frequency wavelength is required for a typical urban transmitter. This antenna separation is typically not enough to decorrelate the channels in LOS or near LOS conditions, resulting in a performance degradation if Delay Diversity is applied. Several methods of overcoming this effect are currently being researched.

Previous published works [5][6] present DVB-T/H software simulations of the DD gain with MIMO uncorrelated channels, while [7] extends the results to MIMO correlated channels. The coverage improvement of DVB-H networks with DD is presented in [8], while [10] and [11] show the impact of this technique on LOS channels. Measurement results deploying a real DVB-T receiver in a laboratory test bench are described in [12][13]. Preliminary results for DVB-T field trials are presented in [14][15]. This paper presents an extensive and carefully planned DVB-T field trial performed from 2007 to the summer of 2008 in Uxbridge (UK). The experiments were also extended to DVB-H to verify generically that any OFDM system can exploit diversity gains predicted by theory. This generic understanding can then be applied to different standards such as DVB-SH, DAB/DMB and MediaFLO. The outline of this paper is as follows. The experimental network deployed for the field tests is described in Section II. The different investigated scenarios for mobile reception are discussed in Section III. Section IV presents the parameters used to analyze the performance. The results for the DVB-T experiment are presented in Section V. Section VI presents the results for DVB-H network. Finally, the conclusions are presented in Section VII.

II. EXPERIMENTAL NETWORK

The experimental network is presented in this section. First the transmitter set-up is described, then, the receiver set-up.

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The transmitter and receiver calibration is also detailed.

A. Transmitter

The transmitter is located at Brunel University in Uxbridge, in the west outskirts of London, 1.2 km south of Uxbridge. The measurement area is relatively flat and representative of a typical suburban area. The field trial used two power amplifiers, rated at 100W, feeding a linear array of directive antennas. In the tests quality of reception in the measurement area when either all power was transmitted from a single antenna (Single Input system) or half power from each of two

separate antennas (Multiple Input system) was compared. The EIRP measured was 18.4 dBW for both the single transmitter and dual transmitter configurations on channel 53 which has a central frequency of 730 MHz and bandwidth of 8 MHz. A linear array of directive antennas was installed at the top of one of the university buildings (named Tower D), pointing towards the east. The antennas are horizontally polarized panels with a gain of 12 dB, a half-power beam-width of 53° degrees in the H plane and 24° degree in the V plane. The antennas radiation pattern is presented in [16].

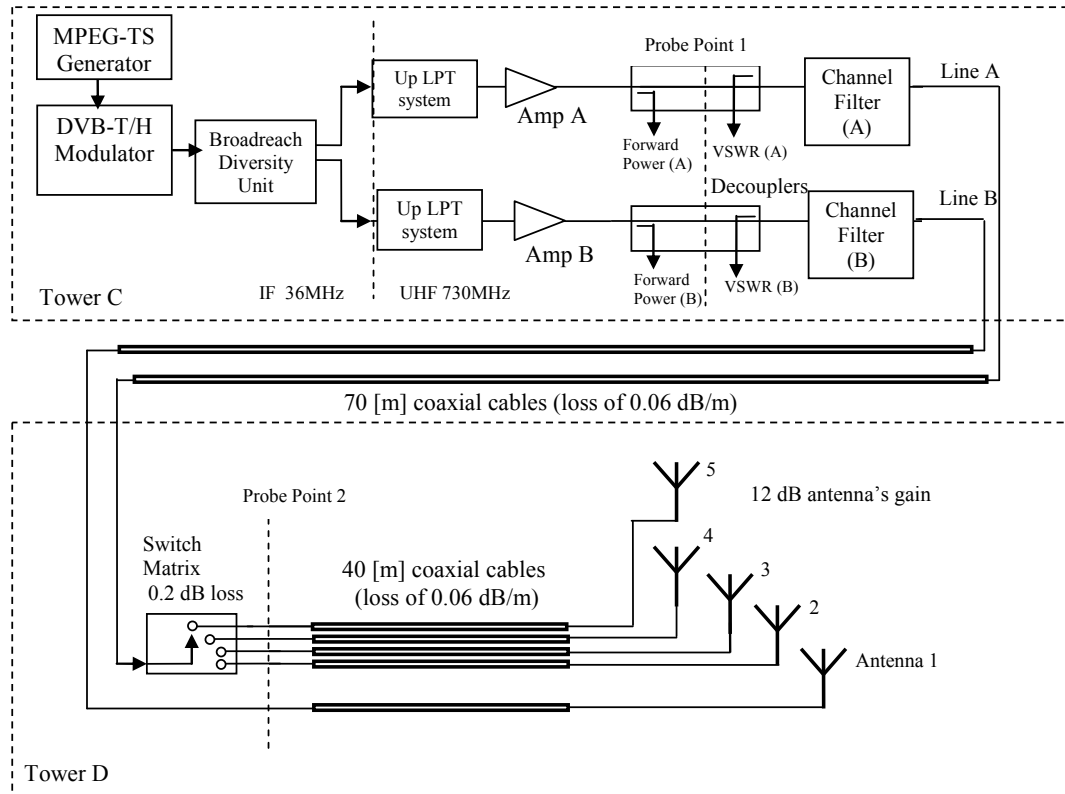


Fig. 2. The RF diversity transmit system

A maximum number of two antennas (out of five) were active at any time. In that way, the horizontal spatial separation between active antennas could be selected from 7 to 20 wavelengths. A vertical separation of 5 wavelengths can be optionally selected. Table I summarizes the main technical characteristics of the transmission system. Fig. 2 shows the schematic of the transmit system. The transport stream comprised Pseudo Random Binary Sequence (PRBS) packets for field measurements; the system is also capable of delivering multimedia content, encoded into MPEG-2 Transport Stream (TS) packets and transmitting it over the network for demonstration purposes.

In case of DVB-H tests, sample video streams described in Section VI were transmitted. A standard DVB-T Modulator was used to feed IF signals directly into the Broadreach Diversity Unit (custom made), introducing a 1.1μs relative delay between the two transmitted signals. Previous works based on simulations and laboratory tests proved the highest

diversity gain is reached when adopting such a delay value [7] [8]. The Diversity Unit has been designed to aid research into transmit diversity for DVB-T and DVB-H. The unit digitizes the input signal and passes it to a Digital Signal Processor (DSP). This DSP allows the signal to be split into 2, each signal being processed by a number of digital filter stages before being passed to 2 independent upconverter/modulator devices. The low power transmitter (LPT) up converts the signal to 730 MHz. The signal is then amplified and filtered. The Amplifier A and Amplifier B have similar performance. The total feeder loss was 6.8 dB and the switch matrix connecting the amplifier B with one of the diversity antennas had a loss of 0.2 dB.

MISO tests were carried out using two transmit antennas, out of five. For SISO tests just one transmit antenna is used.

TABLE I
TECHNICAL CHARACTERISTICS OF THE TRANSMISSION

Transmitter Centre	Uxbridge
Broadcaster	Brunel University
Coordinates	51.532367N; 0.473218W Decimal Degrees (DD)
Frequency	730 MHz
Bandwidth	8 MHz
EIRP	18.4 dBW
Antenna	Directive/Horizontal Polarized
Antenna(s) gain	12 dB
Antenna separations	7 λ , 14 λ , 20 λ horizontal or 20 λ horizontal and 5 λ vertical.
Total feeders loss	6.8 dB (6.6 dB + 0.2 dB)
Height of the antenna above the ground	25 m

Signal quality was tested at several stages in the transmit chain to ensure it was acceptable. A typical Modulation Error Rate (MER) of 30.5 dB was measured with a standard receiver [9] at the output of both amplifiers for both SISO and MISO configurations. The relative levels of the spectrum shoulders are fully compliant with the RF signal spectrum mask of DVB-T standard [17][18]. The two amplifiers did not introduce any significant non-linear effects within the power operational range. The power transfer system was calibrated and the power levels were carefully measured, adjusted and monitored during the measurements using a power measurement device with calibration traceable to national standards [15][17]. In the MISO case each antenna transmitted half of the EIRP of the SISO case. The signal quality at full output power was comparable for both transmitters. A preliminary set of driving measurements presented in [15] was performed on a radial route to test the average received signal strength indication (RSSI), carrier to noise ratio (CNR) and reception quality

B. Receivers

Mobile reception was measured using a purpose developed DVB-T receiver provided by Broadreach Systems. This receiver allowed measurement of uncorrectable Reed-Solomon blocks, Carrier to Noise Ratio (CNR), the Received Signal Strength Indication (RSSI) and delay spread all tagged with a GPS position, time and speed. A single antenna receiver system was used in all cases. The equipment was thoroughly calibrated and tested in a simulation laboratory so that its performance compared to theoretical predictions was understood [12][19]. From these measurements we would be able to derive the impact of diversity on other OFDM based broadcast standards.

Mobile reception was measured using a car equipped with the Broadreach DVB-T receiver. Fig. 3 illustrates the integrated system used to record seconds in which uncorrectable Reed-Solomon blocks are observed and from whom the Errored Second Ratio (ESR) is calculated. The CNR and RSSI are also measured together with location coordinates acquired using a GPS receiver.

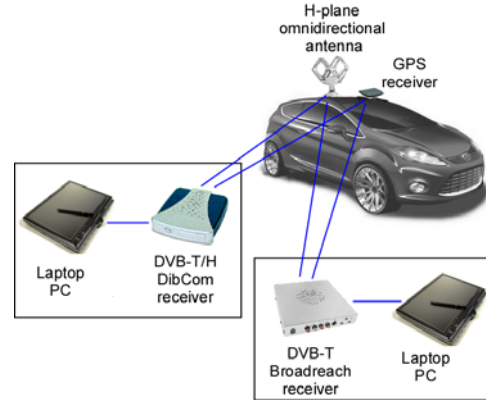


Fig. 3. The car experimental set-up

After the initial measurement campaign using the Broadreach receiver a second campaign was performed using a proprietary DVB-H receiver provided by Dibcom [21]. This campaign enabled us to check that our DVB-T measurements could be correlated with DVB-H performance in accordance with theoretical predictions. A locked DVB-H receiver can receive DVB-H frames, which are either correct or incorrect. Incorrect tables can (sometimes) be corrected by the Multi-Protocol Encapsulation Forward Error Correction (MPE-FEC) code. The DVB-H receiver was supplied with a tool which logs parameters such as Carrier to Noise Ratio (CNR), Frame Error Rate (FER), and Multi-Protocol Encapsulation FER (MFER). MFER is the ratio of the number of residual erroneous frames (i.e., not recoverable) and the number of received frames. FER is the ratio of the number of erroneous frames before MPE-FEC correction and the number of received frames [22]. Location and speed are recorded with a GPS device. The signal was received using an omnidirectional horizontally polarized antenna, installed on the rooftop of the test vehicle. The antenna radiation pattern is presented in [16].

III. AREA CLASSIFICATION AND SELECTION

Fig. 4 and 5 show the two selected routes which covered mainly suburban zones and included wide and medium roads in all directions reaching marginal areas of Brunel's service coverage. Route A was in the main direction of the transmit power and it is approximately 13.2 km long. Route B was also in the main direction of the transmit power and it was selected to ensure similar propagation features and a more constant speed during the tests. It should be mentioned that the measurements were repeated two or three times on the same routes. In total more than 500 km of mobile measurements were recorded. The areas are classified in Table II according to the propagation impairments in ITU-R P1411-4 [26] and previous works [28] [26] [30]. The experiment receiving conditions can be associated to a class C reception [22].



Fig. 4. Route A and area classification

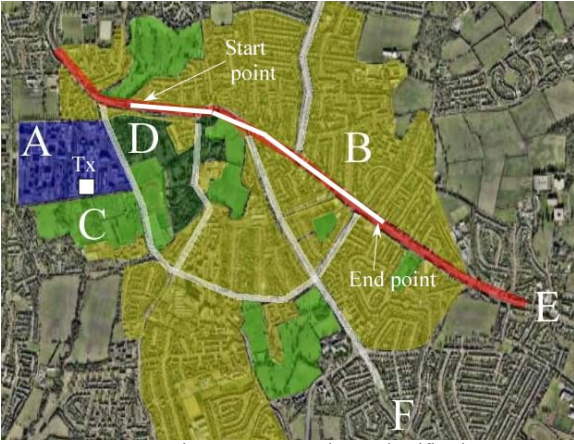


Fig. 5. Route B and area classification

TABLE II
DESCRIPTION OF ZONES

Class	Scenario	Zone	Description
C	Car, 20 km/h	A	High buildings, offices, and residential halls
C	Car, 20 km/h	B	Low density suburban area, with a significant presence of trees and vegetation
C	Car, 20 km/h	C	Sport playgrounds
C	Car, 20 km/h	D	Playgrounds with trees
C	Car, 48.2 km/h	E	Roads with two lanes each way
C	Car, 48.2 km/h	F	Roads with one lane each way

IV. PARAMETERS USED TO ANALYZE PERFORMANCE

This section defines the parameters used to analyze the performance of the DVB-T/H systems.

A. DVB-T parameters

ESR_% denotes the percentage of the time when seconds are marked as erroneous. An erroneous second consists of a second containing at least one faulty TS-MPEG packet.

$$ESR_{\%} = \frac{\text{Erroneous Seconds} \times 100}{\text{Number of Measurement Seconds}} \quad (1)$$

The degradation point is set to 5% value and it is denoted as ESR_{5%} [23].

B. DVB-H parameters

FER_% is defined as the ratio between the number of the

erroneous frames and the total number of frames. A frame is marked erroneous if any TS packet within the frame is erroneous.

$$FER_{\%} = \frac{\text{Number of Erroneous MPE Frames} \times 100}{\text{Total Number of Frames}} \quad (2)$$

The degradation point is set to 5% value and it is denoted as FER_{5%}.

MFER_% is the ratio between the number of erroneous frames after the MPE-FEC correction and the total number of frames.

$$MFER_{\%} = \frac{\text{Number of Erroneous Frames} \times 100}{\text{Total Number of Frames}} \quad (3)$$

The degradation point is set to 5% value and it is denoted as MFER_{5%}. The performance enhancement due to the diversity for ESR_% and FER_% and MFER_% are referred as $\Delta_{ESR_{\%}}$, Δ_{FER} and Δ_{MFER} , respectively.

(5)

V. MEASUREMENT RESULTS FOR DVB-T

This section presents the results of the field trials. First the reception channel features are described. Then, the Diversity Delay performance for DVB-T is evaluated and compared with literature. Finally the results related to antenna separation are presented.

A. DVB-T Tests

The time required for driving along the route A was approximately 30 minutes. The diversity gain was estimated by comparing SISO and MISO driving tests performed sequentially to ensure analogous traffic conditions for the two measurements. Weather conditions were sunny or partly cloudy and background traffic was generally light/medium. Typical speeds were in the range of 0 to 48.2 km/h, with an average of 30 km/h. The measurements taken when the receiver was stationary were removed from the data presented here to eliminate the effects of random stops due to traffic lights on the total reception statistics. The test results presented here were obtained employing the broadcast conditions described in Table III. A 20λ horizontal antenna separation was adopted for the tests because it yielded the highest gain among the possible MISO configurations (as it will be shown in section V.G).

TABLE III
DVB-T SYSTEM PARAMETERS

Configuration Name	SISO	MISO
Code Rate	3/4	
Signal Constellation	QPSK	
DVB-T Mode	2K	
Hierarchy (α)	Non hierarchical	
Guard Interval	1/32	
Bitrate (Mbit/s)	9.05	
EIRP (dBW)	18.4	15.4 (ant. 1) +15.4 (ant. 4)
Antenna separation (λ)	-	20
Diversity Delay (μs)	-	1.1

B. Channel estimation and features

This section describes the methodology and the processing employed to derive the channel features from measurements and a channel model to characterize the propagation scenario. The resulting models represent an outdoor mobile channel for SISO and MISO DVB networks. In [12], the authors show how the transmit DD gain is related to the propagation channel and to its parameters, particularly to the root mean square delay spread (RMS DS). The Broadreach receiver used in this campaign, is capable of capturing channel Impulse Responses (IRs) consisting of 77 sample taps, equally spaced by 74 ns according to the device specification. The IRs were measured every 1 second and stored in a text log file. In this analysis we have chosen an appropriate power threshold to reduce noise. After studying the measurement data, it was concluded that 30 dB is an appropriate value for the dynamic range of the impulse responses. This means that signals which are 30 dB below the strongest power level are considered to be noise. This threshold is also consistent with other published works [24]. Path loss and shadowing effects were removed by normalizing the peak power of each impulse response to 0 dB. For each IR, the tap with maximum power (0 dB) was chosen as reference starting point and the last tap with power exceeding the -30 dB threshold was chosen as last value. Finally, the IRs were averaged yielding an average power delay profile (PDP). A typical number of 1000 IRs are averaged. Three parameters were analyzed from the acquired data: total excess delay, the RMS DS, and the number of taps. The total excess delay by definition is the difference in delay between the first and the last of the received taps. The RMS DS and the excess delay are defined in [20]. The number of taps is considered as the taps within the total excess delay. Table IV shows the average parameters of the SISO and MISO channel models. The second transmitter affects the values of the RMS DS and the number of the taps, by approximately doubling as expected. Moreover, the excess delay is increased to about 1.04 μ s.

TABLE IV
CHANNEL PARAMETERS

	SISO	MISO
Number of IRs used in the estimation	998	1018
RMS DS (us)	0.21	0.59
Excess Delay (us)	2.2	3.2
Number of taps	32	45

Fig. 6 and 7 show the PDP over the route A for SISO and MISO configuration. The second cluster of echoes generated by the second diversity antenna starts at about 1.1 μ s. It should be noted that the average peak power of the second cluster is very similar to the peak power of the first cluster (0.2 dB below the first cluster peak), providing a qualitative confirmation of the equal average power radiated from the two transmit antennas.

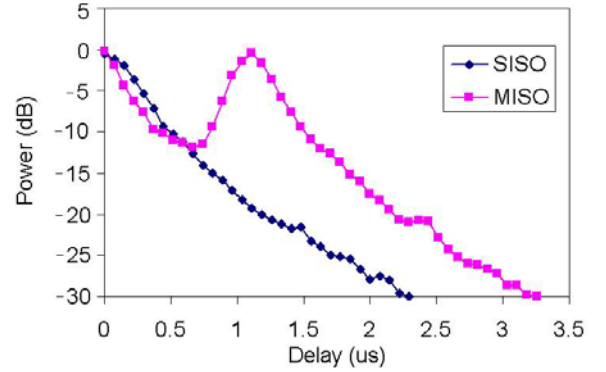


Fig. 6. Average power delay profile

The exact delay and power values of the taps for the SISO and MISO models are given in Table V. The reasons for showing just the first 31 taps were as follows: to unify the two models and to find a compromise between accuracy and complexity of the channel models (both models report taps to at least -20 dB).

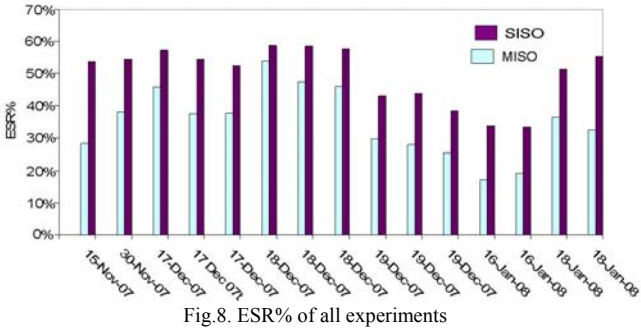
TABLE V
SISO AND MISO POWER DELAY PROFILE MODELS

Delay [us]	PDP (dB) SISO	PDP (dB) MISO	Delay [us]	PDP (dB) SISO	PDP (dB) MISO
0	0	0	1.184	-19.5	-1.4
0.074	-0.7	-1.7	1.258	-20.2	-3.5
0.148	-1.4	-4.2	1.332	-20.7	-5.6
0.222	-3.2	-6.1	1.406	-21.3	-7.4
0.296	-4.9	-7.4	1.48	-21.0	-9.2
0.37	-6.7	-9.5	1.554	-22.8	-10.7
0.444	-8.8	-10.0	1.628	-23.5	-11.9
0.518	-9.8	-10.8	1.702	-24.5	-12.4
0.592	-10.7	-11.1	1.776	-24.7	-13.5
0.666	-12.1	-11.7	1.85	-25.0	-15.0
0.74	-13.6	-11.2	1.924	-26.2	-15.8
0.814	-14.5	-9.2	1.998	-27.4	-17.4
0.888	-15.4	-6.1	2.072	-27.1	-18.1
0.962	-16.6	-3.0	2.1	-27.5	-19.2
1.036	-17.8	-1.3	2.22	-29.1	-20.55
1.11	-18.7	-0.3	-	-	-

Comparisons of the SISO channel model with previous published works show good agreement. The mobile DVB channel profile with single transmitter published in [24] is very close to the PDP shown in Fig. 6 and Table V, while the RMS DS and excess delay, 0.25 μ s and 2.21 μ s, match well with the SISO channel parameters proposed in Table IV.

C. Diversity Delay performance over different days

Fig. 8 shows the ESR_% for the entire route A for SISO and MISO configuration. The measurements were taken during different days with different traffic and weather conditions. In each case, multiple measurements were conducted during the same day. It was noted that the MISO performances are always better than SISO.



A 95% confidence interval (CI) derived from Student's *t*-distribution [25] and referred to the sample mean is estimated in Table VI. The *t*-student distribution is usually adopted to calculate the confidence interval when the sample size is small. The two SISO and MISO 95% CI intervals do not overlap, suggesting that there is less than 5% of possibility for MISO ESR% to reach values as high as SISO ESR%. The ESR% values out of the confidence interval are probably due to significant variations of the traffic conditions for the measurements compared. Impulsive noise due to car engine ignition systems also should be considered [22]. The sample mean of $\Delta_{ESR\%}$ is about 14.7%.

TABLE VI
SAMPLE MEAN AND VARIANCE OF THE GAIN MEASUREMENTS AND
CONFIDENCE INTERVALS DERIVED FROM STUDENT'S T-DISTRIBUTION

	ESR% Sample Mean	ESR% Sample Variance	Number of samples	95% CI Lower bound	95% CI Upper bound
SISO	48.42	81.50	23	45.19	51.65
MISO	33.71	130.15	23	29.63	37.80

D. ESR% gain estimation

The ESR_{5%} for different values of RSSI was estimated using all data presented in section C. The RSSI value is provided from the receiver and is computed directly from the automatic gain controls (AGC) outputs. Approximately 2.5×10^6 data measurement seconds are used for the processing. Fig. 10 shows the SISO and MISO ESR% against the RSSI values. Per each RSSI point, at least 100 seconds are considered to calculate the ESR%. Each ESR% point is calculated taking data from a 3 dB interval. The curves show a diversity gain at ESR_{5%} of about 4 dB.

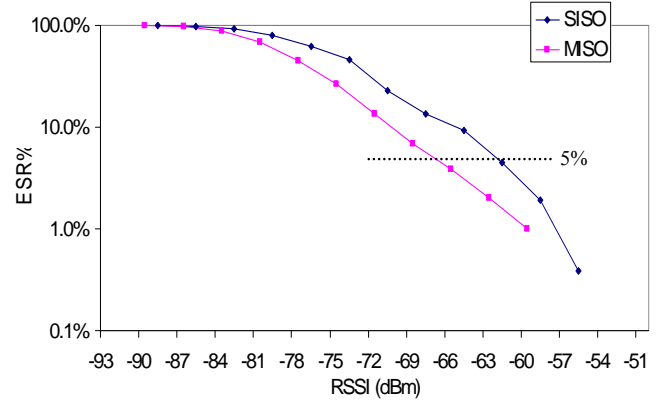


Fig. 10. SISO and MISO ESR% vs. RSSI

It is possible to compute the SISO and MISO coverage percentage from the same set of data. The ESR% shown in Fig. 10 can also be seen as coverage percentages. A similar approach can also be found in [30]. Thus per each value of SISO coverage a corresponding value of MISO coverage can be mapped for the same RSSI. Fig. 11 shows that a coverage of network planning reference 95% and 70% (e.g. "good" and "acceptable" reception, respectively) [22] with MISO transmitter corresponds to 88% and 50% coverage respectively with SISO.

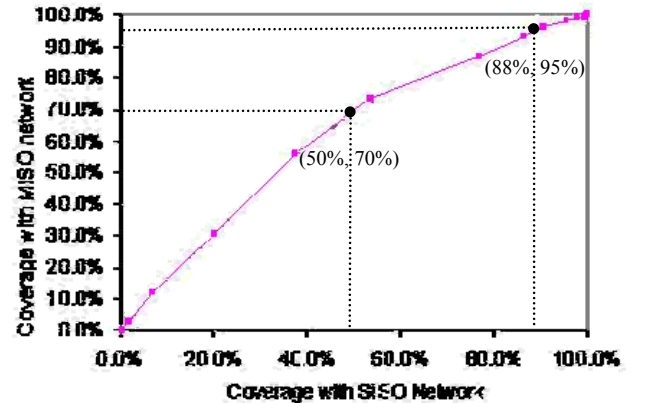


Fig. 11. MISO vs. SISO coverage

E. Capacity improvement estimation

An additional set of measurements along the route A has also been conducted to explore how transmit diversity might be used to enhance system throughput capability. SISO and MISO ESR% was compared at 3 different code rates of 1/2, 2/3 and 3/4. The tests were repeated over 4 different days. Table VIII shows the detailed measured ESR% values. From these measurements the throughput of a SISO network with a code rate 2/3 can be achieved with the same or better reception quality by using a MISO network with a code rate 3/4. [31] shows that at least 2.1 dB is required to achieve the same ESR_{5%} when the code rate changes from 2/3 to 3/4 in a portable outdoor (PO) channel. The 4 dB gain estimated at ESR_{5%} in subsection C ensure that a SFN network can be

planned for mobile reception using a QPSK 3/4 modulations with MISO set-up and having the same or better reception quality of a standard SISO QPSK 2/3 set-up network, resulting in a throughput improvement of 1 Mbps.

TABLE VIII
SISO AND MISO ESR_%
WITH DIFFERENT CODES RATES.

CODE RATE DATE	SISO ESR _%			MISO ESR _%		
	1/2	2/3	3/4	1/2	2/3	3/4
30/11/2007	14.0	35.83	45.23	3.44	21.82	22.05
25/01/2008	35.0	44.91	54.40	23.41	33.20	37.98
31/01/2008	39.0	52.79	56.78	24.73	43.78	45.06
07/02/2008	10.9	29.34	37.78	3.47	14.10	27.33
Throughput (Mbps)	6.03	8.04	9.05	6.03	8.04	9.05

F. Comparison with literature

Table IX shows the SISO RMS DS calculated for the COST 207 TU6 (Typical Urban) and RA (Rural Area) channel models and compares this to the RMS DS estimated in Table IV. It can be seen that the measured RMS DS is 0.24 μ s and falls between the TU6 and RA channel RMS DS figures [32]. The second part of Table IX compares the diversity gain measured in a simulated environment for Doppler Frequency of 1 Hz and 50 Hz in TU6 and 1 Hz in RA. The channel cross-correlation is 0.25. No data for RA frequency higher than 1 Hz were available at the time of writing this paper. The laboratory measurement conducted in [12] was compared with the field trials. The average maximum Doppler shift of driving tests was 20 Hz while the minimum and the maximum Doppler shifts were 4.4 Hz and 32.3 Hz, respectively. It can be seen that the estimated diversity gain is within the expected range from 2 to 5.0 dB for TU6 thus validating our measured 4 dB of gain at 20 Hz for ESR_{5%}.

TABLE IX
DELAY SPREAD AND TRANSMIT POWER GAIN

SISO channel RMS DS (μ s)			Gain at ESR _{5%} (dB)			
COST 207			COST 207			Estimated in Section V.D
TU6	RA	From Table IV	TU6, Max F _D = 1 Hz	TU6, Max F _D = 50 Hz	RA, Max F _D = 1 Hz	Typical Max F _D = 20.2 Hz
1	0.1	0.21	2.0	5.0	5.2	4

G. Antenna separation

This section presents the ESR_% measured at different MISO antennas separations. The same set of experiments was repeated on two consecutive days, yielding near identical results and it was decided not to conduct further tests. The SISO reference set-up yielded an ESR_% of 67.2. The MISO set-up with antennas 1-2 (e.g. 7 λ -H), 1-3 (14 λ -H) and 1-4 (20 λ -H) yielded an ESR_% of 58.53, 54.01, and 44.55, respectively. As expected, the MISO set-up with the largest antennas horizontal separation produced the lowest ESR_%

among the MISO test cases. According to the theoretical channel cross-correlation model presented in [4], a 20 λ antenna separation at the transmitter should be enough to achieve decorrelated diversity channels. So, it is not expected to lower the ESR_% deploying higher antenna separations. A vertical plus horizontal antenna separation has been also tested with antennas 1-5 (20 λ +5 λ), leading to an ESR_% of 44.85. The antenna at a higher position led to a higher K factor at the receiver, thus reducing the transmit diversity gain [11]. The results suggest that high elevation transmitter antenna would tend to reduce the diversity gain because of the increased K factor value.

VI. DVB-H TESTS

In this section, a sample application to DVB-H is presented. Previous works based on software simulations present the impact of diversity at the bit error rate (BER) level (e.g. after the Viterbi decoder) [6][7] while [5] shows the DD gain taking into account also the impact of the MPE-FEC encoding. Since the implementation of MPE-FEC is not compulsory and it requires a parity overhead from 12.5% to 50% of the total bit rate, it is worthwhile to investigate in which situations the Delay Diversity can help to improve DVB-H performance without MPE-FEC. The transmitter set-up is the same as the previous DVB-T investigation, except for the fact that here the DVB-H transport stream (TS) with video content is transmitted instead of PRBS. Table X shows the three MPE streams contained in the DVB-H transport stream and related to four different packets identification numbers (PIDs):

TABLE X
DESCRIPTION OF THE CONTENT TS ADOPTED FOR THE DVB-H TESTS.

PIDs	MPE-FEC	Frame rows	Content
4097	7/8	512	ESG
4098	7/8	1024	Star Wreck Trailer
4099	7/8	256	Light and Life

In DVB-H forward error correction is defined separately for each MPE stream. In these tests we monitored the FER and the MFER of the PID 4099. The transmission parameters are summarized in Table XI.

TABLE XI
SET-UP ADOPTED FOR THE DVB-H TESTS

Constellation	QPSK
FFT Size	2k
Guard Interval	1/32
Bandwidth	8 MHz
Code Rate	3/4
Transmit Antenna Separation	20 λ

The DVB-H receiver can monitor one MPE stream at a time, by logging the CNR, and the DVB-H parameters every second.

A. FER% and MFER% estimation

Fig. 18 presents the FER% and MFER%, for different values of CNR estimated along the route A. Unlike the DVB-T receiver, the DVB-H receiver does not provide the RSSI level. Attenuators rated at 0 dB, 6 dB and 12 dB were fitted to the receiver's antenna input were found to have more data at different levels of CNR. Curve points are calculated by taking into account at least 100 tables as recommended in [22] within 1 dB CNR interval. The curves presented in Fig. 18 show a gain of about 2.5 dB and 1 dB for FER_{5%} and MFER_{5%}, respectively.

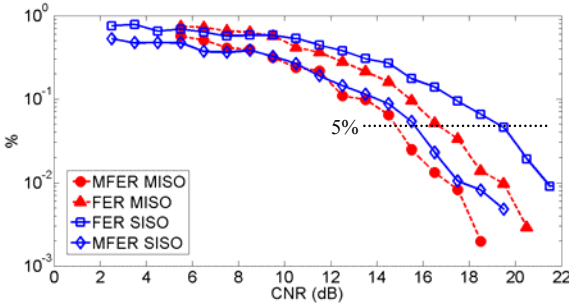


Fig. 18. MISO and SISO MFER and FER along route A

MFER% is lower than FER% since the MPE-FEC decreases the CNR demand by 5 dB to 8 dB [31]. The DD transmit diversity gain is more obvious when the MPE-FEC is not taken into account, since this already partly exploits time diversity by introducing a virtual time-interleaving. The application of DD would have a significant impact only on the DVB-H SFN network with the MPE-FEC disabled.

B. FER% and MFER% estimation along route B

Tests along route B benefit from a more constant speed and more uniform reception environment. The time required for driving along the route B was approximately 12 minutes. Fig. 18 shows the sample means of 2k and 8k mode tests. Per each set-up, 6 test repetitions were considered. The chart also shows error bar representing the t-student 95% CI intervals. The 8k set-up provides better average performances than 2k set-up. A possible explanation comes from the fact that 8k is more resistant than 2k to impulse noise produced by car engine ignition systems [22].

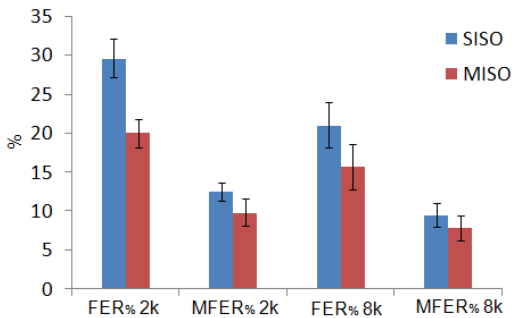


Fig. 19. FER% and MFER% sample mean along the Route B.

The $\Delta_{FER\%}$ and the $\Delta_{MFER\%}$ for the 2k are 9.7 and 2.7, respectively, while the $\Delta_{FER\%}$ and the $\Delta_{MFER\%}$ for the 8k are 5.3 and 1.7, respectively. Also in this test case, $\Delta_{FER\%}$ is significantly higher compared to the $\Delta_{MFER\%}$. Although Fig. 18 shows that DD is effective also for 8k, the performance improvements are significantly smaller compared to 2k. In case of MFER% with 8k, the small amount of gain cannot be considered as statistically significant since the CI are almost completely overlapped.

C. Comparison with literature

Previous laboratory tests employing the Dibcom chipset [29] show a diversity gain in TU6 uncorrelated channel at $F_D=50$ Hz for FER_{5%} and MFER_{5%} of about 3 dB and 1.7 dB, respectively. These results are a good match with the FER_{5%} and MFER_{5%} gain presented in Fig. 18. The discrepancy of about 0.5 dB between field trials and laboratory tests is probably due to the different test conditions.

The DVB-H FER_{5%} gain is expected to be similar with what would be achieved using the DVB-T ESR_{5%} criterion to the transport stream directly [22]. However, Fig. 18 shows a FER_{5%} gain of about 2 dB smaller than the ESR_{5%} gain measured in Fig. 10. It is envisaged that the gain reduction is due to the different chipset implementations, since the Dibcom receiver implements special proprietary channel estimation algorithms designed for high speed mobility resulting in enhancing of the SISO high mobility reception [21]. However, laboratory results presented in [19] shows that the C/N threshold for MISO ESR_{5%} is the same for both Dibcom and Broadreach receivers. Thus, it can be assumed for network planning design that, when MISO diversity is applied, the ESR_{5%} C/N thresholds are optimal, independent of the chipset implementation and the same for all receivers.

VII. CONCLUSIONS

DVB-T experimental results showed that, when driving in a suburban area, the number of errored seconds observed is greatly reduced and instances of acceptable reception are significantly increased. The diversity gain in terms of ESR_{5%} has been measured and found to generally agree with theoretical predictions. The coverage was improved by about 7% and 20% for the network planning reference coverage of 95% and 70%, respectively. It has been shown that transmit Diversity can be used to provide a data bitrate improvement of 1 Mbps. Finally, higher gain was achieved by adopting a 20λ horizontal separation between transmit antennas. An additional 5λ vertical separation reduced the gain as the Ricean K factor figure increased. Dibcom's DVB-H experimental results shows approximately 2.5 dB and 1 dB of gain measured for FER_{5%} and MFER_{5%}, respectively. The FER_{5%} gain is significantly smaller than the ESR_{5%} measured with Broadreach receiver, since the chipset implementation is already optimized for high mobility reception. The MFER_{5%}

gain is reduced compared to FER_{5%} because of time interleaving effects of the MPE-FEC encoding. The DVB-H gain has been also measured for 8K FFT size.

Current measurements campaigns are exploring the effectiveness of transmit diversity for indoor reception and evaluating the impact on radio network design. Resulting

DVB broadcast networks could have fewer transmitter sites, lower EIRP or support higher data bitrates due to the increased performance and thus would be more cost-effective. Now that this technique has been shown to be viable, more complex implementations can be investigated that would further improve the effectiveness and deliver higher gains.

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