Using Frequency-Orthogonal Pseudonoise (FOPN) Sounding Sequences To Identify Signals from Multiple Transmit Antennas in Mobile Double-Directional and Relay Channel Sounding Systems

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Abstract

A method previously reported by the authors for identifying simultaneous signals from different Tx antennas is applied for double-directional channel sounding between a channel sounder base station (CSBS) and a channel sounder mobile station (CSMS), as well as for single input single output (SISO) channel sounding on relay channels in urban microcell-type Tx/Rx scenarios. Using this method, multiple-orthogonal signals are produced from one pseudo-noise code by using it to modulate RF carriers at pre-calculated offset frequencies. The frequency spectra of the resulting signals are interleaved and they occupy the same overall frequency band, but the spectral lines from different transmitters are separable using Fourier analysis of signals sampled at the CSMS receiver output. In theory, any arbitrary number of links from different transmitters can be measured simultaneously using this method. However, in practice, Doppler spreads limit the number of simultaneous soundings that can be made with acceptable isolation among resulting impulse response estimates. Herein, examples are given of results from double-directional channel sounding using a linear array of 4 Tx antennas at the CSBS and of relay channel sounding with one Tx antenna at the CSBS and one Tx antenna at a channel sounder relay station (CSRS).

1. Introduction

For either double-directional or relay system channel sounding, one must identify the signal transmitted from each of multiple Tx antennas. Identification can be achieved by transmitting signals that are orthogonal in time, code or frequency. Techniques for generating time-orthogonal signals by switching both Rx and Tx antennas require absolute time synchronization between the Tx and the Rx and involve delays that limit mobile station (MS) speeds. Switched Tx arrays can be used with multichannel receive systems, but this is only practical with chirp sounders, the outputs of which have narrow bandwidths, allowing multiple low cost data collection systems [1]. One can also use Delay-Offset (DO) methods, wherein each Tx antenna transmits the same code, having a delay with respect to transmissions from all other antenna elements by more than the maximum anticipated multipath spread on the channels of interest. A drawback here, however, is that maximum multipath spreads need to be known a priori.

Code-orthogonal sounding signals can be generated using Kasami codes, Loosely Synchronous (LS) codes, and Modified LS (MLS) codes. Kasami codes are interference-limited due to their cross-correlation characteristics, while LS and MLS codes are noise-limited due to their low energy efficiency [2,3]. To compensate for these limitations, one needs to have very long sequences, resulting in a requirement for low MS speeds.

This paper reports measurements that were made using a technique for multiple-transmit-signal identification previously described in [4]. Using this technique, frequency-orthogonal pseudo-noise (FOPN) signals are transmitted from different antennas that could either be part of the same Tx array or could be widely separated, for example, with one Tx antenna a CSBS and the other at a CSRS. The use of FOPN signals has three main advantages: (1) there is lower cross-correlation among signals from different transmitters and greater power efficiency than when their counterpart Kasami, LS and MLS codes are used, (2) there is no requirement for time synchronization between the Tx and the Rx, and (3) there is no requirement for detailed a priori knowledge of multipath spreads. A disadvantage is that isolation among the radio links from different Tx antennas deteriorates as Doppler spreads become larger. Simulation results reported in [4], however, show that there is only 3 dB

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degradation in SINR at a CSMS as the number of links sounded simultaneously increases from 4 to 32 when Doppler spreads are in the range associated with typical urban MS speeds.

2. Tx Configuration for the Generation of FOPN Sounding Signals

FOPN signals were generated for the double-directional measurements reported herein according to the theory presented in [4] using the transmitter configuration of Fig. 1. A baseband PN sequence of length L=255, and rate R=50 Mchps, generated using a field programmable gate array (FPGA), and clocked with the output from a 50 MHz phase locked oscillator slaved to a 10 MHz Rb frequency standard, was applied to a 4-way resistive power splitter. Each of the 4 outputs from the splitter was applied through an isolation amplifier to the baseband port of a double balanced modulator (DBM). Knowing that the spacing between spectral lines in PN signal transmissions is given by df=R/L, sine wave local oscillator (LO) signals spaced by 0, df, 2df, and 3df, respectively, from 330 MHz were each applied to an LO port on one of the 4 DBMs. This configuration generated the required 4 sounding signals with interleaved spectra, occupying the band between 280 MHz and 380+3df MHz. In the final stage of the transmitter, each of these 4 signals was upconverted to 2250 MHz using the same 1920 MHz LO signal, then filtered to a bandwidth of 100 MHz, amplified to +37 dBm and fed to a quarter-wavelength vertical monopole element with four drooping radials via 6.1 metres of RG214 transmission line. For the relay channel measurements, two of the transmitters were deactivated. One of the remaining transmitters was used at the CSBS, and the modulator and upconverter sections of the other were moved to the CSRS, and excited using a second, identical PN sequence generator, clocked by a sine wave from second 50 MHz PLO that was slaved to a second 10 MHz reference signal from a second Rb frequency standard. The signals from the two Rb frequency standards were conditioned to be in phase using timing signals received from the global positioning system (GPS).

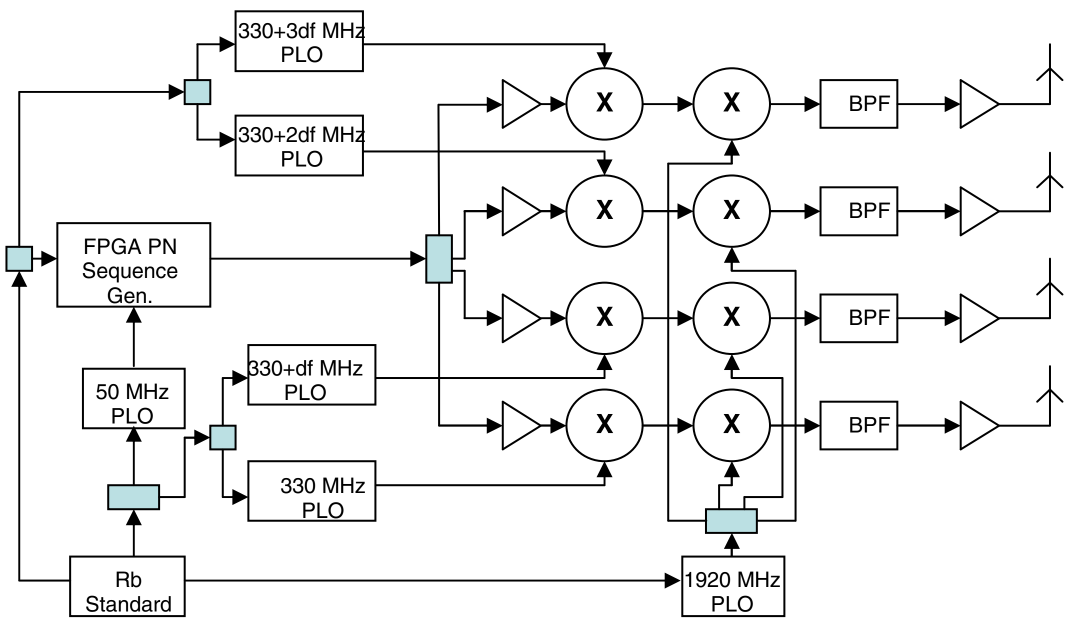

Fig. 1. FOPN channel sounder transmitter block diagram.

3. Measurements, Data Analysis and Results

At both the CSRS and the CSMS, received signals were amplified, converted to baseband in a complex downconverter, and sampled at a rate of 100 Msamples/s in 4-sequence-length (20.4 μs) "snapshots" that were recorded at a rate of 250 per second. During later processing, each snapshot of data was Fourier transformed, resulting in spectral energy (lines) at intervals of df (2df in the relay channel system), and the spectral lines associated with each Tx signal were grouped to compile the spectrum of the signal received from that transmitter. Each of these was then multiplied by the spectrum of a reference signal recorded when the Tx and Rx were connected via transmission line used to represent an ideal channel, and each result was then inverse-Fourier transformed to form an associated radio link impulse response estimate (IRE).

For the initial analysis reported here, every tenth snapshot of data from the double-directional measurements was processed using the ISI-SAGE algorithm to estimate the relative powers, phases, delays, angles of departure (AODs) in azimuth at the CSBS and corresponding angles of arrival (AOAs) in azimuth of up to 50 multipath components (MPCs) impinging on the 32-element uniform circular array used at the CSMS. Fig. 2 is a plan view of the area where measurements were conducted, showing the location of the 4 metre-high, 4-element CSBS Tx array, surrounding buildings and the trajectory of the CSMS along adjacent streets. The figure also shows the primary paths by which MPCs arrived at the CSMS while on street sections E and F, based on ISI-SAGE results plotted in Fig. 3. It can be seen that while on street section E, the highest powered MPCs arrived at the CSMS from behind (180 deg with respect to vehicle heading), via the street intersection at 120 degrees with respect to the CSBS Tx antenna array line. However, when the CSMS turned the corner and was driven along street section F, there were two changes. First, the received MPCs arrived directly from the CSBS array, with AODs from that array in a narrow angular region centred on 70 degrees, rather than from 120 deg. as on street section E. Also, the MPCs with the greatest powers are seen to arrive from ahead of the CSMS, rather than from behind as on street section E. These results demonstrate the effectiveness of the FOPN system for double-directional measurements.

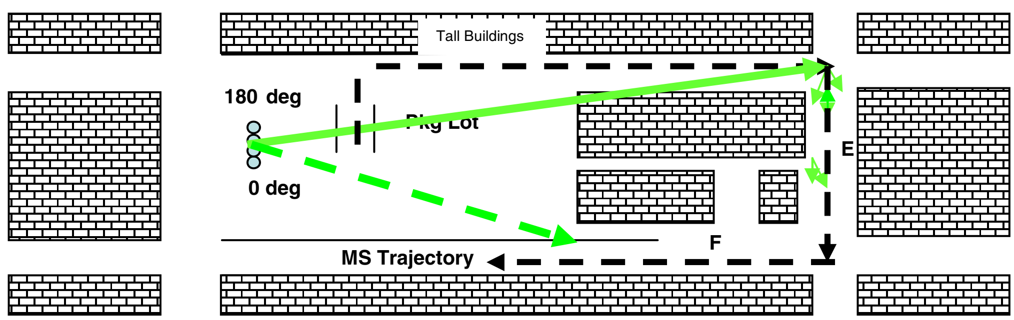

Fig. 2 Plan View of the area where the double directional measurements were made

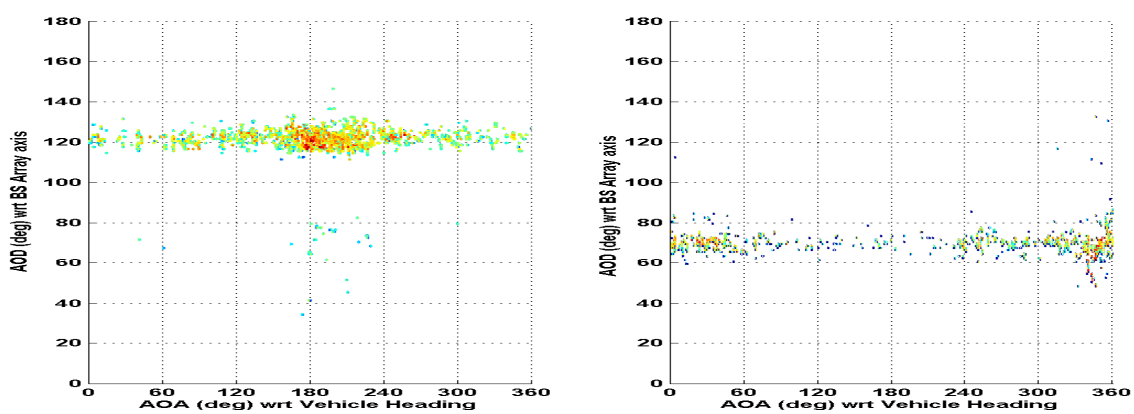

Fig. 3 Scatter plot of AOAs vs AODs, with relative powers represented via colour code: (a) for the CSMS trajectory along street section E, (b) for the CSMS trajectory along street section F.

During the relay channel measurements, transmission was from both the CSBS and the CSRS, and switching at the CSRS, required to avoid simultaneous transmission and reception, was controlled using a clock derived from the 10 pps output of a GPS receiver. An identical 10 pps output from a second GPS receiver at the CSMS was used to control a clock that ensured sampling of the received signal at the CSMS only occurred while the CSRS was transmitting. The IREs $h_{BS\text{-}MS}$ and $h_{RS\text{-}MS}$, for the CSBS-CSMS and CSRS-CSMS links, respectively, were derived from the data recorded at the CSMS and were therefore simultaneous estimates. IRE $h_{BS\text{-}RS}$ for the CSBS-CSRS link was derived from data quasi-simultaneously recorded at the CSRS during periods when the CSRS was not transmitting. The interval between interleaved recordings at the CSMS and the CSRS was 2 ms. During post processing, $h_{BS\text{-}RS}$ was convolved with $h_{RS\text{-}MS}$ to derive an IRE for the indirect link between the CSBS and the CSMS via the CSRS. A gain factor equivalent to the measured loss between the fixed CSBS and the fixed CSRS was then applied to this result. Fig. 4 is a plan view of the measurement set up. Fig. 5 shows the calibrated wideband power on all 4 links in the system as a function of time when the CSMS was driven along the trajectory shown in Fig. 4.

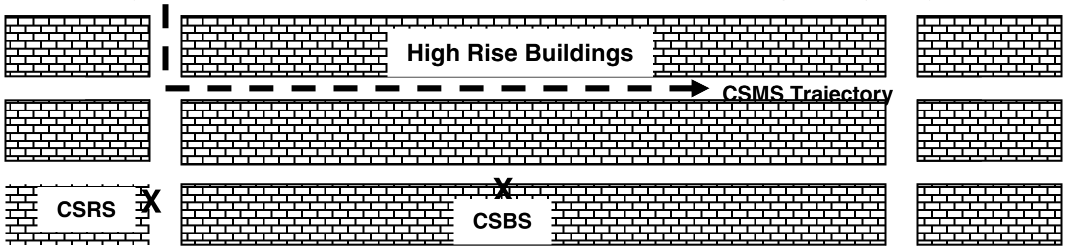

Fig. 4. Plan view of the downtown area where the relay channel measurements were conducted.

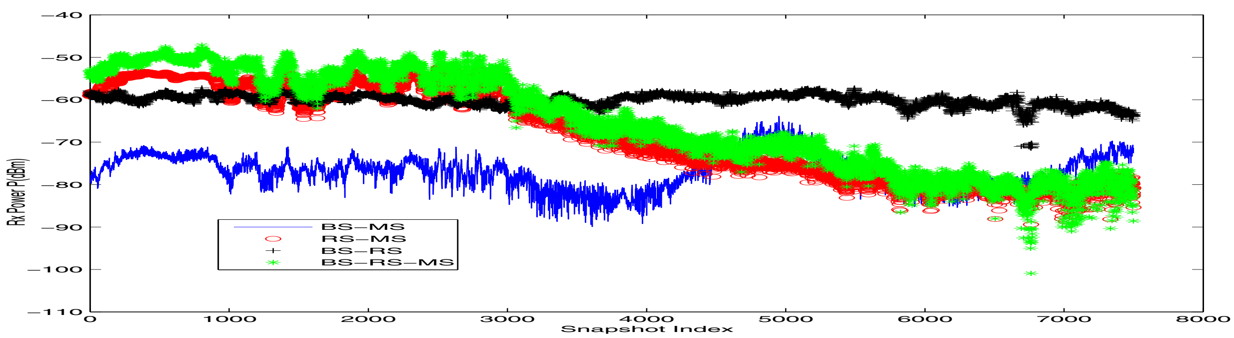

Fig. 5. Wideband received powers on all 4 links sounded during the relay channel measurements.

It can be seen in Fig. 5 that at the beginning of the CSMS trajectory, BS-MS power is low due to the NLOS conditions, whereas the RS-MS power from the LOS CSRS is greater until the CSMS turns the corner, after which this power drops monotonically. The effectiveness of the relay configuration is clear, providing a BS-RS-MS signal that is stronger than the BS-MS signal at almost all times. Based on the consideration of physics, results in Fig. 5 are intuitively correct, demonstrating also the effectiveness of the FOPN technique for sounding relay channels.

4. Summary

This paper briefly described a novel multiple input, multiple output channel sounding system reported previously by the authors. Examples were also given of credible results obtained using the system in Tx/Rx configurations suitable for both double-directional and relay channel sounding in urban microcells.

5. References

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