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High Accuracy Decentralized Time Synchronization Using SNR Based Weighting

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***Abstract*—We present a decentralized approach to wireless picosecond-level synchronization of distributed antenna array elements that weights its connections based on the signal-to-noise ratio of the links between nodes. Time synchronization is a critical aspect of distributed phased array performance, and is a principal factor limiting the bandwidth of distributed beamforming operations. We previously demonstrated decentralized synchronization with picosecond-level accuracy using a consensus averaging approach, where nodes iteratively share information among their neighbors to converge to the global average of the time offsets between nodes. Ensuring that all nodes in a distributed array reach consensus on a common time reference depends on the accuracy of the individual links, however, and low SNR links will generate poor time estimates, increasing the residual error of the converged state. Here, we propose a new weighting strategy based on evaluating the SNR in every iteration to allow for time information sharing only between the nodes with highest received SNR. We evaluate the approach experimentally through the implementation of a six-node system using software defined radios (SDRs), yielding in an order of magnitude improvement in accuracy relative to the case of a fully connected antenna array with a static topology.**

I. Introduction

Distributed antenna arrays are of increasing interest in wireless applications due to their potential for improving the performance of sensing, communications, and other wireless applications [1], [2]. Coherent distributed operation in distributed arrays requires accurate coordination of the time, phase, and frequency of the elements of the array. Recent research has focused on the problem of coordinated consensus [3], [4] for network models under the assumption of ideal communication links between the nodes [5]. Generally in these approaches, the signal-to-noise ratios (SNRs) of the links between nodes impacted performance, but the connectivity was constant. Previously, we proposed a method for achieving decentralized time synchronization of distributed antenna arrays using the average consensus method with relatively high SNR characterizing all the links in the network [6].

In this work, we propose a weighting strategy based on modifying the internodal connectivity each iteration by disconnecting the links that have SNR lower than a predefined threshold before constructing the weighting matrix with the properties discussed in [6]. Hence the individual impact of each link on the iteration process can be adjusted with the goal of reducing the residual error after convergence. The algorithm allows dissemination of time information through only those links with high SNR, removing those links that would result in poor delay estimates. Frequency syntonization and participation of all nodes were ensured by retaining at least one link (with sufficiently high SNR) for each node.

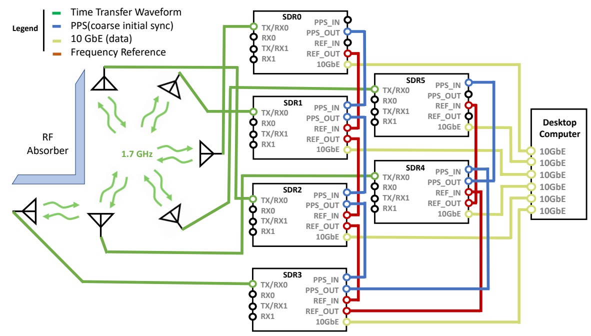

Fig. 1. Experimental setup. The system maintained syntonization through a 10 MHz cabled frequency reference and was initially time aligned to an accuracy of hundreds of nanoseconds using a pulse-per-second (PPS) link.

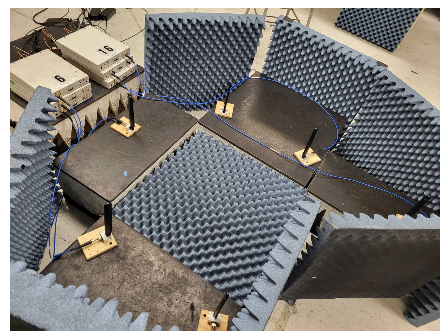

Fig. 2. Photo of the experimental setup. Absorbing material was used to degrade the link between two nodes.

II. Experimental Configuration

The method was evaluated through the implementation of a six-node distributed antenna array using six software defined radios (SDRs). The schematic and setup are shown in Figs. 1 and 2, respectively. Each SDR (Ettus Research X310 with a UBX-160 daughterboard) had a sample rate of 200 MSa/s, and all SDRs were controlled by a single desktop computer using GNU Radio software. Six multiband swivel-mount dipole antennas (SPDA24700/2700) were connected through six foot cables to the SDRs. The antennas were placed at differing separations to introduce variations in the channel SNR values over a range from 15 to 36 dB. A 10 μs two-tone waveform at a carrier frequency of 1.7 GHz and a tone separation of 40 MHz was transmitted between each pair of nodes in the array using a time-division multiplexing (TDMA) method such that only one node transmitted at a time. In this experiment, the system was frequency syntonized through a 10 MHz cabled

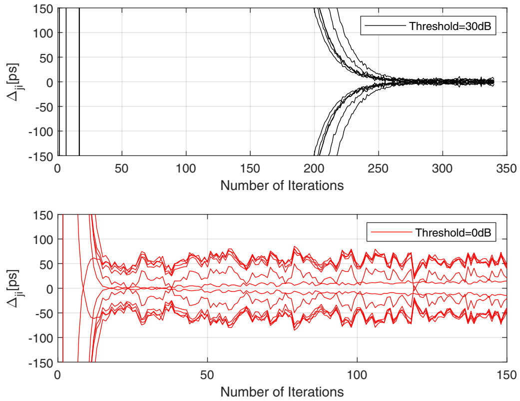

Fig. 3. Time offsets Δ_{ji} between pairs of connected nodes (SNR threshold 30 dB) for a six-node antenna array system. *Top*: Offsets between the nodes with 30 dB SNR threshold, computed over 340 iterations. *Bottom*: Offsets between the same links as in the case of 30 dB threshold, but with 0 dB threshold (fully connected case) computed over 150 iterations.

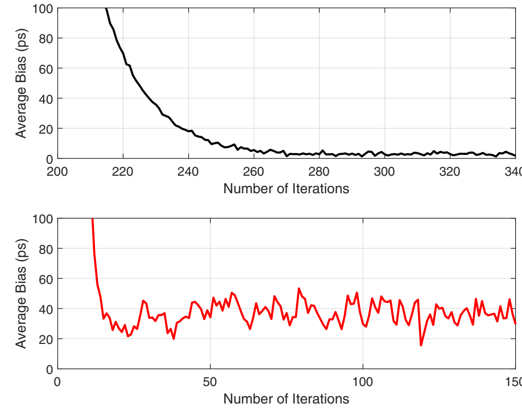

Fig. 4. Average bias for a six-node antenna array system. The decentralized time synchronization algorithm was applied to achieve time synchronization for the six nodes in the system with SNR based weighting. *Top*: Average bias between the nodes with SNR threshold of 30 dB computed over 340 iterations. *Bottom*: Average bias with 0 dB threshold (fully connected case) computed over 150 iterations.

frequency reference daisy chained from node 0 to node 5. In addition, a pulse-per-second (PPS) initial coarse alignment was used once at the start of the experiment in order to align the clocks to within a few clock ticks (thereby producing a time synchronization accuracy of hundreds of nanoseconds) [7]. The experiment was performed multiple times with SNR thresholds 0, 15, 20, 25, and 30 dB. During the first run, the SNR threshold was set to 0 dB to illustrate the case of a fully connected network and to compare its accuracy with that of the new weighting strategy. In each run the SNR values were estimated using the eigenvalue decomposition method, and the weighting matrix was reconstructed during every iteration based on the evaluation of the SNR values.

III. Experimental Results

The time offsets Δ_{ji} between each pair of nodes j and i in the network are presented in Fig. 3 for two cases: weighting with 30 dB threshold, and 0 dB threshold or fully connected network. Only the links with SNR of at least 30 dB are plotted for comparison. Convergence takes longer for the network with 30 dB threshold as time information is disseminated through fewer links. Fig. 4 shows the average bias for the same two cases; the bias decreased from about 50 ps to less than 5 ps under the weighting strategy with 30 dB threshold which represents an order of magnitude improvement in accuracy. Lastly, Fig. 5 presents the average standard deviation computed over 50 iterations while varying the SNR threshold between 15 and 30 dB. The results in this figure suggest an improvement in the average precision with increased SNR threshold, achieving an average precision of around 2 ps with 30 dB threshold. It is seen that the implementation of SNR based weighting strategy accomplishes high accuracy and high precision wireless decentralized time synchronization for a syntonized multi-node distributed antenna array system. This new strategy, while slower to converge than the fully connected network, ensures convergence with less error.

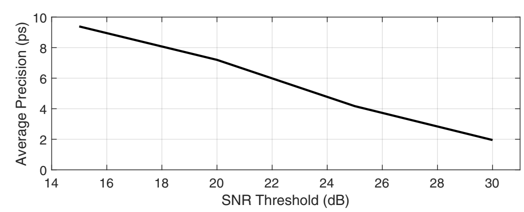

Fig. 5. Average standard deviation computed for 50 samples over a sweep of SNR threshold values (15, 20, 25, and 30 dB).

Acknowledgment

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