SFN Channel Measurements in Brazil

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***Abstract*— In this paper, field measurements carried out in a suburban SFN network with two synchronized transmitters are reported. It is found that the radio signal coverage of the distributed transmission scheme is distinctly improved when compared to a single transmitter system. The path loss gain and improvement associated to the SFN scheme are obtained as well as the multipath channel parameters including the mean and RMS delay spread. A tapped delay line is used to model the average power delay profile (PDP) in the distributed transmission cases and shows rather different features than the single transmission case.**

***Index Terms*—** single frequency networks, digital television, broadcast channel modeling.

I. INTRODUCTION

In a DTV traditional wireless transmission scenario, only one transmitter is used to transmit the wanted signal in an assigned channel to a given user. Signals from other transmitters are taken as interferences and should be kept out of the assigned frequency or time or coding channel of the given user. In such case, the signal strength variation is characterized by the path loss, as given by [1,2], and the time delay dispersion of received signal, expressed by power delay profile (PDP) [3], that is usually modeled by an exponential decay.

In digital systems, alternative transmission scenarios with the utilization of distributed transmitters are possible and have been found to be efficient to improve signal coverage. One application of this idea is the Single Frequency Network (SFN) [4], which uses distributed radio transmitters to broadcast the same signal over the same frequency channel to improve coverage and improve reception on shadowed areas.

The channel characteristics for SFN transmission differ from the traditional single transmitter case due to the presence of signals reaching the receiver originating from more than one transmitter. These signals create a severe artificial multipath propagation environment at the receiver as observed by Tang et.al.[5], Zhao et. al. [6] and Guerra et. al.[7]. It translates not only into intersymbol interference

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(ISI), but also in interchannel interference (ICI) [8].

In OFDM systems the delay spread of the received signal is controlled by using a longer transmitted symbol than the actual interval observed by the receiver. The signal with time interval Ts consists of a useful symbol part with time interval Tu and a guard interval Tg. If the delay spread of a signal is smaller than the guard interval, no intersymbol interference occurs and the signal contributes totally to the wanted signal. Signals arriving later than Ts are treated as interfering signals. A method that is often used as a countermeasure against self-interferences is to increase the total symbol duration (the actual symbol length and the guard space). The receiver can then make use of the multiple received signals, thus yielding a diversity gain. The performance limits are still set by interference from very large delayed signals, which are inherent to the structure of SFN.

To properly design a SFN system, the propagation characteristics of channel with distributed transmission have to be studied carefully. It is known that the power delay profile (PDP) in a SFN channel shows rather different features than in the single transmission cases and cannot be modeled simply by an exponential decay due the existence of distributed transmitters [5]. Thus, it is necessary to obtain data from field measurements in different scenarios to derive appropriate SFN channel models.

In this paper, preliminary results of field measurement carried out in a suburban SFN scenario with two synchronized transmitters are reported. The path loss gain and improvement associated to the SFN scheme are obtained, as well as the multipath channel parameters, including the mean delay and RMS delay spread. A tapped delay line is used to model the average power delay profile (PDP) in the distributed transmission cases and shows rather different features than the single transmission case.

II. EXPERIMENTAL SETUP

Measurements were performed in a commercial broadcast ISDB-T system with two-transmitters SFN, deployed in a suburban area in Rio de Janeiro, Brazil. The OFDM modulation scheme with dense net of pilot carriers used in the ISDBT-T system [9] allows the evaluation of channel parameters by processing the received signals from regular transmissions.

A network analyzer ANRITSU MS8901A, with the capability to measure channel impulse response and amplitude/phase characteristics was used. The measurements were performed at 563 MHz, with a channel bandwidth 6MHz. The modulation parameters were FFT=8k, GI 1/16 and 64 QAM.

The campaign data includes static measurements performed at 31 points with both a directional antenna of 14 dB gain and an omnidirectional antenna, positioned 13.4 m above ground level. Fig. 1 shows the transmitter sites (Sumaré and Pena) and the 31 measurement points, chosen over the main roads and highways in the coverage area. Fig. 2 shows the mobile unit and the receiver set-up.

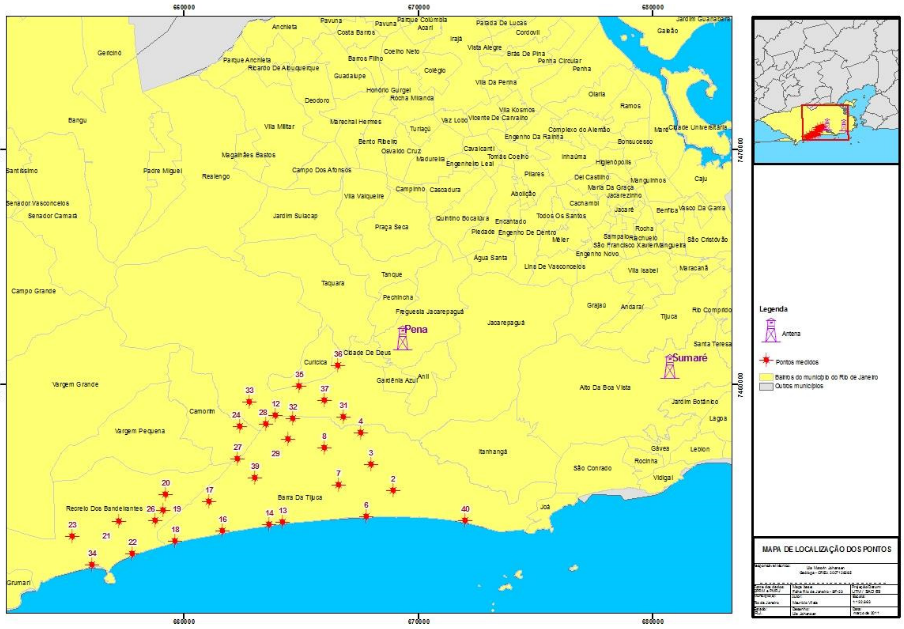

Figure 1. Transmitter sites and measurement points

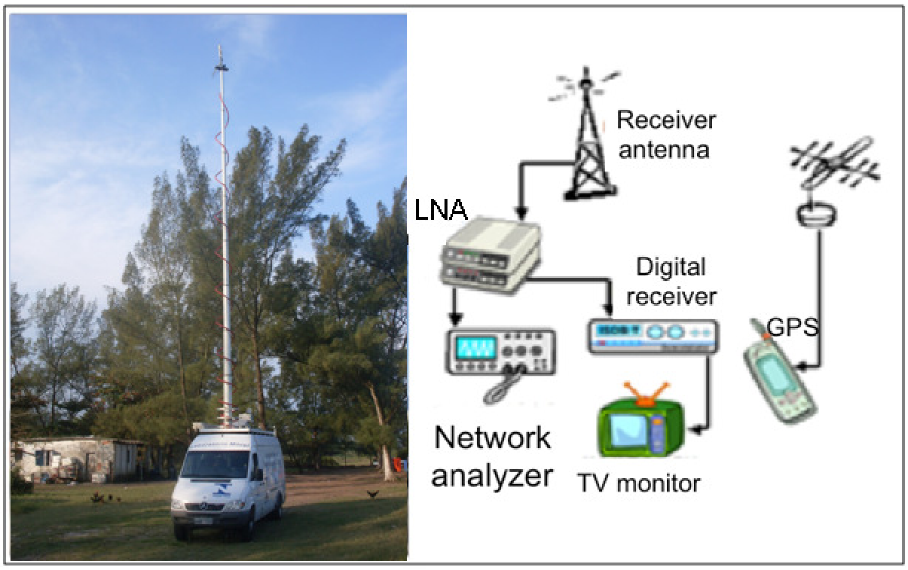

Figure 2. Mobile unit and receiver setup

III. TRANSMISSION LOSS MEASUREMENTS

A. Path loss for a single transmitter

Conventionally, in point-to-point transmission systems, the signal strength variation is measured by the path loss describing the range dependence of the signal strength, which is defined as

$$PL(d)[\mathrm{dB}] = 10log_{10}\left(\frac{P_r(d)}{P_t G_t G_r}\right) \tag{1}$$

where PL is path loss, d is the distance between the transmitter and receiver; P_t and P_r are the transmitted and received power, respectively; G_t and G_r are the transmitter and receiver antenna gain, respectively.

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Fig. 3 shows the measured path loss at the static measurements points. Also shown is a comparison with the free space loss and the path loss given by ITU-R Recommendation P.1546-3 [1], which provides a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz. At some points in our scenario there are major obstacles to the signal from the main transmitter (Sumaré), which is located near by the top but on the eastern side of the highest hills in the region, as indicated in Fig. 4. Due to the obstruction of the signal transmitted by this main source, we observed higher losses in the measured points that are closer to the main site. Although ITU-R P.1812 [2] could provide more accurate results for this type of environment, it requires detailed information about the terrain profile that is not available in this case.

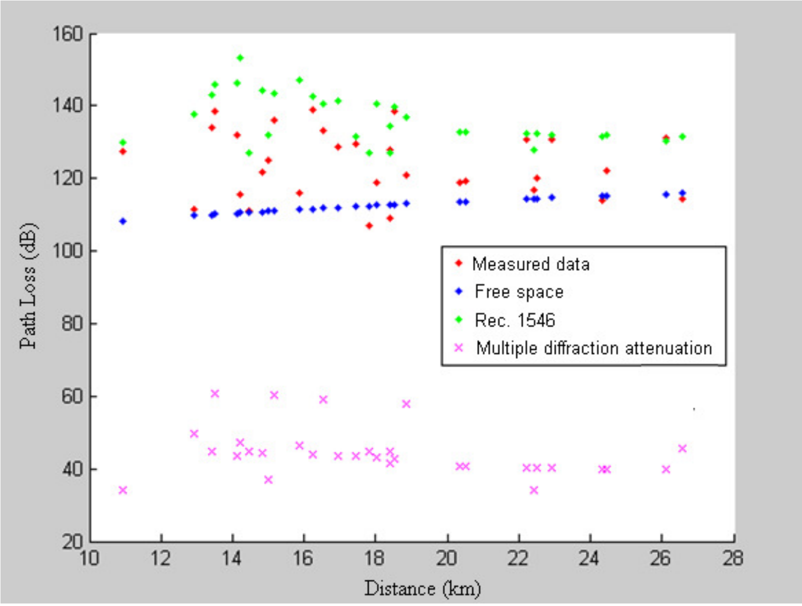

Figure 3. Measured path loss in single transmitter scenario.

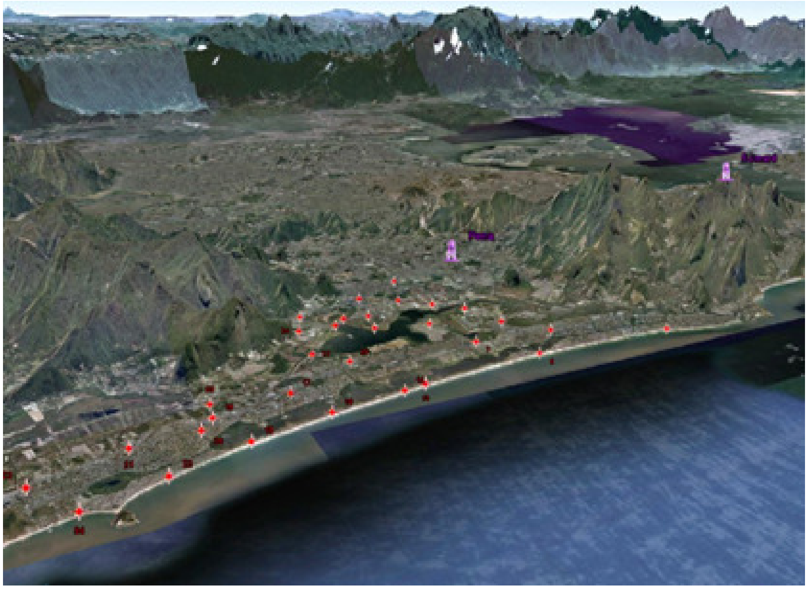

Figure 4. Location of measurement points and terrain topography

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B. Transmission loss in a Single Frequency Network

In a SFN, where multiple distributed transmitters are used to broadcast the same signals to every user in the same frequency channel, the conventional range (d) between a specific user (or receiving point) and the transmitter (or transmitting point) cannot be defined, so that the concept of "path loss" is not suitable in this case. If there are N transmitters, the received power cannot be defined as $P_r(d)$ but as $P_r\ (d_1,\ d_2,\ldots,d_n)$. Tang et. al. [5] define the combined transmission loss TL as the ratio of the received power of a receiver at certain position to the effective power sum of all the transmitters in the SFN.

$$\mathrm{TL[dB]} = 10\log_{10}\left[\frac{\mathrm{P_r}(\mathrm{d_1},\mathrm{d_2},\cdots,\mathrm{d_N})}{(\mathrm{P_{t_1}G_{t_1}}+\mathrm{P_{t_2}G_{t_2}}+\cdots+\mathrm{P_{t_N}G_{t_N}})\mathrm{G_r}}\right] \qquad (2)$$

where N is the number of transmitters in the SFN. $\mathrm{P_{t_N}}$ and $\mathrm{G_{t_N}}$ is the transmitter power and antenna gain for the nth transmitter.

Fig.5 shows the cumulative distributions of the transmission loss in SFN and the path for a single transmitter scenario, with the transmitted power in SFN kept the same as in the single transmitter scenario.

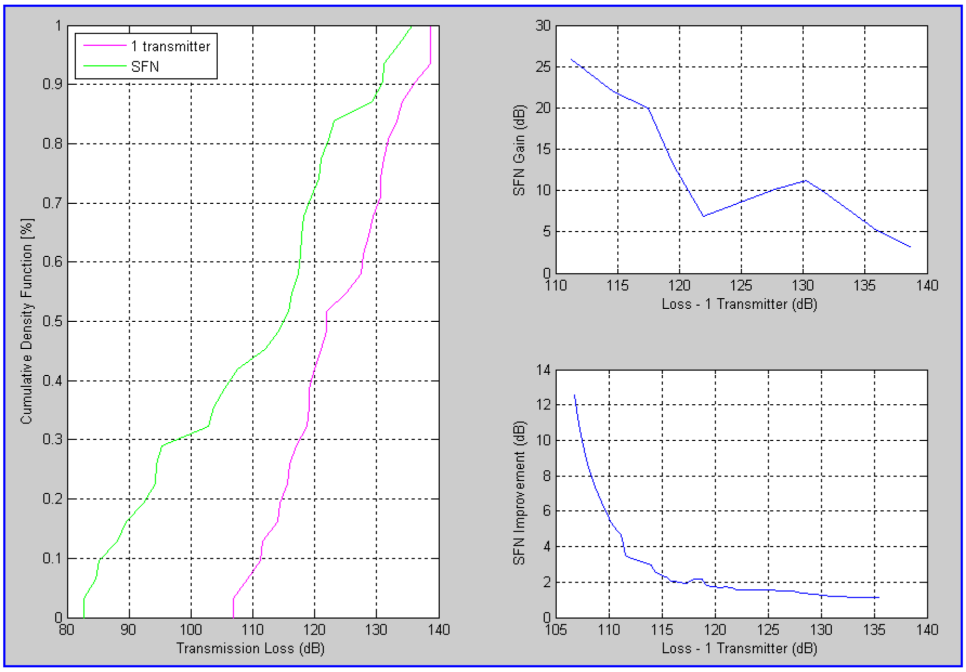

Figure 5. Cumulative distribution of transmission loss in SFN and single transmitter scenarios.

It is clear that the transmission loss in SFN is significantly lower than that in single transmitter. The second and third right hand side graphs in Fig. 5 show the diversity gain (G) and the diversity improvement (M), obtained in the SFN, defined by:

$$G(PL) = PT(p) - PL(p)\ (\mathrm{dB}) \tag{3}$$

and

$$M(PL) = \frac{p(PT=PL)}{p(PL)} \tag{4}$$

where p denotes probability of exceedance. PL is the path loss of a single transmitter and PT is the SFN loss. This gain, i.e. the decrease of transmission loss, results from the fact that the SFN provides multiple opportunities for the receiver to acquire the signal. Even if one or several paths are blocked, others may provide enough intensity for the signal to be decoded by the receiver.

IV. WIDEBAND CHANNEL CHARACTERIZATION

A. SFN Channel Delay Spread

Typical average PDPs extracted from the measured data are shown in Fig. 5 and Fig. 6. Compared to the average PDP received from a single transmitter, the average PDP received from two transmitters is evidently sparse. Moreover, the PDP of distributed transmission system has the long delay echoes due to the multiple transmitters.

The delay dispersion is usually characterized by the mean excess delay τ_{m} and the root mean square (RMS) delay spread τ_{rms}, which are defined as the first central moment and the square root of the second central moment of the instantaneous PDP [10].

To calculate the delay dispersion parameters, a threshold must be defined, below which the multipath components will be ignored. Three different threshold levels were considered at 10, 15 and 20 dB below the maximum value of the PDP. The obtained values of mean excess delay τ_{m} and (RMS) delay spread τ_{rms} for each threshold are shown in Table I.

It can be observed that the maximum excess delays and RMS delay spreads are practically independent of the threshold considered. The mean values, on the other hand, increase as the threshold decreases. Also, the values of both the excess delay and the RMS delay spread are much higher than those observed in single transmitter measurements, as reported in [11,7].

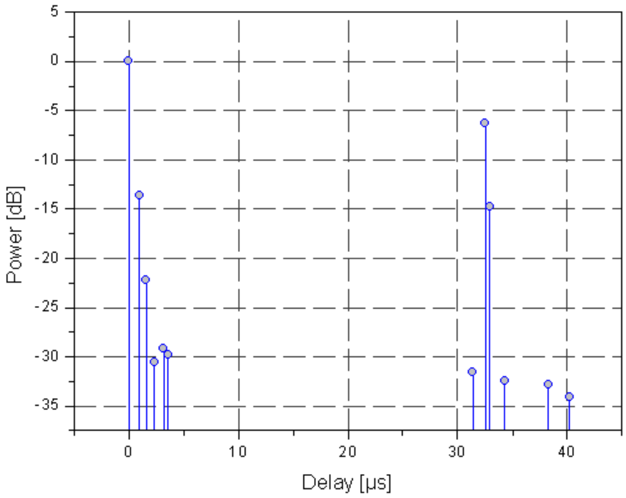

Figure 6. Power delay profile – measurement point 6.

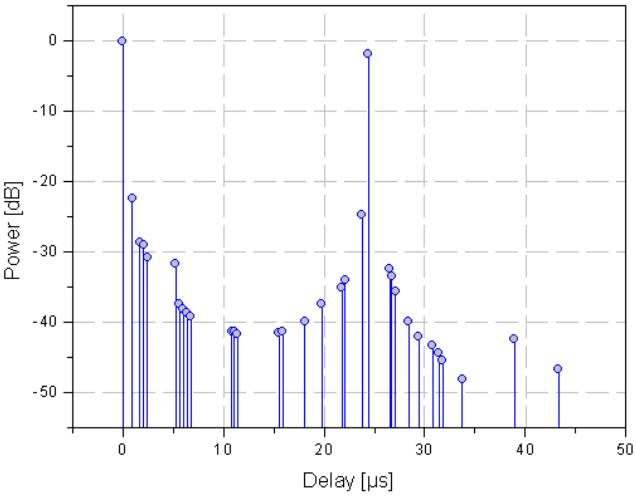

Figure 7. Power delay profile – measurement point 16

TABLE I. DELAY PARAMETERS FOR TWO TRANSMITTERS SFN MEASUREMENTS

Threshold	**Excess delay (μs)**		**RMS delay spread (μs)**	
	Mean	**Max**	**Mean**	**Max**
- 20 dB	1,86	12,7	3,72	13,1
- 15 dB	2,36	12,7	4,04	13,1
- 10 dB	3,83	12,5	5,85	12,7

B. Tapped Delay Line Model for SFN Channels

Tapped delay line (TDL) models are often used to model the average PDP for computational or laboratory simulations [6]. These models represent the channel by a transversal filter structure with distinct taps corresponding to delays τ_{rms}. Their calculation is based on the average power delay profile $\overline{|h(\tau,t)|^2}$ obtained from the collected data which is processed before in order to eliminate the effects of noise and produce the valid echoes (thresholding) [12].

Using fixed time delays in a channel model conflicts somewhat with the concept of a real channel, but identifying significant delay cells using information derived from graphs of e.g. $\overline{|h(\tau,t)|^2}$ is considerably easier, and more realistic, than computing them from Poisson-distributed random numbers [13]. Compared with the single transmission case, the PDP in SFN channels should contain more taps and have significantly longer delays [5,13,6].

Similarly to the calculation of RMS delay spread, thresholds must be set to include the significant multipath components in the TDL model derivation. Examples of the TDL models obtained for the SFN channel considered in this paper is shown in Table II. The threshold levels are [10; 15; 20] dB below the maximum value in the PDP.

TABLE II. TDL MODELS FOR THE TWO TRANSMITTER SFN CHANNELS

This Work									**Tang [5]**		
-10 dB			-15 dB			-20 dB			-20 dB		
TAP no.	Delays [µs]	Mag [dB]	TAP no.	Delays [µs]	Mag [dB]	TAP no.	Delays [µs]	Mag [dB]	TAP no.	Delays [µs]	Mag [dB]
1	0	0	1	0	0	1	0	0	1	0	0
2	19,8	-4,5	2	0,48	-13,7	2	0,48	-13,7	2	0,48	-7,2
3	20,0	-5,5	3	0,60	-13,0	3	0,60	-13,0	3	3,14	-2,2
4	20,4	-9,8	4	19,8	-4,5	4	0,72	-16,3	4	19,23	-1,6
5	24,4	-6,9	5	20,0	-5,6	5	0,96	-17,9	5	20,08	-13,5
6	32,5	-6,3	6	20,4	-9,8	6	1,08	-19,1	6	22,25	-6,5
			7	22,4	-13,2	7	1,68	-16,6			
			8	24,4	-6,9	8	19,8	-4,5			
			9	32,5	-6,3	9	20,0	-5,6			
			10	32,9	-14,7	10	20,2	-15,3			
						11	20,4	-9,8			
						12	21,0	-19,2			
						13	22,4	-13,2			
						14	24,4	-6,9			
						15	27,5	-19,9			
						16	32,5	-6,3			
						17	32,9	-14,7			
						18	33,5	-17,2			

Comparing the model derived in this work with those also reported by Tang et. al. [5] for the distributed transmitter case, the hilly nature of the area where the experiments have been carried out explains the increased number of taps and the longer delays presented in Table II. Notice the results reported in [5] were derived from measurements on a highway located in a plain area with elevated transmitters at the two ends.

V. CONCLUSIONS

Results of field measurements performed in a SFN network with two ISDB-T digital TV transmitters, performed in a suburban environment, are reported in this paper.

The path loss prediction method given in Rec. ITU-R P.1546 overestimates the measured values by up to 20 dB. The transmission loss in SFN is significantly lower than that in single transmitter. A minimum diversity gain of about 5 dB was obtained and a gain of 7 dB was exceeded at 50% of time.

The mean excess delay τ_m and the root mean square (RMS) delay spread τ_{rms} for the two transmitters SFN were obtained. The values are more than one order of magnitude higher than those usually observed for single transmitter configurations.

Tapped Delay Line models for computer or laboratory simulation of two-transmitter SFN channels were also derived. As expected, when compared with single transmission cases, the PDP models for the SFN channel contain more taps and have significant longer delays.

Though the results reported in this paper are drawn in a specific setup in a suburban area, they are expected to contribute to the study of SFN channel characteristics.

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