Evaluation of Diversity Gains for DVB-T Systems

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Abstract: **The requirements for future DVB-T/H networks demand that broadcasters design and deploy networks that provide ubiquitous reception in challenging indoors and other obstructed situations. It is essential that such networks are designed cost-effectively and with minimized environmental impact. The EC funded project PLUTO has since its start in 2006 explored the use of diversity to improve coverage in these difficult situations. The purpose of this paper is to investigate the performance of transmit and receive diversity gains with two antennas to improve the reception of DVB-T/H systems operating in different realistic propagation conditions through a series of tests using the Spirent dual channel emulator.**

Keywords: Transmit Delay diversity (DD), MISO, SIMO, DVB-T/H, Errored Second Ratio (ESR), Spatial Correlation, Doppler frequency, MIMO.

1 INTRODUCTION

Although transmit diversity is a commonly used technique for most wireless communication systems such as mobile telephony and WLAN, (e.g. GSM, UMTS, IEEE 802.11/a,b,g,n), it has not been applied for DVB-T/H or DAB systems. The main advantage of transmit diversity over other (Multiple Input Multiple Output) MIMO techniques is that it can be applied to standards based systems such as DVB-T/H, DAB/DMB without modification. Transmit diversity can complement receive diversity by adding an additional diversity gain and in situations where receiver diversity is not practical, transmit diversity alone delivers a comparable amount of diversity gain.

This paper documents measurement made using actual receiver equipment in simulated laboratory conditions. The laboratory set-up includes a DVB-T modulator, a wireless channel emulator and a DVB-T receiver. The objective of the lab tests is to confirm that transmit and receiving diversity gains reported in the literature [1][2][3] predicted by mathematical modeling can be realized in realistic conditions using actual equipment.

2 TRANSMIT DELAY DIVERSITY

Delay Diversity (DD) consists of transmitting a main signal and its delayed replica through two or more antennas. Fig. 1 shows the block diagram of N-transmit antennas applied to an OFDM system with DD. The Orthogonal Frequency-Division Multiplexing (OFDM) modulated signals are transmitted using N antennas. The individual signals only differ in an antenna specific delay shift δ. After the insertion of the cyclic prefix or Guard Interval (GI), the delay δ is inserted. The functional blocks "UC" and "DC" stand for up-conversion and down-conversion, respectively, of the signals from the baseband into RF-band and vice versa.

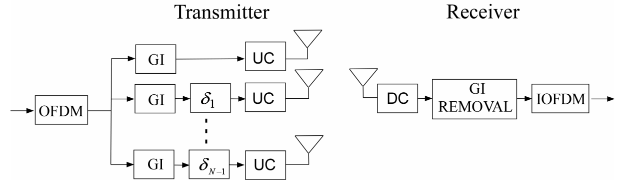

Fig. 1. Transmit delay diversity applied to an OFDM system

DD can be applied to a standard DVB-T/H implementation because its signal processing is performed on the Orthogonal Frequency-Division Multiplexing (OFDM) output symbols in the time-domain.

DD transforms the spatial diversity into frequency diversity; in other words the Multiple Input Single Output (MISO) channel is transformed into a Single-Input Single-Output (SISO) channel with increased frequency-selectivity. Therefore, the coherence bandwidth is decreased.

As shown in Fig. 1, the cyclic prefix should be added before the delay operations. No Intersymbol Interference (ISI) occurs if:

$$\delta_i \le N_g - \tau_{\max}, \quad i = 0,1,\ldots.N-1 \qquad (1)$$

where N_g and $\tau_{\max}$ are the guard interval length and maximum channel delay respectively.

If this condition stands, it can also be proven that DD is equivalent to other diversity techniques, e.g. Cyclic Delay Diversity (CDD) and Phase Delay (PD) [1][2]. To achieve any diversity effects (i.e. to obtain constructive and destructive interference within the OFDM signal bandwidth B), the delays δ_i (in samples) have to fulfill the relation

$$\delta_i \ge \frac{1}{B \cdot T_s} \qquad (2)$$

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where Ts denotes the sampling time of the OFDM time domain signal. Results reported in [1] show that a delay of $\delta_i \geq 1.5\mu s$ results in no further improvement of the diversity gain, defined as the offset between the Carrier to Noise Ratios (C/N) needed to achieve the same performances in single and multiple antennas diversity system. In [3], it was shown that diversity gain is fully effective over uncorrelated channels. However, in reality, the respective signal paths between spatially separated antennas and the mobile receiver are likely to be correlated to a certain degree because of insufficient antenna separation at the transmitter and the lack of sufficient multipath in the channel. Finally, it could be mentioned that some transmit diversity gain is already achieved by SFN configurations of DVB-T or DVB-H, especially in closed-cell structures.

3 LABORATORY SET-UP FOR TRANSMIT DELAY DIVERSITY TESTING

This section describes the laboratory simulation set-up as depicted in Fig. 2. A test signal was generated by a standard DVB-T modulator, the output signal was then split into two paths and fed directly into the Spirent SR5500 radio channel emulator. Testing was conducted in the UHF band at channel 24 (498 MHz).

The Spirent SR5500 [4] is a two-path wireless channel emulator that simulates the characteristics of complex wideband radio channels, including time-varying multipath delay spread, fast and slow fading, path loss and variable amounts of correlation between the paths. The output signals were combined to simulate the signal at a single receive antenna. Additive White Gaussian Noise (AWGN) was generated by a variable noise source and added to the main signal to vary Carrier to Noise ratio at the receiver input. A band-pass filter was used to cut off the out-of-band noise, preventing saturation of the receiver broadband amplifier. Additional fixed attenuators were used to adjust the power to be within the dynamic range of receivers A splitter finally fed the faded signals into a spectrum analyzer and the three receivers. The results published here are for the Broadreach Monitor Station and Dibcom receiver.

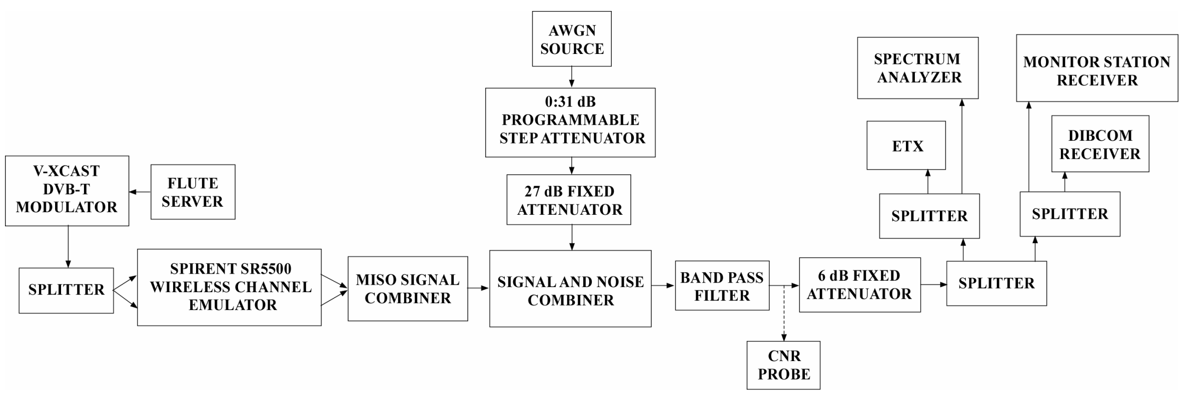

Fig. 2. Block diagram of laboratory test bench

4 MEASUREMENT METHODOLOGY AND MAIN SYSTEM PARAMETERS

Testing was performed with 2 simulated transmit antennas. The delay value δ between the two signals was introduced by the Spirent channel emulator. In real word applications, the delay between signals would be introduced by a dedicated device or by using a specialized modulator designed specifically for transmit diversity. It is important to note that the overall transmitted power was normalized for all measurements, i.e. either 100% of the power was transmitted through a single antenna or 50% of the power was transmitted by each of 2 antennas.It ha been adopted the ESR5 metric (erroneous seconds ratio at 5%) to denote a maximum of one erroneous second in 20 seconds as the maximum rate for acceptable reception. The ESR was measured as a function of C/N.

To determine the ESR, the signal power was kept at a constant level at least 20dB above the receiver's noise floor, and the level of additive excess noise increased by changing the step attenuator, as recommended in [5]. The signal power and the noise level were measured after the Signal and Noise combiner using a power meter. A simple calculation is used to map each ESR point to its corresponding C/N. The power meter had been set-up with 4096 points to establish the average, corresponding to 5 minutes of power integration in the time domain. The measurements precision was estimated to be within 0.5 dB.

Basic transmission parameters are defined for an 8 MHz channel by the DVB-T standard [8]. In this paper two system configuration have been adopted fot hte tests :

- FFT size=2K, Code Rate (CR)=3/4, GI=1/32, 16 QAM (UK mode)

- FFT size=2K, Code Rate (CR)=3/4, GI=1/32, 4 QAM (4 QAM UK mode)

Tests were performed using 2 different simulated scenarios. These were the Indoor "Commercial B", [6] and COST 207 [7] outdoor environments.

5 EXPERIMENTAL RESULTS

The system set-up was verified by performing a bench mark test, measuring the receiver's sensitivity in an AWGN channel and comparing it to that published in the DVB-T standard specifications [8]. Analysis of the bench mark test showed that the sensitivity measured for each mode was within 1 dB of that published in the DVB specifications confirming the validity of the measurement setup and procedure.

The simulation results reported in the literature suggest an achievable delay diversity gain of approximately 4 to 6 dB in Indoor channels and 3 dB to 5 dB in (typical urban) TU [1][2][3] The results presented in this section show that the predicted performance can be achieved with actual equipment in simulated signal conditions.

The results shown in Fig. 5 illustrate the relationship between correlation and diversity gain in the indoor channel with a delay value $\delta = 1\mu s$ and a Doppler frequency Fd=1Hz for the UK mode. These results show that when the cross correlation coefficient is less than 50%, a gain of approximately 4 dB can be achieved and the full gain of over 6.5 dB could be achieved with the theoretical 0% correlation. However, it is important to note that in this simulated indoors scenario, the optimal diversity gain can be achieved with a relatively high cross correlation of 50%.

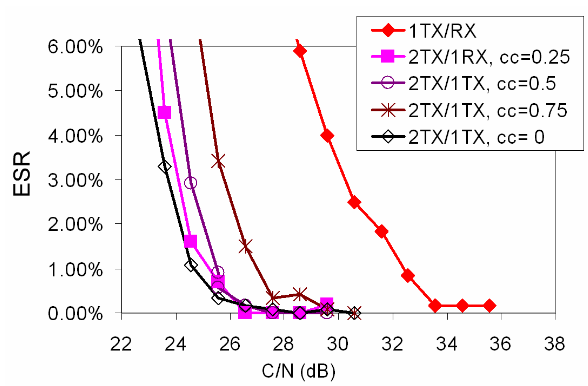

Fig. 5. ESR vs. C/N for indoor channel, UK mode $\delta = 1\mu s$, Fd=1 Hz

Fig. 6 illustrates the effectiveness of diversity in a typical urban (TU) environment at a high Doppler frequency of Fd=50Hz. It can be seen that in the SISO case, the ESR value cannot reach 0% even at high C/N ratio. The introduction of a transmit diversity signal with delay of $0.5\mu s$ or above provides 5 dB of diversity gain at an ESR of 5% and enables 0% error rate to be achieved. The effect of the Doppler frequency on diversity performances of the 4 QAM UK mode is shown in Fig. 7. The 4-QAM is more likely to be adopted for fast mobile receiver applications. Fig. 7 shows that the SISO curve diverges from the MISO curve as the Doppler frequency increases. This results in 5 dB diversity gain at 50 Hz Doppler frequency in the MISO case. As the Doppler frequency increases further, the single transmitter curve reaches the failure point faster than the MISO curve.

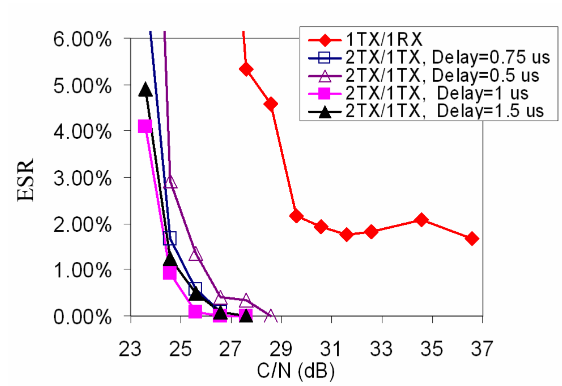

Fig. 6. ESR vs. C/N for TU channel, UK mode, $\rho = 0.25$, Fd=50 Hz

From Fig. 7 it can be concluded that for $Fd \geq 120$ Hz, the receiver cannot track fast channel variations even in the diversity case, resulting in the failure of signal demodulation even with very high C/N levels. For low Doppler frequencies (~1 Hz) as in a quasi-static channel, a diversity gain of approximately 3 dB was achieved.

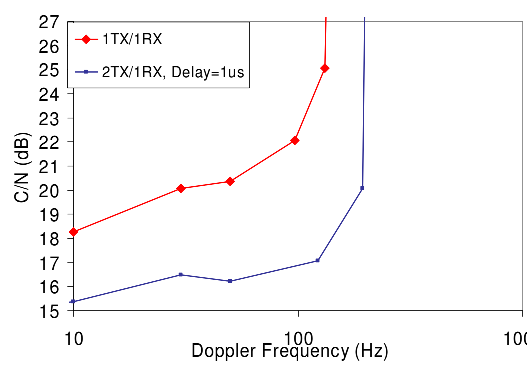

Fig. 7. C/N at TOV vs. Doppler Frequency, TU, 4-QAM UK mode, ESR= 5%, $\rho = 0.25$, $\delta = 1\mu s$

6 COMPARISONS WITH MRC RECEIVE DIVERSITY

The target of this section is to compare the performance of transmit delay diversity with conventional receive diversity with Maximum Ratio Combining (MRC). The Dibcom dual diversity receiver is used with the Spirent channel emulator in a SIMO (Single Input Multiple Output) configuration. The transmission mode selected is 4 QAM targeting high speed mobile and handheld applications. The selected environment for the tests is TU6 and the transmit delay diversity value is 1µs. Tests are conducted for low and high Doppler values for different channel cross correlations. The diversity gain is evaluated for ESR of 5%.

It is concluded that similar to the transmit diversity cases reported above, the receive diversity gain increases with the cross correlation value between the channels decreases for high and low Doppler as shown in Fig. 8.

Receive diversity gain is higher than transmit diversity gain especially at low Doppler frequencies at the cost of increased receiver complexity as shown in Table I.

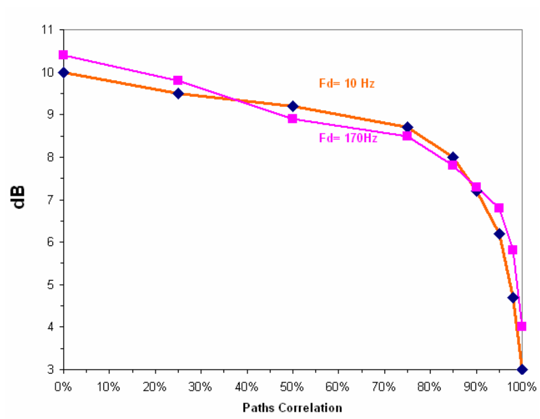

Fig. 8. Dibcom SIMO Receive Diversity Gain for different Channel Cross Correlations (2K, QPSK ¾, 1/32) for a TU6 Channel at low and high Doppler.

Table 1: Comparison of Transmit and Receive Diversity Gains

Doppler Frequency (Hz)	MISO Gain (dB)	SIMO Gain (dB)
10	2.5	9.5
170	7	9.8

7 CONCLUSIONS

In this paper, the simulated performance of transmit delay diversity has been reported for DVB-T systems. Measurement results confirm that transmit delay diversity (DD) achieves significant diversity gain for de-correlated channels.

For mobile reception, DD significantly improves receiver performance until the impact of Doppler on inter symbol interference becomes unacceptably high for a particular receiver's implementation. It has also been confirmed though practical measurements that the gain predicted form previous theoretical simulations can be realized or exceeded using actual equipment in realistic propagation conditions. It was shown that the diversity gain obtained from MRC receive diversity is higher than transmit diversity gains especially at low Doppler at the cost of expensive processing at the receiver. The gap between MISO and SIMO gains reduce considerably as the Doppler frequency increases.

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