Modified Quadrature Correlation Delay Estimation for Time Alignment in Distributed Arrays

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We present a new approach for passive time delay estimation between nodes in a distributed wireless system. Coherent distributed arrays are distributed wireless systems that are wirelessly coordinated to enable phase-coherent operation between the nodes. Such systems in the future can be used for surface imaging, soil moisture mapping and other remote sensing applications (Nanzer et al., Open-Loop Coherent Distributed Arrays, IEEE Trans. on MTT, 65(9), 1662-1672, 2017). Coordinated transmission improves transmitted power as well as reduces cost of building a complex and expensive single platform transmitter. The transmit power scales proportionally to the number of platforms squared in a coherent distributed array, meaning that large collections of low-cost platforms can be used to achieve transmit powers equivalent to or greater than that achieved in single-platform systems with potentially lower overall system cost.

In order to achieve sufficient coordination for distributed beamforming, the wireless systems on each platform must be aligned in phase and time. In prior work, we have demonstrated wireless phase alignment using with high-accuracy ranging and wireless frequency transfer. In addition to distributed phase alignment, the waveforms transmitted by each system must also be time synchronous such that the pulses or symbols arrive at the designated location with sufficient overlap. We base our work on the time-stamp free synchronization protocol (Brown & Klein, Precise Timestamp-Free Network Synchronization, CISS 2013), which relies on delay estimates of a pulse exchanged between the physical layer of any two nodes.

While the generalized cross correlation method (Knapp & Carter, The Generalized Correlation Method For Estimation of Time Delay, IEEE Trans. on ASSP, 24(4) 320-327, 1976) is known to improve the peak detection in the presence of uncorrelated noise, refinement techniques such as the quadrature correlation (Li, et. al., A Real-Time Implementation of Precise Timestamp-Free Network Synchronization, ASILOMAR 2015) are better at estimating sub-sampled time delays. Our modified quadrature correlation approach combines the best of both methods for improved delay estimates. This paper is focused on the performance of the modified quadrature correlation delay estimation scheme in various SNR regions. We show that with a sufficient number of channel estimates the mean-square error is several orders of magnitude lower than the Barankin bound and approaches the Cramer-Rao Lower Bound in low to moderate signal-to-noise ratios.