

# Measurements, Processing Functions and Laboratory Test-bed Experiments for Evaluating Diversity in Broadcast Network

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## Abstract

*This paper presents a test-bed development and measurement plan for evaluating transmit diversity and on-channel repeaters in the Digital Video Broadcasting Network. Transmit diversity reduces the complexity and improves the power consumption of the personal receiving devices by enhancing the transmission of signals in NLOS cluttered environments. It is more practical than receive diversity due to the difficulty of locating two receive antennas far enough apart in a small mobile device. The on-channel repeater is to extend the coverage of the DVB-T/H network in areas where services are inaccessible by receiving the DVB-T/H signals off air, amplifying and then retransmitting it on the same frequency as received. Test service scenarios were developed to illustrate the benefits of such technologies so that effectiveness can be researched in a variety of service and terrain scenarios using purpose built test systems.*

## Keywords

DVB, CDD, DD, Diversity, On-channel Repeaters, Laboratory test-bed, test fields.

## 1. INTRODUCTION

The objective of this paper is to investigate the experimental relationships between performances of a broadcasting network, reception enhancement techniques and physical layer features. It has been established from simulation results that Transmit Diversity [1-4] and low cost on-channel repeaters [5] have the potential to improve reception in areas of poor coverage such as for mobile reception, indoors and sparsely populated or obscured locations. These techniques can be applied to Digital Video Broadcasting Terrestrial (DVB-T), DVB-H and/or DAB systems that use Orthogonal Frequency Division Multiplexing (OFDM). Spatial diversity techniques can be implemented easily without affecting the compatibility of standard systems. Two simple methods called cyclic delay diversity (CDD) and delay diversity (DD) are proposed for the DVB-T/H systems [2].

Single Frequency Networks (SFN) are an effective and economical approach for realizing DVB-T/H coverage. The main purpose of an on-channel repeater is to extend the coverage of the DVB-T/H network in areas where services are inaccessible. The on-channel repeater receives the DVB-T/H signals off air, amplifies it and then retransmits it on the same frequency as received. In this way, the repeater

system improves reception in areas of poor reception as in sparsely populated areas, indoors and obstructed mobile reception thus extending DVB-T/H coverage through hole filling. In order to validate the simulation results the Physical Layer DVB Transmission Optimization (PLUTO) project is developing a demonstrator to capture real time measurements. Several measurement campaigns are planned and will be focused mostly in places where the OFDM system presents poor performances, that is in rich scattering environments like indoor and urban. Thanks to transmit diversity and on-channel repeater equipments employed in the test-bed; these experiments will validate the improved system performances i.e. received power, SNR and bit error rate of DVB-T/H predicted through simulation results. It will be beneficial to study the relationships between the system's performances and the optimization techniques used in different transmission environments. Post-processing will be used to model the channels and to estimate their characteristics.

This paper is arranged as follows. Section 2 describes briefly the theoretical background underlining the expected gain from diversity and on-channel repeaters in a Digital Video Broadcasting system. Section 3 focuses on the description of the planned measurement campaigns and setups. Section 4 covers post processing. Finally, Section 5 concludes the paper.

## 2. THEORETICAL GUIDELINES

In this section, some theoretical results are presented as general guidelines for system design of transmit diversity and deployment of on-channel repeaters to enhance the quality of the received signals in a DVB-T/H broadcasting network.

### Transmit Diversity

To achieve transmit diversity gain, signals from different antenna elements should be sufficiently uncorrelated that is at least less than 0.7 correlation between antennas. Moreover, the transmitted signals should ideally have equal average power (less than 3 dB difference). Simulation results show that when two antennas are used to provide diversity gain, a minimum separation of half wavelengths is required at the receiver while the required separation is at least ten wavelengths at the transmitter [6-7]. A simulation example with two transmit antennas is used to highlight the relationships between antennas separations at the transmitter, the Rician K factor of the channel and the

achieved cross correlation coefficients as shown in Figure 1. The simulation is based on cross the correlation model described in [6] and it implements the von Mises angular distribution (with parameter  $k=3$ ) for the nonuniform Angle of Arrival (AOA) (non-isotropic scatterers around the receiver). The angle spread is  $2^\circ$  degree. The Doppler shift is equal to zero and the delay between two channels is  $1\mu s$

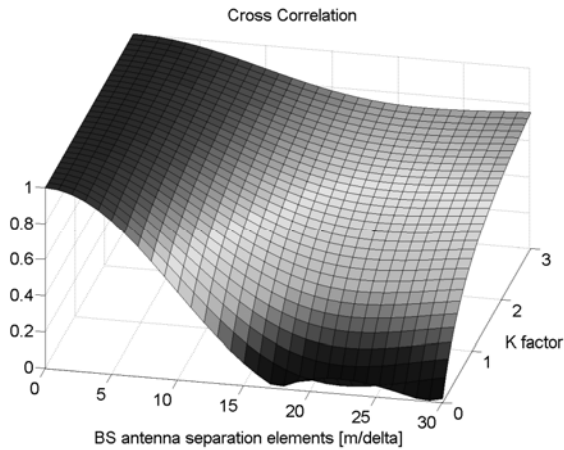


Figure 1. Simulation of Cross correlation Vs. the BS antenna spacing and the Ricean K factor.

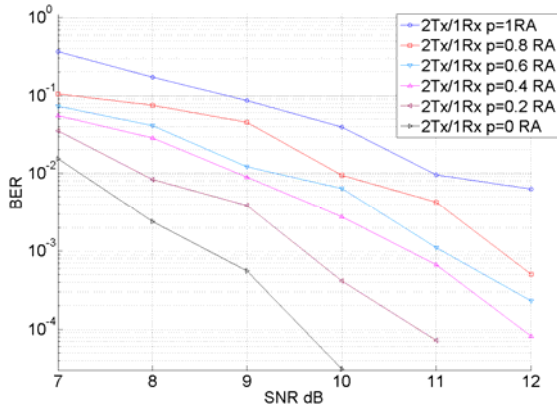


Figure 2. BER vs. SNR for DVB-H 4k mode QPSK for Rural Area correlated channels.

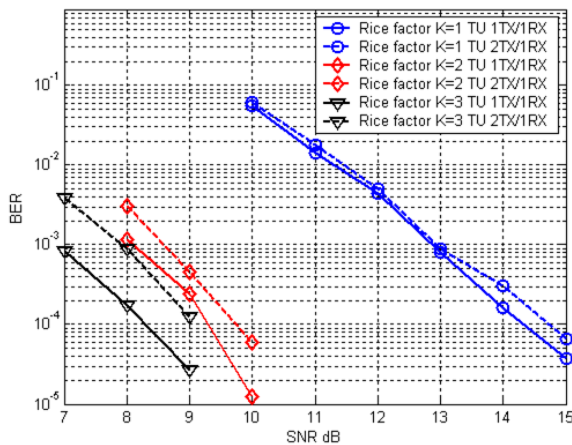


Figure 3. BER vs. SNR for DVB-H 4k mode QPSK for Rural Area for different values of Ricean K factor.

When the Ricean K factor is about zero (NLOS), a minimum cross correlation 0.7 is achieved by separating the two transmit antennas by almost 7 wavelengths. The cross correlation reduces to almost zero when the antenna elements are separated by at least 16 wavelengths. This result matches well with the previously reported predictions of the required separation for base station antennas [7]. To get similar channel decorrelation with increasing values of the K factor (LOS), higher antenna separations are required (e.g. for  $K=3$ , the cross correlation is less than 0.7 with about 20 wavelengths antenna separation). The transmit diversity techniques are effective in the NLOS situations where the K-factor is small. **Error! Reference source not found.** and 3 show two examples of transmit diversity gains using Delay Diversity (DD). The simulation transmission parameters are for QPSK modulation DVB-H 4K mode. **Error! Reference source not found.** presents the BER versus SNR over different levels of channel cross correlation adopting the COST 207 Rural Area channel model [4][9]. **Error! Reference source not found.** shows the impact of the Ricean K factor on the diversity performances when the COST 207. These results verify the loss of the diversity gain as the Ricean K factor increases.

### On-channel repeater with echo cancellers

The basic on-channel repeater is an amplifier and acts as an additional transmitter in the network. The general requirements of such systems are usually an adequate gain, large dynamic range, good selectivity as well as good isolation between transmit and receive antennas. Our proposed approach for a DVB-T/H echo canceller to be used within a low cost on-channel repeater relies on an open loop channel estimator based on training sequences [5]. It is believed that this approach will both allow a low processing delay as well as operation with comparatively poor isolation between receive and retransmission antennas and more importantly unconditional stability of the on-channel repeater. A low power training sequence is buried in the transmitted OFDM signal for unwanted channel estimation based on the correlation principal. At startup, only the training sequence is fed to the transmitting antenna for initial channel estimation. This approach is selected since the training sequence is uncorrelated with the transmitted DVB-T/H OFDM signal and hence ensures good estimation. The update rate of the channel estimator should match the rate of change of the channel. The drawback of this approach is that the training sequence will act as an unwanted interference and would slightly degrade the OFDM signal. The training sequence level should hence be as low as possible. Once the channel complex coefficients are estimated, the taps of a Finite Impulse Response (FIR) filter are updated and the output of the filter is subtracted from the input ideally canceling the unwanted echoes and ensuring the stability of the on-channel repeater which is the main purpose of the echo canceller.

The isolation performance of the on-channel repeater with echo canceller was simulated under different radio channel conditions [5]. In a 2K DVB-T system (e.g. systems deployed in the UK) and if the maximum allowable processing delay is 20  $\mu$ s, then the maximum number of taps is restricted to 20 at 10 MHz sampling. In this case, the isolation improvement figure of the echo canceller would be better than 20 dB for all profiles except for long channels like Bad Urban or Hilly Terrain where more taps are needed to replicate the unwanted feedback channel.

### 3. THE MEASUREMENTS

The test-bed test plan will be arranged into two phases: the Laboratory and the field measurement campaigns. In the preliminary laboratory tests, the new equipments, which were developed especially for this project to provide diversity are used to initially validate the theoretical simulation results in a controlled laboratory environment. The field tests that will be carried out in the 2nd phase will provide the realistic figures of performance gains in the real environments.

#### Laboratory measurement setup

The laboratory test system is designed to validate the performance results predicted from the theoretical simulation experiments in emulated real-world deployment conditions. The equipments are used in the subsequent field measurement campaigns. Figure 4 shows a block diagram of the system architecture in the laboratory environment.

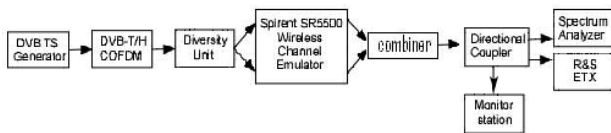


Figure 4. The system layout of the laboratory environment.

In laboratory environment, multimedia content is encoded into the MPEG-2 transport streams (TS). A multiplexer multiplexes the programmes and sends transport streams to a DVB-T modulator. Diversity Unit encodes the modulated signal using Delay Diversity techniques [1][3]. It also enables a novel technique to mitigate the diversity loss in LOS scenario using discontinuous Doppler diversity [12].

The RF signals from the modulator are then fed directly into a two-channel wireless channel emulator. Finally a directional coupler feeds the faded signals into several signal analyzers representing the professional, industrial and experimental technologies. The modulated signals are measured with a Spectrum Analyzer and two other receivers – the Rohde and Schwarz ETX and a purpose built Monitor Station. The spectrum analyzer is required to check the signals feeding the receiver. The monitor station allows the measurements and storage of the parameters of interest over time as will be described in the next section. At this first stage, it is only planned to probe and calibrate the Diversity Unit and the Monitor Station according to the

industrial standards and to perform preliminary series of tests to confirm the theoretical benefits of transmit diversity.

#### Test field measurement setup

In this section the design of field measurement campaign is described. The main objective of this part is to measure the actual gain of the diversity techniques for various system configurations. Figure 5 shows the block diagram of the system architecture. At the transmit side, the delay diversity unit feeds MPEG-2 OFDM signals into two power amplifiers. The signals are then fed to equally powered transmit antennas. The total transmitted power is planned to be 10dBW in the UHF band (at 730 MHz). The antenna is horizontally polarized, with a half-power beam-width of 53° degrees in the H plane and 24° degree in the V plane. A maximum number of two antennas is active at any time (out of five mounted). According the recommendations from the previous section, the spatial separations will be from 8 to 27 wavelengths. At the receiver side, an omnidirectional antenna, a DVB receiver, a GPS unit and a computer are interconnected to each other. The receivers with dual diversity and Maximum Ratio Combining will also be tested to validate the benefits of a MIMO system. The receiver apparatus is either set in a fixed position or carried around on a buggy or car to study performance in stationary slow fading and moving fast fading environments. Finally, it is planned to design a web-based system to manage and monitor remotely the receiving devices and store the measured data over a long time. This will also enable the study of atmospheric effects.

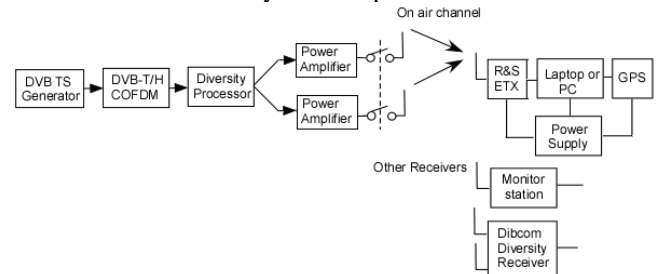
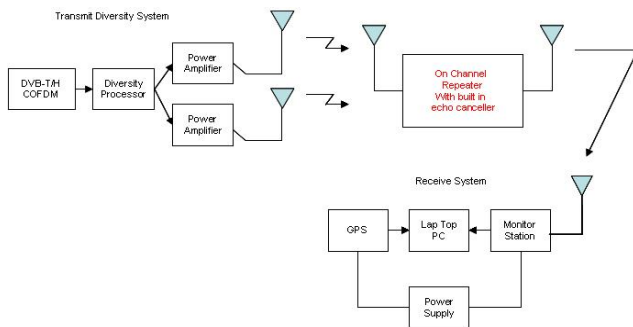


Figure 5. The layout of the field measurement design.

To test the performance of the network including on-channel repeaters described above, the measurement setup as depicted in Figure 6 will be used. The on-channel repeater will be placed at the edge of coverage area of the main transmit diversity system. The received signal levels will be compared at locations within poorly covered areas before and after the introduction of the on-channel repeater. The main design parameters that can be optimized for the on-channel repeater include amplifier gain, number of taps used in echo cancellation and the level of training sequence used in the channel estimation process. Of particular interest for the on-channel repeater measurement campaign, is testing the optimum training sequence level necessary for adequate channel estimation without causing excessive interference to the received signal.



**Figure 6. Network Measurement setup for on-channel repeater field tests**

### The measurements campaign

Each experiment session requires a rational classification of all the tunable and output parameters with which the operator can deal with. The system parameters that can be tuned during an experiment session consist of more than thirty variables include the signal constellation (QPSK, 16/64-QAM), the code rate (1/2, 2/3, 3/4, 5/6, 7/8), the cyclic prefix length (1/4, 1/8, 1/16, 1/31) and the number of carriers (2k, 4k, 8k). Other additional parameters system parameters are as follow:

- i. The number of antennas (up to 2 at transmit side, extendable to 5 for future experiments. At receiver side, up to 2)
- ii. The antennas element separations at transmit and receiver side (from 8 to 27 wavelengths at transmit side, from half to two wavelengths at receiver sides for practical dimension)
- iii. the delay of the DD code (in the order of fractions of microseconds)
- iv. The antenna polarizations at receiver side (horizontal, vertical or rotated)
- v. The on-channel repeaters settings (type and level of the training sequence, number of filter taps)

All the previous parameters are grouped together in the experiment input metadata. The field tests will be performed in three different test sites: the University of Tampere in Finland, the Brunel University in UK and the Telediffusion de France in France. The selection of test environments includes 1) indoor scenarios (typical situation with poor reception where diversity and on-channel repeaters can provide a considerable benefit), 2) LOS (such as urban rooftop and canyon, to evaluate the loss of gain due to diversity mentioned before), and 3) driving tests (to evaluate the system in the fast fading). The information stating the climate conditions needs to be measured as well and stored beside the other measurement parameters foresaid. These data include general weather condition (wind speed, rain, etc), classification of the test site according to foliage and the level of first Fresnel zone shadowing. The description of the propagation environment is classified as an environment configuration. The figures of performance gains will be evaluated by measuring the following parameters:

- i. MER, BER before Viterbi, Viterbi BER, Packet error rate (PER) and DVB-H error set (RSBER, RSFER and RSSER)
- ii. SNR and CNR
- iii. Radio Frequency (RF) Power level
- iv. Channel Impulse Response (CIR)
- v. Receiver location
- vi. Receiver time

It is planned to evaluate these parameters over a long term campaign as well, to validate the gain of the diversity techniques in DVB system under the effects of various seasonal and weather conditions. All the above parameters are grouped together in the experiment output metadata.

### 4. DATA PROCESSING

It is desirable to establish representative relationships between system performance and enhancement techniques for each environment. Post-processing is then required to model the channels and to estimate their properties.

#### The signal power and the SNR

Although in principle the SNR is a more significant quantity for diversity than signal power itself, in practice it is of a less general interest as it depends not only on intrinsic sources of noise (such as thermal noise), but also on more extrinsic sources like the oscillator phase noise. After a preliminary stationarity analysis to choose the correct data segmentation frame, a moving mean filter processes the data separating the short term fading from the long term. In practical situations, it is almost impossible to keep the vehicle in motion all the time or, to keep it above the minimal speed which may invalidate the measured samples for a correct separation of the short-term and long-term fading components. Moreover it may cause the samples to lose their uncorrelated characteristic and therefore, be invalid for a proper channel characterization. So, a simple elimination process can guarantee the uncorrelation of the samples. The information derived consists of the level cross rate, the average fading duration and the fading distribution of the RF signal with and without diversity. In the case of the long term measurements campaign, the power level attenuation due to rain drops can be estimated. In fact, rain drops can cause attenuation by scattering in the L-band (for DVB-H). The data will also be used for radio planning tools calibration.

#### The channel power delay profile

Each environment can be characterized by a power delay profile, resulting from the processing of a large number of channel impulse responses (CIR). A preliminary post-processing is required. Using a classic tapped delay line for the channel model, the relative amplitudes, the distribution and the parameter values of the coefficients, the Doppler spectrum form, the number of taps and their relative delays have to be chosen from measurements. The phases can be assumed to be uniformly distributed within  $[0, 2\pi]$ . The analysis will be completed with function outputs that statistically characterize the other fundamental channel

properties, such as the delay spread. Also, it is important to compare the resulting power delay profile with the most used statistical channel models (e.g. COST 207, Saleh-Valenzuela, JTC, etc.) to establish a model that best fits the channel resulting from measurements or to enhance the existing models.

### The cross correlation

In diversity measurements, channel cross correlation is key to evaluate the diversity gain (refer to Figure 2 **Error! Reference source not found.**). Also, an important aim is to confirm the theoretical figures resulting from the statistical channel models e.g. COST 273, 3GPP Spatial Channel Model, etc.

### The Ricean K factor

The Ricean K factor is of great importance regarding the diversity gain as shown in Figure 1. In a LOS situation, the two channels are highly correlated and hence it is expected small gain (or even loss) when diversity is applied (refer to Figure 3) **Error! Reference source not found.** Hence post-processing that is to find out the figures of K factor from the CIR will be based on the maximum likelihood estimation [10]. In the case of diversity tests, the gathered data will be related to the cross correlation values and the diversity gain. This knowledge also provides the opportunity to quantify the impact of novel techniques to decorrelate channels in the LOS scenario, such as the antenna polarization or the transmitted signal spectrum shaping. Correlation the K factor and the climate changes will also be evaluated through long term campaign. It has been established that the K factor highly depends on the median excess path loss, average wind speed and seasonal changes from summer (more leaves) to winter (less leaves) [11]. This information is useful for the most likely LOS scenarios such as, rooftop. In the post-processing phase, the long term measured data, will be segmented and averaged for instance, every 30 minutes.

### The system performances

The processing of the system performance data is mainly averaging the measured number of error over a time frame long enough to guarantee unbiased estimation. The figures of highest interest are the BER and the Packet Loss Ratio (PER). The study of discrepancies from the theoretical analysis is carried out at the same time with figures such as the channel estimation or synchronization error at the receiver's side.

### The system optimization

The benefit of the effects of diversity and on-channel repeater consists of system performances improvement of parameters such as the improvement of BER or coverage area. The cross-analysis of the system performances, the enhancement techniques and channel properties will also provide the network planner/operator with the insights performance for making overall system optimizations. In fact, it has been planned to compile look-up tables predicting which experiment input metadata can affect the

experiment output metadata for every environment and system configuration. The measurement campaign will prove and quantify each of these relationships between the metadata and will reveal the best trade-off among performances and parameters handling. This analysis will provide the operator with sufficient relevant information for selecting the optimal solution for the DVB network performance improvement and for designing future ones.

## 5. CONCLUSIONS

This paper presented an overview of planned DVB measurements and relevant experiments to analyze the performance of transmit diversity and on-channel repeater system. The demonstrator has been designed to validate the simulation results and provide realistic performance figures. The design of the presented test-bed is expected to be able to test the enhancement techniques that can potentially accommodated by existing DVB broadcasting system without changing the standards or the receivers. The resulting digital broadcasting network would have fewer transmitter sites and thus be more cost-effective and have less environmental impact.

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