CHANNEL SOUNDING IN HIGH SPEED RAIL ENVIRONMENTS USING DOPPLER-DELAY TECHNIQUES

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During the past fifteen years, designers have increasingly turned to MIMO-based architectures based upon multi-element antenna arrays to increase the capacity, reliability and immunity to interference of both wide and local area wireless communication systems. In recent years, various groups have expressed interest in producing a next generation standard for wireless train control and signalling system that utilizes MIMO technology and which will represent the next step beyond GSM-R. While knowledge of path loss, fading statistics and delay spread are sufficient to permit assessment of classical wireless communication systems, accurate simulation and design of MIMO-based wireless systems also require knowledge of the directions of departure and arrival (DoD and DoA) of individual multipath components. Spatial channel models that capture the spatial distribution of the scatterers that surround a transmission path provide a convenient method for capturing this information [1,2].

Most conventional approaches to characterizing spatial channels based on measured channel response data require either mechanically steerable directional antennas or multiple antenna systems at both the transmitter and receiver to resolve the directions of arrival and departure. When either the receiving or transmitting platform is moving with a constant velocity, as in the case of high speed rail, however, the channel measurement system can be simplified considerably by exploiting the manner in which the signal associated with a multipath component located at a given angle with respect to the direction of travel is Doppler shifted. The manner in which the Doppler shift experienced by multipath components depends upon their angle of arrival with respect to the direction of motion of the receiving platform gives rise to a Doppler spectrum is well-known. The shape of the Doppler spectrum, i.e., the ratio of the maximum to minimum value of the Doppler spectrum amplitude, depends on a variety of factors including scatterer density and the elevation angle distribution, however. As a result, accurate determination of the strength of a scatterer observed at a given angle/Doppler-frequency is difficult. At first glance, developing a practical channel sounder based on Doppler spreading seems intractable.

When the receiving platform moves in a straight line at constant velocity, as in the case of high-speed rail, the scenario begins to resemble that of a bistatic synthetic aperture radar. Because we can predict the range-Doppler history of the returns from each scatterer observed over time, we can extract the family of returns from a given scatterer over time and focus them into a single point. In this manner, we can vastly improve both the amplitude and angular resolution of the system. In synthetic aperture radar, the technique is often referred to as Doppler focusing [3]. Exploitation of the range-Doppler history of a given scatterer to resolve its amplitude and location allows us to dramatically reduce the complexity of the measurement system required to collect spatial channel data. The system of antennas and receivers usually associated with MIMO channel sounders can be reduced to a single receiver equipped with a broad beam antenna.

Transformation of range-Doppler information into a map or image that shows the relative position of scatterers within the field has been the mainstay of digital synthetic aperture radar processing for over thirty-five years. Several canonical algorithms have been developed. Most are based upon the assumptions that: 1) the transmitter and receiver are co-located, as is usual for radar scenarios, and 2) the scatterers are located at a great distance from the transmitter/receiver. This allows the bulk of the processing to take place in the Fourier domain and exploit the computational efficiency of the Fast Fourier transform. If the transmitter and receiver are widely separated, the scenario is referred to as bistatic. The equations that describe the range-Doppler history become more complex but Fourier domain techniques may still be applied [4]. In the case of wireless channel sounding from a trackside base station to a high-speed train, however, the combination of the close proximity of the scatterers and the wide separation between the transmitter and receiver make Fourier domain techniques untenable. Instead, a time domain technique called back projection is much more appropriate [5]. Although the computational load imposed by such an approach has historically been daunting, recent advances in GPU co-processing and software technology such as the CUDA API have largely addressed this issue and made this approach quite tractable.

We have demonstrated the validity of the back projection approach by constructing a simulator that transforms a map of scatterers into the range-Doppler information that the receiver would record then applies back projection to reconstruct the map. Our success paves the way for the next steps: 1) Development of a channel sounder suitable for deployment in a high speed rail environment, 2) operation of the instrument during train runs conducted in representative environments and 3) reconstruction of the distribution of scatterers that give rise to multipath propagation in such environments.

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