Modeling and Mitigating RF Vulnerabilities of Cellular Networks for UAS Communication

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Problem Statement

Unmanned aerial systems (UAS), even when operating autonomously, depend on a pervasive, low-cost, low-latency, resilient communications infrastructure for real-time telemetry (*e.g.,* sensor and video streaming for situational awareness), supervisory command and control and, increasingly, links to cloud services. Single-transmitter networks are suitable for limited, line-of-sight UAS applications, but as operations expand from single vehicles to fleets and swarms operating under non-line-of-sight (NLOS) conditions, the importance of pervasive network coverage grows. Autonomous vehicles need to coordinate with each other (both directly and through the network) for collision avoidance. Piloted vehicles need to relay image and telemetry reliably, and pilot actions need to be relayed flawlessly. Multi-transmitter networks offer clear advantages over single-transmitter networks in meeting these needs. Of the available alternatives, cellular systems seem a good choice. Modulation and coding schemes designed for LTE support both stationary and fast-moving terminals. Network management for cellular systems is very mature. These attributes can in principle benefit both military applications (rapidly-deployable secure cellular networks) and commercial applications (re-purposing and hardening the existing cellular infrastructure for UAS is an economically attractive alternative to building a special-purpose network).

Unfortunately, direct application of cellular technologies and/or networks for UAS is not possible. A key risk remains un-addressed: cellular networks *were not designed with aerial "terminals" in mind.* Network planning, coverage mapping, base station placement and even antenna aiming have all been done on the presumption that the served terminals are on the ground or in buildings. The third dimension has been largely ignored until now.

Our early research into the subject confirms limitations in both the equipment and network deployments. Aerial measurements taken using a purpose-built UAS reveal substantial coverage holes that are, in fact, characteristic of today's equipment and deployments despite a clear line-of-sight between the vehicle and the cellular antenna, even in perfectly flat terrain with no buildings or other obstructions. We call this the *hole-in-the-sky* vulnerability. UAS operations are vulnerable to the extent that holes are unknown or known and not avoided/eliminated. We must view the problem as dynamic and not simply static.

We explore techniques for measuring and modeling the first-order RF propagation effects that bear on UAS communication via multi-transmitter networks. We examine approaches for minimizing the likelihood of loss-of-signal.

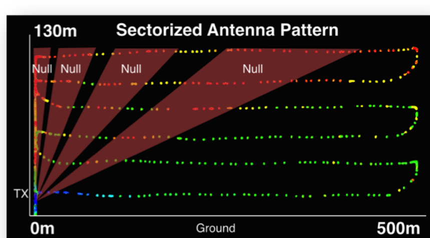

Figure 1: Signal strength from a sectorized antenna. Measured nulls are indicated in red.

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Prof. Bob Iannucci leads the CyLab Mobility Research Center at Carnegie Mellon University. Previously, he served as Chief Technology Officer of Nokia and Head of Nokia Research Center (NRC). Bob spearheaded the effort to transform NRC into an Open Innovation center, creating"lablets" at MIT, Stanford, Tshinghua University, the University of Cambridge, and EPFL. Under his leadership, NRC's previously established labs and the new lablets delivered fundamental contributions to the worldwide Long Term Evolution for 3G (LTE) standard; created and promulgated what is now the MIPI UniPro interface for high-speed, in-phone interconnectivity; created and commercialized Bluetooth Low Energy – extending wireless connectivity to coin-cell-powered sensors and other devices; and delivered new technology initiatives including TrafficWorks (using mobile phones to crowd source traffic patterns), part of the Mobile Millennium Project, Point and Find (Augmented Reality using the mobile phones camera for image recognition and zero click search – identified by MIT Technology Review as one of the TR10 Breakthrough Technologies), and the Morph Concept (identifying opportunities to use nanotechnology to significantly improve mobile phone functionality and usability).

Bob earned his Ph.D. from MIT in 1988, and his dissertation was on the hybridization of dataflow and traditional von Neumann architectures, offering advantages over both. He has served on a number of scientific and engineering advisory boards and was on the program committees for the 3rd and 4th International Symposia on Wearable Computing. Bob also served as a member of the selection committee for the Millennium Technology Prize in 2008.

Bob's group at CMU explores architectures for wireless networks including RF performance in three dimensions, time-awareness in both networking and computation, and the ability to deliver vital services when traditional lifeline systems have failed.