Mobile Phone Sensing Systems: A Survey

Wazir Zada Khan, Yang Xiang, *Member, IEEE,* Mohammed Y Aalsalem, and Quratulain Arshad

Abstract—Mobile phone sensing is an emerging area of interest for researchers as smart phones are becoming the core communication device in people's everyday lives. Sensor enabled mobile phones or smart phones are hovering to be at the center of a next revolution in social networks, green applications, global environmental monitoring, personal and community healthcare, sensor augmented gaming, virtual reality and smart transportation systems. More and more organizations and people are discovering how mobile phones can be used for social impact, including how to use mobile technology for environmental protection, sensing, and to leverage just-in-time information to make our movements and actions more environmentally friendly. In this paper we have described comprehensively all those systems which are using smart phones and mobile phone sensors for humans good will and better human phone interaction.

Index Terms—Mobile Phone Sensing, Urban Sensing, Smart Phone Sensors.

Fig. 1.   Areas leveraging Mobile Phone Sensors

I. Introduction

MOBILE phones are ubiquitous mobile devices and there are millions of them in use around the world. Sensors have become much more prevalent in mobile devices over the last few years by incorporating more and more sensor into phones. Mobile phone as a sensor serves to collect, process and distribute data around people [1]. Todays top end mobile phones have a number of specialized sensors including ambient light sensor, accelerometer, digital compass, gyroscope, GPS, proximity sensor and general purpose sensors like microphone and camera. By affixing a sensory device to a mobile phone, mobile sensing provides the opportunity to track dynamic information about environmental impacts and develop maps and understand patterns of human movement, traffic, and air pollution [2]. Researchers and engineers are making efforts in developing new more powerful and constructive applications and systems by leveraging the increasing sensing capabilities found in these sensors based mobile phones. Nowadays smart phones are not only the key computing and communication mobile device, but a rich set of embedded sensors which collectively enable new applications across a wide variety of domains like homecare, healthcare, social networks, safety, environmental monitoring, ecommerce and transportation. The areas which make use of smart phone sensors are shown in Figure 1.

Smart Phones are becoming increasingly successful in the area of health monitoring. The commonality of Health monitoring systems is that they use either in-built sensors
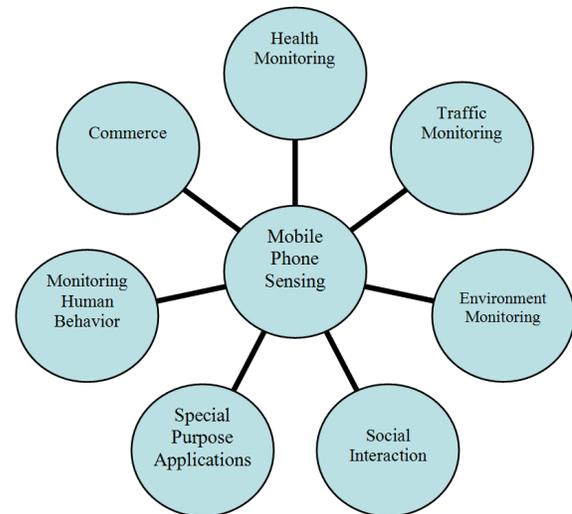
of smart phones, or a combination of biosensors and smart phone sensors for collecting information about persons health like blood pressure, pulse, Electrocardiogram (ECG), Electroencephalogram (EEG) etc, depending upon the system requirements. These systems work in following way: First the data is collected from the sensors and is transferred through wireless transmission using Bluetooth, GPRS, GSM for further processing. Individual mobile phones collect raw sensor data from sensors embedded in the phone including camera, GPS, microphone etc. The information is extracted from the sensor data by applying machine learning and data mining techniques. These operations are performed either directly on the phone or in the central processing unit. After this processing, the data is informed to a medical center or hospital. In some systems the information is used for persuading a person to give attention to his health. These types of systems have proven to be effective in improving health such as encouraging more exercise. Important examples of such health monitoring systems include [3] [4] [5] [6] [7] [8] [9] [10]. Smart phone sensors which provide unprecedented monitoring capabilities are also used for traffic monitoring for example monitoring road and traffic conditions, detecting road bumps, honks, potholes etc. Such traffic monitoring systems include [11] [12] [13] [14] [15]. The field of commerce also leverages the mobile phone sensors like camera, and microphone. Examples of such systems include [16] [17] [18]. Mobile phone sensors are also used for environmental monitoring like pollution, weather and noise monitoring etc. Examples of such systems include [19] [20] [21]. Smart Phones can also be used for modeling and monitoring human behavior [22] [23] and inferring every day human activities like brushing teeth, riding in an elevator,

cooking and driving etc, using supervised learning techniques. Some mobile phone sensing systems are used for special purposes and in these systems only mobile in-built sensors are used, for example in case of document processing systems only mobile in-built sensor i.e., camera is used, in case of individual tracking only GPS is used. Examples include [24] [25] [26].

Smart phones are also used for finding friends and social interactions. Such mobile social networking applications provide many attractive ways to share information and build community awareness. Examples of such systems are [1] [27] [28]. In case of social sensing the information is shared among friends of the social group or community and in personal sensing the information is shared with only the user and not publicly shared for security purposes. As these community sensing systems and applications collect and combine data from millions of people, there is a serious risk of unattended leakage of personal sensitive information e.g users location, users personal health information, speech, or potentially sensitive personal images and videos. Thus, people are very conscious about privacy and security concerns in mobile phone social networking applications. There are some mobile social networking systems including [29] [28] [30] which provide reasonable security and privacy.

Motivations:

The mobile phone is well on its way to becoming a personal sensing platform in addition to a communication device. Sensors are becoming more prevalent in mobile devices in recent years making mobile phone a sensor gateway for the individual. Todays main focus of researchers is on people-centric sensing which shifts important design challenges away from those that apply to static, specialized, highly embedded networks. The increasing interest in people centric sensing and the growing usage of these sensor enabled mobile phones motivates us to do a detailed analysis and bring to light some important existing work in this area.

Our contributions:

- The key contribution is the collection and study of all the mobile phone sensing systems and applications, highlighting the existing work done so far in this field of research. We have enumerated the working and functionality of each system which make use of smart phone sensors and are referenced in the paper.
- The novel contribution is that we have categorized all the urban sensing systems into two broader categories, participatory and opportunistic sensing systems both of which are further subcategorized into three classes namely personal, social and public sensing systems. The area of application of each system is also identified.
- Overall maturity score of all the systems is shown in the form of tables expressing all the technical details regarding all the mobile phone sensing systems.

We hope that this effort will instigate further research on this critical topic encouraging application and system designers to develop valuable and appealing mobile phone sensing systems and also to embed security and privacy features prior to deploying systems.

The rest of the paper is organized as follows: Section II describes Urban sensing and classification of urban sensing systems. Section III and Section IV present a detailed view of all the participatory and opportunistic mobile phone sensing systems respectively. In Section V the existing work in the area of security of mobile phone sensing is discussed. Section VI highlights detailed discussion & research challenges. Finally Section VII concludes the paper.

II. URBAN SENSING

There are many elements that comprise the urban landscape e.g. people, buildings, trees, environment, vehicles etc. Deploying sensors for collecting data from the urban landscape and then make decisions accordingly is called Urban Sensing. Urban sensing is a new approach that empowers all of us to illuminate and change the world around us. The term urban sensing is used because almost all the developed mobile phone sensing systems are being deployed and used in urban areas but it does not mean that they are restricted to urban areas only but they can also be used in rural or any other areas where mobile phone communication system works. Urban sensing can be categorized into two major classes in accordance to the awareness and involvement of people in the architecture as sensing device custodians.

1. Participatory Sensing (User is directly involved)
2. Opportunistic Sensing (User is not involved)

1.Participatory Sensing: In Participatory Sensing, the participating user is directly involved in the sensing action e.g. to photograph certain locations or events. This approach includes people into significant decision stages of the sensing systems, deciding actively what application requests to accept. Through participatory sensing, people who are carrying everyday mobile devices act as sensor nodes and form a sensor network with other such devices. A large number of mobile phones, PDAs, laptops and cars are equipped with sensors and GPS receivers, which are potential candidate devices for participatory sensor nodes [31]. The collection and dissemination of environmental sensory data by ordinary citizens is made possible by using participatory sensing through devices such as mobile phones [32]. It does not require any pre-installed infrastructure.

2.Opportunistic Sensing: In opportunistic Sensing the user is not aware of active applications. He is not involved in making decisions instead the Mobile phone or Smart phone itself make decisions according to the sensed and stored data. Opportunistic sensing shifts the burden of supporting an application from the custodian to the sensing system, automatically determining when device can be used to meet application requests [33]. When we consider different aspects of a person and his/her social setting like where he is and where he is going, what he is doing, what he is seeing, what he eats and hears, what are his likes and dislikes, his health related conditions etc, while developing mobile phone sensing systems then this is called People Centric Urban Sensing. In a people centric sensing system, the focal point of sensing are humans instead of buildings or machines and the visualization of sensor-based information is for the benefit of common
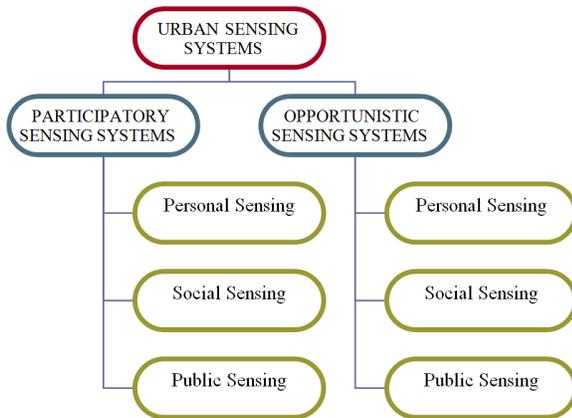
Fig. 2.   Classification of Urban Sensing Systems

citizens and their friends, rather than domain scientists or plant engineers [34]. Furthermore, People Centric Urban sensing is classified into three main groups.

1.Personal Sensing: This type of sensing focuses on personal monitoring. Personal sensing systems monitor or share custodians personal information i.e., the information that the custodian of the sensing device deems is sensitive. Such systems collect custodians information about his/her daily life patterns and physical activities, health (e.g. heart rate, blood pressure, sugar level etc), personal and social contacts and location etc for further processing.

2.Social Sensing: In this type of sensing information is shared within social groups. Social sensing systems collect and share custodians social information with his/her friends, social groups and communities.

3.Public Sensing: In this type of sensing the data is shared with everyone for public good. Public sensing systems collect/sense and share data like environmental data (noise, air pollution etc) and fine grained traffic information (free parking slots, traffic jam information, detecting road bumps and potholes etc) which is beneficial for all the general public.

Figure 2 gives a picture of classification of urban sensing systems. The criteria according to which these urban mobile phone sensing systems are classified is two fold, either the user/custodian of the sensing device (mobile phone, PDA etc) is participating in significant decision stages of the sensing system or he may not be aware of active applications and the system itself takes decisions intelligently without human intervention.

III. PARTICIPATORY SENSING SYSTEMS

So far, many participatory sensing systems have been developed. In this section we have categorized all of them into Personal, Social and Public participatory sensing systems.

A. Personal Participatory Mobile Phone Sensing Systems

The details of personal participatory mobile phone sensing systems are as follows:

1) NeuroPhone: Andrew T. Campbell et al [35] have proposed a system called NeuroPhone, using neural signals to control mobile phones for hands-free, silent and effortless human-mobile interaction.

Until recently, devices for detecting neural signals have been costly, bulky and fragile but NeuroPhone allows neural signals to drive mobile phone applications on the iPhone using cheap off-the-shelf wireless electroencephalography (EEG) headsets. A brain-controlled address book dialing app is used which works on similar principles to P300-speller brain-computer interfaces. The phone flashes a sequence of photos of contacts from the address book and a P300 brain potential is elicited when the flashed photo matches the person whom the user wishes to dial. EEG signals from the headset are transmitted wirelessly to an iPhone, which natively runs a lightweight classifier to discriminate P300 signals from noise. When a persons contact photo triggers a P300, his/her phone number is automatically dialed. The system is implemented using wink and think modes for Dial Tim application.

For evaluation, the authors have tested the wink and think modes in a variety of scenarios (e.g., sitting, walking) using two different Emotiv headsets and three different subjects. The authors have used a laptop to relay the raw EEG data to the phone through WiFi. Upon receiving the EEG data, the phone carries out all the relevant signal processing and classification. The initial results are promising for a limited set of scenarios and many challenges remain unsolved.

2) EyePhone: EyePhone [36] is the first system capable of tracking a user's eye and mapping its current position on the display to a function/application on the phone using the phone's front-facing camera. It allows the user to activate an application by simply blinking at the app, emulating a mouse click. While other interfaces could be used in a hand-free manner, such as voice recognition, the authors have focused on exploiting the eye as a driver of the HPI. The EyePhone algorithmic consist of four phases: The First phase is an Eye detection phase for which a motion analysis technique is applied which operates on consecutive frames. This phase consists on finding the contour of the eyes. The eye pair is identified by the left and right eye contours. The second phase is an open eye template creation phase which creates a template of a user's open eye once at the beginning when a person uses the system for the first time using the eye detection algorithm. The template is saved in the persistent memory of the device and fetched when EyePhone is invoked. The third phase is an eye tracking phase which based on template matching. The template matching function calculates a correlation score between the open eye template, created the first time the application is used, and a search window. The fourth phase is a Blink detection phase in which a thresholding technique is applied for the normalized correlation coefficient returned by the template matching function. The authors have used four threshold values rather than using one threshold value, in order to handle the situation that phone's camera is generally closer to the person's face.

The front camera is the only requirement in EyePhone. EyePhone is implemented on the Nokia N810 tablet and experimental results are presented in different settings. Results indicate that EyePhone is a promising approach to driving mobile applications in a hand-free manner.

3) SoundSense: Hong Lu et al [37] have proposed a system called SoundSense, a scalable framework for modeling sound events on mobile phones. It is implemented on the Apple

iPhone representing the first general purpose sound sensing system specifically designed to work on resource limited phones. SoundSense uses a combination of supervised and unsupervised learning techniques to classify both general sound types (e.g., music, voice) and discover novel sound events specific to individual users. The system runs solely on the mobile phone with no back-end interactions.

SoundSense first senses the data through mobile phones microphone and after that it is preprocessed for segmenting the incoming audio streams into frames and performing frame admission control by identifying when frames are likely to contain the start of an acoustic event (e.g., breaking glass, shouting) that warrants further processing. After preprocessing course category classification is performed through feature extraction, decision tree classification and Markov model recognizer. After this step is complete only features are retained and the raw samples are discarded. All the audio data is processed on the phone and raw audio is never stored. When a new type of sound is discovered, users are given the choice to either provide a label for the new sound or mark the new sound rejected in which case the system does not attempt to classify such an event in the future. The user has complete control over how the results of classification are presented either in terms of being visualized on the phone screen. Then further analysis of sound events is done differentiating between human voice and music. The SoundSense prototype implements a high-level category classifier that differentiates music, speech, and ambient sound; an intra-category classifier is applied to the voice type and distinguishes male and female voices; and finally, the unsupervised adaptive classifier uses 100 bins for the purpose of modeling ambient sounds.

Authors have done implementation and evaluation of two proof of concept people centric sensing applications and it is demonstrated that SoundSense is capable of recognizing meaningful sound events that occur in users everyday lives.

4) CAM: Tapan S. Parikh and Paul Javid [24] have presented a mobile document processing system called CAM in which a camera phone is used as an image capture and data entry device. This system is able to process paper forms containing CamShell programs - embedded instructions that are decoded from an electronic image. The authors have combined paper, audio, numeric data entry, narrative scripted execution and asynchronous connectivity to synthesized their experience into a system that is well-suited for an important set of users and applications in the developing world. Document interaction is specified using CamShell (a narrative document-embedded programming language). For accessing networked information services, CAM unites a user interface, a programming language and a delivery mechanism. The CAM client application is called the CamBrowser, and has currently been implemented for Nokia Series 60 camera phones. CamBrowser is designed to process specially designed CamForm documents. CAM interaction consists of two primitives. The user can either scan codes from low-resolution images taken by the viewfinder in real time, or click codes by taking a high resolution image using the joystick button.

An initial evaluation of a prior version of this system is conducted in rural Tamil Nadu. This helped in identifying the basic usability issues, many of which have been rectified in the current design. The users response to the system was very positive.

5) AndWellness: John Hicks et al [38] have implemented a system called AndWellness which is a personal data collection system. It uses mobile phones to collect and analyze data from both active, triggered user experience samples and passive logging of onboard environmental sensors. AndWellness contains three subsystems: an application to collect data on an Android mobile device, a server to configure studies and store collected data, and a dashboard to display participants statistics and data. This system prompts participants on their mobile device to answer surveys at configured intervals, then uploading the responses wirelessly to a central server. The responses are parsed into a central database and can be viewed by both the researchers and participants in real-time. The end-to-end data collection system also contains three main components: campaigns, sensors, and triggers. Studies can be defined as a campaign which contains a number of surveys, data collection types, and other parameters.

Each campaign can be assigned any number of users, who have roles such as administrator, who can design and edit the campaign, researcher, who can visualize all users data and other statistics from the campaign, or participant, who can upload data but only view their own data and statistics. Campaigns contain surveys and other continuous data collection types or sensors. Sensors allow the researcher to collect continuous data from a participant. Sensors can be sampled at any resolution and provide finer grained detail than prompting the participant for manual data entries. Triggers provide an expressive way to prompt participants by launching surveys based on time, location, or other contextual clues. A researcher can attach a trigger to each survey defined in a campaign.

The AndWellness mobile application is implemented using the standard Android development framework in the Java programming language. The system is designed to ensure that the software has the flexibility to meet current standards of privacy. The privacy of participant data is important to allow users to trust the data collection process. Several focus groups with colleagues are organized to motivate and refine the design of AndWellness and potential studies are also done using AndWellness. These groups include both researchers and potential participants drawn from the intended audience of each study.

6) CONSORTSS: Akio Sashima et al [25] have proposed a mobile sensing platform called CONSORTS-S, that provides context-aware services for mobile users by accessing surrounding wireless sensor networks. This platform provides facilities like communicating to wireless sensor networks via a mobile sensor router attached to a users mobile phone, analyzing the sensed data derived from networks by cooperating with sensor middleware on a remote server to capture ones contexts, and providing context aware services for mobile users of cellular telephones. The platform is designed to process the sensed data effectively through cooperation between a mobile phone, a mobile sensor router, and a sensor middleware SENSORD on a remote server. A mobile sensor router is attached to mobile phones for communicating with surrounding wireless sensor networks, collect and aggregate sensed data, and relay them to the phones. Then, the phones analyze the sensed data

by cooperating with sensor middleware on remote servers, recognize users contexts, and provide suitable services through the mobile phones. The authors have developed the healthcare service as a prototype application of CONSORTS-S which is aware of users conditions such as heartbeat, posture, and movement through monitors of physiological signals (e.g., electrocardiograph, thermometer, and 3-axis accelerometer) and environmental conditions (e.g. room temperatures) by communication with environmental sensors. It monitors users health conditions and room temperatures using a popular 3G phone and wireless sensors. A sensor to monitor physiological signals must be attached to a users chest by sticking electrodes of the sensor on tightly with a peel-off adhesive seal. Once it is attached to a users chest, it can detect the inclination and movement of the upper half of a users body using a 3-axis accelerometer. On the other hand, the sensor to monitor room temperature is set in a room. Sensed data of the device are sent to the mobile phone through the mobile sensor router. The mobile phone shows messages of analytic results of the physiological signals, such as the users posture, and also shows the users health conditions as graphs of the physiological signals, such as electrocardiography. Furthermore, environmental information (e.g. room temperature) obtained using the environmental sensors can be communicated with the mobile phones.

7) SPA: Kewei Sha et al [3] have proposed a smart phone assisted chronic illness self-management system (SPA), which greatly aided the prevention and treatment of chronic illness. The SPA can provide continuous monitoring on the health condition of the system user and give valuable in-situ context-aware suggestions/feedbacks to improve the public health. SPA system consists of three major parts, a body area sensor network to collect biomedical and environmental data, a remote server to store and analyze data, and a group of health care professionals to check records and give health care suggestions. The body area sensor network includes a smart phone, a set of biosensors and a set of environmental sensors. A set of biosensors, such as pulse oximeter, blood pressure meter and activity graph, are attached to participant, periodically sampling the heart rate, blood pressure and movement respectively. In addition, environmental sensors are used to sample sound, temperature, humidity, and light. The communication within the body area sensor network is via Bluetooth. The system is first deployed and then field test is performed on a small sample of urban citizens to ensure its acceptability and functionality. Then the validity of the obtained data is demonstrated by sending to participants brief survey questions via the text option on the cell phone. After sufficient data is collected, the inside rules are mined by cooperating with health care professionals. Finally, the current questions assessed the participants stress, activity, and environment.

8) BALANCE: Tamara Denning et al [4] have proposed BALANCE (Bioengineering Approaches for Lifestyle Activity and Nutrition Continuous Engagement), a mobile phone-based system for long term wellness management. The BALANCE system automatically detects the users caloric expenditure via sensor data from a Mobile Sensing Platform unit worn on the hip. Users manually enter information on foods eaten via

an interface on an N95 mobile phone. The MSP combines an Intel XScale processor with 8 different sensing capabilities including 3-D accelerometer, barometric pressure, light sensors, humidity, sound, and position using a GPS. The unit has modest storage capacity to perform calculations in real time. The inference engine of MSP recognizes when a user is performing gross motor patterns such as sitting, walking, running and bicycling.

The BALANCE system has a mobile phone interface for entering consumed foods, adding custom exercises that are not detected, such as swimming or primarily upper-body movements, and providing a quick summary of the users current food-exercise balance. To support ease of food entry, the BALANCE software consists of two primary food databases. The first is an extensive master database with detailed nutrition information Most people tend to eat a smaller number of foods fairly consistently, so there is an additional personal food database which consists of all foods that the individual user has ever entered. The first time the user eats a food, she is required to search the master database to find the item. The item is then copied into the personal food database, which makes it easier to reenter in the future. The personal food database is also used to store custom entries, such as a favorite brand or flavor of yogurt that may not be in the master database. In addition to being able to search the master and personal databases for foods that have been eaten, the software allows the specification of Favorites. The Favorites list includes both single food items and meals (or recipes) consisting of several food items. The user can construct a common meal such as a typical breakfast of cornflakes with bananas, milk and orange juice and then easily add all or part of the items to her daily food diary. The software offers an interface for adding custom exercise entries that is similar to the food interface as well as a screen for viewing that days detected exercises.

Initial validation experiments measuring oxygen consumption during treadmill walking and jogging have shown that the systems estimate of caloric output is within 87% of the actual value.

9) UbiFit Garden: To address the growing rate of sedentary lifestyles, Sunny Consolvo et al [39] have developed a system, UbiFit Garden, which uses technologies like small inexpensive sensors , real-time statistical modeling, and a personal, mobile display to encourage regular physical activity. It is designed for individuals who have recognized the need to incorporate regular physical activity into their everyday lives but have not yet done so. The UbiFit Garden system consists of three components: first is fitness device which automatically infers and communicates information about several types of physical activities to the glanceable display and interactive application. The second is an interactive application which includes detailed information about the individuals physical activities and a journal where activities can be added, edited, and deleted. The third is glanceable display which uses a non-literal, aesthetic representation of physical activities and goal attainment to motivate behavior. It resides on the background screen or wallpaper of a mobile phone to provide a subtle reminder whenever and wherever the phone is used. UbiFit Garden relies on the Mobile Sensing Platform (MSP). A 3-

week field trial is conducted in which 12 participants used the system and report findings focusing on their experiences with the sensing and activity inference.

10) HyperFit: P. Jarvinen et al [40] have proposed Hyperfit to develop communicational tools for personal nutrition and exercise management. The main result of the HyperFit project is the HyperFit application, an Internet service for personal management of nutrition and exercise. It provides tools for promoting healthy diet and physical activity. The principle of the service is to mimic the process of personal nutrition counseling. It includes self-evaluation tools for assessing eating and exercise habits and for defining personally set goals, food and exercise diaries, and analysis tools. The service also gives feedback and encouragement from a virtual trainer. Recommendations by the Finnish National Nutrition Council are used as the nutritional basis for the service. HyperFit uses a food database that contains the nutritional information on approximately 2,500 foods, either product-specific or average. The products that are not included in the database are replaced with the average foods. Hybrid media and mobile technology are applied to improve the usability and interest to use the system, especially among younger and technically-oriented people. The service can be used both with a mobile phone and a PC. The HyperFit system is integrated with the Nutrition code system by Tuulia International, where the consumer can follow the nutritional quality of his/her food basket in relation to nutritional recommendations. Through the integration HyperFit users get lists of purchased foods to be added to the food diary. A Quick barcode system was built in order to lower the threshold to add food and exercise data to the diaries. With the system users can print lists of barcodes containing favorite foods, exercise activities, common meals and snacks, and then insert them into the diaries with the camera phone. A heart rate monitor is integrated with the system. With a simple interface exercise information can be sent from the heart rate monitor direct to the HyperFit exercise diary. In the project the mobile phone product information service was adjusted for visually impaired people. A beeping sound was added to the barcode reader to give an indication of the reading process. After recognition the product information from the HyperFit web pages was converted to speech in the mobile phone.

11) HealthAware: Chunming Gao et al [5] have presented a novel health-aware smart phone system named HealthAware, which utilizes the embedded accelerometer to monitor daily physical activities and the built-in camera to analyze food items. The system presents the users physical activity counts at real time to remind how much daily activity is needed to keep healthy. The user takes pictures of food items and the system provides health related information regarding to the food item intakes. The system is composed of an on device database which holds the user specific data and food item information. HealthAware consists of four components: user interface , on-device database, physical activity analysis system, and food item classification system. The user interface is simple and easy to use as it includes a monitoring display screen and an interactive window. It displays daily activities in walking steps and running steps, as well as the steps needed to take for the day. It gives the suggested steps to burn the intake food items. It reports when the user takes

the last activity, the users current location and any alarming message generated by the system. The on-device database holds user specific data and general information regarding food items like food names, picture feature data, calories etc. The user specific data includes user physical activity data and food item intake data. The physical activity analysis system works at background to obtain the users physical activity by analyzing the accelerometer readings. The food item classification system is responsible to take a food picture, extract meta data from the picture and index into the database.

12) PACER: Chunming Gao et al [26] have proposed which is a gesture-based interactive paper system and supports fine-grained paper document content manipulation through the touch screen of a camera phone. Using the phones camera, PACER links a paper document to its digital version based on visual features. It adopts camera based phone motion detection for embodied gestures (e.g. marquees, underlines and lassos), with which users can flexibly select and interact with document details (e.g. individual words, symbols and pixels). The touch input is incorporated to facilitate target selection at fine granularity, and to address some limitations of the embodied interaction, such as hand jitter and low input sampling rate. This hybrid interaction is coupled with other techniques such as semi-real time document tracking and loose physical-digital document registration, offering a gesture based command system. PACER is demonstrated in various scenarios including work-related reading, maps and music score playing. The PACER system consists of three bottom-up layers, namely paper document recognition and tracking, command system and applications.

A preliminary user study on the design has produced encouraging user feedback, and suggested future research for better understanding of embodied vs. touch interaction and one vs. two handed interaction.

13) Mobicare Cardio Monitoring System: X Chen et al [10] have presented a cellular phone based online ECG processing system for ambulatory and continuous detection called Mobicare Cardio Monitoring System. It aids cardiovascular disease (CVD) patients to monitor their heart status and detect abnormalities in their normal daily life. This system is a solution to supplement the limitations in conventional clinic examination such as the difficulty in capturing rare events, off-hospital monitoring of patients' heart status and the immediate dissemination of physician's instruction to the patients.

The Mobicare Cardio Monitoring System consists of a cellular phone embedded with real time ECG processing algorithms (MobiECG), a wireless ECG sensor, a web based server, a patients' database and a user interface. The wireless ECG sensor used in this system serves to capture one channel ECG, one 3D accelerometer signal and to transmit those signal data via Bluetooth to cell phones. The key role of MobiECG here is to work as a local processor to process data in real time. It receives ECG and accelerometer data from wireless ECG sensor via Bluetooth, filters the data, detects QRS complex, identifies Q onset and T offset, and calculates intensity of patient's body movement using obtained accelerometer data. A context-aware (patient's activity) ECG processing is carried out by MobiECG and it will send the abnormal ECG data over a cellular network (GPRS/3G) to

hospitals or care centers to alarm physician only when it detects abnormal ECG signal. In order to avoid the continuous transmission of normal ECG data to physicians and to prevent the loading of the telecommunication channel, no ECG data is sent out by MobiECG when abnormality is not detected. The duration of the ECG data forwarded is from a fixed amount of time before the point of detection followed by a similar fixed amount of time after the point of detection. A Web server is set up to receive data from the cellular network and route the data to terminals in hospitals or care centers. The physicians at the hospitals or care centers will examine the ECG data through the user interface and further verify/diagnose whether the patient is at high or low risk, so the hospitals or care centers will act accordingly by sending ambulance immediately or give the patient an instruction through GPRS/3G. A patients' database is developed to record patients' personal particulars, clinical history and all ECG data logs.

To validate the framework, two separate experiments were conducted. The purpose of the first experiment was to validate the correct usage and reliability of the framework under controlled simulated conditions. In the first experiment, it was successfully demonstrated that the signals are only shown on the Mobicare. This demonstrates that the ECG Signal Processing has correctly identified the relevant abnormal conditions and proceeded to forward the detected conditions to the Mobicare Monitoring GUI. The purpose of the second experiments was to validate the feasibility usage on an average person going about his/her daily activities. In the second experiment, the ECG sensor was attached onto a person as a test subject. The test subject was then asked to go through a series of non-strenuous activities like moderate jogging and stair climbing. The ECG signal though received, processed and recorded on the mobile phone was not sent to the Mobicare Monitoring GUI as none of the two alarm conditions are fulfilled. Over all the Signal Processing Program was able to identify correctly under normal circumstances, the ECG signal should not be forwarded.

An overall Maturity Score is produced in Table I for Personal Participatory Systems.

B. Social Participatory Mobile Phone Sensing Systems

The details of social participatory mobile phone sensing systems are as follows:

1) CenceMe: Emiliano Miluzzol et al [28] have presented a system called CenceMe, a personal sensing system that enables members of social networks to share their sensing presence with their buddies in a secure manner. Sensing presence captures a users status in terms of his activity (e.g., sitting, walking, meeting friends), disposition (e.g., happy, sad, doing OK), habits (e.g., at the gym, coffee shop today, at work) and surroundings (e.g., noisy, hot, bright, high ozone). CenceMe injects sensing presence into popular social networking applications such as Facebook, MySpace, and IM (Skype, Pidgin) allowing for new levels of connection and implicit communication between friends in social networks. The CenceMe architecture includes the following components: physical sensors (e.g., accelerometer, camera, microphone) embedded in off-the-shelf mobile user devices and virtual

software sensors that aim to capture the online life of the user, a sensor data analysis engine that infers sensing presence from data, a sensor data storage repository supporting any-time access via a per-user web portal, a services layer that facilitates sharing of sensed data between buddies and more globally, subject to user-configured privacy policy.

The CenceMe system is implemented, in part, as a thin-client on a number of standard and sensor-enabled cell phones and offers a number of services, which can be activated on a per-buddy basis to expose different degrees of a users sensing presence. These services include, life patterns which maintains current and historical data of interest to the user, my presence which reports the current sensing presence of a user including activity, disposition, habits, and surroundings, friend feeds which provides an event driven feed about selected buddies, social interaction which uses sensing presence data from all buddies in a group to answer questions such as who in the buddy list is meeting whom and who is not?, significant places which represents important places to users that are automatically logged and classified, allowing users to attach labels if needed, buddy search which provides a search service to match users with similar sensing presence profiles, as a means to identify new buddies, buddy beacon which adapts the buddy search for real-time locally scoped interactions (e.g., in the coffee shop), and above average, which compares how a user is doing against statistical data from a users buddy group or against broader groups of interest.

Through prototype implementation successful integration is demonstrated with a number of popular off-the-shelf consumer computer communication devices and social networking applications and the evaluation results are promising.

2) DietSense: Sasank Reddy et al [41] have developed a system DietSense to support the use of mobile devices for automatic multimedia documentation of dietary choices with just-in-time annotation, efficient post facto review of captured media by participants and researchers, and easy authoring and dissemination of the automatic data collection protocols. There are four components involved in the DietSense architecture: (1) mobile phones, (2) a data repository, (3) data analysis tools, and (4) data collection protocol management tools. Mobile phones act as sensors, worn on a lanyard around the neck with the camera facing outwards. The phones run custom software to autonomously collect time-stamped images of food choice, as well as relevant context, such as audio and location. To lower the self-reporting burden and increase data integrity, devices implement adaptive data collection protocols for dietary intake, which are created by researchers. A participant data repository receives the annotated media collected by the devices and, via tools like ImageScape, allows individuals private access to their own data for auditing purposes. Participants approve which media and information to share with health care professionals. Data analysis tools, including a more feature-rich version of ImageScape, provide researchers mechanisms with which to rapidly browse the resulting large image sets and code or tag them. Such tools will support assessment of dietary intake for direct communication to the participant and to suggest modification to protocols for data collection. In order to explore the DietSense concept and discover the projects challenges, a series of pilot studies is conducted in

TABLE I
PARTICIPATORY PERSONAL SENSING SYSTEMS

Project Title/ System	Hardware Description	Software Description	Communication Modules	Types Of Sensors	Applications	Area
NeuroPhone [35]	WEEG Headsets, iPhone	Software for Emotivehead sets	WiFi	Biosensor	Dial Time	Special Purpose Application
EyePhone [36]	Nokia N810, Nokia N900	GStreamer SDK, COpen CV	Not Mentioned	Phone's Front Camera	Eye Menu, Car Driver Safety	Special Purpose Application
SoundSense [37]	iPhone	C/C++, Mobile Sensing Platform (MSP)	Not Mentioned	Phone's Microphone	Audio Daily Diary, Music Detector	Special Purpose Application
CAM [24]	Nokia Series 60	CAM Shell (XML)	Bluetooth, WiFi	Phone's Camera	CamBrowser	Special Purpose Application
AndWellness [38]	G1 Mobile Phones	Java 1.6, Apaache Tom Cat 6.0, MySql 5.1, JavaScript, Android OS.	Bluetooth	Phone's GPS	AndWellness application	Special Purpose Application
PACER [26]	HTC Touch Pro cell phone	C++/C#, Windows Server 2003, Windows Mobile 6 Professional SDK	WiFi, GSM Network	Phone's Camera	Mobile Reader Assistant (MRA), PACER Map, Music Scores Playing	Special Purpose Application
CONSORTS-S [25]	Mobile Sensor Router, NTT-DoCoMo OMA N903i, 3G Phone	J2ME CLDC	2.4 GHz ISM band, W-CDMA	wireless sensor, MESI RF-ECG	Healthcare service	Health Monitoring
SPA [3]	Nokia N95-1, Nonins purelight 8000 AA-Wo Adult firger Clip, Noin's Arant 4100 Wriest worn Patient Module.	J2ME, Java MIDP 2.0, Windows XP SP2, S60 Software	Bluetooth, WiFi	Biomedical sensor, Phone's GPS Sensors	Prototype Health Care Suggestions applications	Health Monitoring
BALANCE [4]	Nokia N95, MSP's Barometer, Heart Rate Moni-Device	Not Mentioned	Bluetooth	Phone's Accelerometer, GPS,	BALANCE application	Health Monitoring
UbiFit Garden [39]	MSP Fitness Device, Barometer	MyExperience Framework	Bluetooth	3D Accelerometer	Ubifit Garden's Interactive Application	Health Monitoring
Hyper Fit [40]	Nokia 6630, Polar S625X Heart Rate monitor	JSP, Java Servlet, C, C++, J2EE, HTML, XHTML, UML, Microsoft Windows, Data Access Object (DAO),	GSM, Infrared	Phone's Camera	Hyperfit barcode reader application, Energy Calculator, Food and Exercise Diary	Health Monitoring
HealthAware [5]	HTC Touch Diamond Device	C++, Windows Mobile 6.1 SDK	WiFi, GSM Network	Phone's Camera Accelerometer, GPS Sensor	Obese Prevention application	Health Monitoring
Mobi Care Cardio [10]	Dopod 595, Windows Mobile, 2 electrodes ECG Sensor	O2 Xphone II	Bluetooth, GPRS/3G	Wireless ECG Sensor, Phone's Accelerometer	Mobicare Cardio Monitoring System	Health Monitoring

which students wore cell phones that captured images and other context information automatically throughout the day. The studies suggest the tools needed by a user to choose what data to share and also to help researchers or health care professionals to easily navigate contributed data.

3) TripleBeat: Rodrigo de Oliveira et al [42] have presented TripleBeat, a mobile phone based system that assists runners in achieving predefined exercise goals via musical feedback and two persuasive techniques: a glance able interface for increased personal awareness and a virtual competition. It is based on a previous system named MPTrain and encourages users to achieve specific exercise goals.

It allows users to establish healthy cardiovascular goals from high-level desires (e.g. lose fat), provides real-time musical feedback that guides users during their workout, creates a virtual competition to further motivate users, and then displays relevant information and recommendations for action in an easy-to-understand glanceable interface. TripleBeats software and hardware architectures are based on MPTrains architecture which is a mobile phone based system that takes advantage of the influence of music in exercise performance, enabling users to more easily achieve their exercise goals. TripleBeat system has three main components: first a set of physiological

and environmental sensors (electrocardiogram -ECG- and 3-axis accelerometer), second a processing board that receives and digitizes the raw sensor signals and third a Bluetooth transmitter to get the processed data and send it wirelessly to the Mobile Computing Device (cell phone, PDA, etc.). The Bluetooth Receiver gets the sensed data and makes it available to TripleBeats software, which then processes the raw physiological and acceleration data to extract the users heart-rate and speed. After logging this and other relevant information (e.g. song being played, percentage of time inside the training zone, etc.), the software selects and plays a song from the users Digital Music Library (DML) that would guide the user towards following his/her desired workout: a song with faster tempo than the current one will be chosen if the user needs to speed up, with slower tempo if the user needs to slow down and with similar tempo if the user needs to keep the current pace. TripleBeat adds new functionality to the basic MPTrain for validation of the TripleBeat prototype.

A user study is conducted with 10 runners and it is unanimously preferred over MPTrain by all participants. From the study, it is concluded that TripleBeat is significantly more effective in helping runners achieve their workout goals.

4) PEIR: Min Mun et al [19] have presented the Personal Environmental Impact Report (PEIR) that uses location data sampled from everyday mobile phones to calculate personalized estimates of environmental impact and exposure. PEIR system includes mobile handset based GPS location data collection, and server-side processing stages such as HMM-based activity classification, automatic location data segmentation into trips, lookup of traffic, weather, and other context data needed by the models; and environmental impact and exposure calculation using efficient implementations of established models. It uses mobile handsets to collect and automatically upload data to server-side models that generate web-based output for each participant. It provides web-based, personalized reports on environmental impact and exposure, currently focusing on mobility-related impacts and exposures, using only the commodity sensors built into everyday smart phones. Participants' mobile phones run custom software that uploads GPS and cell tower location traces to a private repository, where they are processed by a set of scientific models. The processing pipeline includes an activity classifier to determine whether users are still, walking, or driving. It then uses both dynamic data sources, such as weather services, and more slowly changing GIS data, for example the location of schools and hospitals, or classes of food establishments to provide other inputs needed for model calculations. In a private user account, the results are presented to participants in an interactive, graphical user interface. Users can share and compare their PEIR metrics to those of other users via a network rankings web page, or via Facebook by running a custom application. One quality that distinguishes PEIR from existing web-based and mobile carbon footprint calculators is its emphasis on how individual transportation choices simultaneously influence both environmental impact and exposure.

PEIR provides users with information for two types of environmental impact, and two types of environmental exposure. Carbon Impact, Sensitive Site Impact, Smog Exposure and Fast Food Exposure. These metrics are selected because of their social relevance, and their ability to be customized for individual participants using time-location traces. Map-matching approach is evaluated with a data gathered from five PEIR users over the course of two hours.

5) MoVi: Xuan Bao and Romit Roy Choudhury [1] have built MoVi, a Mobile Phone based Video Highlights system using Nokia phones and iPod Nanos, and have experimented in real-life social gatherings. MoVi is a collaborative information distillation tool capable of filtering events of social relevance. MoVi it is an assistive solution for improved social event coverage. A Trigger Detection module scans the sensed data from different social groups to recognize potentially interesting events. Once an event is suspected, the data is correlated with the data from other phones in that same group. Confirmed of an event, the View Selector module surveys the viewing quality of different phones in that group, and recruits the one that is best". Finally, given the best video view, the Event Segmentation module is responsible for extracting the appropriate segment of the video, that fully captures the event.

Experiments in real social gatherings, 5 users were instrumented with iPod Nanos (taped to their shirt pockets) and Nokia N95 mobile phones clipped to their belts. The iPods

video-recorded the events continuously, while the phones sensed the ambience through the available sensors. The videos and sensed data from each user were transmitted offline to the central MoVi server. The server is used to mine the sensed data, correlate them across different users, select the best views, and extract the duration over which a logical event is likely to have happened. Capturing the logical start and end of the event is desirable, otherwise, the video-clip may only capture a laugh and not the (previous) joke that may have induced it. Once all the video-clips have been short listed, they are sorted in time, and stitched" into an automatic video highlights of the occasion. The measurements/results are drawn from three different testing environments. (1) A set of students gathering in the university lab on a weekend to watch movies, play video games, and perform other fun activities. (2) A research group visiting the Duke SmartHome for a guided-tour. (3) A Thanksgiving dinner party at a facultys house, attended by the research group members and their friends. Results have shown that MoVi-generated video highlights (created offline) are quite similar to those created manually, (i.e., by painstakingly editing the entire video of the occasion).

An overall Maturity Score is produced in Table II for Social Participatory Sensing Systems.

C. Public Participatory Mobile Phone Sensing Systems

The details of public participatory mobile phone sensing systems are as follows:

1) EarPhone: Rajib Kumar Rana et al [2] have presented the design, implementation and performance evaluation of an end-to-end participatory urban noise mapping system called Ear-Phone. Ear-Phone, for the first time, leverages Compressive Sensing to address the fundamental problem of recovering the noise map from an incomplete and random samples obtained by crowd sourcing data collection. It also addresses the challenge of collecting accurate noise pollution readings at a mobile device. It is used for monitoring environmental noise, especially roadside ambient noise. The key idea is to crowd source the collection of environmental data in urban spaces to people, who carry smart phones equipped with sensors and location-providing Global Positioning System (GPS) receivers. The overall Ear-Phone architecture consists of a mobile phone component and a central server component. Noise levels are assessed on the mobile phones before being transmitted to the central server. The central server reconstructs the noise map based on the partial noise measurements. Reconstruction is done because the urban sensing framework cannot guarantee that noise measurements are available at all times and locations.

The system performance is evaluated in terms of noise-level measurement accuracy, resource (CPU, RAM and energy) consumption and noise-map generation. Extensive simulations and outdoor experiments have demonstrated that Ear-Phone is a feasible platform to assess noise pollution, incurring reasonable system resource consumption at mobile devices and providing high reconstruction accuracy of the noise map.

2) Micro-Blog: Shravan Gaonkar et al [43] have presented the architecture and implementation system, called Micro-Blog. In this system the authors have identified new kinds

TABLE II
PARTICIPATORY SOCIAL SENSING SYSTEMS

Project Title/ System	Hardware Description	Software Description	Communication Modules	Types Of Sensors	Applications	Area
DietSence [41]	Nokia N80, GPS Reciver	Python, MySql, php, XML, Adobe Flash	Bluetooth	Phone's Camera Microphone, GPS	Image Scape	Health Monitoring
Triple Beat [42]	Alivetec ECG, Accelerometer monitor, Andioox SMT 5600, Cingular 2125	Triple Beat Software	Bluetooth	2lead ECG Sensor, 3-axis Accelerometer	TripleBeat software	Health Monitoring
PEIR [19]	Nokia N80, Nokia N95, E71	S60, Windows Mobile (Samsung Black Jack II), Sun Solaris	GSM Network	Phone's GPS	Carbon Impact, Sensitive Site Impact, Smog Exposure, Fast Food Exposure	Environmental Monitoring
CenceMe [28]	Nokia N95, Nokia N5500 Sport, Nokia N80, Nokia N800, Apple iPhone, BlueCel Accelerometer	Python, Symbian OS, Linux OS, MySQl, WEKA Work	GPRS, TCP/IP, Wifi, Bluetooth, GSM	Phone's Camera Microphone, Accelerometer, GPS, Radio, BlueCel Snsor	Bicycling, Weight Lifting, Golf Swing Analysis	Social Interaction
MoVi [1]	Nokia N95, iPod Nanos	Matlab, Google Goggles	Bluetooth, GSM Network	Phone's Microphone, Accelerometer, Camera	Three testing environments, University Students watching Movies and doing other activities in LAB, SmartHome Laboratory, Thanksgiving party	Social Interaction

of application-driven challenges. The authors have described several potential applications that may emerge on the Micro-Blog platform. A localization service is consulted to obtain a reasonable location estimation. Even when GPS is available, its continuous use may not be energy-efficient. Hence, the localization service selects one among several localization schemes (WiFi, GSM, GPS, or combinations thereof) that meet the applications accuracy/energy requirements. The location-tagged blog is transported to an application server over a WiFi or cellular connection, which in turn forwards it to a back-end database. The blogs are organized/indexed appropriately, based on blog originators, access permissions, themes, or other keys. When a client wants to access a microblog, it contacts a web server to retrieve it. The web server provides only those blogs that the user has permissions to access. Phones periodically update the Micro-Blog server with their own locations, which maintains per-phone location in its localization database. When a user sends a query to a specific region, R, the server first determines if the query can be serviced from the database of blogs. If feasible, the server retrieves all microblogs that match the time, location, and permission attributes, and returns them to the user in reverse chronological order. Otherwise, the server selects phones located in the region R (that have declared themselves available) and forwards the query to them. Phones that arrive later at R also receive the query. When some phone responds to this query, the response is linked to the query and placed on the map as a new, interactive microblog. Queries are active for a pre-specified lifetime, configured by its originator. Upon expiry, they are removed from the server. Data from phones is received at a Micro-Blog application server. The server accepts TCP connections from phones, and forwards all received data to a back-end database server. Depending on whether the data contains blogs, localization information, or user profile configuration, it is appropriately stored in relational tables.

It is implemented on Nokia N95 mobile phones, and it was distributed to volunteers for real life use. Feedback from users was promising which has suggested that Micro-Blog can be a deployable tool for sharing, browsing, and querying global information.

3) V-Track: Arvind Thiagarajan et al [12] have proposed a system called VTrack for travel time estimation using this sensor data and it addresses two key challenges: energy consumption and sensor unreliability. While GPS provides highly accurate location estimates, it has several limitations and considering those limitations the authors have proposed that VTrack can use alternative, less energy-hungry but noisier sensors like WiFi to estimate both a users trajectory and travel time along the route. VTrack processes streams of time stamped, inaccurate position samples at time-varying periodicity from mobile phones. It uses a Hidden Markov Model (HMM) to model a vehicle trajectory over a block level map of the area. VTrack performs map matching, which associates each position sample with the most likely point on the road map, and produces travel time estimates for each traversed road segment. VTrack provides real-time estimates recent to within several seconds to users. It also compiles a database of historic travel delays on road segments.

The authors key contribution is an extensive evaluation of VTrack on a large dataset of GPS and WiFi location samples from nearly 800 hours of actual commuter drives, gathered from a sensor deployment on 25 cars. The data was gathered from two sources: an iPhone 3G application, and from embedded in-car computers equipped with GPS and WiFi radios. It is shown that VTrack can tolerate significant noise and outages in these location estimates, and still successfully identify delay-prone segments, and provide accurate enough delays for delay-aware routing algorithms. The best sampling strategies have been studied for WiFi and GPS sensors for different energy cost regimes.

4) TraffiicSense: Prashanth Mohan et al [13] have presented TrafficSense to monitor road and traffic conditions in a setting where there are much more complex varied road conditions (e.g., potholed roads), chaotic traffic (e.g., a lot of braking and honking), and a heterogeneous mix of vehicles (2-wheelers, 3-wheelers, cars, buses, etc.). TrafficSense performs rich sensing by piggybacking on smart phones that users carry around with them. The focus is specifically on the sensing component, which uses the accelerometer, microphone, GSM radio, and/or GPS sensors in these phones to detect potholes, bumps, braking, and honking. TrafficSense addresses several challenges including virtually reorienting the accelerometer on a phone that is at an arbitrary orientation, and performing honk detection and localization in an energy efficient manner. The idea of triggered sensing is also used in this system, where dissimilar sensors are used in tandem to conserve energy. The authors first contributions is that, they have developed algorithms to virtually reorient a disoriented accelerometer along a canonical set of axes and then use simple threshold-based heuristics to detect bumps and potholes, and braking. Secondly they have used heuristics to identify honking by using audio samples sensed via the micro- phone. Third is the evaluation of the use of cellular tower information in dense deployments in developing countries to perform energy-efficient localization and finally triggered sensing techniques are used wherein a low-energy sensor triggers the operation of a high-energy sensor.

The system is evaluated to calculate the effectiveness of the sensing functions in TrafficSense based on experiments conducted on the roads of Bangalore, with promising results

5) MobileMillennium: Mobile Millennium [14] is a pilot project of such a technology which allows the general public with supported devices to participate. Its relevance for urban traffic and travel in urban environments is of specific interest, since it potentially will be able to unveil traffic patterns previously unobserved with dedicated monitoring infrastructure. The aim of Mobile Millennium is to estimate traffic on all major highways in and around the target area, as well as on major arterial roads. The system architecture consists of a physical component: GPS-enabled smart phones onboard vehicles (driving public), and three cyber components: a cellular network operator (network provider), cellular phone data aggregation and traffic service provision (Nokia/Navteq), and traffic estimation (Berkeley/Navteq). On each participating mobile device (or client), an application is executed which is responsible for collecting traffic data through a privacy aware spatial sampling technique based on Virtual Trip Lines (VTLs) and displaying the current traffic estimates which are produced from the aggregate data of all participants. A back end server aggregates data from a large number of mobile devices and pushes the data to UC Berkeley estimation engine for data assimilation, which combines the cell phone data with other information such as loop detectors to produce the best estimate of the current state of traffic. The map data server provides the Navteq Navstreets digital map data which is required for the network based traffic flow models. Multiple estimation algorithms are run in parallel as part of ongoing research, including arterial traffic models.

6) TARIFA: Georgios Adam et al [15] have proposed a system called TARIFA (Traffic and Abnormalities Road Instructor For Anyone) that estimates road traffic as well as road abnormalities, and makes the collected information available to anyone that has Internet access. This system is capable of spotting potholes and can also provide information for the traffic using the GPS receiver. The architecture of the system consists of two independent parts. A smart phone that is equipped with an accelerometer and a GPS receiver is placed inside a car. There is also a local database for the temporary storage of data. Every second the cars location is estimated by the GPS. In the same time, the decision of whether a pothole is present is taken consulting the accelerometers indication. This piece of information is then stored in the local database. Then the data is sent to the main server where the central database is hosted. Using Open Street Maps a user interface is provided with a marker for every pothole. The amount of traffic is indicated by differently colored segments of streets. Low traffic is presented using green lines, medium traffic with yellow lines and high traffic with red lines. A very simple yet effective heuristic algorithm is used to detect potholes and other surface abnormalities.

The system is implemented on a smart phone connected with a GPS device, where the information is stored and processed in order to be visible to Internet users. The system, periodically, attempts to establish a connection with the server in predefined time gaps. Timeouts are also used for this purpose in order to prevent the blocking of the connection. When the connection is established the smartphone side sends its ID to the server and gets the unix timestamp with most recent value that is stored in the TARIFA server.

7) LiveCampare: Linda Deng et al [16] have presented LiveCampare that leverages the ubiquity of mobile camera phones to allow for grocery bargain hunting through participatory sensing. The authors have utilized two-dimensional barcode decoding to automatically identify grocery products, as well as localization techniques to automatically pinpoint store locations. LiveCompare assumes that each participating grocery-store shopper has a camera phone with Internet access. The participants use their camera phones to snap a photograph of the price tag of their product of interest. From the photograph, the users phone extracts information about the product using the unique UPC barcode located on the tag. In most grocery stores, price-tag barcodes are identical to the barcodes on the actual products and facilitate global product identification. Once the barcode has been decoded on the device, the numerical UPC value and the just-taken photograph are transferred to LiveCompares central server. This data is stored in Live- Compares database for use in future queries, and the UPC value determines the unique product for which price comparisons are requested. The client also sends its GPS or GSM cell information to the server so that the current store can be identified. This location information allows LiveCompare to limit query results to include only nearby stores (where a distance threshold may be set by the user). To ensure data integrity, LiveCompare provides high-quality data through two complementary social mechanisms. First, LiveCompare relies on humans, rather than machines, to interpret complex sale and pricing information.

The only part of a price tag that must be interpreted by a computer is the barcode to retrieve a Universal Product Code (UPC). Because of this, LiveCompare does not need to rely on error-prone OCR algorithms to extract textual tokens or on linguistic models to make sense of sets of tokens. Second, each LiveCompare query returns a subset of the data pool for a user to consider. If an image does not seem relevant, the user can quickly flag it. This allows users to collectively identify malicious data. If a particular user is found to be the owner of several suspicious entries, he may be banned. The primary drawback of LiveCompares architecture is that it does not scale down well i.e., when few queries have been submitted, query results are unlikely to be helpful. To cope with this issue, LiveCompare can fall back on existing price pools such as online grocery stores and drugstores to provide comparisons when data is scarce.

To determine the usefulness and feasibility of LiveCompare, field work is conducted in seven different brick and mortar stores throughout Durham, North Carolina. It is shown that price dispersion can be observed across a variety of grocery items, that typical store price tags contain sufficient information to enable LiveCompares infrastructure, and that data transfer performance is reasonable over an HSDPA network.

8) MobiShop: MobiShop [17] a novel people-centric application is presented which facilitates sharing of product pricing information amongst consumers. This system is implemented on an off-the-shelf Nokia N95 mobile phone and it has two principal modes of operation: product price and user query. To contribute information, the user captures a digital image of the store receipt, which lists the products and corresponding prices using the mobile phone camera. MobiShop implements Optical Character Recognition (OCR) on the mobile device to extract the pricing information from the image. The products and prices are uploaded along with the GPS (Global Position System) coordinates of the user and the time of purchase to the central server. The server collates the user inputs and maintains an updated repository of the product prices at different stores. This database is interfaced to a GIS (Global Information System) street map populated with store locations. In the query mode, a MobiShop user can request for the prices of a particular product in her neighborhood. The query sent to the server includes the GPS location of the user. The server replies back with a list of the stores featuring this product along with their prices in the vicinity of the user.

9) PetrolWatch: PetrolWatch [18] is a system which automatically collects fuel prices using camera phones. This system is implemented as a client-server program and has two principal modes of operation: fuel price collection and user query. The fuel price collection is completely automated and only requires the camera phone to be mounted on the dashboard, with the camera lens pointing towards the road. The system automatically triggers the mobile phones to photograph the roadside fuel price boards when they approach service stations. Sophisticated computer vision algorithms are used to scan these images and retrieve the fuel prices. To deal with a non-structured environment, and to reduce computer vision complexity, it relies on the GIS database and GPS location to know the service station brand and uses the fact that each brand uses a specific color for its price board. The metadata

(location coordinates, brand and time) are extracted and stored separately. The images and fuel brand data are passed on to the image processing engine, which is implemented on the mobile phone. The first step detects the existence of a fuel price board. For each fuel brand, a tailored color thresholding is employed that can capture regions within the images, having a color scheme similar to the fuel brand price board. In certain situations, surrounding objects in the image may have colors resembling the board, e.g. the blue sky may be similar to the Mobil price board. In this case, post processing techniques are used to narrow the search. The price board dimensions are used to exclude some of the candidate regions selected by color thresholding. This is further refined by comparing the color histogram of all candidate regions with that of a sample price board image. The image is cropped to contain only the board, and normalized to standard size and resolution. The color image is converted to binary and connected component labeling is used to extract the individual numeral characters. A Neural Network algorithm is used to classify the digits. The extracted prices are uploaded to the server and stored in a database, linked to a GIS road network database populated with service station locations. The server updates fuel prices of the appropriate station if the current price has a newer timestamp. History is also maintained to analyze pricing trends.

10) Learmometer: Laermometer [21] is developed to solve the problems of creating noise maps by utilizing mobile phones and their built-in microphones. Laermometer consists of two main parts. The first one is a mobile phone application, which is responsible for the sound recording and provides functionality like different visualization of sound points, administrating comments, viewing the noise maps at different points of time via the timeline etc. The second one is the server that is used to store, upload and retrieve sound points.

The main functionality is to provide noise information for any place in the world. Users can add further information like a noise description or comments about the location and its sound level. Every user can view the noise maps and comments, anywhere using their mobile devices. The basic idea of Laermometer is to use mobile phones to create so-called noise maps. Noise maps visualize differences in noise levels of different areas. The Laermometer concept of creating noise maps is based on using the built-in microphones of mobile phones to collect the required data to create noise maps. In order to get exact current position of the device GPS modules of the mobile phone (either built-in or external) are used. The next step is to analyze the sound level of the environment, so, the microphone of the mobile phone is used. Now, with these two types of information, so-called sound level points are created. To combine sound levels with GPS coordinates, Laermometer utilizes geo-tagging which is commonly used to enhance maps with additional useful information. The Laermometer concept has two main advantages compared to the usual approaches: Firstly, it is based on real recorded sound levels and thus more precise than modeling based systems. Second, no extra costs despite the internet connection are generated, because already existing hardware the users mobile phones is used. Laermometer automatically does everything to analyze the sound level and upload it to the

server. Only comments have to be uploaded actively by the users. The evaluation of this system is not yet performed but for this, a user study is planned. Participants will be equipped with Laermometer enabled devices and given some specific tasks over a period of several days (or weeks). This is done to gather qualitative information about the system and to find further enhancements.

11) MobGeoSen: Eiman Kanjo et al [44] have developed a system called MobGeoSen which enables individuals to monitor their local environment (e.g. pollution and temperature) and their private spaces (e.g. activities and health) by using mobile phones in their day to day life. The MobGeoSen is a combination of software components that facilitates the phone's internal sensing devices (e.g. microphone and camera) and external wireless sensors (e.g. data loggers and GPS receivers) for data collection. It also adds a new dimension of spatial localization to the data collection process and provides the user with both textual and spatial cartographic displays. While collecting the data, individuals can interactively add annotations and photos which are automatically added and integrated in the visualization file/log. This makes it easy to visualize the data, photos and annotations on a spatial and temporal visualization tool. In addition, the authors have presented ways in which mobile phones can be used as noise sensors using an on-device microphone.

In order for the phone to simultaneously collect sensor data from the datalogger and location from GPS, an advanced component was developed which establishes multiple Bluetooth device connection and communicates over those connections. Bluetooth GPS and datalogger act as slaves and wait for other devices such as the mobile phone to connect to it. Once the connections are established, messages can be sent from the master device to the connected slaves to start reading data. The sound sensor application turns the mobile phone into a low-cost data logger for monitoring environmental noise. The software combines the sound data with the external GPS receiver data in order location data in order to generate a map of sound levels encountered during a journey. The software prompted the users to add geo-coded annotations and place marks during their journey. Images could be embedded in the data log with no further action required.

In order to demonstrate the domain and use of MobGeoSen kit ,the project worked closely with science teachers and children at two schools. Sixty pupils involved in the project were given mobile phones to monitor pollution levels on their journey to and from school over two weeks. Results of Google Earth analysis of the sessions and teacher interviews suggest that this context inclusive approach is significant.

12) NoiseTube: NoiseTube [20] is a new approach for the assessment of noise pollution involving the general public. The goal of this project is to turn GPS-equipped mobile phones into noise sensors that enable citizens to measure their personal exposure to noise in their everyday environment. Thus each user can contribute by sharing their geo-localized measurements and further personal annotation to produce a collective noise map. NoiseTube consists of an application that the users must install on their smart phones and a server collecting, analyzing and visualizing the information sent from the phones. The mobile sensing application runs on GPS-equipped mobile phones. This application collects local information from different sensors (noise level, GPS coordinates, time, user input) and sent them to the NoiseTube server. The server centralizes and processes the data sent by the phones. Although untested, many other phone brands and models are supported as well, as long as the device supports the Java J2ME platform, with multimedia and localization extensions.

13) Citizen Journalist: Citizen Journalist [45] is an application inspired by Micro-Blogs and involves participatory sensing, wherein PRISM provides location-based triggers to alert human users, who are in the vicinity of a location of interest, to respond to the application. Responses could take the form of answering simple queries, taking pictures of interesting events, etc. Such an application could be used, for example, by small news organizations to collect information for particular events of interest. In this context, two types of application requirements exist. Firstly the critical queries where fast response to application queries is necessary (e.g., someone reports an accident and the news organization requires a citizen to take a photograph of the scene). Secondly the queries that are not latency sensitive but may need answers from areas that are sparsely populated (e.g., someone writing an article about the condition of school buildings in remote villages and requires a recent photograph of the same). The application requests PRISM to deliver the sensing task to a certain number of camera-equipped phones in the vicinity of the desired location. The location is specified by (lat, long) and includes a coarse radius for deployment and a fine radius for actual execution. If matching phones are not readily available, PRISMs trigger mechanism is used to deploy at the location as and when PRISM clients register/send updates from the desired location.

The citizen journalist application was deployed on a small-scale using ten volunteers. The volunteers were given windows mobile phones with GPRS (2G) data subscription and they carried the phones whenever they left work (e.g., to go home or for walks). A total of 30 locations of interest was identified in an area of few square kilometer in the vicinity of the Microsoft Research India lab in Bangalore. Custom tasks seeking responses from users at these locations, were generated periodically by the application server and sent to the PRISM server for deployment. For example, a task would ask the user how heavy the traffic is at an intersection and also ask them to optionally take a picture. Given that the speed limit in the area of interest was 30kmph and many volunteers used the system at walking speeds, a fine-grain radius of 30m and a coarse-grain radius of 75m were chosen for vast majority of the tasks. These choices ensure a high application launch success rate with ample notification time based on the micro-benchmark results reported earlier.

14) Party Thermometer: Party Thermometer [45] is an application which is also a human-query application, where queries are directed to users who are at parties. For example, a query could be how hot a particular party is. Like in the citizen journalist application, location is a key part of the predicate used to target the queries. However, unlike in the citizen journalist application, location alone is not enough for targeting because there is a significant difference between

a person who is actually in a party and a person who is just outside, possibly having nothing to do with the party. Thus, in addition to location, (party) music detection is also employed using the microphone sensor to establish the users context more precisely. The location predicates used in the party thermometer application must be more precise than, say, in the citizen journalist application since the application has to perform an energy intensive activity (detecting music through microphone sensing) before even determining whether to involve the user. To enable a precise fine-grain predicate, the location of the party down to a building is chosen as the top-level predicate and further require that the phone be stationary (e.g., within the building) before deploying applications to the phone. Once the application is deployed, the second level predicate requires music to be heard for the application to launch, thus ensuring that the user is prompted only when he is present in the party. To detect music, one simple heuristic is to perform a Fast Fourier Transform (FFT) of the audio samples and examine the spikes in the frequency domain for harmonics. Since, this operation is required to be done efficiently, an off-the-shelf efficient FFT code written in C is used to build a dynamic linked library that is downloaded with the party application.

D. Hybrid Participatory Mobile Phone Sensing Systems (containing personal, social and public sensing elements)

The details of Hybrid participatory mobile phone sensing systems are as follows:

1) BikeNet: Andrew T. Campbell et al [46] have presented BikeNet, a mobile sensing system for mapping the cyclist experience. BikeNet is built leveraging the MetroSense architecture to provide insight into the real-world challenges of people-centric sensing. It uses a number of sensors embedded into a cyclists bicycle to gather quantitative data about the cyclists rides. It exploits dual-mode operation for data collection, using opportunistically encountered wireless access points in a delay-tolerant fashion by default, and leveraging the cellular data channel of the cyclists mobile phone for real-time communication as required. BikeNet also provides a Web-based portal for each cyclist to access various representations of her data, and to allow for the sharing of cycling-related data (for example, favorite cycling routes) within cycling interest groups, and data of more general interest (for example, pollution data) with the broader community. Sensors collect cyclist and environmental data along the route. Application tasking and sensed data uploading occurs when the sensors come within radio range of a static Sensor Access Point (SAP) or via a mobile SAP along the route. Sensed data mulling can occur when cyclists come within mutual radio range. Data is collected about the cyclist (heart rate, galvanic skin response), about the cyclists performance (wheel speed, pedaling cadence, frame tilt, frame lateral tilt, magnetic heading), and about the cyclists surroundings (sound level, carbon dioxide level, cars). Characteristics of this system include: Cyclist Performance/Fitness Measurement, Environment/Experience Mapping, Long-Term Performance Trend Analysis, Data Collection and Local Presentation, Data Query and Remote Presentation, Disconnected Operation. Existing technologies such as SSL or IKE are used as appropriate to provide for data security. Several groups of experiments are performed targeting at: quantifying the cyclist experience from sensed data collected about a single cyclist and his environment; looking at performance aspects of key BikeNet subsystems; and measuring the real-time performance of a deployed system across the Dartmouth campus and in adjacent areas of the town of Hanover, NH, USA. Initial results are encouraging.

2) MPCS: Mobile-phone based Patient Compliance System (MPCS) [9] is proposed that can reduce the time-consuming and error-prone processes of existing self-regulation practice to facilitate self-reporting, non-compliance detection, and compliance reminders. The novelty of this work is to apply social behavior theories to engineer the MPCS to positively influence patients compliance behaviors, including mobile-delivered contextual reminders based on association theory; mobile-triggered questionnaires based on self-perception theory; and mobile enabled social interactions based on social-construction theory. The self-regulation approach is described which is used for patient centered chronic illness care. A self-regulation model of patient compliance typically uses a negative feedback loop. The patients regimen-relevant behavior is monitored and compared with the recommended treatment regimen. When deviation is detected, an error signal is generated as a feedback to the patient. If the patient is motivated to comply, he will adjust his behaviors, which will be continuously monitored for the full self-regulation loop. In practice, patients can use a logbook for self-recording and compliance deviation can be identified during periodic patient visits. MPCS connects patients with their community using social-construction theory, which suggests that a person will conform to others behavior, such as adopting new technology, as consensus expectations of a workgroup in which members share similar goals The clinician can submit a recommended treatment regimen, as a set of rules, to the MPCS server, which also receives compliance self-reports gathered from the patients mobile phone, either using manual inputs or automatic sensing. The users context information is also periodically inferred and sent to the server, which uses the user context and historical data to determine an optimal reminder delivery schedule. The server also detects non-compliance by comparing the treatment regiment and the self-reports, and triggers a rating questionnaire on the patients mobile phone. Family members can also log in to see the patients health conditions and compliance activities. Patients themselves can interact with their social community through their mobile phones. In particular, they can browse group-level compliance activities of their peers and follow detailed compliance actions of their buddies, as permitted by the privacy settings. In addition, a patient may explicitly define some group members as his buddies, such as those he knows in real life, or those introduced by the same clinician, or those he interacts with in the community but decides to establish a closer connection. A patient can receive detailed activity updates from his ego network (friends) as permitted.

TABLE III
PARTICIPATORY PUBLIC SENSING SYSTEMS

Project Title / System	Hardware Description	Software Description	Communication Modules	Types Of Sensors	Applications	Area
Earphone [2]	Nokia N95, HPi-PAQ	Java MySQl, PHP, Nokia Energy Profiles	Wifi	Phones Microphone, GPS Sensor	MobSLM	Special Purpose Application
MicroBlog [43]	Nokia N95	Carbide C++ Symian OS, C++, PHP 5, Ajax, MySQl, Apache 2.0 web server	Wifi, GSM	Phones Microphone, Camera, GPS Sensor, Accelerometer	Tourism, Micro News, Micro Maps	Special Purpose Application
Citizen Journalist [45]	HPiPAQ nw6965, Samsung SGH-i780, HTC Adrantoge 7510,7501	MS Windows Mobile 5.0, 6.1, Windows 7, C#, C/C++	Bluetooth, GPRS, EDGE, 3G Radio	Phones Microphone, Camera, GPS Sensor, Accelerometer	Citizen Journalist	Special Purpose Application
V-Track [12]	iPhone, Nokia N95 embede in car computer	Not Mentioned	Wifi, Bluetooth	Phones GPS Sensor	Detecting and Visualizing hotspots, Real time Route planning	Traffic Monitoring
TrafficSense [13]	HPiPAQ nw6965, Sparkfon WiTilt accelerometer HTC Typhoon	Windows mobile 5.0, Windows Mobile 2003	Bluetooth, Wifi, GSM	Phones Microphone, Camera, GPS Sensor, Accelerometer, GSM Radio	Monitoring of Roads and Traffic Conditions	Traffic Monitoring
LiveCampare [16]	Nokia N95	Symbian OS	HSDPA, GPS, Wifi, GSM	Phones Camera, GPS Sensor, GSM Radio	Price Dispersion	Commerce
MobiShop [17]	Nokia N95 8GB, GPS Reciver	My SQl, Java ME, Windows/Linux Symbian OS 9.2, OCR engine, Tomcat	GPRS, HSDPA, Wifi, GSM	Phones Camera, GPS Sensor	Price Dispersion	Commerce
PetrolWatch [18]	Nokia N95	J2me, Open source JJIL Imaging Library	GSM, GPRS, 3G	Phones Camera, GPS Sensor	Price Dispersion	Commerce
Laermometer [21]	Any Mobile device equipped with Microphone	MySQL, XML, Apache Sever	GSM Network	Phones Microphone, GPS Sensor,	Noise Map Creation and Visualization	Environmental Monitoring
MobGeoSen [44]	Nokia Series 60 Camera Phones, GPS Reciver, Sensor Datalogger	XML Google Earth	Bluetooth, GPRS	Phones Camera, GPS Sensor, Microphone	Monitoring Sound level	Environmental Monitoring
NoiseTube [20]	Nokia N95, GPS Reciver	Java, Symbian S60 OS, MySQl, Google Earth and Google Maps	Bluetooth	Phones Microphone, GPS Sensor	Mobile Sensing Application	Environmental Monitoring
Party Thermometer [45]	HPiPAQ nw6965, Samsung SGH-i780, HTC Adrantoge 7510,7501	MS Windows Mobile 5.0, 6.1, Windows 7, C#, C/C++	Bluetooth	Phones Microphone, Camera, GPS Sensor	Party Thermometer	Social Interaction

IV. OPPORTUNISTIC SENSING SYSTEMS

Many opportunistic sensing systems have been developed so far, In this section we have categorized them into Personal, Social and Public opportunistic sensing systems.

A. Personal Opportunistic Mobile Phone Sensing Systems

The details of personal opportunistic mobile phone sensing systems are as follows:

1) PerFallID: Nicholas D Lane et al [8] have proposed PerFallID, utilizing mobile phones as a platform for pervasive fall detection system whose only requirement is a mobile phone which has an accelerometer. PerFallD has few false positives and false negatives; it is available in both indoor and outdoor environment; it is user-friendly, and it requires no extra hardware and service cost. It is also lightweight and power efficient. The design of this system is general and it is not constrained to a particular brand or type of mobile phone. It is divided into five major components: user interface, monitoring daemon, data processing, alert notification and system configuration. After the program starts, a user profile is loaded. A user dependent profile contains basic fall detection configuration such as the default sampling frequency, default detection algorithm, emergency contact list, etc. In different scenarios, users activity patterns have varying degrees of

rapidity, and it is more efficient to use different sampling frequencies in different scenarios. After the user profile is loaded, users are provided the chance to adjust the sampling frequency when interfaces that invoke sensor functions at different frequencies are provided. Then the main program, working as a background daemon is launched. If information collected in real time satisfies a certain preset condition, the pattern matching process begins to determine if a fall occurs. If no fall is detected, execution immediately returns to the daemon. If a fall is detected, the daemon service transmits a signal that triggers an alarm and starts a timer. If the user does not manually turn off the alarm within a certain time period, the system automatically calls contacts stored in the emergency contact list according to their priorities. Data of falls is collected with different directions (forward, lateral and backward), different speeds (fast and slow) and in different environment (living room, bedroom, kitchen and outdoor garden). Data of activities of daily living (ADL) including walking, jogging, standing and sitting is also collected.

Experiments are conducted to evaluate the system. In particular, PerFallDs performance is compared with that of existing work and a commercial product. Experimental results show that PerFallD achieves strong detection performance and power efficiency. PerFallD outperforms existing algorithms, and achieves better balance between false negative and false positive when compared with the commercial product.

2) I-Fall: IFall [47] system is presented which is an alert system for fall detection using common commercially available electronic devices to both detect the fall and alert authorities. An Android based smart phone is used with an integrated tri-axial accelerometer. Data from the accelerometer is evaluated with several threshold based algorithms and position data to determine a fall. The threshold is adaptive based on user provided parameters such as: height, weight, and level of activity. The algorithm adapts to unique movements that a phone experiences as opposed to similar systems which require users to mount accelerometers to their chest or trunk. If a fall is suspected a notification is raised requiring the users response. If the user does not respond, the system alerts pre-specified social contacts with an informational message via SMS. If a contact responds the system commits an audible notification, automatically connects, and enables the speakerphone. If a social contact confirms a fall, an appropriate emergency service is alerted.

This system provides a realizable, cost effective solution to fall detection using a simple graphical interface while not overwhelming the user with uncomfortable sensors. A service allows the fall monitor to constantly run in the background. When the monitor suspects a fall, an intent is sent to an iFall activity. This wakes up the application and attempts to get the users attention by repeatedly vibrating, flashing LEDs and screen, and playing an audio message. The app prompts the user with a simple pop-up window telling them to press an on-screen button or verbally state if they require help. A canceled alert closes iFall and the interrupted activity is restored.

3) HeartToGo: HeartToGo [7] is a cell phone-based personalized medicine technology for cardiovascular disease (CVD), capable of performing continuous monitoring and recording of ECG in real time, generating individualized cardiac health summary report in laymans language, automatically detecting abnormal CVD conditions and classifying them at any place and anytime. Specifically, an artificial neural network (ANN)-based machine learning technique is developed, combining both individualized medical information and clinical ECG database data to train the cell phone to learn to adapt to apt to its users physiological conditions to achieve better ECG feature extraction and more accurate CVD classification results. To acquire real-time ECG signals, Alive Technologys state-of-the-art wireless ECG and heart monitor is employed, which is a light-weight, low-power wearable 2-lead ECG sensing device capable of recording 300 8-bit samples per second. It is equipped with a Bluetooth transmitter, which can send its data to cell phones or other wireless devices.

In addition to the constructed physical test bed, the complete platform includes an efficient ECG processing module capable of taking the collected ECG data and dynamically extracting various ECG features, such as detecting P wave, QRS complex, and T wave, and producing a ECG summary report that may include, but are not limited to: the heart rate, rhythm, axis, RR interval, QRS duration, ST segment, P/Q/R/S/T wave morphologies. The produced ECG summary report will be similar to those generated by stationary ECG machines used by cardiologists in many hospitals. First, a rule-based method is implemented to perform a quick, first pass of CVD detection. This serves as a light-weight checker for diagnosing CVDs on the cell phone platform in real time. Upon the acquisition of each heart beat, this light-weight CVD checker will process and analyze each heart beat and classify it by condition, be it normal or a condition indicating a CVD, for example premature ventricular contraction (PVC). After being processed by the rule-based checker, the initial classification results will be fed into a Hybrid Fuzzy Network based neural classifier to determine the possible indications for any abnormal CVDs.

In order to perform a rapid prototyping of the algorithms, a LabVIEW-based platform has been developed. Using LabVIEW Mobile Module, the algorithms implemented in MATLAB are tested on the Windows Mobile cell phone in order to assess their performance for being deployed in real-time mobile environments.

4) HealthGear: HealthGear [6] is a real-time wearable system for monitoring, visualizing and analyzing physiological signals. HealthGear consists of a set of non-invasive physiological sensors wirelessly connected via Bluetooth to a cell phone which stores, transmits and analyzes the physiological data, and presents it to the user in an intelligible way. HealthGear is implemented using a blood oximeter to monitor the users blood oxygen level and pulse while sleeping. Two different algorithms are described for automatically detecting sleep apnea events and the performance of the overall system in a sleep study with 20 volunteers is illustrated. HealthGear with an oximeter constantly monitors and analyze the users blood oxygen level (SpO2), heart rate and plethysmographic signals in a light-weight fashion.

In HealthGear the authors have implemented two methods for the automatic detection of sleep apnea events. The first method operates in the time domain, while the second operates

in the frequency domain. The experiment consisted of using HealthGear by each participant for one full night in their own homes. After the meeting, the participants took the hardware with them and wore it during that night in their homes. They returned the system the next morning. After the experiment, they were asked to fill out a second questionnaire which focused on rating the experience and the usability of HealthGear. The experiment was successful as in the sleep study (1) None of the volunteers experienced any technical problem and they all collected data successfully, (2) Automatic Obstructive Sleep Apnea (OSA) detection algorithms identified with 100% accuracy all 3 cases of known OSA and clearly identified 1 case of severe and 2 cases of mild OSA, among the pool of participants who suspected they might be suffering from the condition, but had not undergone any medical diagnosis; (3) 100% of participants were willing to wear HealthGear to monitor their sleep on a regular basis and have recommend the system to friends and family.

5) EmotionSense: EmotionSense [48] is a mobile sensing platform for social psychological studies based on mobile phones. The key characteristics of this system include the ability of sensing individual emotions as well as activities, verbal and proximity interactions among members of social groups. This can be used to understand the correlation and the impact of interactions and activities on the emotions and behavior of individuals. EmotionSense system consists of several sensor monitors, a programmable adaptive framework based on a logic inference engine, and two declarative databases (Knowledge Base and Action Base). Each monitor is a thread that logs events to the Knowledge Base, a repository of all the information extracted from the on-board sensors of the phones. The system is based on a declarative specification (using first-order logic predicates) of facts, i.e., the knowledge extracted by the sensors about user behavior (such as his/her emotions) and his/her environment (such as the identity of the people involved in a conversation with him/her). actions, i.e., the set of sensing activities that the sensors have to perform with different duty cycles, such as recording voices (if any) for 10 seconds each minute or extracting the current activity every 2 minutes. By means of the inference engine and a user-defined set of rules (a default set is provided), the sensing actions are periodically generated. The actions that have to be executed by the system are stored in the Action Base. The Action Base is periodically accessed by the EmotionSense Manager that invokes the corresponding monitors according to the actions scheduled in the Action Base. Users can define sensing tasks and rules that are interpreted by the inference engine in order to adapt dynamically the sensing actions performed by the system.

The authors have presented the design of two novel subsystems for emotion detection and speaker recognition which are built on a mobile phone platform. These subsystems are based on Gaussian Mixture methods for the detection of emotions and speaker identities. EmotionSense automatically recognizes speakers and emotions by means of classifiers running locally on off-the-shelf mobile phones. A programmable adaptive system is proposed with declarative rules. The rules are expressed using first order logic predicates and are interpreted by means of a logic engine. The rules can trigger new sensing

actions (such as starting the sampling of a sensor) or modify existing ones (such as the sampling interval of a sensor). The results of a real deployment designed in collaboration with social psychologists are presented. It is found that the distribution of the emotions detected through Emotion-Sense generally reflected the self-reports by the participants.

6) Darwin: Emiliano Miluzzo et al [22] have presented Darwin, an enabling technology for mobile phone sensing that combines collaborative sensing and classification techniques to reason about human behavior and context on mobile phones. Darwin advances mobile phone sensing through the deployment of efficient but sophisticated machine learning techniques specifically designed to run directly on sensor-enabled mobile phones (i.e., smart phones). Darwin is a collaborative reasoning framework built on three concepts: classifier/model evolution, model pooling, and collaborative inference. Darwin can be applied to other mobile phone sensing applications and systems which use the microphone as an audio sensor. Darwin can be integrated in a mobile social networking application, a place discovery application, and a friend tagging application. It uses classifier evolution to make sure the classifier of an event on a phone is robust across different environments. Darwin operates in three steps. In the first step each mobile phone builds a model of the event to be sensed through a seeding phase. Over time, the original model is used to recruit new data and evolve the original model. The intuition behind this step is that, by incrementally recruiting new samples, the model will gather data in different environments and be more robust to environmental variations. The phone computes the feature vector locally on the phone itself and sends the features to a backend server for training. In the second step when multiple mobile phones are co-located they exchange their models so that each phone has its own model as well as the co-located phones' models. Model pooling allows phones to share their knowledge to perform a larger classification task (i.e., in the case of speaker recognition, going from recognizing the owner of the phone to recognizing all the people around in conversation). After models are pooled from neighboring mobile phones, each phone runs the classification algorithm independently. However, each phone might have a different view of the same event i.e., different phone sensing context. In third step the collaborative inference exploits this diversity of different phone sensing context viewpoints to increase the overall duality of classification accuracy. The raw sensor data never leaves the mobile phone nor is it stored on the phone. Only models and features are stored which are computed from the raw sensor data.

Darwin represents a general framework applicable to a wide variety of emerging mobile sensing applications, a speaker recognition application and an augmented reality application are implemented to evaluate the benefits of Darwin. In the case of the speaker recognition application, the content of a conversation is never disclosed, nor is any raw audio data ever communicated between phones. The data exchanged between phones consists of classification confidence values and event models. Mobile phone users always have the ability to opt in or out of Darwin, hence, no model pooling and collaborative inference would take place unless the users make such a determination.

Experimental results are shown from eight individuals carrying Nokia N97s and it is demonstrated that Darwin improves the reliability and scalability of the proof-of-concept speaker recognition application without additional burden to users. The results indicate that the performance boost offered by Darwin is capable of setting problems with sensing context and conditions and presents a framework for scaling classification on mobile devices.

7) Activity Recognition system: Jennifer R. Kwapisz et al [11] have described and evaluated a system that uses phone-based accelerometers to perform activity recognition, a task which involves identifying the physical activity a user is performing. For implementation of this system the authors have collected labeled accelerometer data from twenty-nine users as they performed daily activities such as walking, jogging, climbing stairs, sitting, and standing, and then aggregated this time series data into examples that summarize the user activity over 10- second intervals. Then the resulting training data is used to induce a predictive model for activity recognition. The activity recognition model allows to gain useful knowledge about the habits of millions of users passively just by having them carry cell phones in their pockets. Applications of this system includes automatic customization of the mobile devices behavior based upon a users activity (e.g., sending calls directly to voicemail if a user is jogging) and generating a daily/weekly activity profile to determine if a user (perhaps an obese child) is performing a healthy amount of exercise.

B. Social Opportunistic Mobile Phone Sensing Systems

The details of social opportunistic mobile phone sensing systems are as follows:

1) WhozThat: WhozThat [27] is a system that achieves the vision of seamless social interaction through MoSoNet technology by implementing a basic two step protocol that first shares identities between any two nearby cellular smart phones (e.g., via Bluetooth or WiFi) and then consults an online social network with the identity to import the relevant social context into the local context to enrich local human interaction. WhozThat is a context-aware music player in a bar that could adapt its song playlist based on the tastes of the people in the bar, that is, on the social profiles obtained from the identities advertised by the smartphones of people in that bar. The authors have assumed that smartphones will soon become ubiquitous, and will possess both a local wireless capability e.g., Bluetooth or WiFi and a wide-area wireless connection to the Internet, through either a cellular data plan such as enhanced data rates for GSM evolution (EDGE), a universal mobile telecommunications system (UMTS) etc.

The WhozThat protocol is advantageous for its simplicity, energy/bandwidth efficiency, agnosticism, and extensibility. The two-phase protocol is powerful yet simple to implement, which should substantially ease its deployment on mobile devices. The protocol is also lightweight for mobile devices by expending only a small amount of energy and bandwidth. Modest time/energy is spent periodically transmitting the social ID and small queries to the online social networking site, whereas the rest is consumed in the relatively low-energy task of receiving the fetched social context data. Another

great advantage of design of WhozThat is that it is fully extensible, so that an array of more advanced applications and services can be integrated into the basic information-sharing mechanism.

An application is context-aware music playlist generation application, called WZPlaylistGen. It is implemented on a PC with the Java Standard Edition (SE) run-time environment. After installation, WZPlaylistGen Listens over Bluetooth using the WhozThat protocol for advertised social networking IDs, retrieves the users musical preferences from Facebook, uses the Audio scrobbler API to generate a playlistand then plays that play list in the local environment.

2) OLS: Opportunistic Localization system (OLS) [49] is an opportunistic location system based on smart phone devices. which enables localization services that works seamlessly throughout heterogeneous environment including indoors as opposed to GPS based systems being available only outdoors under unobstructed sky. People are eager to locate their peers on a campus or in buildings and stay connected with them and OLS makes that simple. OLS is a phone-centric localization system which grasps at any location related information readily available in the mobile phone. In contrast to most of the competing indoor localization systems, OLS does not require a fixed dedicated infrastructure to be installed in the environment making OLS a truly ubiquitous localization service. OLSs architecture is migrated from the original client-server to the current service-oriented architecture to cope with increasing demands on reusability across various environments and platforms and to scale up to service a large number of various clients. The server side runs the main OLS services such as the location, management, registration and communication service, data fusion engine, database, and visualization provider. OLS can also interface third-party external services such as Google Earth. The key feature of OLSs design is its ease-of use and therefore, when interfaced with Google Earth, an OLS customer can build an indoor building environment with Google Sketch-Up drawing tool. OLS then imports the Sketch-Up building model and parses it to the data fusion engine to perform the map filtering upon the fused location information The OLS Server is responsible for hosting the application and providing all the services. The Visualization Provider offers 2D and 3D visualization. The Communication Service is responsible for providing and maintaining communication interface between clients and the OLS Server. The Registration Service registers localized objects and OLS clients, the users of the Location Service. The Location Service provides location updates for localized objects and instantiates and manages the instances of the main processing components of OLS Server. The Data Fusion Engine provides the data fusion service.. The Management Service manages and maintains the OLS Server and facilitates its administration.

The Database stores environment description such as maps and 3D model of buildings. It also stores information necessary for the data fusion algorithm etc. The Mobile Client is a smart phone device, which is localized by the OLS server upon the streamed sensory data from its GPS, GSM/UMTS, accelerometers Wi-Fi and Bluetooth. The Mobile client can also subscribe for location updates in order to further process

TABLE IV
OPPORTUNISTIC PERSONAL SENSING SYSTEMS

Project Title / System	Hardware Description	Software Description	Communication Modules	Types Of Sensors	Applications	Area
PerFall ID [8]	Android Gl Phones	Java Andriod 1.6 SDk, Eclipse	GSM Network, SMS	Phones Accelerometer	Fall Detection System	Special Purpose Application
I-Fall [47]	Android GI Phone	Android SDK	SMS, GSM Network	Phones Tri-axial Accelerometer, GSP Sensor	Fall Detection System	Special Purpose Application
Heart ToGo [7]	Alive Bluetooth ECG Monitor, Alive Heart Activity Monitor, Windows Mobile	MS Visual Stdio, Matlab, LAB View, Visual C++, EPLimited, arrhythmia software package	Bluetooth	ECG sensor, 3-axis Accelerometer	Cardiovascular Disease Detection	Health Monitoring
Heart Gear [6]	Nonins Clex Oximeter, Audiovox SMT5600 GSM Cell phone, XPod and batteries	MS Windows Mobile 2003 OS, Promi ESD-2 module	Bluetooth	Oximetry Sensor	Sleep Apnea Application	Health Monitoring
Emotion Sense [48]	Nokia 6210 Navigator Phone	Nokia Symbian S60, C++, Python, HTKtoolkit, Windows, Linux	Bluetooth	Phones Accelerometer, Microphone	Emotion and Speaker Recognition	Human Behavioral Monitoring
Activity Recognition [11]	Nexus One, HTC Hero, Motorola BackFlip	Android OS	GSM Network	Phones Accelerometer	Activity Recognition	Human Behavioral Monitoring

and visualize its location etc. The Laptop Client is a third-party client typically with higher processing and 3D visualization capabilities. The laptop clients run third-parties location based applications, which further process the location data provided by OLS.

C. Public Opportunistic Mobile Phone Sensing Systems

The details of public opportunistic mobile phone sensing systems are as follows:

1) Nericell: Nericell [11] is a system that performs rich sensing by piggybacking on smart phones that users carry with them in normal course. The authors have focused specifically on the sensing component, which uses the accelerometer, microphone, GSM radio, and/or GPS sensors in these phones to detect potholes, bumps, braking, and honking. Nericell addresses several challenges including virtually reorienting the accelerometer on a phone that is at an arbitrary orientation, and performing honk detection and localization in an energy efficient manner. The authors have used the idea of triggered sensing, where dissimilar sensors are used in tandem to conserve energy. The data is gathered through GPS-tagged cellular tower measurements during several drives over the course of 4 weeks. GPS-tagged accelerometer data measurements are also separately gathered on drives on some of the same routes over the course of 6 days. Cellular tower measurements are also gathered over the course of a few days in the Seattle area.

The system could be used to annotate traditional traffic maps with information such as the bumpiness of roads, and the noisiness and level of chaos in traffic, for the benefit of the traffic police, the road works department, and ordinary users. Nericell uses honk detection to identify noisy and chaotic traffic conditions like that at an unregulated intersection. Localization is a key component of Nericell, as it is in any sensing application. Each phone participating in Nericell

would need to continuously localize its current position, so that sensed information such as honking or braking can be tagged with the relevant location. Thus, an energy-efficient localization service is a key requirement in Nericell. Thus, the authors have relied on using GSM radios for energy-efficient coarse-grain localization and when necessary they have triggered the use of fine-grain localization using GPS.

The effectiveness of the sensing functions in Nericell is evaluated based on experiments conducted on the roads of Bangalore, with promising results.

2) Road Bump Monitor: Road Bump Monitor [45] is an application of PRISM platform which is inspired by Pothole Patrol and Nericell and involves opportunistic sensing, wherein phones equipped with GPS and accelerometer sensors are used to detect and locate road bumps automatically without any user involvement. The application server uses the deploy-or-cancel mode rather than the trigger mode. Also, the sensed (accelerometer) data is processed locally on the phones to extract the desired information (the location of road bumps), before it is shipped back to the server.

To evaluate this application, an experiment was conducted where the 3 accelerometer-equipped phones were taken on a 2.5 km long drive through a neighborhood. The actual locations of the road bumps were manually recorded. Then the road bump monitoring application was opportunistically deployed on the phones and the bumps detected by the application were compared with the manual recording of road bumps.

V. SECURITY AND PRIVACY IN MOBILE PHONE SENSING SYSTEMS

Security and privacy of mobile phone sensing systems is still in its infancy. However some of the existing systems provide reasonable privacy and security which are described below.

TABLE V
OPPORTUNISTIC PUBLIC SENSING SYSTEMS

Project Title / System	Hardware Description	Software Description	Communication Modules	Types Of Sensors	Applications	Area
NeriCell [11]	Nokia N95, Hpi PAQnw6965, HTCTyphoon, Sparkfun witilt Accelerometer	Perl, windows mobile 5.0,Windows mobile 2003, Python, C#	GSM, GPRS, UNTS, EDGE, Wifi, Bluetooth	Phones Microphone, GSM Radio, GPS sensor, Accelerometer, Camera	Bump, Breaking and Honking Detection	Traffic Monitoring
Mobile Century	Nokia N95	VTL database	GSM Network	Phones GPS Sensor	Real Time Traffic Estimation	Traffic Monitoring
Road Bump Monitor [45]	HPiPAQ nw6965, Samsung SGH-i780, HTC Adrantoge 7510,7501	MS Windows Mobile 5.0, 6.1, Windows 7, C#, C/C++	Bluetooth, GPRS, EDGE, 3G Radio	Phones Microphone, Camera, GPS Sensor, Accelerometer	Road Bumps Detection	Traffic Monitoring

A. AnnoySense

AnonySense [50] is a privacy-aware system for realizing pervasive applications based on collaborative, opportunistic sensing by personal mobile devices. AnonySense allows applications to submit sensing tasks to be distributed across participating mobile devices, later receiving verified, yet anonymized, sensor data reports back from the field. The foundation of the AnonySense architecture rests on a dynamic set of mobile nodes (MNs) that volunteer to participate. The authors have assumed that there are a variety of node platforms, including mobile phones, PDAs, laptops, or other personal mobile devices, with widely varying capabilities for sensing the physical and network environment around them. The applications and mobile nodes communicate via the Internet with the systems four core services: the registration authority, the task service, the report service, and a Mix network. These services can be administratively independent, in the sense that they are operated by autonomous entities, with trust relationships.

The Mobile Nodes (MNs) are devices with sensing, computation, memory, and wireless communication capabilities. Mobile nodes are carried by people, or are attached to objects such as vehicles. The Registration Authority (RA) is responsible for registering nodes that wish to participate, and for issuing certificate to the task service and the report service so that applications and nodes can verify the authenticity of the services. The Task Service (TS) receives task descriptions from applications, performs some consistency checking (related to the carriers privacy requirements and the feasibility of the task), and distributes the current tasks to mobile nodes when they ask to download new tasks. It returns to the application a token that may be used in retrieving the tasked The Report Service (RS) receives reports from mobile nodes, aggregates them internally to provide additional privacy, and responds to queries from applications who present a token to collect their tasks sensor data. The Mix Network (MIX) serves as an anonymizing channel between mobile nodes and the report service: it de-links reports submitted by MNs before they reach the RS data.

The authors have defined a simple and expressive language called AnonyTL for applications to specify their tasks. AnonyTL allows an application to specify a tasks behavior by providing a set of acceptance conditions, report statements,

and termination conditions. The authors have described their trust model according to which each entity trusts about the others. The two major protocols are presented: one for getting tasks from applications to mobile nodes, and the other for mobile nodes to report sensor data back to applications. These AnonySense protocols according to the given trust model provide anonymity to the MN users and ensures integrity of the sensor data reported to the applications.

The feasibility of this approach is shown through two plausible applications: a Wi-Fi rogue access point detector and a lost-object finder. Results have shown that sensor data can be reliably obtained, from anonymous users, without much overhead.

B. Secure SocialAware

Secure SocialAware [30] is a framework to support secure and anonymous exchange of social network or other personal information throughout a users physical location. It allows for the interaction of social network information with real-world location-based services without compromising user privacy and security. Through exchanging an encrypted nonce (EID) associated with a verified user location, SSA allows location based services to query the local area for social network information without disclosing user identity or any set of information which could be positively matched to users.

The Secure SocialAware (SSA) framework consists of three major components: the stationary component (SC), the mobile component (MC), and the authentication server (AS). The SC is embedded into the users environment, while the MC component resides on mobile devices. The SC is responsible for detecting the presence of users, obtaining information about these users from the AS, and performing actions based on this information. The MC on a users mobile device is responsible for advertising that users encrypted identifier (EID) using a wireless technology such as Bluetooth so that it is available to the SC. The AS generates unique EIDs for each MC, and provides a service to the SC so that the SC can obtain the users information from a social networking web site given an EID. The AS allows SCs and MCs to join the SSA system by signing up for stationary and mobile user accounts, respectively. After a mobile user signs up for a user account, the AS assigns that user a unique EID. The AS provides secure services that the MC uses to determine its EID and

inform the AS of its current location. The AS also provides a secure service that the SC uses to retrieve the mobile users information from a social networking Web site given that users EID.

The authors have implemented a context-aware mobile social networking application, called SocialAwareFlicks, which uses SSA and demonstrates the feasibility of the SSA framework. SocialAwareFlicks displays recommended movie trailers that match the movie preferences of one or more users jointly watching a common display. SocialAwareFlicks could be deployed in locations such as video-rental establishments for marketing purposes, to make customers aware of new video rentals that match their interests. Performance metrics are gathered for the SSA Authentication Server and the results have shown that it works reasonably well.

C. SmokeScreen

Landon P. Cox et al [51] have presented a system called SmokeScreen that provides flexible and power-efficient mechanisms for privacy management. The authors have described two complementary mechanisms. First, to enable flexible sharing between social relations, users broadcast clique signals which can be activated or deactivated depending on the social environment. Second, to enable flexible sharing between strangers, users also broadcast opaque identifiers (OIDs) which are time, place, and broadcaster specific and can only be resolved to an identity via a centralized trusted broker. Together these mechanisms allow users to both manage their location-privacy and reap the full benefit of presence-sharing. Furthermore, these mechanisms are power-efficient since devices can avoid broadcast-time cryptographic work by pre-computing and comfortably storing 48 hours worth of future signals and OIDs.

Trust in SmokeScreen is splited into two categories: 1) users may be trusted to handle shared cryptographic state such as secret keys, and 2) users may be trusted to record a user's presence at a given place and time. The first category of trust is symmetric and established among a group of social relations. The second category is potentially asymmetric and depends on the social context of a particular time and place. SmokeScreen is resilient to collusion among adversaries, but is vulnerable to collusion between adversaries and trusted users. SmokeScreen also cannot prevent an adversary from detecting a user's absence. If a user leaves a location, SmokeScreen will not continue to broadcast their presence information. SmokeScreen is currently focused on device information such as Bluetooth device names and WiFi SSIDs that are easy to change in software, but full presence-privacy also requires eliminating the static MAC addresses broadcast by layer two wireless protocols.

The authors have presented four design goals control, disclosure, isolation, and dispersion and with these goals in mind, they have separated the problem of presence privacy into two cases and applied a separate solution to each case: clique signals regulates haring between social relations and brokered exchanges regulate sharing between strangers. The authors have implemented the prototype system consists of three components: the mobile device, the broker, and the client. The

system is evaluated by doing Reality Mining Analysis, Power consumption analysis and Resolution Performance.

D. Prisense

Jing Shi et al. [52] have presented the design and evaluation of PriSense, a novel solution to privacy-preserving data aggregation in people- centric urban sensing systems. PriSense is based on the concept of data slicing and mixing and can support a wide range of statistical additive and non-additive aggregation functions such as Sum, Average, Variance, Count, Max/Min, Median, Histogram, and Percentile with accurate aggregation results. PriSense can support strong user privacy against a tunable threshold number of colluding users and aggregation servers. PriSense consists of the following two components. The first component aims at additive aggregation functions. Its basic idea is for each node to slice its data into a certain number (say, n+1) of slices before answering the query from an aggregation server. Then it randomly chooses n other nodes, called its cover nodes, to which a unique data slice is sent.

Finally, each node sends to the aggregation server the sum of its own slice left and the slices received from others along with little side information, based on which the aggregation server can compute an accurate additive aggregation result. In this way, a users data will be disclosed only when the aggregation server and all his cover nodes collude. The second component is a non-trivial combination of the slicing and mixing technique and binary search to enable privacy preserving Count queries and to further support a wide range of non-additive aggregation functions like max/min, median, histogram, and percentile, all with accurate results.

The system features a high-speed wireless backbone consisting of M powerful aggregation servers (AS) which also provide network access services for system nodes. Each AS is in charge of a certain region referred to as a cell and interacts with nodes there. The term node is used to indicate a human being who carries a portable device like mobile phones, PDAs, laptops, and MP3 players. A node may join the system at will to participate in data sensing and sharing and also enjoy network access. To prevent fraudulent use of system resources and also provide basic privacy assurance to nodes, the system and nodes need mutually authenticate each other.

The authors have focused on thwarting attacks on breaching nodes data privacy. Other important issues such as DoS defenses are outside the scope. The performance of PriSense is thoroughly evaluated by simulating a cell with N = 100 nodes, among which 50 are malicious, and a malicious AS at the center of the cell. The evaluation results demonstrate that PriSense is very suitable and practical as a solution to privacy-preserving data aggregation in people-centric urban sensing systems.

E. SMILE

Secure MIssed connections through Logged Encounters SMILE [53] is a privacy-preserving missed-connections service in which the service provider is un-trusted and users are not assumed to have pre-established social relationships with each other. At a high-level, SMILE uses short-range

wireless communication and standard cryptographic primitives to mimic the behavior of users in existing missed-connections services such as Craigslist: trust is founded solely on anonymous users ability to prove to each other that they shared an encounter in the past. In SMILE trust is established solely on the basis of shared encounters; the service provider is not trusted to access users location information.

At the heart of the service is the notion of an encounter, which is defined as a short period of co-location between people. This service is modeled after the popular missed-connections services found in newspapers and websites like Craigslist. The key features of a missed-connections service are: (1) strangers who were at the same place and time should be able to contact each other at a later time; (2) once connected, those strangers should be able to prove to each other that they actually encountered one another. Three complementary techniques are used to provide these features without exposing users location information to either the service provider or adversaries claiming to have been physically present at a particular place and time: First is that Co-located participants perform periodic passive key exchange with each other using short-range wireless broadcasts. Second is that Participants use key hashes to establish a rendezvous point at a centralized server without exposing the encounter location to the service provider. And thirst is that Participants limit the service providers ability to infer which pairs of users were involved in an encounter by carefully inducing key-hash collisions at the server and relying on clients to resolve ambiguities. The basic structure of SMILEs messaging protocol is as follows: Firstly mobile users passively exchange cryptographic keys with nearby peers. Secondly users periodically upload batches of key hashes to a central coordinating server. Thirdly a user sends a message to the server encrypted with one such key and labels it with the corresponding key hash. Fourthly the server forwards the encrypted message to all users that have uploaded the same key hash. Lastly only encounter participants are able to decrypt the message. SMILE offers protection against malicious agents attempting to determine or disclose a users location history, encounter history, or private messages.

SMILE is evaluated using protocol analysis, an informal study of Craigslist usage, and experiments with a prototype implementation and found it to be both privacy-preserving and feasible.

F. Serendipity

Nathan Eagle and Alex have presented a system called Serendipity [29]. This system is used for cueing informal interactions using the combination of Bluetooth hardware. It addresses to identify people and a database of user profiles. Serendipity consists of a central server containing information about individuals in a user's proximity and several methods of matchmaking. These profiles are similar to those stored in other social software programs such as Friendster and Match.com. However, Serendipity users also provide weights that determine each piece of information's importance when calculating a similarity score. The similarity score is calculated by extracting the commonalities between two users' profiles

and summed using user-defined weights. If the score is above the threshold set by both users, the server alerts the users that there is someone in their proximity whom might be of interest. The thresholds and the weighting scheme that defines the similarity metric can be set on the phones and correspond to the existing profile types such as meeting, outdoors, silent mode, etc. When it has been determined that the two individuals should have an interaction, an alert is sent to the phones with each user's picture and a list of talking points. Serendipity receives the BTID (Bluetooth Identification Code) and threshold variables from the phones and queries a MySQL database for the user's profile associated with the discovered BTID address. If the profile exists, another script is called to calculate a similarity score between the two users. When this score is above both users' thresholds, the script returns the commonalities as well as additional contact information (at each user's discretion) back to the phones. Unlike other social software introduction systems, Serendipity does not require users to login to a website to register for the service.

A current user just needs to send the installation file (Symbin.sis) to a friend's compatible phone over Bluetooth or IR. When the application is opened and installed, the phone automatically connects to the network and the server creates a new profile with the friend's phone number, BTID, and a link to the original user as a 'friend'. By replying to the introduction message with a number value from one to ten, users can give feedback about the value of the introduction.

The Serendipity system has been tested and iterated upon for almost one year. There are currently one hundred Serendipity users divided into two university departments. The privacy concerns involving Serendipity are numerous. Providing a service that supplies nearby strangers with a user's name and picture is rife with liability and privacy issues. Utmost care must be made to ensure this service never jeopardizes a user's expectation of privacy.

VI. DISCUSSION & RESEARCH CHALLENGES

The development of urban sensing systems is still in its infancy as there exits a lot of interesting and unresolved issues and research challenges within such sensing systems.

A people-centric urban sensing system differs significantly from a traditional wireless sensor network in many ways. For example the system devices are no longer owned and managed by a single authority but belong to individuals with diverse interests. Also system devices have much more powerful resources than sensor nodes and can be charged regularly. Another difference is that sensing data are more related to interactions between people and between people and their surroundings instead of some physical phenomena of interest. Finally, people are no longer just passive data users but also active data contributors. The people-centric architectural approach is not without its challenges. Firstly, reliance on a people-powered mobile architecture means that sensing device characteristics will be heterogeneous, different sensor types (e.g., camera, microphone, accelerometer) will be embedded in different devices and these devices will have different storage, processing and communication capabilities.

TABLE VI
MOBILE SENSING SECURITY SYSTEMS

Project Title / System	Hardware Description	Software Description	Communication Modules	Security Method/Techniques	Applications	Area
AnonySense [50]	Nokia N800, Apple iPhone	SQL, XQuery, Linux server, C++, XML, Open SSL	Bluetooth, WiFiS	HA-1, RSA, Open SSL secure channel	RogueFinder, ObjectFinder	Special Purpose Application
Secure Social Aware [30]	Macbook Pro notebook	Mac OS X 10.5 JME, J2SE 5.0, MIDP 2.0, BlueCove JSR-82 Emulator tool, Open Source SimpleJPA tool, VLC media player	Bluetooth	HTTPS, SHA-1 cryptographic hash function	SocialAwareFlicks	Social Interaction
SmokeScreen [51]	Nokia 6670, Sharp Zaurus SL-5600 PDA, Nokia 6600	Symbian OS, Linux 2.4.18, Python, C++, Postgre SQL 7.4.7, Pretec CompactFlash	Bluetooth, WiFi	RSA, AES	Presence-sharing Apllication	Social Interaction
Serendipity [29]	Nokia Series 60 phone	Mobile Information Device Profile MIDP 2.0, MySQL	Bluetooth, WiFi, GPRS	Privacy Control Policies for Users Proximity	BlueAware, BlueDar	Social Interaction

Secondly, sensors will be carried in a manner most convenient to the human (e.g., in a pocket or purse) and not necessarily in a manner most conducive to high fidelity data gathering for an application. Thirdly, due to the uncontrolled mobility of people, rendezvous among the sensors and the static infrastructure elements may not happen on the time scales best suited to the needs of applications. Together these challenges embody what we call sensor availability problem.

The widespread deployment of urban sensing systems face many obstacles. Both classes of urban sensing systems i.e., participatory and opportunistic have their own challenges and research issues. As participatory sensing begins and ends with people, both individuals and community members, thus human element adds some additional security challenges [54]. Firstly, with respect to privacy, the user may leak more information about his/her identity by the nature of his/her response. Secondly, a users textual response may contain grammatical errors, abbreviations, or other clues about the users identity. Thirdly, with respect to integrity, the user has an easy way to fabricate sensor data of his/her choosing and the reliability of data thus depends upon the ability of the user to respond the task effectively. Also the users can easily suppress data by either not responding to tasks, or by responding to tasks with data that is not useful.

Along with the benefits of opportunistic sensing, the opportunistic model also offers many challenges. Opportunistic sensing systems take on much more of the decision making responsibility and are thus more complex that may use more resources [34]. Providing sensing coverage when sensor mobility is uncontrolled, ensuring consistent sensor calibration, determining sensor context to allow for more targeted sampling and protecting custodian privacy [33] are some of the challenges of opportunistic sensing systems.

Cell phones have become an indispensable tool not only for todays highly mobile workforce but also for general people to transfer and exchange diverse mobile data. Thus, securing

mobile phone users critical data as well as protecting mobile phone based sensing application systems from unauthorized access and diverse attacks is also a major concern of mobile phone sensing systems. Some of the security threats to mobile or cell phones include loss, theft or disposal, unauthorized access, malware, spam, electronic eavesdropping, electronic tracking, cloning and server resident data [55]. As mobile phones are small in size and when are used outside home or office, they can be easier to misplace or to have stolen than a laptop or notebook computer. Also if they do fall into the wrong hands, gaining access to the information they store can be relatively easy. Communications networks, desktop synchronization, and tainted storage media can be used to deliver malware to mobile phones.Malware is often disguised as a game, device patch, utility, or other useful third-party application available for download. Once installed, malware can initiate a wide range of attacks and spread itself onto other devices. Similar to desktop computers, cell phones and PDAs are subject to spam, but this can include text messages and voice mail, in addition to electronic mail. Besides the inconvenience of deleting spam, charges may apply for inbound activity. Spam can also be used for phishing attempts. Electronic eavesdropping on phone calls, messages, and other wirelessly transmitted information is possible through various techniques. Installing spy software on a device to collect and forward data elsewhere, including conversations captured via a built-in microphone, is perhaps the most direct means, but other components of a communications network, including the airwaves, are possible avenues for exploitation. Location tracking services allow the whereabouts of registered cell phones to be known and monitored. While it can be done openly for legitimate purposes, it may also take place surreptitiously. It is also possible to create a clone of certain phones that can masquerade as the original. Server-resident content, such as electronic mail maintained for a user by a network carrier as a convenience, may expose sensitive information

through vulnerabilities that exist at the server. These threats can be countered by using authentication, encryption and temporary identification numbers ensuring the privacy and anonymity of the systems users as well as safeguarding the system against fraudulent use. Some of the existing privacy and security aware mobile phone sensing systems use authentication, encryption and cryptographic techniques (shown in Table V) to confront the above mentioned attacks and threats. In [56] the authors have described three main issues with mobile phone social networking systems which include direct anonymity issues, indirect or k-anonymity issues and eavesdropping, spoofing, replay and wormhole attacks. They have also implemented a system called Identity Server for resolving anonymity problems and countering other attacks.

Although the existing security solutions for mobile phone sensing systems have promising results of forwarding the data securely and without compromising users security and privacy, there is still a need for more and better security and privacy of health monitoring and social networking systems. In case of health monitoring systems, the information about the users health status has to remain secure and should not be allowed to be disclosed to anyone besides to systems wearer and to the physicians who are supervising the user. Users private information also needs to be secured when there is social interaction using mobile social networks. In building novel and effective security solutions, the developers must consider the following needs and challenges [57]. Firstly, the security solutions must be implemented in an energy saving approach by keeping in mind the feature of mobile phones that they have limited battery life and operation time. Secondly, the limited computing capability and processing power of mobile devices restrict the applications of many existing complex security solutions, which require heavy processors. Thirdly, the restricted size of screen and keyboard restricts the input and output capabilities of mobile phones, which cause some security related applications, for example, password protection may not be easy for mobile users. Fourthly, mobile security technologies and solutions must be implemented with a higher portability to address interoperation issues, since mobile devices may be equipped with different mobile platforms and operation environments.

VII. CONCLUSION

This paper reviewed the state of the art in research and development of Mobile Phone Sensing Systems. Smart Phones are getting smarter because of all the sensors being added to them. It is shown that the current status of Smart Phone sensors have the potential to revolutionize various fields of human life. In-built mobile phone sensors have many such capabilities that can improve peoples lives cutting down the time it takes to find things, to prevent people from getting lost, improve health conditions, and even more serious applications are emerging that could actually save lives. Security and privacy is one of the utmost issue that needs more attention while developing mobile phone sensing systems as when Mobile phone is used for social interactions users main concern is to secure their private data. However, this study highlights the fact that there are still a lot of challenges and issues that need to be resolved for mobile phone sensing systems to become more applicable to real-life situations and spawn further research in this area.

REFERENCES

[1] X. Bao and R. Roy Choudhury, "Movi: mobile phone based video highlights via collaborative sensing," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*, ser. MobiSys '10. New York, NY, USA: ACM, 2010, pp. 357–370. [Online]. Available: http://doi.acm.org/10.1145/1814433.1814468

[2] R. K. Rana, C. T. Chou, S. S. Kanhere, N. Bulusu, and W. Hu, "Ear-phone: an end-to-end participatory urban noise mapping system," in *Proceedings of the 9th ACM/IEEE International Conference on Information Processing in Sensor Networks*, ser. IPSN '10. New York, NY, USA: ACM, 2010, pp. 105–116. [Online]. Available: http://doi.acm.org/10.1145/1791212.1791226

[3] K. Sha, G. Zhan, W. Shi, M. Lumley, C. Wiholm, and B. Arnetz, "Spa: a smart phone assisted chronic illness self-management system with participatory sensing," in *Proceedings of the 2nd International Workshop on Systems and Networking Support for Health Care and Assisted Living Environments*, ser. HealthNet '08. New York, NY, USA: ACM, 2008, pp. 5:1–5:3. [Online]. Available: http://doi.acm.org/10.1145/1515747.1515755

[4] T. Denning, A. Andrew, R. Chaudhri, C. Hartung, J. Lester, G. Borriello, and G. Duncan, "Balance: towards a usable pervasive wellness application with accurate activity inference," in *Proceedings of the 10th workshop on Mobile Computing Systems and Applications*, ser. HotMobile '09. New York, NY, USA: ACM, 2009, pp. 5:1–5:6. [Online]. Available: http://doi.acm.org/10.1145/1514411.1514416

[5] C. Gao, F. Kong, and J. Tan, "Healthaware: Tackling obesity with health aware smart phone systems," in *Robotics and Biomimetics (ROBIO), 2009 IEEE International Conference on*, dec. 2009, pp. 1549 –1554.

[6] N. Oliver and F. F. Mangas, "Healthgear: Automatic sleep apnea detection and monitoring with a mobile phone," *Journal of Communications*, March 2007.

[7] Z. Jin, J. Oresko, S. Huang, and A. Cheng, "Hearttogo: A personalized medicine technology for cardiovascular disease prevention and detection," in *Life Science Systems and Applications Workshop, 2009. LiSSA 2009. IEEE/NIH*, april 2009, pp. 80 –83.

[8] J. Dai, X. Bai, Z. Yang, Z. Shen, and D. Xuan, "Perfalld: A pervasive fall detection system using mobile phones," in *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on*, 29 2010-april 2 2010, pp. 292 –297.

[9] G. Chen, B. Yan, M. Shin, D. Kotz, and E. Berke, "Mpcs: Mobile-phone based patient compliance system for chronic illness care," in *Mobile and Ubiquitous Systems: Networking Services, MobiQuitous, 2009. MobiQuitous '09. 6th Annual International*, july 2009, pp. 1 – 7.

[10] X. Chen, C. Ho, E. Lim, and T. Kyaw, "Cellular phone based online ecg processing for ambulatory and continuous detection," in *Computers in Cardiology, 2007*, 30 2007-oct. 3 2007, pp. 653 –656.

[11] P. Mohan, V. N. Padmanabhan, and R. Ramjee, "Nericell: rich monitoring of road and traffic conditions using mobile smartphones," in *Proceedings of the 6th ACM conference on Embedded network sensor systems*, ser. SenSys '08. New York, NY, USA: ACM, 2008, pp. 323–336. [Online]. Available: http://doi.acm.org/10.1145/1460412.1460444

[12] A. Thiagarajan, L. Ravindranath, K. LaCurts, S. Madden, H. Balakrishnan, S. Toledo, and J. Eriksson, "Vtrack: accurate, energy-aware road traffic delay estimation using mobile phones," in *Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems*, ser. SenSys '09. New York, NY, USA: ACM, 2009, pp. 85–98. [Online]. Available: http://doi.acm.org/10.1145/1644038.1644048

[13] P. Mohan, V. N. Padmanabhan, and R. Ramjee, "Trafficsense: Rich monitoring of road and traffic conditions using mobile smartphones," Tech. Rep. no. MSR-TR-2008-59, April 2008.

[14] R. Herring, A. Hofleitner, D. Work, O.-P. Tossavainen, and A. M. Bayen, "Mobile millennium - participatory traffic estimation using mobile phones," in *CPS Forum, Cyber-Physical Systems Week 2009*, San Francisco, CA, April 2009.

[15] D. G. Georgios Adam and I. Oikonomidis, "Tarifa: Traffic and abnormalities road instructor for anyone," in *2nd Student Workshop on Wireless Sensor Networks*, Athens, Greece, October 2009.

[16] L. Deng and L. P. Cox, "Livecompare: grocery bargain hunting through participatory sensing," in *Proceedings of the 10th workshop on Mobile Computing Systems and Applications*, ser. HotMobile '09. New York, NY, USA: ACM, 2009, pp. 4:1–4:6. [Online]. Available: http://doi.acm.org/10.1145/1514411.1514415

[17] S. Sehgal, S. S. Kanhere, and C. T. Chou, "Mobishop: Using mobile phones for sharing consumer pricing information," in *In Demo Session of the Intl. Conference on Distributed Computing in Sensor Systems*, Santorini, Greece, June 2008.

[18] Y. F. Dong, L. Blazeski, D. Sullivan, S. Kanhere, C. T. Chou, and N. Bulusu, "Petrolwatch: Using mobile phones for sharing petrol prices," in *The 7th Annual International Conference on Mobile Systems, Applications and Services*, Krakw, Poland, June 2009.

[19] M. Mun, S. Reddy, K. Shilton, N. Yau, J. Burke, D. Estrin, M. Hansen, E. Howard, R. West, and P. Boda, "Peir, the personal environmental impact report, as a platform for participatory sensing systems research," in *Proceedings of the 7th international conference on Mobile systems, applications, and services*, ser. MobiSys '09. New York, NY, USA: ACM, 2009, pp. 55–68. [Online]. Available: http://doi.acm.org/10.1145/1555816.1555823

[20] N. Maisonneuve, M. Stevens, M. E. Niessen, and L. Steels, "Noisetube: Measuring and mapping noise pollution with mobile phones," in *Information Technologies in Environmental Engineering*, ser. Environmental Science and Engineering, R. Allan, U. Frstner, and W. Salomons, Eds. Springer Berlin Heidelberg, 2009, pp. 215–228, 10.1007/978-3-540-88351-7_16. [Online]. Available: http://dx.doi.org/10.1007/978-3-540-88351-7_16

[21] M. Bilandzic, M. Banholzer, D. Peev, V. Georgiev, F. Balagtas-Fernandez, and A. De Luca, "Laermometer: a mobile noise mapping application," in *Proceedings of the 5th Nordic conference on Human-computer interaction: building bridges*, ser. NordiCHI '08. New York, NY, USA: ACM, 2008, pp. 415–418. [Online]. Available: http://doi.acm.org/10.1145/1463160.1463208

[22] E. Miluzzo, C. T. Cornelius, A. Ramaswamy, T. Choudhury, Z. Liu, and A. T. Campbell, "Darwin phones: the evolution of sensing and inference on mobile phones," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*, ser. MobiSys '10. New York, NY, USA: ACM, 2010, pp. 5–20. [Online]. Available: http://doi.acm.org/10.1145/1814433.1814437

[23] J. R. Kwapisz, G. M. Weiss, and S. A. Moore, "Activity recognition using cell phone accelerometers," *SIGKDD Explor. Newsl.*, vol. 12, no. 2, pp. 74–82, Mar. 2011. [Online]. Available: http://doi.acm.org/10.1145/1964897.1964918

[24] T. S. Parikh, "Cam: A mobile interaction framework for digitizing paper processes in the developing world," in *ACM Symposium on User Interface Software and Technology (UIST)*, Seattle, Washington, October 2005.

[25] A. Sashima, Y. Inoue, T. Ikeda, T. Yamashita, and K. Kurumatani, "Consorts-s: A mobile sensing platform for context-aware services," in *Intelligent Sensors, Sensor Networks and Information Processing, 2008. ISSNIP 2008. International Conference on*, dec. 2008, pp. 417 –422.

[26] C. Liao, Q. Liu, B. Liew, and L. Wilcox, "Pacer: fine-grained interactive paper via camera-touch hybrid gestures on a cell phone," in *Proceedings of the 28th international conference on Human factors in computing systems*, ser. CHI '10. New York, NY, USA: ACM, 2010, pp. 2441–2450. [Online]. Available: http://doi.acm.org/10.1145/1753326.1753696

[27] A. Beach, M. Gartrell, S. Akkala, J. Elston, J. Kelley, K. Nishimoto, B. Ray, S. Razgulin, K. Sundaresan, B. Surendar, M. Terada, and R. Han, "Whozthat? evolving an ecosystem for context-aware mobile social networks," *Network, IEEE*, vol. 22, no. 4, pp. 50 –55, july-aug. 2008.

[28] E. Miluzzo, N. Lane, S. Eisenman, and A. Campbell, "Cenceme: Injecting sensing presence into social networking applications," in *Smart Sensing and Context*, ser. Lecture Notes in Computer Science, G. Kortuem, J. Finney, R. Lea, and V. Sundramoorthy, Eds. Springer Berlin / Heidelberg, 2007, vol. 4793, pp. 1–28, 10.1007/978-3-540-75696-5_1. [Online]. Available: http://dx.doi.org/10.1007/978-3-540-75696-5_1

[29] N. Eagle and A. Pentland, "Social serendipity: mobilizing social software," *Pervasive Computing, IEEE*, vol. 4, no. 2, pp. 28 – 34, jan.-march 2005.

[30] A. Beach, M. Gartrell, B. Ray, and R. Han, "Secure socialaware: A security framework for mobile social networking applications," Department of Computer Science, University of Colorado, Boulde, Technical Report CU-CS-1054-09, June 2009.

[31] J. Burke, D. Estrin, M. Hansen, A. Parker, N. Ramanathan, S. Reddy, and M. B. Srivastava, "Participatory sensing," in *World Sensor Web Workshop, ACM Sensys 2006*, Boulder, Colorado, 2006.

[32] N. Bulusu, C. T. Chou, S. Kanhere, Y. Dong, S. Sehgal, D. Sullivan, and L. Blazeski, "Participatory sensing in commerce: Using mobile camera phones to track market price dispersion," in *Proceedings of the International Workshop on Urban, Community and Social Applications of Networked Sensing Systems - UrbanSense08, in conjunction with ACM SenSys 2008*, Raleigh, USA, Novermber 2008. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=?doi=10.1.1.139.6491

[33] N. D. Lane, S. B. Eisenman, M. Musolesi, E. Miluzzo, and A. T. Campbell, "Urban sensing systems: opportunistic or participatory?" in *Proceedings of the 9th workshop on Mobile computing systems and applications*, ser. HotMobile '08. New York, NY, USA: ACM, 2008, pp. 11–16. [Online]. Available: http://doi.acm.org/10.1145/1411759.1411763

[34] A. Campbell, S. Eisenman, N. Lane, E. Miluzzo, R. Peterson, H. Lu, X. Zheng, M. Musolesi, K. Fodor, and G.-S. Ahn, "The rise of people-centric sensing," *Internet Computing, IEEE*, vol. 12, no. 4, pp. 12 –21, july-aug. 2008.

[35] A. Campbell, T. Choudhury, S. Hu, H. Lu, M. K. Mukerjee, M. Rabbi, and R. D. Raizada, "Neurophone: brain-mobile phone interface using a wireless eeg headset," in *Proceedings of the second ACM SIGCOMM workshop on Networking, systems, and applications on mobile handhelds*, ser. MobiHeld '10. New York, NY, USA: ACM, 2010, pp. 3–8. [Online]. Available: http://doi.acm.org/10.1145/1851322.1851326

[36] E. Miluzzo, T. Wang, and A. T. Campbell, "Eyephone: activating mobile phones with your eyes," in *Proceedings of the second ACM SIGCOMM workshop on Networking, systems, and applications on mobile handhelds*, ser. MobiHeld '10. New York, NY, USA: ACM, 2010, pp. 15–20. [Online]. Available: http://doi.acm.org/10.1145/1851322.1851328

[37] H. Lu, W. Pan, N. D. Lane, T. Choudhury, and A. T. Campbell, "Soundsense: scalable sound sensing for people-centric applications on mobile phones," in *Proceedings of the 7th international conference on Mobile systems, applications, and services*, ser. MobiSys '09. New York, NY, USA: ACM, 2009, pp. 165–178. [Online]. Available: http://doi.acm.org/10.1145/1555816.1555834

[38] J. Hicks, N. Ramanathan, D. Kim, M. Monibi, J. Selsky, M. Hansen, and D. Estrin, "Andwellness: an open mobile system for activity and experience sampling," in *Wireless Health 2010*, ser. WH '10. New York, NY, USA: ACM, 2010, pp. 34–43. [Online]. Available: http://doi.acm.org/10.1145/1921081.1921087

[39] S. Consolvo, D. W. McDonald, T. Toscos, M. Y. Chen, J. Froehlich, B. Harrison, P. Klasnja, A. LaMarca, L. LeGrand, R. Libby, I. Smith, and J. A. Landay, "Activity sensing in the wild: a field trial of ubifit garden," in *Proceedings of the twenty-sixth annual SIGCHI conference on Human factors in computing systems*, ser. CHI '08. New York, NY, USA: ACM, 2008, pp. 1797–1806. [Online]. Available: http://doi.acm.org/10.1145/1357054.1357335

[40] P. Jarvinen, T. Jarvinen, L. Lahteenmaki, and C. Sodergard, "Hyperfit: Hybrid media in personal nutrition and exercise management," in *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, 30 2008-feb. 1 2008, pp. 222 –226.

[41] S. Reddy, A. Parker, J. Hyman, J. Burke, D. Estrin, and M. Hansen, "Image browsing, processing, and clustering for participatory sensing: lessons from a dietsense prototype," in *Proceedings of the 4th workshop on Embedded networked sensors*, ser. EmNets '07. New York, NY, USA: ACM, 2007, pp. 13–17. [Online]. Available: http://doi.acm.org/10.1145/1278972.1278975

[42] R. de Oliveira and N. Oliver, "Triplebeat: enhancing exercise performance with persuasion," in *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services*, ser. MobileHCI '08. New York, NY, USA: ACM, 2008, pp. 255–264. [Online]. Available: http://doi.acm.org/10.1145/1409240.1409268

[43] S. Gaonkar, J. Li, R. R. Choudhury, L. Cox, and A. Schmidt, "Micro-blog: sharing and querying content through mobile phones and social participation," in *Proceedings of the 6th international conference on Mobile systems, applications, and services*, ser. MobiSys '08. New York, NY, USA: ACM, 2008, pp. 174–186. [Online]. Available: http://doi.acm.org/10.1145/1378600.1378620

[44] E. Kanjo, S. Benford, M. Paxton, A. Chamberlain, D. Fraser, D. Woodgate, D. Crellin, and A. Woolard, "Mobgeosen: facilitating personal geosensor data collection and visualization using mobile phones," *Personal and Ubiquitous Computing*, vol. 12, pp. 599–

607, 2008, 10.1007/s00779-007-0180-1. [Online]. Available: http://dx.doi.org/10.1007/s00779-007-0180-1

[45] T. Das, P. Mohan, V. N. Padmanabhan, R. Ramjee, and A. Sharma, "Prism: platform for remote sensing using smartphones," in *Proceedings of the 8th international conference on Mobile systems, applications, and services*, ser. MobiSys '10. New York, NY, USA: ACM, 2010, pp. 63–76. [Online]. Available: http://doi.acm.org/10.1145/1814433.1814442

[46] S. B. Eisenman, E. Miluzzo, N. D. Lane, R. A. Peterson, G.-S. Ahn, and A. T. Campbell, "Bikenet: A mobile sensing system for cyclist experience mapping," *ACM Trans. Sen. Netw.*, vol. 6, no. 1, pp. 6:1–6:39, Jan. 2010. [Online]. Available: http://doi.acm.org/10.1145/1653760.1653766

[47] F. Sposaro and G. Tyson, "ifall: An android application for fall monitoring and response," in *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, sept. 2009, pp. 6119 –6122.

[48] K. K. Rachuri, M. Musolesi, C. Mascolo, P. J. Rentfrow, C. Longworth, and A. Aucinas, "Emotionsense: a mobile phones based adaptive platform for experimental social psychology research," in *Proceedings of the 12th ACM international conference on Ubiquitous computing*, ser. Ubicomp '10. New York, NY, USA: ACM, 2010, pp. 281–290. [Online]. Available: http://doi.acm.org/10.1145/1864349.1864393

[49] M. Klepal, M. Weyn, W. Najib, I. Bylemans, S. Wibowo, W. Widyawan, and B. Hantono, "Ols: opportunistic localization system for smart phones devices," in *Proceedings of the 1st ACM workshop on Networking, systems, and applications for mobile handhelds*, ser. MobiHeld '09. New York, NY, USA: ACM, 2009, pp. 79–80. [Online]. Available: http://doi.acm.org/10.1145/1592606.1592630

[50] C. Cornelius, A. Kapadia, D. Kotz, D. Peebles, M. Shin, and N. Triandopoulos, "Anonysense: privacy-aware people-centric sensing," in *Proceedings of the 6th international conference on Mobile systems, applications, and services*, ser. MobiSys '08. New York, NY, USA: ACM, 2008, pp. 211–224. [Online]. Available: http://doi.acm.org/10.1145/1378600.1378624

[51] L. P. Cox, A. Dalton, and V. Marupadi, "Smokescreen: flexible privacy controls for presence-sharing," in *Proceedings of the 5th international conference on Mobile systems, applications and services*, ser. MobiSys '07. New York, NY, USA: ACM, 2007, pp. 233–245. [Online]. Available: http://doi.acm.org/10.1145/1247660.1247688

[52] J. Shi, R. Zhang, Y. Liu, and Y. Zhang, "Prisense: Privacy-preserving data aggregation in people-centric urban sensing systems," in *INFOCOM, 2010 Proceedings IEEE*, march 2010, pp. 1 –9.

[53] J. Manweiler, R. Scudellari, and L. P. Cox, "Smile: encounter-based trust for mobile social services," in *Proceedings of the 16th ACM conference on Computer and communications security*, ser. CCS '09. New York, NY, USA: ACM, 2009, pp. 246–255. [Online]. Available: http://doi.acm.org/10.1145/1653662.1653692

[54] A. Kapadia, D. Kotz, and N. Triandopoulos, "Opportunistic sensing: Security challenges for the new paradigm," in *Communication Systems and Networks and Workshops, 2009. COMSNETS 2009. First International*, jan. 2009, pp. 1 –10.

[55] W. Jansen and K. Scarfone, *Guidelines on Cell Phone and PDA Security*. National Institute of Standards and Technology Special Publication 800-124, 2008.

[56] A. Beach, M. Gartrell, and R. Han, "Solutions to security and privacy issues in mobile social networking," in *Computational Science and Engineering, 2009. CSE '09. International Conference on*, vol. 4, aug. 2009, pp. 1036 –1042.

[57] N. Jobanputra, V. Kulkarni, D. Rao, and J. Gao, "Emerging security technologies for mobile user accesses," *The electronic Journal on E-Commerce Tools and Applications*, 2008.

Wazir Zada Khan is currently with School of Computer Science, Jazan University, Kingdom of Saudi Arabia. He received his MS in Computer Science from Comsats Institute of Information Technology, Pakistan. His research interests include network and system security, sensor networks, wireless and ad hoc networks. His subjects of interest include Sensor Networks, Wireless Networks, Network Security and Digital Image Processing, Computer Vision.
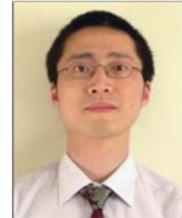
Dr. Yang Xiang received his PhD in Computer Science from Deakin University, Australia. He is currently with School of Information Technology, Deakin University. His research interests include network and system security, distributed systems, and networking. In particular, he is currently leading in a research group developing active defense systems against large-scale distributed network attacks. He is the Chief Investigator of several projects in network and system security, funded by the Australian Research Council (ARC). He has published more than 100 research papers in many international journals and conferences, such as IEEE Transactions on Parallel and Distributed Systems, IEEE Transactions on Information Security and Forensics, and IEEE Journal on Selected Areas in Communications. He has served as the Program/General Chair for many international conferences such as ICA3PP 12/11, IEEE/IFIP EUC 11, IEEE TrustCom 11, IEEE HPCC 10/09, IEEE ICPADS 08, NSS 11/10/09/08/07. He has been t4he PC member for more than 50 international conferences in distributed systems, networking, and security. He serves as the Associate Editor of IEEE Transactions on Parallel and Distributed Systems and the Editor of Journal of Network and Computer Applications. He is a member of the IEEE.

Dr. Mohammed Y Aalsalem is currently dean of e-learning and assistant professor at School of Computer Science, Jazan University. Kingdom of Saudi Arabia. He received his PhD in Computer Science from Sydney University. His research interests include real time communication, network security, distributed systems, and wireless systems. In particular, he is currently leading in a research group developing flood warning system using real time sensors. He is Program Committee of the International Conference on Computer Applications in Industry and Engineering, CAINE2011. He is regular reviewer for many international journals such as King Saud University Journal (CCIS-KSU Journal).

Quratulain Arshad received her BS in Computer Science from Comsats Institute of Information Technology, Pakistan. Her research interests include network security, trust and reputation in sensor networks and ad hoc networks. Her subjects of interest include Network Security, Digital Image Processing and Computer Vision.