Sensor Networks: Introduction

Over the last decade sensor networks have become a discipline in their own right[1]. Several different research areas use the term in different ways, and there is no formal definition of a sensor network -if not given in at least some specificity– that is really useful. There are, however, some common traits that most sensor networks share; for instance, all sensor networks contain nodes with sensor elements that are connected together and share data.

Sensor networks can be analyzed from several perspectives. In the engineering fields, sensor networks are analyzed based on the physics of the sensing elements, the type of information propagated across the network, the topology of the network, and the energy required to perform the sensing and communication operations. Major categories along which sensor networks are evaluated include: transport capacity, correlated traffic, time-varying network topology (mobility), network timing, synchronization, node localization, as well as signal processing methods (distributed and cooperative signal processing).

Possibly the most widely used but least appreciated sensor network in the US and Europe is the electricity grid. Here, structure and dynamics of the networks are linked by intensities, voltages, impedances, but also demand, weather, economics and stakeholder interests and greed. This multi-dimensional linkage makes the electricity grid a particularly complex system, and it should come as no surprise that mathematicians have attempted to analyze the grid and its various failure modes, including blackouts, with tools of complexity theory, resulting in the (less surprising) insight that blackouts occur due to short-term rationality of its designers. Optimization-based design presumes that power engineers make conscious and rational choices to focus resources on preventing smaller and more common disturbances on the lines, and as a result large blackouts occur because (so one group of researchers argue) the grid is not forcefully engineered to prevent them[2].

Arguably the most powerful but least visible sensor network in operation today is the network of satellites circling the globe in various publically known and clandestine orbital configurations. Communication satellites support the backbone of global telephony, television, global radio and military applications[3].

Sensor networks for environmental monitoring have to respond to the fact that environmental processes vary dramatically in space and time. All monitoring systems effectively need to operate at the scale of the observed processes and must be able to integrate larger scale data from multiple sources, including for example maps, aerial photographs and satellite imagery. Also, sensor networks must be designed to withstand harsh conditions, such as extreme temperatures, weather disturbances, pressure changes, or vibration. Meeting all of these requirements can translate into formidable design challenges. Furthermore, sensor networks ‘in the wild’ must deal with limited energy supplies. For this reason, low energy, energy saving and energy harvesting systems are of

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[1] Sadler, M., Fundamentals of Energy-Constrained Sensor Network Systems, 2005.

[2] Rosas-Casals, M, "Power Grids as Complex Networks: Topology and Fragility," Engineering. Complexity in, pp. 21-26, 2010 Complexity in Engineering, 2010.

[3] http://history.nasa.gov/SP-4217/sp4217.htm and http://www.hq.nasa.gov/office/pao/History/satcomhistory.html

great interest. Various projects have investigated solar and wind powered sensor networks and attempted to formalize the design procedures for solar energy networks. This has been a research focus of Scandinavian countries, for example, because solar radiation is severely compromised during the winter months in the northern hemisphere, and any remote sensor network operating with solar energy must take these environmental givens into account from the onset[4]. Energy management issues have also been addressed in recent research into sensor networks for forest fire detection that make use of energy harvested from the natural voltage potential difference between the soil and tree roots to power sensors and communication modules[5].

The types and features of sensors used in sensor networks vary according to the desired data to be collected. What sensor networks can detect is a function of the affordances of the individual sensors as much as the network they are connected by. When sensors can be adjusted and their operational processes modified, a rich domain of sensor-based cognition opens. For example, in radar systems, there is an elaborate interplay between radar operators and radar devices that constitute the knowledge of the radar network. Currently efforts are underway to automate and dynamically adjust radar parameters (such as beam width and power) on both transmit and receive cycles to maximize the extraction of desired information from a scene being surveyed. This might result in radar systems that are similarly adaptable to their environment as the sonar systems of bats and the echo location systems of whales[6]. Similar investigations into *cognitive diversity* and environment awareness have been performed to provide indoor navigation for visually impaired where the missing visual data is replaced by audio cues based on room location and direction of motion[7].

Sensor networks operate not only in the wild, but also where people live and work. Traffic monitoring and traffic flow control are examples of city-wide sensor networks many urbanites take for granted while the ever-growing networks of surveillance cameras continue to irk people, at least for now. The intranets commonly deployed in large corporate and government buildings can also be understood as sensor networks. In particular, healthcare facilities such as hospitals are now heavily invested in sensor network technologies. Some researchers are combining on-body networks that monitor a single patient with building-wide monitoring systems that will redefine the way patients are 'under observation' while in hospital.

A new and important category of sensor networks is the category of variable topology, where the sensor nodes themselves are mobile. This is the case with mobile phone-based sensors, and the location-based data collected from mobile phones has launched a veritable cottage industry of data mining to not only determine location and infer trajectories, but anticipate purchases and – in the case of the reality mining paradigm –

[4] Gakkestad, J., Hanssen, L., Powering Wireless Sensor Networks Nodes in Northern Europe Using Solar Cell Panel for Energy Harvesting, IEEE 2011.

[5] Love, CJ., Zhang S., Mershin A., Source of Sustained Voltage Difference between the Xylem of a Potted Ficus benjamina Tree and Its Soil. PLoS ONE 3(8), 2008.

[6] Baker, C.J., Cognitive diversity sensing, Electromagnetics in Advanced Applications (ICEAA), 2010 International Conference on , pp.875-878, Sept. 2010.

[7] Andò, B., Baglio, S., La Malfa, S., Marletta, V., A Sensing Architecture for Mutual User-Environment Awareness Case of Study: A Mobility Aid for the Visually Impaired, Sensors Journal, IEEE , vol.11, no.3, pp.634-640, March 2011.

infer future behavior patterns[8]. When nodes are mobile they are more difficult to track as they can wander out of range. But they also deliver additional modes of information. For example, mobile nodes that are in the same place at the same time can be used to cross-calibrate a sensor network. This is based on the assumption that identical sensors operating at the same place and at the same time should in principle generate identical readings. Furthermore, mobile nodes allow for *contextualized sensing*. The *rendezvous framework*[9] is a well-studied formal approach used to analyze mobile networks. In mobile network analysis, rendezvous means reaching the critical distance in which data exchange between two networked devices can occur. Understanding the conditions under which rendezvous can occur (or not) also allows sensor network designers to create collaborative networks and fuse data from one source with that of another, for example.

Sensor networks are also of significance in the *Internet-of-Things* (IoT), the attempt to network physical objects across the planet and collect data from these networked objects. Various research groups and industry consortia are working on the infrastructure of the IoT including transmission protocols, data storage, security and information representation. Artists and designers are also considering the potential of the IoT as a way to revitalize cities and as a new public good. One interesting approach to the IoT is the *Pachube* project. This crowd-sourced collection of real-time sensor data from appliances ranging from temperature sensors to alcohol detectors, collected from around the world, is publically accessible, shareable, and encourages collaboration, at least according to the company website[10].

Sensor networks need not be understood as purely technical systems. Sensor networks that combine human and technical communication, are under design by *InSteDD*, an organization that focuses on bridging communication gaps in life-threatening conditions in humanitarian response situations. The InSteDD philosophy is based on a culturally situated approach to communication that combines every communication method known today, from walking, horseback riding, walkie-talkie to mobile telephony and the Internet.

At the local level, InSteDD projects have ranged from implementing an appointment reminder system for HIV/AIDS patients in Cambodia to supporting maternal child health workers in Mexico by offering text-messaging services for vital information exchange with patients. At the policy level, InSteDD are advising organizations like the United Nations, the World Health Organization, and the U.S. Centers for Disease Control on the strategic implementation of health information systems and collaboration technology ventures. InSteDD attempts to ensure that such systems can be managed, financed and maintained by those who use them. This can result in the design of novel interface devices that mediate between the literate world and the illiterate world. For example, the *Reporting Wheel* is a non-electronic device that simplifies data reporting for workers in the field, including those with limited literacy. The Reporting Wheel consists of small cardboard wheels that can encode a series of values or pictograms to report into a number that can be sent in via an SMS, and a backend service that collects the reports and assists a remote administrator in responding to the situation on the ground. InSteDD also considers the economic robustness of its communications systems and works with non-

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[8] http://reality.media.mit.edu/

[9] Honicky, R.J. , Understanding and Using Rendezvous to Enhance Mobile Crowdsourcing Applications, Computer , vol.44, no.6, pp.22-28, June 2011.

[10] https://pachube.com/

profit micro-finance organizations, such as *Grameen Bank*[11] to ensure that the local workers who maintain the networks are paid and can afford to perform the work. As such, InSteDD redefines the idea of robust communication and designs its systems for long term operation in some of the most remote and challenging locations on the planet.

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[11] http://www.grameen-info.org/