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Research Statement

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Driven by the scaling of computation at the edge and improved access to low-level wireless front-ends, we are seeing a shift towards a new generation of intelligent software defined radio systems. Wireless signals can now not only be used to transfer data, but can also be used for sensing materials, people, and spaces. My research explores this duality of wireless communication and sensing at the intersection of radio platform design, networking, and signal processing. With the proliferation of mobile and autonomous systems, there is an increased demand for faster, smarter, and more resilient networks that should not only deliver data, but also digitize their environment. This will require new radios, new channel models, new processing pipelines, and high-level management techniques that provide services like synchronization and spatial awareness for distributed coherent combining antenna arrays. My research started off by looking at local area RF sensing (health monitoring applications) and has now expanded towards large-scale wide area systems (smart cities).

My thesis work looked at RF sensing for healthcare applications, like monitoring breathing for opioid patients and in-home elderly care. The key capability in both examples is being able to process low-level RF signals to track motion ranging from macro-movements [SECON '14] to micro periodic changes related to breathing [HotWireless '16]. This required custom hardware and innovative processing on channel state information that culminated in a 20-person clinical trial [Mobicom '18]. I am now expanding upon current radio-based sensing to provide tracking of people in 3D spaces, monitoring of breathing rate, and the ability to infer human gestures. This is challenging outside of extremely controlled lab environments because of the dynamic behavior of the wireless channel and the limited bandwidth and frequency range of current radios. Fortunately, next-generation radio technologies (e.g. mmWave, TV whitespace, WiFi 6GHz spectrum) along with improvements in machine learning are providing access to new channels and frequency ranges that will provide the basis for higher fidelity sensing.

My work has also investigated mechanisms to support time synchronization, which is a core element of distributed wireless systems. In the absence of my faculty advisor (who left for a startup), I assumed responsibility for the University of Utah's portion of an NSF CPS Frontiers grant that investigated more generally the role of timing across the system stack. This gave me a unique early opportunity to build out an RF lab, which we used to produce multiple RF sensing platforms. Most notably, I developed a versatile system that synchronizes the frequencies of low-cost oscillators [Sensys '16, IPSN '18] using common carrier waves while also providing low-level access to channel state information. This platform not only helped support the sensing work in my thesis, but also laid the groundwork that I intend to apply to future wireless distributed MIMO systems and mmWave communication.

During my post-doc at Carnegie Mellon University, I built upon my work in time synchronization by applying it towards indoor device-based localization (as opposed to my earlier device-free work). This entailed designing multiple platforms used for communication and localization in extreme environments. The first was based on a firefighter safety system where the goal was to track people entering a burning structure in real-time. We built a UWB-based peer-to-peer body worn unit that would opportunistically map and localize fixed beacons in the environment and IMU-based odometry. This involved custom hardware and novel filtering and estimation algorithms for pedestrian SLAM. The system won first place at the 2018 Microsoft Indoor Localization competition at CPS Week. I am now building upon this platform in collaboration with Carnegie Mellon University's DARPA Subterranean Challenge team to support communication and localization in underground environments where single-hop RF is obstructed by rock. Networking in extreme environments with autonomous robots leads to questions about how, where, and when physical nodes and data should be routed in order to optimize a variety of mission objectives. You need to be able to estimate and predict the quality of the channel to maintain connectivity and provide adequate geometric dilution of position for localization. We can develop better channel models by capturing the physical topology from a combination of local area sensing and by using new low-cost depth cameras and visual inertial odometry. With the rise of autonomous vehicles, it is only a manner of time before robots play a lead role in managing and optimizing city-scale communication infrastructure.

My most recent work has looked at wide-area communication and sensing applied to low-power wide-area networking (LP-WAN). The goal of LP-WAN is to provide last-hop connectivity to IoT devices that are often battery operated and in remote locations. We leverage the fact that LP-WAN systems are comprised of an abundance of high-powered gateway devices with workloads that, compared to cellular, are forgiving in terms of latency and throughput. We designed a system that uses coherent combining in the cloud to form a massive synthetic antenna that can decode signals that any individual signal base station could not [IPSN '18]. We won best paper for this work that showed we were able to improve coverage by up to 2x and reduce client energy by up to 4x. I am now interested in expanding this approach to distributed MIMO systems. There is also a unique opportunity to expand this approach to support radio-based tomography sensing at city scale for things like snow fall detection, traffic sensing, or micro-weather monitoring.

My research tends to be both applied and geared towards cross-domain problems, where I am fortunate to collaborate with civil engineers, mechanical engineers, medical doctors, and biomedical/mechanical engineers. This work has already been sponsored by a diverse set of sources including NIH, NSF (CPS, SCC, SCH, PAWR), ARPA-E, SRC/DARPA, and industry.

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