Characterization of Wireless Feedback Channels near a Highway Based on Sounding Measurements

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Abstract: This paper presents the method of measuring the feedback channel, which is developed between the transmit and receive antennas of a wireless repeater by receiving the transmit singal from its tranmit antenna at the receive antenna of the identical repeater, and experiment results otained by anlyzing the measurements. This experiment uses 2GHz W-CDMA signal and is carried out near a highway. The high-speed mobiles on highways cause feedback signals with high Doppler frequencies and large energy. In order to characterize the feedback channel, the power delay profile and the scattering function are estimated to identify the delay spread, the Doppler spread, the number of fingers, and the attenuation with delay. Since the feedback channel is constructed between the fixed TX and RX antennas, which is dependent upon the multipaths developed due to moving or fixed objects around the antennas, the channel has different properties comparing to the conventional channel between the base station and the mobile station. Therefore, the results presented in the paper will provide guidelines for designing and evaluating the wireless repeater systems.

2. Measurement Setup

Recently, the wireless communications have been developed with high-speed and large-capacity transmissions. For this reason, the cell sizes become smaller and many repeaters are required to improve service quality. A co-channel repeater is very efficient solution to this problem. Comparing to the existing repeater using optical cables, the co-channel repeater cost less expensive in maintenance and its installation and maintenance is easy.

The co-channel repeater usually has feedback channels, through which the transmitted signal from the transmit antenna is received at its receive antenna. The feedback channels consist of the direct path between the transmitter (TX) and receiver (RX) antennas and multi-paths due to surrounding various objects. The signal from this feedback channel operates as interference to degrade the performance of the co-channel repeater. In general, the co-channel repeater uses the finite impulse response (FIR) filter to remove or mitigate the feedback interference from the TX antenna to the RX antenna and employs a channel estimation technique. For the purpose of designing a interference canceller and furthermore constructing efficient communication system, we need to measure and analyze the propagation properties of the feedback channels including the number of the multi-paths, attenuation according to the delays, Doppler shift, delay spread and so on. The existing researches on mobile channels mainly focused on the channels between a base station and a user equipment while the study on the feedback channels is scarce.

The sounding measurements were carried out at a side of the highway at Namhae, Kyoungnam, Korea, where fast frequency-selective fading due to high-speed vehicles has been observed, because co-channel repeaters malfunctioned due to high interference and fast frequency selective fading. Therefore, the purpose of this paper is to characterize the feedback interference channel that is built up between the TX and RX antennas of the co-channel repeater.

This paper is organized as follows. Section 2 describes the measurement setups and approaches for probing feedback channels. Section 3 provides the channel analysis results from the measurement data. Finally, section 4 concludes this paper.

2. Measurement Setup

The channel considered in this paper represents the multipath, through which the signal generated by a signal generator is transmited from the TX antenna and received by the RX antenna. In order to measure the feedback channel, we use a W-CDMA signal generator to generate a W-CDMA signal, which has 2 GHz carrier frequency, 3.84 Mcps chip rate, 5 MHz bandwidth, and 10 ms period for repeatition. Since this period is longer than the maximum delay spread of the feedback channel, it is immaterial to the sounding experiment [1]-[4].

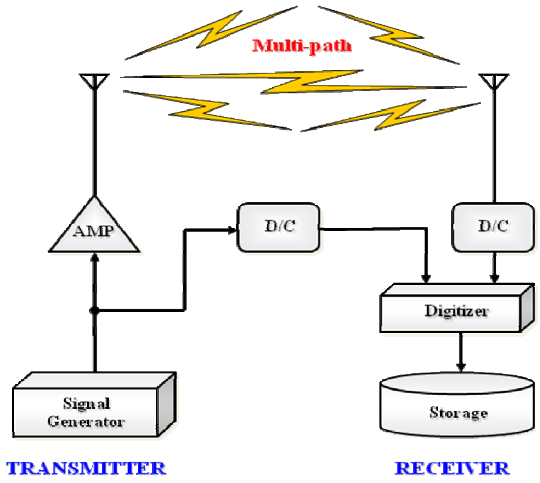

Figure 1. A schematic representation of the measurements setup.

2. 1 Measurement Equipment

In this measurement experiment, we employ signal generators, a transmit amplifier, transmit and receive antennas, a receive amplifier, filters, down converters, analog-to-digital (A/D) converters, and storage systems. The signal generator is E4438C ESG from Agilent Technologies, and the data storage system is based on PXI-1044 of National Instrument with real-time embedded controllers and a digitizer of 2 channels, 14 bits, and 100 MHz sampling frequency. The sampled data are saved in a hard disk drive in real time. The transmit amplifier operates on 2 GHz band with 5W maximum power. The receive amplifier is a low noise amplifier (LNA) operating 2 GHz band. Surface acoustic wave (SAW) filters are utilized as filters. An array antenna for base stations is used as a transmit antenna while the directional parabola antenna is used as a receive antenna.

2. 2 Measurement Method

The sounding measurements were carried out at a side of the highway at Namhae, Kyoungnam, Korea, where several one- or two-story houses and warehouses are scattered and no multistory building is located. The antenna is installed ten meter high and main scatters are the adjacent buildings and the automobiles on the highway. Fast frequency-selective fading has been observed near the highway due to high-speed vehicles, and co-channel repeaters malfunctioned due to high interference and fast frequency selective fading. For these reasons, we select this area. Figure 1 shows the schematic block diagram of the measurement setup. In order to measure the feedback channels, the signal generator produces a W-CDMA signal of 2 GHz center frequency. The W-CDMA signal is divided into two; one goes to a down-converter while the other is input into the transmit amplifier. The output signal from the transmit amplifier is radiated through the transmit antenna. The radiated signal travels through multi-path and arrives at the receive antenna. The received signal is amplified by the LNA, processed by SAW filter, and saved in the storage system. The down-converters change the 2GHz signals from the signal generator and from the receive antenna, respectively, into the IF signals of 3.125MHz center frequency. The two-channel digitizer samples the two signals from the down-converters with the sampling frequency of 12.5 MHz and 14 bits [5].

3. Analysis of Measurements

In order to model the feedback channel, we use the tapped delay line (TDL) model, which can be implemented in a FIR filter and its coefficients are equivalent to the power delay profile [6]. Since the sampling rate is 12.5 MHz, one tap of the TDL corresponds to 0.08 µs. The number of taps in the TDL model should be greater than the maximum delay spread of the multipath. According to the experiment results, the maximum delay spread is less than 10 µs. Thus, we used 125 taps (equivalent to 10 µs) in the TDL model. In order to obtain the power delay profile of the channel, the IF received signals are translated into the baseband ones, which are utilized for the least square (LS) algorithm to estimate filter coefficients. The filter coefficients are low-pass filtered with pass band of 2.5MHz. The LS algorithm is one kind of block algorithms, which minimizes error for a given interval. In this study, we choose 12500 samples (1 msec) as a block size for the LS algorithm. The LS algorithm is as follows [7].

$$\hat{\mathbf{w}} = \mathbf{\Phi}^{-1}\mathbf{z} \tag{1}$$

Where $\hat{\mathbf{w}}$ represents a $M \times 1$ vector consisting of the M TDL filter coefficients while $\mathbf{\Phi}$ is the correlation matrix of the transmit data $u(i)$, which is defined by

$$\mathbf{u}(i) = \left[u(i), u(i-1), \ldots, u(i-M+1)\right]^T \tag{2}$$

$$\mathbf{\Phi} = \sum_{i=M}^{N} \mathbf{u}(i)\mathbf{u}^H(i) \tag{3}$$

The vector $\mathbf{z}$ is a cross-correlation vector between transmit data $u(i)$ and receive data $r(i)$,

$$\mathbf{z} = \left[z(0), z(-1), \ldots, z(-M+1)\right]^T \tag{4}$$

$$z(-k) = \sum_{i=M}^{N} u(i-k)r^*(i), \quad 0 \le k \le M-1 \tag{5}$$

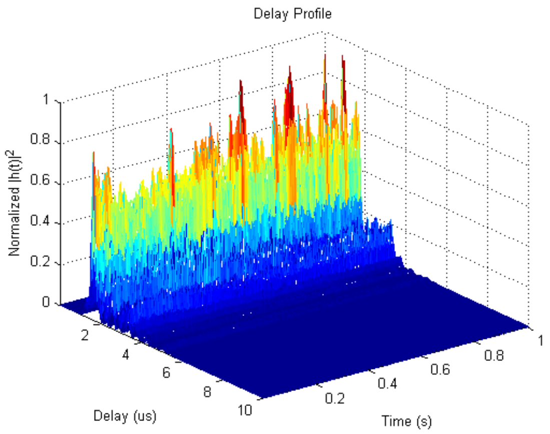

Figure 2. Delay profile with respect to time and delay.

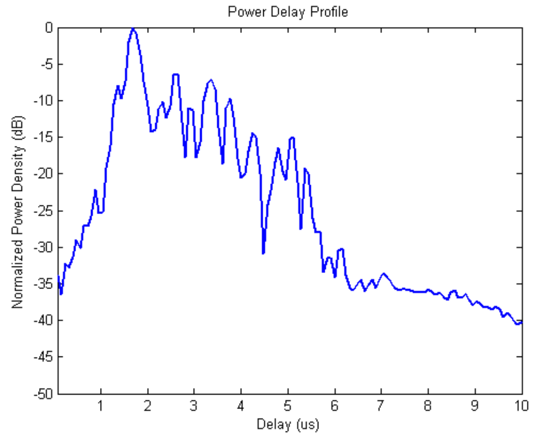

Figure 3. Power delay profile average.

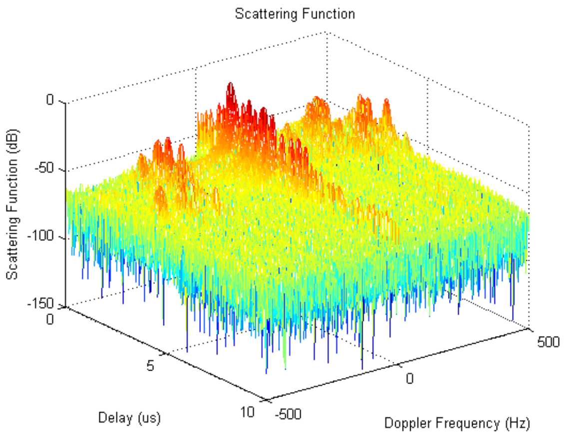

Figure 4. Mesh diagram of the scattering function.

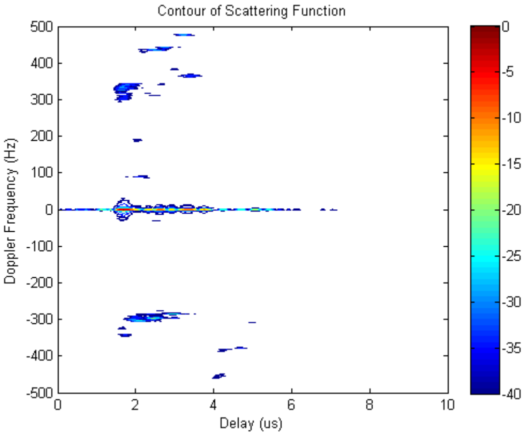

Figure 5. Contour diagram of the scattering function.

After estimating the power delay profile using this scheme, we can find the scattering function $S(\tau, \upsilon)$, which consists of two variables, delay τ and Doppler frequency υ, assuming that the channel is wide-sense stationary uncorrelated scattering (WSSUS) random process [8].

The feedback channel is investigated when the highway traffic is smoothly flowing. Figure 2 presents a mesh plot of the normalized power delay profiles of 1 msec period, whose time length is 1 second. The figure provides the delay range up to 10 μs and we can observe the high fingers that are located from 0 to 4 μs. The wide fluctuation of the coefficient's energy during 1 second indicates the strong influence of the Doppler effect. The first finger is highest while the remaining become smaller according to delays. The fluctuation of the finger magnitude is serious, but the delays of the fingers seem to be constant.

Figure 3 shows the average power delay profile over one second. According to the figure, the effective delay spread is up to 5.5 μs and the first path appears around 1.7 μs, which gives the difference of 3.8 μs. This implies that the last finger is far 570 m away from the first finger. The power of the feedback signal is decreasing in log scale with delay.

Figure 4 displays the scattering function obtained from the feedback channel's delay power profiles. The scattering function is generated by FFT of the 1000 delay profiles of 1 second. Its resolution is 1 Hz with a Doppler spread of +500 Hz to -500 Hz and its delay spread is up to 10 μs. Figure 5 is the contour plot of the mesh plot of Figure 4 with -40 dB contour of delay and Doppler frequency. The peak is 60 dB above the noise level and located at 0 Hz and 1.7 μs. The Doppler frequency widely spreads from +450 Hz to -450 Hz. The components at +300Hz and -300Hz have large energy that is less than the peak by 20 dB and exist from 1.7 to 3 μs in the delay domain. The components consist of 7 fingers.

4. Conclusion

In this paper, we characterized its properties of the feedback channel based on the sounding measurements. The TDL model was identified by applying the LS algorithm to the digitized transmitted and received samples. The power delay profile and the scattering function are estimated from the measurements to investigate the feedback channel. The analysis results indicate that the feedback channel suffer high Doppler frequency and it is decreasing in log scale with delay.

Through this analysis, we will provide the statistical channel model, which enables us to verify the system performance and to predict the performance using computer simulation.

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