A statistical model of the signal strength imbalance between RF channels in a DTT network

J. J. Giménez, D. Gozálvez, D. Gómez-Barquero and N. Cardona

This letter proposes a model for the received signal strength imbalance between radio frequency (RF) channels in the UHF band. The model is fitted to field measurements carried out in the commercial DVB-T (Digital Terrestrial Broadcasting) network of Sweden. The analysis of the measurement data reveals large differences in the received signal strength between channels according to the reception scenario and the frequency spacing. The model presented in this letter is a valuable tool to investigate the potential network planning gains of time-frequency slicing (TFS), a technique that was described in the DVB-T2 standard and that will be included in the future DVB-NGH (Next Generation Handheld) standard for improved frequency diversity.

Introduction: Digital terrestrial TV (DTT) operators usually make use of several radio frequency (RF) channels in the UHF band to broadcast services in a particular network. However, the received signal strength is not the same in all the RF channels, even with equal transmitted power (ERP), due to the frequency dependent characteristics of the transmitter site, the receiver, and the propagation channel [1]. One source of imbalance between RF channels comes from the irregularities in the antenna diagrams of the transmitting and receiving antennas on the horizontal plane, as these depend on azimuth, frequency and bandwidth. Moreover, the propagation attenuation is in general higher at the upper UHF channels compared with lower channels. A given received field strength at the antenna input will also result in a lower signal strength with higher frequencies even when the antenna gain is identical. For example, receiving at twice the RF frequency will decrease the signal level in 6 dB for the same propagation conditions and antenna gains. Due to the propagation channel (e.g. Rayleigh), there will be also a frequency-dependent signal strength variation with the position of the receiving antenna. This applies to both non line-of-sight and line-of-sight reception conditions, as in the latter case there will be a ground echo, which may amplify or attenuate the received signal depending on its received phase, which is frequency-dependent at the antenna input. All these sources will add to a very significant frequency-dependency of the received signal strength.

The next generation mobile broadcasting standard DVB-NGH will incorporate Time-Frequency Slicing (TFS) as a technique to compensate for the signal imbalance between RF channels (both wanted and unwanted signal components) in the UHF band [2]. TFS increases the frequency diversity by spreading the services across multiple channels by means of time slicing and frequency hopping. With TFS, the possibility of receiving all transmitted services at any given location depends on the average signal strength across all the active RF channels instead of the weakest signal [3]. A thorough investigation of the imbalance in the received signal strength between different RF channels is therefore essential to evaluate the potential gains of TFS in DTT networks. To this purpose, we have developed a model based on field measurements that characterizes the received signal strength imbalance between pairs of RF channels in the UHF band.

Data description and processing: The measurement data for this study was provided by the Swedish DTT operator, Teracom. The data was obtained by measuring, in mobile reception conditions, the signal strength of 4 different RF channels in a cyclic manner [1]. The measurements were taken in 6 different areas of Sweden for RF channels located between 498 and 802 MHz. The complete measurement data in each area comprises around 60000 points (signal strength values). The recorded data was calibrated in order to remove frequency-dependent variations of the actual receiver antenna gain. The resulting calibrated antenna was in line with the assumptions commonly used in network planning, which is to assume an antenna with a constant gain over the frequency band.

Signal model: The proposed model for the received signal strength imbalance between two RF channels in the UHF band is characterized by means of two different factors. The mean value of the difference between the signal strength of two channels is modelled by means of an offset component which depends on the nominal value of the frequency of each RF channel. The evolution of the received signal strength imbalance in the time and space domains is modelled by means of a statistical component which depends on the frequency separation between the channels. According to these considerations, we assume that the model may be described as follows:

$$\Delta P(dB) = \Delta P_{PL}(f_2/f_1) + \Delta P_{FS}(\Delta f), \qquad (1)$$

ΔP_{PL} represents the mean value of the imbalance between RF channels (f_1 and f_2) according to $\Delta P_{PL} = K_{PL}\log_{10}(f_2/f_1)$, [4], whereas ΔP_{FS} represents the variability of the imbalance by means of a normally distributed (for the signal strength in dB) random variable $\Delta P_{FS} \sim N(0, \sigma_{FS})$. In turn, the standard deviation of ΔP_{FS} has been modelled as an exponential-based function with three parameters:

$$\sigma_{FS} = K_1 + K_2 \cdot e^{-\frac{\Delta f}{K_3}},\ \Delta f\ \in [1{,}384]\text{ MHz}, \qquad (2)$$

where Δf is the channel spacing calculated as $f_2 - f_1$, and K_1, K_2 and K_3 have to be estimated. In order to parameterize the model to the measurement data, we have used the nonlinear function minimization method described in [5]. The parameters have been computed using the complete set of measurement data as a manner to obtain a common model for the 6 different areas considered during the measurement campaign.

Model verification: Fig. 1 illustrates the mean value of the received signal strength imbalance for every pair of RF channels in the whole set of measurements as a function of the ratio between the nominal frequency of each channel in a pair. The dash-dot curve corresponds to the mean value of the imbalance ΔP_{PL} computed with the model in (1) and $K_{PL} = 44$.

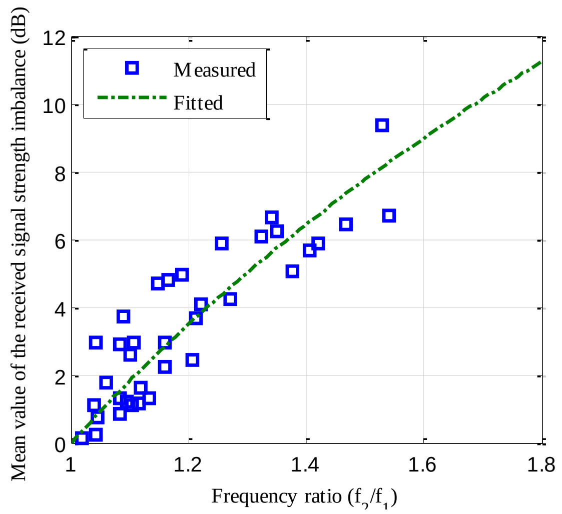

Fig. 1 *Mean value of the received signal strength imbalance between two RF channels as a function of the ratio between the nominal frequencies f_2 and f_1.*

Fig. 2 depicts the standard deviation of the received signal strength imbalance for every pair of RF channels according to the frequency separation between the channels in each pair. According to the figure, we can see that the standard deviation varies between 2.5 dB and 5 dB depending on the frequency separation. The dash-dot line represents the standard deviation obtained by the model in (1) and K_1=6.4, K_2=-4, and K_3=327.

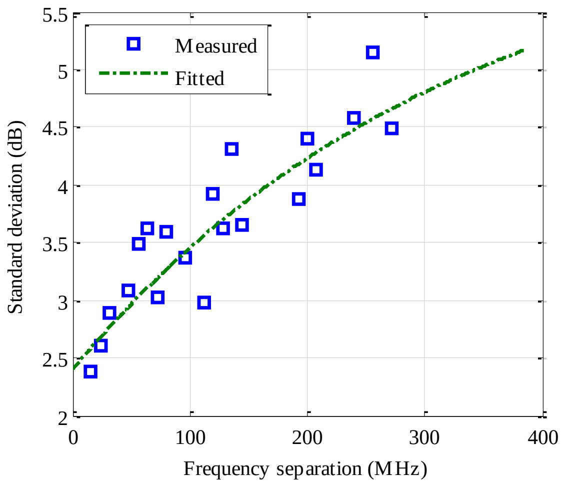

Fig. 2 *Standard deviation of the received signal strength imbalance between two RF channels as a function of the frequency separation.*

Finally, Fig. 3 compares the PDFs of the received signal strength imbalance computed with the model in (1) and the real imbalance obtained in the measurement data. In the figure, we can see that the model approximates quite closely the measurement data.

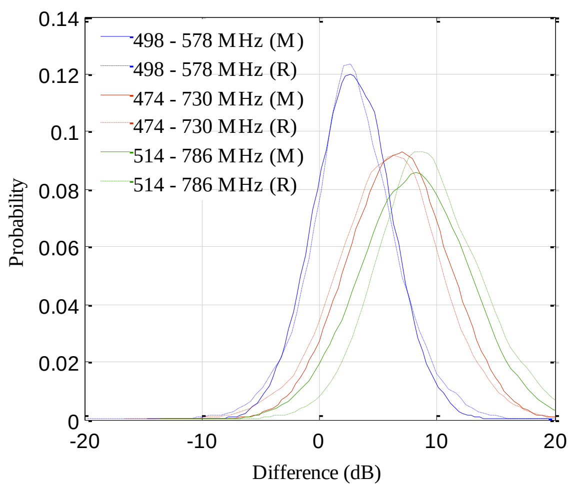

Fig. 3 *PDFs of the received signal strength imbalance between two RF channels with different frequency separations according to the proposed model (M) and the measurement data (R).*

Conclusions: This letter has presented a model to characterize the received signal strength imbalance between pairs of RF channels in the UHF band. The model includes a constant component that characterizes the mean value of the received signal strength imbalance between channels, and a random variable with normal distribution that models the variability of the imbalance over time. In turn, the standard deviation of the normal distribution depends on the frequency separation, and is approximated by an exponential function parameterized by the measurement data. The model presented in this letter is a valuable tool for investigating the potential network planning gains of TFS in the next generation of mobile TV networks.

J. J. Giménez, D. Gozálvez, D. Gómez-Barquero and N. Cardona (*Mobile Communications Group, iTEAM, Universitat Politècnica de València, Camí de Vera S/N, 46022 Valencia, Spain*)

E-mail: jorgigan@iteam.upv.es

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