NOKIA
Connecting People

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Sensing the World with Mobile Devices

The Vision

We have an insatiable desire to make sense of the world around us. How do we best observe and record the details of time, nature, location, events, and our own personal experiences? How can we understand the interactions among data and utilize them with intelligence and responsibility? To explore these questions, Nokia has spurred an explosion of sensor-based research in which the mobile phone plays a front-line role in sensing, processing, and communicating an array of valuable information.

Humans in the Loop

Until now, sensor-based networks relied primarily on the ubiquitous placement of tiny fixed nodes to report on the physical world. These automatic systems required specially designed hardware, making them expensive and ultimately inflexible. Nokia has shifted the thinking about observational systems by promoting the mobile phone as a vastly more flexible—and broadly available—sensing method.

This device-centric approach quickly leads to a people-centric vision of sensor systems. By putting mobile phones in the hands of human participants, we can take advantage of users as creators, custodians, actuators, and publishers of the data they collect.

That's a good thing, because the physical world contains more sensory data than we can possibly comprehend. Even while moving across great distances, humans narrow down observations via critical decisions, reality checks, and inferences. Which data is important? How much do we need? How can we use the data to tell a better story? Humans make opportunistic choices on the spot, taking into consideration immediate factors not possible using digital methods.

Ecosystem for Data

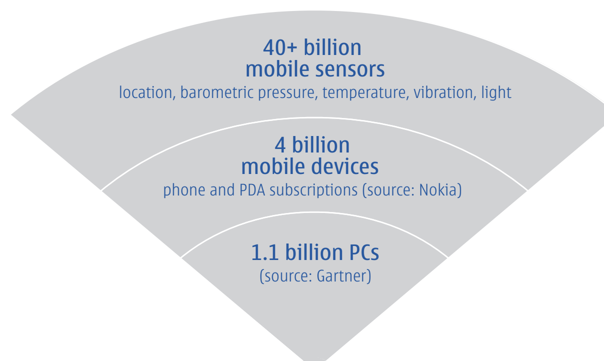
A people-centric sensing network would behave much like a self-organizing organic system, with personal data interplaying in fluid and unpredictable ways with environmental, community, and global data. And since the data is organic by nature, it calls to mind an ecosystem more than an architecture—capable of self-assembling dynamically as the data and its constructs shift and expand.

Nokia is supporting the evolution of these data ecosystems through research partnerships with leading institutions. The goal of this open community is to share data, APIs, architectures, and other innovations—generated through autonomous projects—and translate them into application mashups that benefit individuals, communities, and entire populations.

Sensing and sensors everywhere

As mobile device subscriptions pass the four billion mark, we're looking at the world's most distributed and pervasive sensing instrument. Thanks to an increasing number of built-in sensors—ambient light, orientation, acoustical, video, velocity, GPS—each device can capture, classify, and transmit many types of data with exceptional granularity. The perfect platform for sensing the world is already in our hands.

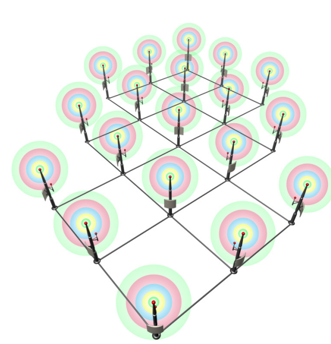
2009 Projection



Human trumps automatic

Unlike the "traditional" embedded sensor model, a device-centric approach gives people the power to choose what to sense and how to modify, enhance, and share the data they collect.

2002	2008
Traditional sensor networks	**Participatory sensing**
Specially designed and deployed hardware	Leveraging available devices
Fully automatic and standalone systems	Humans in the loop
Thousands of small devices	Systems of heterogeneous devices
Fixed, static devices	Total mobility



The Participation

Nokia is working with research partners around the world to drive sensor-based projects that make the most of humans being in the loop. On the one hand, these projects are application specific, working at a local level, sensing things that the participants care about—for example, collecting personal or community data for their direct benefit. At the same time, the projects serve as testbeds for solving large-scale sensor network challenges, such as data analysis and mining, privacy protection, network architectures, and machine learning.

UCLA: Environmental Impact Gets Personal

Researchers at the UCLA Center for Embedded Network Sensing (CENS) have deployed an online tool called Personal Environmental Impact Report (PEIR). With this tool, participants use GPS-enabled phones to regularly and securely upload location data, from which their transportation mode is abstracted and mashed up with GPS data to assess an individual's environmental impact and exposure.

Extending that idea, CENS is teaming with the Go Green Foundation to introduce a similar application to Silicon Valley teens. Equipped with Nokia phones, kids make pledges to change their behavior—for example, to use public transportation or ride their bikes. The application uses sensed data to verify their progress and to share it for fun and competition.

CENS is investigating other grass-roots projects as well in which communities can use everyday mobile phones to observe, document, analyze, and query data—for example, about transit routes or neighborhood walkability—and can communicate the aggregated data to build a case for policy change.

Dartmouth: Sensor-Based Recreation Networking

The MetroSense Project at Dartmouth is exploring novel ways to blend the virtual world and the sensed physical world. In their BikeNet mobile sensing system, bikes are outfitted with custom Tmote Invent motes, and sensor-enabled Nokia phones are attached to cyclists' helmets.

Twenty-five sensors collect data quantifying various aspects of the cycling experience: cyclist's personal data (heart rate, galvanic skin response), cyclist's performance (wheel speed, pedal cadence, frame tilt), and location-specific data (sound level, carbon dioxide level, proximity of cars).

Sensor data is uploaded when the bike comes within radio range of a sensor access point—and can be shared with other cyclists in real time. Sharing also occurs over short-range radio, either directly (bike to bike) or indirectly through neutral storage and aggregation devices.

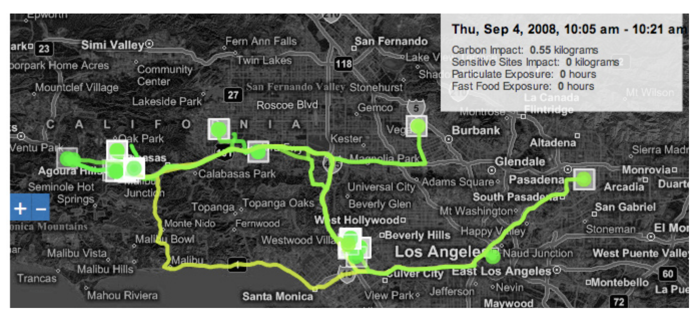
Ecosystem of partnerships

SensorPlanet is a Nokia-initiated research framework for mobile device–centric sensor networks. Through partnerships with research institutions around the world, SensorPlanet supports research into innovative sensing applications.

Testbeds for large-scale participatory sensing solutions

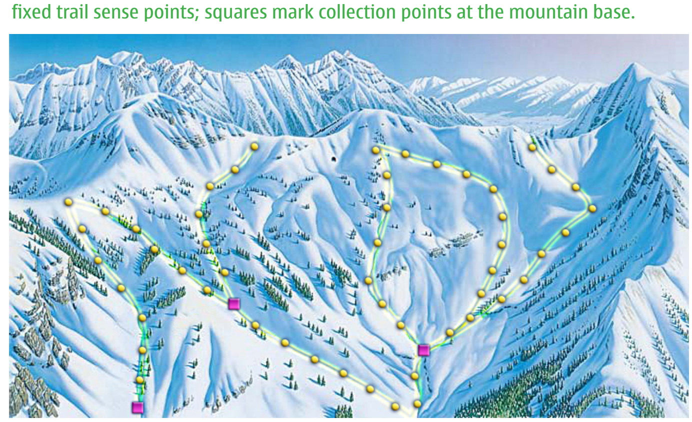
Local/global mashup

PEIR allows users to explore their own activity patterns and how their environmental impact and exposure relate to specific locations. Participants can even share and compare their PEIRs with friends on Facebook.



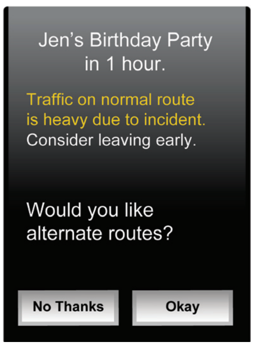
An instrumented SkiScape

Another Dartmouth project, SkiScape, gathers data about downhill trail conditions for immediate feedback to ski resorts and the skier population, while also tracking skier mobility to enable real-time response and long-term trace analysis. Dots mark fixed trail sense points; squares mark collection points at the mountain base.



University of California, Berkeley: Probe Cars for Real-Time Traffic Reports

In early 2008, Nokia, the California Department of Transportation (CalTrans), and UC Berkeley's California Center for Innovative Transportation (CCIT) ran a one-day "100-car experiment" to test how traffic flows can be monitored from mobile phones. Drivers traveled in a loop along a 10-mile stretch of highway throughout the day, as their phones sent periodic speed and location readings. These individual GPS feeds were compiled to create a real-time traffic picture.



Nokia is modeling applications that aggregate real-time traffic data and connect it with the user's current position, calendar, and commute patterns.

The mobile traffic reports were considerably more accurate than those provided by static road-based sensors, at a significantly reduced cost. Additionally, all data transmissions were completely anonymous and encrypted, reducing a potential barrier to adoption.

With congestion causing billions of extra travel hours in the United States alone, the potential impact of this research is great. And since the system can work with the input of 5 percent of drivers on any given highway, we may see real benefits in the not-so-distant future. On November 10, 2008, Nokia launched a much-expanded field test involving 10,000 cars. Called Mobile Millennium, the test expanded across a wider area of Northern California and included the participation of the U.S. Department of Transportation.

MIT: Observing Nature in the Field

The Owl Project at MIT's Media Lab has established a community for interacting with owls in the forests of Maine and Connecticut. Using cell phones equipped with GPS, compasses, and directional microphones, Audubon volunteers can emit a variety of owl sounds and listen to the responding hoots—recording directional, atmospheric, and TDOA (time difference on arrival) data.

The original idea, initiated by visiting MIT professor Dale Joachim, was to use technology to replace on-the-spot human field researchers. But now he sees the advantages of a hybrid approach. For example, people can sense the direction of sounds just by turning their heads—more efficient than using microphone arrays—and can make observations informed by experience. As a result, part of Joachim's research has to do with comparing data collected by technology with data collected by note-taking citizen researchers.

Following on the Owl Project, Joachim has signed up for several international collaborations for observing nature across long distances.

Data ecosystem for local and global mashups

A loose organization of research participants will yield new applications that make sense of the world and its phenomena.

- Mobile devices sense physical data from thousands of content subjects, or act as a gateway to mesh sensor networks.
- Humans in the loop collect, modify, and use the data.
- Innovative research partners manage data collection, processing, and compilation.
- Standard formats and APIs enable data and applications to be shared among partners.
- New facts merge with vastly expanded data and contextual understanding.
- Information can be reassembled organically and visualized in myriad new ways.
- Partners can learn from one another's work in an open source framework.
- Partners can create application and service mashups, as yet unimagined.
- Populations of subscribers can access data through a single user interface.

The vision of ubiquitous human-carried sensor networks challenges the fundamentals of current network technologies. In order to manage transmissions from trillions of sensors collecting vastly varied data (multiplying over many years), the solution must be intelligent, open, modular, and rapidly scalable. Interoperability among devices, systems, and services must be assured, with clear interfaces and boundaries of privacy and security.

Privacy and User Data

Opportunistic people-centric sensing heightens existing concerns about data privacy. Nokia is doing research on various privacy-enhancing technologies. For example, the need to provide sensitive data could be minimized and control mechanisms could be applied on the subsequent usage of the sensitive data. Even as Nokia, UCLA, Dartmouth, and others focus research on privacy-aware architectures that protect sensitive personal information, there persists a slippery notion of data ownership and identity. The interest of Nokia is in opening the debate among policies and viewpoints, toward a common understanding of users' rights to control their data and its use.

Shaping a New Architecture

Interoperability among public, commercial, and user-created sensor networks (and among the sensors themselves) demands a robust, standards-based platform. We imagine an open service architecture—with normalization of data syntax, protocols, sampling, and query models—that blends cloud and client-server computing into a single abstraction layer. As the ecosystem takes shape, with flexible and modular technology assets, Internet-type mashup development can proliferate, along with applications and services that will provide immeasurable value in both established and emerging markets.

Socio-Geographical Networks

A lot of research effort has been devoted to the understanding of social networks. On the other hand, researchers have been trying to understand the mobility patterns of individuals. Together with university partners in Switzerland, Nokia is trying to combine these two aspects, since most of our social interactions still occur in physical proximity.

This paper is provided by Nokia Research Center (NRC) (research.nokia.com). Looking beyond Nokia's current business, NRC engages in open collaboration with consumers and research universities alike, seeking to explore the creative collision between what's valuable and what's possible. For more information about Nokia's research efforts—or to learn about opportunities to join our team—visit research.nokia.com.

Possibilities in a sensor-filled world

Through high-fidelity, real-time observation of the physical world, we can effect positive change across many realms.

- Anticipate and track disease outbreaks across populations
- Ensure compliance and public accountability
- Monitor the health of aging, disabled, and remote individuals and communities
- Protect endangered species and natural resources
- Share real-time data about weather and environmental hazards
- Plan roads, transit services, utilities, and urban systems

For further reading

UCLA: Center for Embedded Networked Sensing
research.cens.ucla.edu

Go Green Foundation
gogreenfoundation.com

Dartmouth: MetroSense
Metrosense.cs.dartmouth.edu

Mobile Millenium
traffic.berkeley.edu

MIT Media Lab: The Owl Project
owlproject.media.mit.edu

Nokia SensorPlanet Project
research.nokia.com/research/projects/sensorplanet

Nokia Research Center: Lausanne
research.nokia.com/research/labs/nrc_pervasive_communications_laboratory

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