White paper for the
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Background and Experience. My research in sensor networking spans eight years, and has focused on developing the underlying principles, architecture and testbed implementation of a sensor network system consisting of low-power X-band radars that detect and predict hazardous weather via distributed, collaborative, adaptive sensing (DCAS) of the lowest few kilometers of the earth's atmosphere. Such a system find use in many application scenarios including hazardous wind (e.g., tornado) and precipitation sensing, in both resource-rich and resource-challenged environments. *Distributed* refers to the use of a number of small radars, spaced close enough to "see" close to the ground in spite of the Earth's curvature and avoid resolution degradation caused by radar beam spreading. *Collaborative* operation refers to the coordination (when advantageous) of the beams from multiple radars to view the same region in the atmosphere. *Adaptive* refers to the ability of these sensor networks to dynamically reconfigure in response to changing weather conditions and end-user needs. In our NSF ERC for Collaborative Adaptive Sensing of the Atmosphere (where I served as a Co-PI and Associate Director for 6 years, and PI for a semester), we have instantiated the DCAS paradigm in an operational testbed for hazardous wind sensing in southwestern Oklahoma (operational for three years, with end users that include the National Weather Service and emergency response managers), and in a "resource-challenged" testbed in Massachusetts (funded in part by GENI) where low-power radars operate via harvested solar energy and long-distance 802.11 links. The sensor networks I consider are richer in terms of their information, computation, actuation, storage and end-users interactions that more "traditional" mote- or cell-phone based sensors. While my past and current research has taken place in the context of radar-sensing systems, many of the challenges, and solutions we have adopted, are applicable in other sensing environments with actuated sensors (e.g., PTZ camera networks, networks of deployable/controllable sensors).

Participant Vision. The key challenges I have pursued are driven by the need for actuation (closed-loop control) of a sensors than must serve many end-users, based on the needs of these end users. This has led to our developing a utility-based framework in which *multiple* end-user preferences are combined with policy considerations into utility functions that are used to allocate system resources "when and where user needs are greatest." Our ongoing and planned future research includes *(i) Virtualizing DCAS networks*. Here, our efforts are aimed at providing users with the abstraction of a virtualized private sensor network, extending GENI's slice abstraction to include virtualized access/control of sensors and energy harvesting/management, in addition to more conventional resources such as computation, memory, storage, and network bandwidth. Multiple users interact with the sensing system at a detailed, low-level of abstraction, downloading code into network nodes to control the node's sensing, communication, and power resources. The resource allocation problem is particularly rich since network resources allocated to one user group (e.g., to sense a particular portion of the atmosphere) may be of partial utility to others. *(ii) Model-based control of sensing.* At the heart of such any closed-loop observational system is the abstract model used to adaptively steer the system. I am interested in determining the right level of complexity for such a model. For example, simple, parsimonious models may rapidly move from sensed data to an abstract model of detected meteorological features; more sophisticated approaches, however, might maintain a detailed model of the space-time variability, using techniques such a principal component analysis to target sensing resources at fine time and space scale.

Promise of major advances in the field. The need for actuation (closed-loop control) based on context-dependent end-users utility will be central in developing a next generation of cyber-physical sensing systems.

Lastly, I note that I have begun to work with NSF program managers (Sajal Das, Krishna Kant, and Harriet Taylor) on a joint US/India effort that would hold two workshops and develop the foundation for jointly funded Indo-US collaborations in the area of pervasive communications, networking, and computing. I would hope that Workshop on Pervasive Computing at Scale (PeCS) would broaden my research horizons beyond sensor networks, in particular in higher-level (architecturally) aspects of pervasive computing and applications.