High Accuracy Wireless Distributed Coherent Array Synchronization

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***Abstract*—Recent advances in radio frequency (RF) systems and software-defined radios (SDRs) have enabled these arrays to perform fully coherent beamforming operations synchronized in time, frequency, and phase at the wavelength levels at frequencies up to ∼3 GHz. This paper summarizes and highlights the achievements accomplished towards fully coherent distributed antenna arrays and their applications over the past year which have been supported in part by the MTT-S Graduate Fellowship. These results include coherent beamsteering, performance of time–frequency synchronization under non-line-of-sight (NLoS), distributed radar operations, and distributed interferometry.**

***Index Terms*—Distributed antenna arrays, distributed beamforming, networked radar, remote sensing, wireless sensor networks, wireless synchronization.**

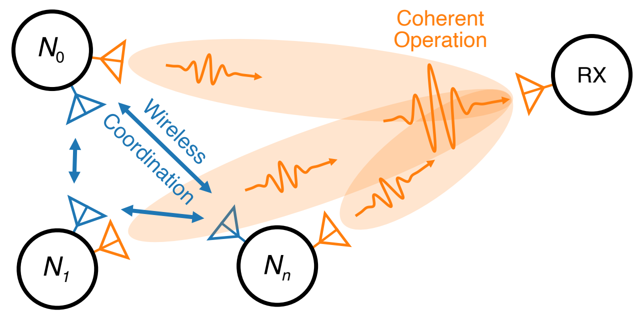

Fig. 1. Conceptual overview of multiple antenna elements in a wirelessly coordinated distributed coherent array beamforming in the direction of a remote receiver node.

I. Introduction

Wireless coherent distributed antenna arrays (CDAs), shown conceptually in Fig. 1, will become a core part of future communication and sensing systems with applications of interest ranging from space-borne observatories [1, TX05.2.6] to airborne 6G communications arrays [2]. However, in order for these arrays to operate coherently, they must be synchronized in time, phase, and frequency to the wavelength level. This requires timing alignment on the order of picoseconds for most waveforms to achieve high levels of coherent gain in the direction of beamforming [3] while carrier frequencies must be stable to below ∼18° [4]. While there has been significant prior work in the area of microwave system synchronization, very few have shown sub-nanosecond timing synchronization using microwave synchronization links. Our work has focused on fully coherent systems aligned to the picosecond-level with carrier frequency synchronization of $< 18°$ at the carrier frequency enabled by our prior works [5], [6].

II. Wireless Distributed Array Performance and Applications

Work supported in part by the fellowship included investigations and demonstrations on distributed coherent transmit beamsteering [7] and non-line-of-sight (NLoS) wireless time–frequency synchronization performance [8] which set the foundation for system-level demonstrations of distributed coherent radar beamforming measurements [9] and distributed interferometric radar for tangential velocity measurement [10].

The results of the distributed coherent beamsteering experiments from [7] are summarized in Fig. 2. This experiment demonstrated the ability of the system to maintain coherence while frequency hopping and steering across multiple frequencies, in this case 3.25 GHz and 3.35 GHz. A constant internode ranging bias was noted of ∼88 mm which was calibrated out in post processing prior to plotting the time of arrival and phase errors in Fig. 2(b). These experiments demonstrated the capability to form and steer a coherent beam in a fully wireless two node array in the 3 GHz band supporting maximum theoretical datarate of up to ∼2 Gbps for BPSK modulation based on the analysis in [3].

Investigations of the NLoS performance presented in [8] are summarized in Fig. 3. In these experiments two nodes were separated by RF absorbing barriers and time and frequency coordination was performed via indirect paths through the environment in scenes both with and without clutter. This experiment demonstrated the ability of the system to perform at up to ∼4.5 Gbps with a carrier of up to 5.7 GHz in the single scatterer scenario, and up to ∼3 Gbps with a carrier of up to 1.4 GHz in the cluttered multipath scenario, indicating that there is degradation in performance for highly cluttered environments; however, the overall system beamforming inter-arrival time standard deviation was still found to be 32 ps, marking an improvement of orders of magnitude over prior works.

Following these characterization experiments, applications using a two-node wireless CDA were demonstrated. The first experiment implemented a fully-wireless distributed coherent beamforming radar demonstration [9] measuring both a static scene and a moving target in a cluttered outdoor environment. The cooperative beamforming sensing results yielded median gains of 2.12 dB with a maximum gain of 2.86 dB, or 96.5 % coherent gain of the ideal summation of the individual power levels received at each element. This was followed by a wire-

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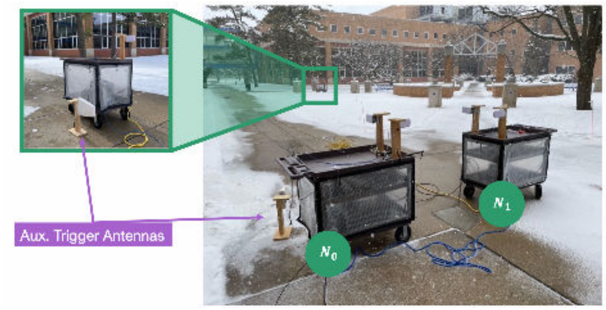
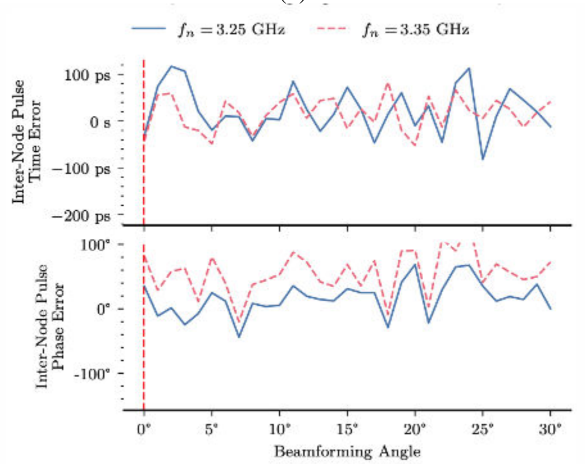
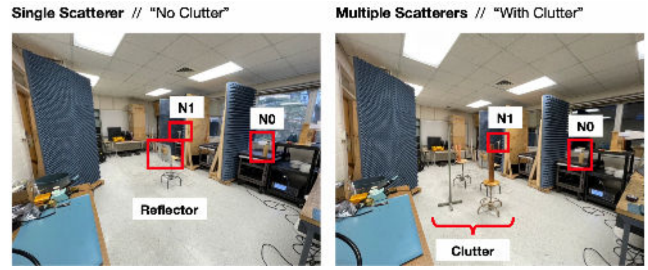


(a)

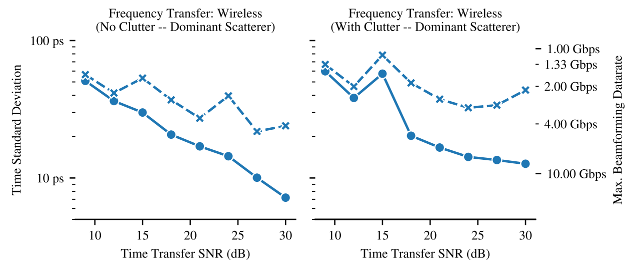


(b)

Fig. 2. (a) Experimental setup of the beamsteering measurements in [7]; inset shows the receiving node with an oscilloscope inside the cart. (b) Internode time and phase errors measured at the target for various beamforming angles after an internode ranging bias calibration was performed; red vertical dashed line shows the angle the receiving node was located at.



(a)



(b)

Fig. 3. (a) Experimental setup of the NLoS measurements in [8]. (b) NLoS time synchronization measurements indicating timing standard deviation and maximum theoretical data rate achievable based on the synchronization level for the estimated time synchronization standard deviation between devices (solid line with • markers) and for the measured inter-channel inter-arrival time of beamforming pulses measured at an oscilloscope connected via cables (dashed line with × markers).

lessly separated two-element correlation interferometer with an active continuous-wave illuminator for measuring angular velocity of tangentially moving objects [10], which will show the ability to measure pedestrians walking tangentially past the array.

III. Conclusion

With the support of the MTT-S graduate fellowship, several experiments validating the performance and practical applications of wireless CDAs have been shown. The results of these experiments have demonstrated the usefulness CDAs and has motivated their consideration for further development and deployment in next generation sensing and communication systems of the future.

IV. Career Plans and Acknowledgement

I am currently considering future career paths both in academia and in industry research roles; however, during the fellowship I have refined my areas of interested focusing in on system software-defined radio networks, digital signal processing, and digital RF system design. In addition, I am grateful for the support provided by MTT-S to attend the International Microwave Symposium (IMS) in San Diego, CA to present our research on wireless CDA coordination [11] and network with other researchers and professionals in the field of microwaves.

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