CrowdSourcing: State of the Art Review

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Abstract

In this state-of-the-art survey, we tries to give an overview of crowdsourcing systems with special focus on mobile crowdsourcing applications and their potential in practices. We discuss a number of leading application areas, services, key challenges, new paradigms that have emerged in the literature recently.

Contents

1 Introduction

The art of collecting information and work from the crowd is not new, but with the emergence and help of web and mobile technologies, it has grown in unprecedented scale. Crowdsourcing is based on a simple but powerful concept: Virtually anyone has the potential to plug in valuable information [17]. In essence, we can say that a crowdsourcing system enlists and utilizes a crowd of users to collaborate to build a system that is beneficial to the whole community. In other words, we can say that crowdsourcing systems try to utilize a multitude of humans (and possibly their devices) to help sovle a wide variety of problems. In fact, as is typical for an emerging area, this kind of systems has appeared under many names, including peer production, user-powered systems, user-generated content, collaborative systems, community systems, social systems, collective intelligence, crowd wisdom, human computing, and assumably many more. The collaboration can be either explicit or implicit, which results in different kinds of systems respectively. Since the main sources of information and knowledge are gathered from human beings directly or indirectly through their devices, crowdsourcing systems face many human-centric challenges such as privacy, trust, security as well as the users habits, willingness to participate (incentive issues).

The integration of sensing and embedded everyday computing devices at the edge of the Internet will result in the evolution of an embedded Internet of Things (IoT). As an example, many of today's mobile devices and their corresponding sensing capabilities are available . As a result, in mobile crowdsourcing system, the challenges involves many new aspects as well, e.g. sensing capabilities and preciseness, localized analytics capabilities, resource limitations, data integrity, aggregate analytics and architecture for such a system to be materialized [15].

As mentioned, sensing capability of mobile devices proved to be the key in the success of mobile croudsensing system. Consequently, this state-of-the-art survey will pay special attention in discussing these capabilities of the mobile devices in a mobile croudsoucing system and the challenges emerged with in different circumstances. Today's smartphone not only serves as the key computing and communication mobile device of choice, but it also comes with a rich set of embedded sensors, such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera [25]. Collectively, these sensors are enabling new applications across a wide variety of domains, such as healthcare, social networks, safety, environmental monitoring, and transportation, and give rise to a new area of research called mobile phone sensing. Until recently mobile sensing research such as activity recognition, where people's activity (e.g., walking, driving, sitting, talking) is classified and monitored, required specialized mobile devices (e.g., the Mobile Sensing Platform (MSP)) to be fabricated. Mobile sensing applications had to be manually downloaded, installed, and hand tuned for each device. User studies conducted to evaluate new mobile sensing applications and algorithms were small-scale because of the expense and complexity of doing experiments at scale. As a result the research, which was innovative, gained little momentum outside a small group of dedicated researchers. Although the potential of using mobile phones as a platform for sensing research has been discussed for a number of years now, in both industrial and research communities, there has been little or no advancement in the field until recently. All that is changing because of a number of important technological advances. First, the availability of cheap embedded sensors initially included in phones to drive the user experience (e.g., the accelerometer used to change the display orientation) is changing the landscape of possible applications. Now phones can be programmed to support new disruptive sensing applications such as sharing the user's real-time activity with friends on social networks such as Facebook, keeping track of a person's carbon footprint, or monitoring a user's well being. Second, smartphones are open and programmable. In addition to sensing, phones come with computing and communication resources that offer a low barrier of entry for third-party programmers (e.g., undergraduates with little phone programming experience are developing and shipping applications). Third, importantly, each phone vendor now offers an application store allowing developers to deliver new applications to large populations of users across the globe, which is transforming the deployment of new applications, and allowing the collection and analysis of data far beyond the scale of what was previously possible. Fourth, the mobile computing cloud enables developers to offload mobile services to back-end servers, providing unprecedented scale and additional resources for computing on collections of large-scale sensor data and supporting advanced features such as persuasive user feedback based on the analysis of big sensor data. The combination of these advances opens the door for new innovative research and will lead to the development of sensing applications that are likely to revolutionize a large number of existing business sectors and ultimately significantly impact our everyday lives. Many questions remain to make this vision a reality. For example, how much intelligence can we push to the phone without jeopardizing the phone experience? What breakthroughs are needed in order to perform robust and accurate classification of activities and context out in the wild? How do we scale a sensing application from an individual to a target community or even the general population? How do we use these new forms of largescale application delivery systems (e.g., Apple AppStore, Google Market) to best drive data exploit the availability of big data shared by applications but build watertight systems that protect personal privacy? While this new research field can leverage results and insights from wireless sensor networks, pervasive computing, machine learning, and data mining, it presents new challenges not addressed by these communities.

In additon to sensing issue, we this survey also tries to discuss the issue of processing (local analytics) and aggregating (aggregation analytics) the sensed data and how to make the best out of them to produce useful application and services. As computing involved in a mobile device, resource limitations will also be properly addressed. Issues with privacy, trust, security will be discussed in detail as key challenges for mobile crowdsourcing systems.

1.1 Example Applications

Smart dialing The goal is to share users' availability for answering a call. This information is an enriched presence, e.g., user is driving, on a meeting, etc. Similar use cases are in [38].

Traffic state Traffic state for driving: collecting and distributing road conditions [38].

Grassroots Sensing of Pollution Sources Sensing diesel truck traffic on residential road by local residents [16].

Climate change Supporting evidence that a changing climate is affecting our ecosystems [16].

Personal health monitoring in elder-care to provide information to elders, their family and doctors about changes in lifestyle, which is an early warning of diminishing health [16].

Bike commutation sensing and distributing road and path availability, air quality, traffic and accidents, bright sunlight, etc. that all affect the quality of the ride [16].

Campus sensing and actuation In [31] the authors created a Sensor Andrew architecture for campus wide sensing and actuation (see Sec. 2.3.2). They explored applications for collecting occupancy-correlated energy usage patterns and detecting energy anomalies.

1.2 Definitions

The term *crowdsourcing* was initially used by Jeff Howe and Mark Robinson in 2006 for describing a new web-based, distributed problem-solving and production model that has emerged in recent years. Howe offers the following definition:

"Crowdsourcing is the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call."[21]

Similarly, *participatory sensing* will task deployed mobile devices to form interactive, participatory sensor networks that enable public and professional users to gather, analyze and share local knowledge[4, 16]. Later, Goldman et al. have also described participatory sensing in [16] as the process of citizens and community groups to sense and document their life where they live, work and plan.

Finally, *urban sensing* is defined where mobile users continuously gather, process, and share location-sensitive sensor data (e.g., street images, road condition, traffic ow). The key enablers of urban sensing are the smartphones (e.g., iPhones and Android phones) equipped with onboard sensors (e.g., cameras, accelerometer, compass, GPS) and various wireless devices (e.g., WiFi and 2/3G). [1]

1.3 Structure

In this state-of-the-art survey, we tries to give an overview of crowdsourcing systems with special focus on mobile crowdsourcing applications and their potential in practices. We discuss a number of leading application areas, services, key challenges, new paradigms that have emerged in the literature recently.

The rest of this document is structured as follows: In Sec. 2 we introduce frameworks, protocols and architectures and in Sec. 3 we discuss crowdsourcing related services. In Sec. 4 we list key challenges of crowdsourcing and finally we conclude our work in Sec. 5.

2 Frameworks, Protocols and Architectures

2.1 Automated sensing

In [38] the authors discussed the challenges for automated sharing. They identified the following issues to be solved in this context:

- Resource management: to balance between the need of continuous sensing and transmission versus the devices' recourse consumption (e.g., battery, bandwidth use). Approaches to solve the problem includes profiling based on historic usage patterns to estimate use and next charging opportunities; use of policies and priorities to alter the frequency of sensing bases on resource levels; policies to optimize transmissions (e.g., buffering, preferred network types, etc).
- Access control: sensing involves the collection of personal data, which users might mind sharing with others. The sensitivity to sharing personal data usually depends on who we share with. Therefore, fine grained access (sharing) control is necessary with low cognitive load on the user. This later part is very difficult and systems typically do a bad job on this.
- Data transformation: to present useful information to users from the collected raw data. Methods involve data mining, aggregation and service/application specific analytics.

2.2 Social networks and XMPP

2.2.1 Social Backbone (SBone)

Social Backbone (SBone) in [38, 40] is based on the XMPP protocol and the Jabberd2 XMPP server. They chose the XMPP platform since the protocol provides mechanisms for naming, presence and messaging. They implemented two applications of the SBone platform, the SmartDial and RoadSense. They did not provide any performance analysis on the client/server protocols.

2.2.2 Buddycloud

Buddycloud [8] is a new architectural concept to social networking, whereby user communities run and control their own buddycloud server. These servers are connected into a federation, but user groups are allowed to have full control of their social environment unlike in centralized approaches. This results in an open and distributed social network. In the heart of the buddycloud architecture is the XMPP protocol [34] (see Fig. 2).

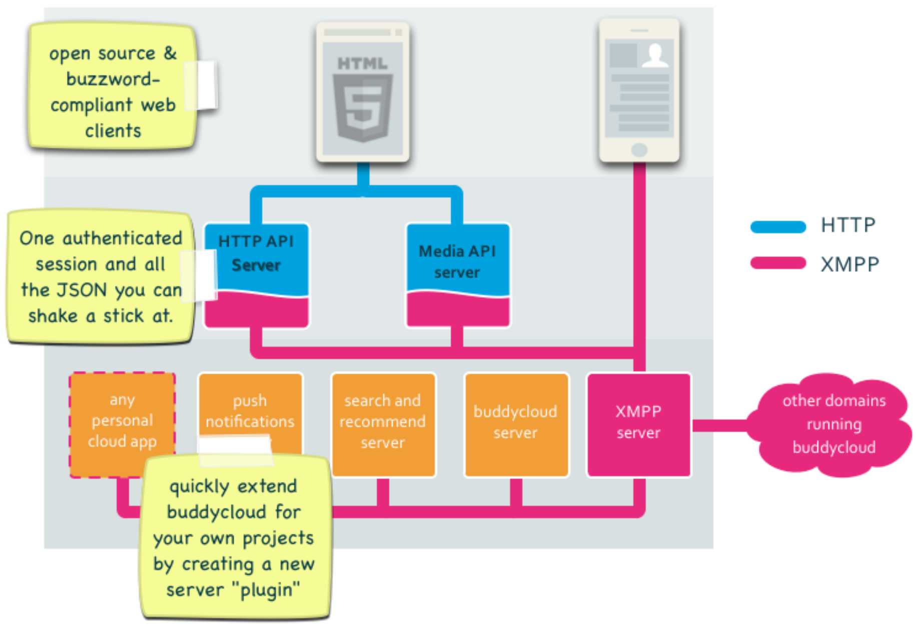

Figure 1: BuddyCloud architecture

2.2.3 OneSocialWeb

OneSocialWeb[19] came to life with a dream of connecting all social networks together in One Social Web. Their primarily goal was to define a language to bridge these social networks hence enabling federation of server. They started to use XMPP for this bridging language/protocol, and built an experimental prototype. They supported their choice of XMPP based on the following grounds:

- social networking is similar in communication needs to instant messaging;
- XMPP is a standardized;
- XMPP tackles basic security issues;
- push based, real-time operation;
- XMPP is already a kind of social network on its own for instant messaging.

2.2.4 Ushahidi

Ushahidi[42] is platform which uses multiple channels to crowd-source information including Twitter, email, SMS and the Web. This open source software platform enables volunteers to map everything from local events to globally relevant incidents. When an event occurs a volunteer sends a brief report via the Web or text message and the software annotates it with time and location information. Thus, the platform provides powerful geographical mapping tools, but unfortunately it does not handle automatically the built-in smartphone sensors.

2.3 Sensing frameworks

2.3.1 Funf

Funf[26] is yet another approach to create open frameworks from the scratch for crowd-sourced data collection and smart city services. Funf defines an extensible sensing and data processing framework for mobile devices. It provides an open source, reusable set of functionalities, enabling the collection, uploading and configuration of different data types. Funf is using probes as basic data collection objects. These probes can be remotely configured and collect on-phone sensor and many other types of data, such as application usage or browsing history.

Figure 2: Funf architecture

2.3.2 Sensor Andrew: large scale campus sensing

Sensor Andrew[31] is an infrastructure for Internet-scale sensing and actuation across a wide range of heterogeneous devices designed to facilitate application development developed at the Carnegie Mellon University. The core of their architecture is the XMPP protocol, which is used as an unifying communication layer. Sensor Andrew is focused on how to bring sensors and actuators into this architecture.

2.4 Internet of Things

Kirsche and Klauck in [24] have proposed to bring XMPP into the Internet of Things. For the same reason to have a unifying protocol architecture, they have investigated whether XMPP can be used in embedded systems. They concluded with experiments that XMPP can be minimized to run on resource constrained devices and being able to communicate with full fledged clients. Based on their results it will be possible to not only bring smartphone based sensing into the common platform of XMPP, but also smart objects.

2.5 Publish-Subscribe interaction schemes

Eugster et al. in [13] analyzed the different faces publish-subscribe interaction schemes. A reference model of the publish-subscribe interaction model can be seen in Fig. 3. The argue, that the strength of the publish-subscribe scheme lies in the full decoupling in *time*, *space* and *synchronization* between *publishers* and *subscribers*.

space Neither publishers nor subscribers (necessarily) know about each others. Events pass through indirectly between publishers and subscribers through the event services (act as a proxy).

time Publishers and subscribers do not need to be actively participating in the interaction at the same time.

synchronization Neither parties are blocked by any interaction; subscribers are asynchronously notified of the occurrence of events while dealing with their other activities. Production and consumption do not happen in the main flow of control.

3 Crowdsourcing-based Services

3.1 Services for Smart Cities

Smart city visions have been around for quite some time but they are yet to be realized in their full potential. Pervasive computing technologies can enable very flexible situated collaboration patterns among citizens and, via crowdsourcing, can promote a participatory way of contributing to the wealth and quality of life of our urban environments, such as smart cities. The work presented in [43] firstly sketches a future vision of pervasive computing rich and crowdsourcing-enabled urban environments. Then, it presents several case studies showing how such environments can be of great use and highly impactful from both the individual and societal viewpoint. Finally, it discusses several open research challenges to be faced for these ideas to become reality.

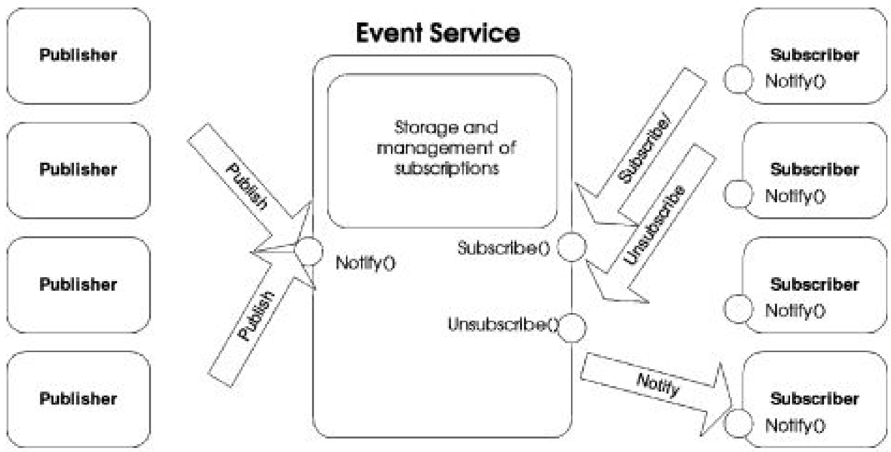

Figure 3: Publish-subscribe interaction scheme

3.1.1 Location/Positioning Services

Location-based services are growing in popularity due to the ubiquity of smartphone users. The relevance of location-based query results is very important, especially for mobile phones with limited form factor. Location-based data is real-time and highly dynamic; this introduces challenges in indexing and ranking places. The growing popularity of mobile social networks, such as Twitter, FourSquare and Facebook Places, presents an opportunity to leverage user interactions on these networks to build better location-based services. In [39] , the authors presented SocialTelescope, a location-based service that automatically compiles, indexes and ranks locations, based on user interactions with locations in mobile social networks. They implemented their system as a location-based search engine that uses geo-tweets by Twitter users to learn about places. They then evaluated the coverage and relevance of their system by comparing it against current state-of-the-art approaches including page-rank (Google Local Search), expert-based (Zagat) and user-review based (Yelp). Their results showed that a crowdsourced location-based service returns results that are at least as relevant as those returned by current approaches, at a substantially lower cost.

Location is rapidly becoming the next "killer application" as location-enabled mobile handheld devices proliferate. One class of applications that has yet-to-emerge are those in which users have an incentive to lie about their location. These applications cannot rely solely on the users' devices to discover and transmit location information because users have an incentive to cheat. Instead, such applications require their users to prove their locations. Unfortunately, today's mobile users lack a mechanism to prove their current or past locations. Consequently, these applications have yet to take off despite their potential. In [36], the authors presented a simple mechanism that enables the emergence of mobile applications that require p̈roofőf a userś location. A location proof is a piece of data that certifies a receiver to a geographical location. Location proofs are handed out by the wireless infrastructure (e.g., a Wi-Fi access point or a cell tower) to mobile devices. The relatively short range of the wireless radios ensures that these devices are in physical proximity to the wireless transmitter. As a result, these devices are capable of proving their current or past locations to mobile applications. They described a mechanism to implement location proofs. They also presented a set of six future applications that require location proofs to enable their core functionality.

Urban sensing where mobile users continuously gather, process, and share location-sensitive sensor data (e.g., street images, road condition, traffic flow) is emerging as a new network paradigm of sensor information sharing in urban environments. The key enablers are the smart phones (e.g., iPhones and Android phones) equipped with onboard sensors (e.g., cameras, accelerometer, compass, GPS), and various wireless devices (e.g., WiFi and 2/3G). In [1], the authors designed a scalable sensor networking platform where millions of users on the move can participate in urban sensing and share location-aware information using always-on cellular data connections. They proposed a two-tier sensor networking platform called GeoServ where mobile users publish/access sensor data via an Internet-based distributed P2P overlay network. The main contribution of their work is two-fold: a location-aware sensor data retrieval scheme that supports geographic range queries, and a location-aware publish-subscribe scheme that enables efficient multicast routing over a group of subscribed users. They proved that GeoServ protocols preserve locality and validate their performance via extensive simulations.

3.1.2 Road Traffic Management Services

It should be mentioned that there is a close link between location-based services and services for smart management of public transportation systems. Public transportation is an environment with great potential for applying location-based services through mobile devices. In [14], the authors provided the underpinning rationale for research that will be looking at how the real-time passenger information system deployed by the Translink Transit Authority across all of South East Queensland in Australia can provide a core platform to improve commuters' user experiences. This system relies on mobile computing and GPS technology to provide accurate information on transport vehicle locations. The proposal builds on this platform to inform the design and development of innovative social media, mobile computing and geospatial information applications. The core aim is to digitally augment the public transport environment to enhance the user experience of commuters for a more enjoyable journey.

Intelligent transportation systems increasingly depend on probe vehicles to monitor traffic: they can automatically report position, travel time, traffic incidents, and road surface problems to a telematics service provider In [20]. This kind of traffic-monitoring system could provide good coverage and timely information on many more roadways than is possible with a fixed infrastructure such as cameras and loop detectors. This approach also promises significant reductions in infrastructure cost because the system can exploit the sensing, computing, and communications devices already installed in many modern vehicles. This architecture separates data from identities by splitting communication from data analysis. Data suppression techniques can help prevent data mining algorithms from reconstructing private information from anonymous database samples.

In [32], the authors described the technical challenges in utilizing mobile crowdsourcing in vehicular ad-hoc networks, pointed out relevant research directions, and outlined possible starting points for solutions. In the context of vehicular ad-hoc networks $VANETs$, a number of highly promising convenience applications have been proposed. These include collecting and distributing information on the traffic situation, distributed monitoring of road and weather conditions, and finding available parking places in a distributed, cooperative manner. Unfortunately, all of these applications face major problems when a VANET is used as a means to distribute the required information. In particular a large number of vehicles needs to be equipped with dedicated VANET technology before these applications can provide a useful service. Even if customers were willing to purchase a system which is not immediately useful, it would still take quite some time until the required density of equipped cars is reached. In contrast, affordable always-on mobile Internet access is already mainstream. Such Internet connectivity could be used to build the proposed applications in a different fashion: by using peer-to-peer communication, essentially creating a peer-to-peer network of cars sharing traffic information. This allows to overcome the limitations of VANETs, while it preserves their key benefits of decentralization and robustness.

Urban sensing where mobile users continuously gather, process, and share location-sensitive sensor data (e.g., street images, road condition, traffic flow) is emerging as a new network paradigm of sensor information sharing in urban environments. The key enablers are the smart phones (e.g., iPhones and Android phones) equipped with onboard sensors (e.g., cameras, accelerometer, compass, GPS), and various wireless devices (e.g., WiFi and 2/3G). The goal of this paper is to design a scalable sensor networking platform where millions of users on the move can participate in urban sensing and share location-aware information using always-on cellular data connections. In [1]. the authors proposed a two-tier sensor networking platform called GeoServ where mobile users publish/access sensor data via an Internet-based distributed P2P overlay network. The main contribution of their work is two-fold: a location-aware sensor data retrieval scheme that supports geographic range queries, and a location-aware publish-subscribe scheme that enables efficient multicast routing over a group of subscribed users. They proved that GeoServ protocols preserve locality and validate their performance via extensive simulations.

Future scenarios for the transport sector are increasingly confronted with the finite nature of fossil-based resources (petrol, natural gas) and an urgent need for reductions of negative transport-related effects (CO2 and other exhaust emissions, noise, land consumption). In view of limited technical advances and efficiency improvements, along with growing traffic volumes, behavioural changes towards more sustainable travel futures have attained a crucial importance. In [28], the authors discussed initial results from a 2-year project (funded by the British Economic and Social Research Council ESRC) which aims to develop the notion of sustainability-related mobility as a context for applying targeted social marketing policies to specific population segments. Based on ten focus group discussions and a survey of more than 1500 participants in the South West of England, two segmentation approaches are used to identify gaps between different domains of individual travel behaviour and the varying role of attitudes for travel decisions. The results demonstrated the usefulness and limitations of existing segmentation approaches and underline the need for more complex and comprehensive mobility style frameworks as basis for measures aiming at behavioural change towards sustainable mobility.

In [33], the authors proposed a traffic information system based on the distribution of knowledge provided by the cars themselves. Prior work in this area attempted to realize this distribution via vehicular ad-hoc networks, i.e., by direct communication between cars. Such an approach faces serious problems due to capacity constraints, high data dissemination latencies, and limited initial deployment of the required technology. In this work, the authors presented a solution that is not based on ad-hoc networking, but is still fully decentralized. It establishes a peer-to-peer overlay over the Internet, using cellular Internet access. We present a structure for the overlay, a prototype implementation in a simulation environment, and results that underline the feasibility of such a system in a city scenario. They also provided an estimate of expected user benefits when our system is used for dynamic route guidance.

In [37], the authors developed a deeper understanding of the research on climate change mitigation in transport. They suggested that work to date has focused on the effects of improvements in transport technologies, changes in the price of transport, physical infrastructure provision, behavioural change and alternative institutional arrangements for governing transport systems. In terms of research methodologies, positivist and quantitative analysis prevails, although there are signs of experimentation with non-positivist epistemologies and participatory methods. These particular engagements with climate change mitigation reflect mutually reinforcing tendencies within and beyond the academic transport community. They first drawed on a revised version of Thomas Kuhn's philosophy of science to explore the path dependencies within transport studies, which are at least partly responsible for the predisposition towards quantitative modelling and technology, pricing and infrastructure oriented interventions in transport systems. We then employ the governmentality perspective to examine how transport academics engagements with climate change mitigation depend on and align with more general understandings of climate change in UK society and beyond. The analysis makes clear that ecological modernisation and neoliberal governmentality more generally provide the context for the current focus on and belief in technological, behaviour change, and especially market-based mitigation strategies.

3.2 Environmental Services

There is a strong link between human commuting habits, road traffic management and the environment. In particular, in developed nations a growing emphasis is being placed on the promotion of environmental behaviours amongst individuals, or citizen-consumers, as a means to reduce personal carbon emissions in the light of climate change. Within the UK, focus has tended towards the segmentation of consumers into lifestyle groups and the subsequent development of so-called social marketing behaviour change strategies, promoted as a way to encourage environmental behaviours. In the context of travel and tourism research, this approach has been operationalised through the notion of mobility styles as a way of understanding the motivations and barriers different groups of consumers face when making pro-environmental travel decisions. However, this paper argues that the issue of climate change presents a major challenge for those attempting to promote behavioural changes using a single mobility styles approach because of the ways in which issues such as climate change transcends the spatial and motivational contexts for travel behaviours. Using data gathered as part of a UK-based project on sustainable travel, the work in [3] demonstrated the potential conflicts that emerge when exploring daily travel behaviour and travel for short-breaks and holidays using a single mobility styles approach. The authors argued that the discord between daily and holiday travel raises important questions for adopting a single and sptatial mobility styles approach for promoting behaviour change. This in turn highlights the challenges faced by a wider community of both researchers and policy makers in the environmental social sciences who seek to use segmentation as the basis for understanding and promoting behavioural change. Again on the relation between the transport sector and the environment, future scenarios for the transport sector are increasingly confronted with the finite nature of fossil-based resources (petrol, natural gas) and an urgent need for reductions of negative transport-related effects (CO2 and other exhaust emissions, noise, land consumption), [28], as discussed also in previous section.

In addition, the authors in [6] examined the influence that the provision of environmental information might be able to make on personal travel behaviour through analysis of the views of members of the public expressed in a study for the UK Department for Transport on attitudes towards carbon calculator tools. A three-stage qualitative survey taking an ideographic approach to analysing public attitudes to the use of carbon calculator tools in relation to making transport decisions. With respect to methodology, interviews and discussion groups with stakeholders, non-users and users providing extensive data that were analysed using the British Market Research Bureau's matrix mapping methodology. Despite considerable awareness of climate change as an issue, personal carbon emissions were not found to have much influence on personal transport choice, which could be seen as being dominated by issues of cost (both in time and money), comfort and convenience. The spatial and temporal dislocation of the cause and effects of climate change make it difficult to link the impacts of personal travel behaviour with specific activities. If environmental- and health-based information is to be provided as a lever to change travel behaviour, it may be necessary to provide information on issues such as local air pollution and personal health impacts in order to link wider benefits with a travel user's self-interest.

Transport accounts for 26% of global CO2 emissions and is one of the few industrial sectors where emissions are still growing [5]. Car use, road freight and aviation are the principal contributors to greenhouse gas emissions from the transport sector and this review focuses on approaches to reduce emissions from these three problem areas. An assessment of new technologies including alternative transport fuels to break the dependence on petroleum is presented, although it appears that technological innovation is unlikely to be the sole answer to the climate change problem. To achieve a stabilisation of greenhouse gas emissions from transport, behavioural change brought about by policy will also be required. Pressure is growing on policy makers to tackle the issue of climate change with a view to providing sustainable transport. Although, there is a tendency to focus on long-term technological solutions, short-term behavioural change is crucial if the benefits of new technology are to be fully realised.

Environmental monitoring faces a variety of complex technical and socio-political challenges, particularly in the urban context. Data sources may be available, but mostly not combinable because of lacking interoperability and deficient coordination due to monolithic and closed data infrastructures. In [30], the authors presented the Live Geography approach that seeks to tackle these challenges with an open sensing infrastructure for monitoring applications. Our system makes extensive use of open (geospatial) standards throughout the entire process chain from sensor data integration to analysis, Complex Event Processing (CEP), alerting, and finally visualisation. They discussed the implemented modules as well as the overall created infrastructure as a whole. Finally, they showed how the methodology can influence the city and its inhabitants by making the abstract real, in other words how pervasive environmental monitoring systems can change urban social interactions, and which issues are related to establishing such systems.

The Personal Environmental Impact Report (PEIR) is a participatory sensing application that uses location data sampled from everyday mobile phones to calculate personalized estimates of environmental impact and exposure. It is an example of an important class of emerging mobile systems that combine the distributed processing capacity of the web with the personal reach of mobile technology. The work in [27] documents and evaluates the running PEIR system, which includes mobile handset based GPS location data collection, and server-side processing stages such as HMM-based activity classification (to determine transportation mode); 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. Additionally, we describe the user interface components of PEIR and present usage statistics from a two month snapshot of system use. The paper also outlines new algorithmic components developed based on experience with the system and undergoing testing for integration into PEIR, including: new map-matching and GSM-augmented activity classification techniques, and a selective hiding mechanism that generates believable proxy traces for times a user does not want their real location revealed.

This paper in [37] seeks to develop a deeper understanding of the research on climate change mitigation in transport. The authors suggest that work to date has focused on the effects of improvements in transport technologies, changes in the price of transport, physical infrastructure provision, behavioral change and alternative institutional arrangements for governing transport systems. In terms of research methodologies, positivist and quantitative analysis prevails, although there are signs of experimentation with non-positivist epistemologies and participatory methods. These particular engagements with climate change mitigation reflect mutually reinforcing tendencies within and beyond the academic transport community. The authors first draw on a revised version of Thomas Kuhn's philosophy of science to explore the path dependencies within transport studies, which are at least partly responsible for the predisposition towards quantitative modelling and technology, pricing and infrastructure oriented interventions in transport systems. We then employ the governmentality perspective to examine how transport academics engagements with climate change mitigation depend on and align with more general understandings of climate change in UK society and beyond. The analysis makes clear that ecological modernisation and neo-liberal governmentality more generally provide the context for the current focus on and belief in technological, behaviour change, and especially market-based mitigation strategies. While current research trajectories are important and insightful, we believe that a deeper engagement with theoretical insights from the social sciences will produce richer understandings of transport mitigation in transport and briefly outline some of the contributions thinking on socio-technical transitions and practice theories can make.

4 Key Challenges

In essence, crowdsourcing systems, as many other systems "in the wild", face the key issue of carefully balancing openness and quality. This can be divided into a few challenges to make a successful crowdsourcing system.

Five key challenges can be identified that crowdsourcing systems face: How to recruit (and retain) contributors (incentive issues), what the contributors can do (e.g. localized analytics), how to combine their contributions (e.g. aggregate analytics), security, trust and privacy issues, and last but not least, resource limitations.

4.1 How to Recruit Contributors or Incentive Issues

In web-based crowdsourcing systems, users (humans) directly involve and contribute to the systems through the web. But even in mobile crowdsourcing systems, because devices are onwed and carried by individual users, humans are eventually involved in the loop. In such cases, on one hand, the intelligence and mobility of humans can be leveraged to help application collect high-quality or semantically complex data that might otherwise require sophisticated hardware and software. For example, human can easily identify available street parking spots and report with pictures or text messages, whereas an ultrasound based scanning system not only requires special hardware, but also sophisticated processing algorithms to ensure the reliability of data. On the other hand, humans naturally have privacy concerns and personal preferences that are not necessarily aligned with the end goals of the mobile crowdsourcing applications. The user may not want to share sensor data that contains or reveals private and sensitive information, such as their current location. These concerns, if not properly addressed, would pose difficulties in convincing and recruiting the contributors to join the systems.

Another important implication for human involvement is incentive because participating individuals (devices) may incur energy and/or monetary costs, or even explicit efforts by the owner of the device for censing, processing, and communicating desired data. Unless there are strong enough incentive, the owners may not be willing to contribute their resources. The question is then how to design incentive mechanisms to motivate the users to join (an stay in) the crowdsourcing systems.

4.2 What the Contributors Can Do or Localized Analytics

Contributors (possibly with the help of their devices) in crowdsourcing systems sense, collect data, and process the collected data make them available to different kinds of applications. In web-based crowdsourcing systems, the contributors are the users themselves (human beings), the information processing is usually simple in nature as we cannot expect much localized analytics here (would be cumbersome for the users). However, in machine-based crowdsourcing applications, in particular in mobile crowdsourcing applications, raw sensor data are collected on devices and processed by local analytics algorithms to produce consumable data for different applications. Various sensors such as GPS, accelerometer, microphone and camera are available on mobile devices. The operating systems allows applications to access the sensors and extract raw sensing data from them. However, depending on the nature of the raw data and the needs of applications, the physical reading from the sensors may not be suitable for the direct consumption of the applications. As a result, some local analytics performing certain primitive processing of the raw data on the devices are needed. They produce intermediate results, which are sent to the back-end for further processing and consumption. Furthermore, this task is important because raw data can be (very) large, and unnecessarily transfer very large amount of data over network would unnecessarily consume system resources. The tasks to be carried out at local analytics level include different categories. One category of functions is data mediation, such as filtering of outliers, elimination of noise, or filling in data gaps. For example, GPS samples acquired may not be accurate or missing, in which event outliers need to be eliminated or missing samples extrapolated. Another common category of functions is context inference, e.g. context related to transportation mode (whether the user is on a car, bus, train or on foot). Other examples include the kinetic modes of humans (walking, standing, jogging, running), the social settings (in a meeting, on a phone call, watching TV, etc.). The heuristics and algorithms used to carry out local analytics are usually application-specific. Hence, the exact algorithms used for context inference depend on the nature of the application and the characteristics of the context.

With the help of local analytics, croud-sourced real-time transit tracking can be made possible. Real-time transit tracking is gaining popularity as a means for transit agencies to improve the rider experience. However, many transit agencies lack either the funding or initiative to provide such tracking services. In [9], the authors described a crowd-sourced alternative to official transit tracking, which they call cooperative transit tracking. Participating users install an application on their smart-phone. With the help of built-in sensors, such as GPS, WiFi, and accelerometer, the application automatically detects when the user is riding in a transit vehicle. On these occasions (and only these), it sends periodic, anonymized, location updates to a central tracking server. The contributions of this work include an accelerometer-based activity classification algorithm for determining whether or not the user is riding in a vehicle, a memory and time-efficient route matching algorithm for determining whether the user is in a bus vs. another vehicle, a method for tracking underground vehicles, and an evaluation of the above on real-world data. By simulating the Chicago transit network, the authors showed that the proposed system would shorten expected wait times by 2 minutes with only 5% of transit riders using the system. At a 20% penetration level, the mean wait time is reduced from 9 to 3 minutes.

Another example showing the role of local analytics in mobile crowdsourcing applications can be seen in the design, implementation, evaluation, and user experiences of the CenceMe application [11], which represents the first system that combines the inference of the presence of individuals using off-the-shelf, sensor-enabled mobile phones with sharing of this information through social networking applications such as Facebook and MySpace. The work involves the design and tradeoffs of split-level classification, whereby personal sensing presence (e.g., walking, in conversation, at the gym) is derived from classifiers which execute in part on the phones and in part on the backend servers to achieve scalable inference. Performance measurements that characterize the computational requirements of the software and the energy consumption of the CenceMe phone client are reported. The authors also validated the system through a user study where twenty two people, including undergraduates, graduates and faculty, used CenceMe continuously over a three week period in a campus town. From this user study we learn how the system performs in a production environment and what uses people find for a personal sensing system.

4.3 How to Combine Contributors' Contributions or Aggregate Analytics

Real-world deployments must address the data integrity problem in order to provide meaningful conclusions from the aggregate sensor data. Techniques involved include data mining, data warehousing techniques, etc.

As an example, with the maturity and wide availability of GPS, wireless, telecommunication, and Web technologies, massive amounts of object movement data have been collected from various moving object targets, such as animals, mobile devices, vehicles, and climate radars. Analyzing such data has deep implications in many applications, such as, ecological study, traffic control, mobile communication management, and climatological forecast. In this article, we focus our study on animal movement data analysis and examine advanced data mining methods for discovery of various animal movement patterns. In particular, the authors introduced a moving object data mining system, MoveMine, which integrates multiple data mining functions, including sophisticated pattern mining and trajectory analysis. In this system, two interesting moving object pattern mining functions were developed: (1) periodic behavior mining and (2) swarm pattern mining. For mining periodic behaviors, a reference location-based method is developed, which first detects the reference locations, discovers the periods in complex movements, and then finds periodic patterns by hierarchical clustering. For mining swarm patterns, an efficient method is developed to uncover flexible moving object clusters by relaxing the popularly-enforced collective movement constraints. In the MoveMine system, a set of commonly used moving object mining functions are built and a user-friendly interface is provided to facilitate interactive exploration of moving object data mining and flexible tuning of the mining constraints and parameters. MoveMine has been tested on multiple kinds of real datasets, especially for MoveBank applications and other moving object data analysis. The system will benefit scientists and other users to carry out versatile analysis tasks to analyze object movement regularities and anomalies. Moreover, it will benefit researchers to realize the importance and limitations of current techniques and promote future studies on moving object data mining. As expected, a mastery of animal movement patterns and trends will improve our understanding of the interactions between and the changes of the animal world and the ecosystem and therefore help ensure the sustainability of our ecosystem.

4.4 Security, Trust and Privacy Issues

An important aspect of crowdsourcing systems is that they potentially collect sensitive sensor data pertaining to individual. For example, GPS sensor readings can be utilized to infer private information about individual, such as their location information as well as other information relating to the routes they take during their commutes. The challenging task is to preserve the security and privacy of an individual, but at the same time enable crowdsourcing applications. Another concern is trust. Despite the popularity of adding sensors to mobile devices, the readings provided by these sensors cannot be trusted. Users can fabricate sensor readings with relatively little effort. This lack of trust discourages the emergence of applications where users have an incentive to lie about their sensor readings, such as falsifying a location or altering a photo taken by the camera.

In [35], the authors present a broad range of applications that would benefit from the deployment of trusted sensors, from participatory sensing to monitoring energy consumption. They present two design alternatives for making sensor readings trustworthy. Although both designs rely on the presence of a trusted platform module (TPM), they trade-off security guarantees for hardware requirements. While their first design is less secure, it requires no additional hardware beyond a TPM, unlike their second design. Finally, they present the privacy issues arising from the deployment of trusted sensors and they discuss protocols that can overcome them.

A popular approach to preserving privacy of data in crowdsourcing applications is to utilize anonymization techniques, which remove any identifying information from the sensor data before sharing it with a third party. The drawback of such an approach is that anonymized location (e.g. GPS) sensor measurements can still be used to infer the frequently visited locations of an individual and, consequently, to derive their personal details. Another approach to preserving privacy is secure multiparty computation, where cryptographic techniques are used to transform the data in order to preserve privacy. The drawback with this approach is that the applied cryptographic techniques are usually and non scalable because they require the generation and maintenance of multiple keys.

Another approach is based on data perturbation. Data perturbation approaches rely on adding noise in such a manner that the privacy of an individual is preserved but at the same time it is possible to compute the statistics of interest with high accuracy (due to the nature of noise added). In addition to security and privacy, crowdsourcing systems must also address the data integrity problem in order to provide meaningful conclusions from the aggregate sensor data.

In [41], the authors proposed *AnonySense*, 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, thus providing the first secure implementation of this participatory sensing model. In this paper, the authors also described their security goals, threat model, and the architecture and protocols of *AnonySense*. In addition, the author demonstrated how *AnonySense* can support extended security features that can be useful for different applications. They evaluated the security and feasibility of *AnonySense* through security analysis and prototype implementation. Finally, they showed the feasibility of our approach through two plausible applications: a Wi-Fi rogue access point detector and a lost-object finder.

In participatory crowdsourcing applications, reputation systems can be used rate the contributions to participatory sensing campaigns from each user by associating a reputation score. The reputation scores are used to weed out incorrect sensor readings. However, an adversary can de-anonmyize the users even when they use pseudonyms by linking the reputation scores associated with multiple contributions. Since the contributed readings are usually annotated with spatiotemporal information, this poses a serious breach of privacy for the users. In [7], the authors addressed this privacy threat by proposing a framework called *IncogniSense*. Their system utilizes periodic pseudonyms generated using blind signature and relies on reputation transfer between these pseudonyms. The reputation transfer process has an inherent trade-off between anonymity protection and loss in reputation. They investigated by means of extensive simulations several reputation cloaking schemes that address this tradeoff in different ways. It's claimed that their system is robust against reputation corruption and a prototype implementation of the proposed system demonstrated that the associated overheads are minimal.

The ubiquity of mobile devices has brought forth the concept of participatory sensing, whereby ordinary citizens can now contribute and share information from the urban environment. However, such applications introduce a key research challenge: preserving the location privacy of the individuals contributing data. In [22], the authors proposed the use of micro-aggregation, a concept used for protecting privacy in databases, as a solution to this problem. They compared micro-aggregation with tessellation, the current state-of-the-art, and demonstrate that each technique has its advantage in certain mutually exclusive situations. They proposed a hybrid scheme called, Hybrid Variable-Size Maximum Distance to Average Vector (V-MDAV), which combines the positive aspects of both these techniques. Our evaluations based on real-world data traces show that hybrid V-MDAV improves the percentage of positive identifications made by the application server by up to 100% and decreases the information loss by about 40%. Furthermore, there studies showed that perturbing user locations with random Gaussian noise can provide users with an extra layer of protection with very little impact on the system performance.

To sum up, due to specific characteristics of crowdsourcing systems, many challenges with security and privacy are still ahead, as suggested in [23, 18, 20, 29, 31, 22]. The reason for this is manyfold. First, it is because privacy, concerns about security are very user specific, that is each individual has a different perception on privacy and security. For example, one person may be willing to share his or her location information continuously, where another may not. As a result, developing privacy preserving techniques that address variation in individual preferences is a real challenge for crowdsourcing systems.

4.5 Resource Limitations

In addition to the challenges mentioned above, crowdsourcing applications also face the challenging issue of resource limitations. In web-based crowdsourcing systems, this can come up as server overload, link congestion, etc. However, the issue is more visible with mobile crowdsourcing applications when the limitations of the mobile handsets could pose serious practical problems. Despite the fact that the mobile handsets possess much more computing, bandwidth, and energy resources than mote-class sensors, they nevertheless face resource limitations and constraints with respect to these resources. First, the set of devices that are collecting sensor data are highly dynamic in availability and capacities. Due to this highly dynamic nature, modeling and predicting the energy and bandwidth requirements to accomplish a particular task is harder than traditional sensor networks. Second, when there are a large number of available devices with diverse sensing capabilities, identifying and scheduling sensing and communication tasks among them under resource constraints are more complex.

Also, there is an issue of quality and resource consumption tradeoff here. For example, location data can be provided using GPS, WiFi, and GSM, with decreasing level of accuracy. Compared to WiFi and GSM, continuous GPS location sampling drains the battery faster, but could provide much better results.

In [10], the authors proposed CTrack, which is an energy-efficient system for trajectory mapping using raw position tracks obtained largely from cellular base station fingerprints. Trajectory mapping, which involves taking a sequence of raw position samples and producing the most likely path followed by the user, is an important component in many location-based services including crowd-sourced traffic monitoring, navigation and routing, and personalized trip management. Using only cellular (GSM) fingerprints instead of power-hungry GPS and WiFi radios, the marginal energy consumed for trajectory mapping is zero. This approach is non-trivial because we need to process streams of highly inaccurate GSM localization samples (average error of over 175 meters) and produce an accurate trajectory. CTrack meets this challenge using a novel two-pass Hidden Markov Model that sequences cellular GSM fingerprints directly without converting them to geographic coordinates, and fuses data from low-energy sensors available on most commodity smart-phones, including accelerometers (to detect movement) and magnetic compasses (to detect turns). They have implemented CTrack on the Android platform, and evaluated it on 126 hours (1,074 miles) of real driving traces in an urban environment. They found that CTrack can retrieve over 75% of a user's drive accurately in the median. An important by-product of CTrack is that even devices with no GPS or WiFi (constituting a significant fraction of today's phones) can contribute and benefit from accurate position data.

With respect to smart phone-based applications, many of them are enabled by the ability to capture videos on a smartphone and to have these videos uploaded to an Internet-connected server. This capability requires the transfer of large volumes of data from the phone to the infrastructure. Smartphones have multiple wireless interfaces, 3G/EDGE and WiFi, for data transfer, but there is considerable variability in the availability and achievable data transfer rate for these networks. Moreover, the energy costs for transmitting a given amount of data on these wireless interfaces can differ by an order of magnitude. On the other hand, many of these applications are often naturally delay-tolerant, so that it is possible to delay data transfers until a lower-energy WiFi connection becomes available. In [12], the authors presented a principled approach for designing an optimal online algorithm for this energy-delay tradeoff using the Lyapunov optimization framework. Their algorithm, called SALSA, can automatically adapt to channel conditions and requires only local information to decide whether and when to defer a transmission. They evaluated SALSA using real-world traces as well as experiments using a prototype implementation on a modern smartphone. Their results show that SALSA can be tuned to achieve a broad spectrum of energy-delay tradeoffs, is closer to an empirically-determined optimal than any of the alternatives we compare it to, and, can save 10-40% of battery capacity for some workloads.

In [2], the authors investigated if WiFi access can be used to augment 3G capacity in mobile environments. They conducted a detailed study of 3G and WiFi access from moving vehicles, in three different cities. They found that the average 3G and WiFi availability across the cities is 87% and 11%, respectively. WiFi throughput is lower than 3G through-put, and WiFi loss rates are higher. They also designed a system, called Wiffler, to augments mobile 3G capacity. It uses two key ideas leveraging delay tolerance and fast switching, to overcome the poor availability and performance of WiFi. For delay tolerant applications, Wiffler uses a simple model of the environment to predict WiFi connectivity. It uses these predictions to delays transfers to offload more data on WiFi, but only if delaying reduces 3G usage and the transfers can be completed within the application's tolerance threshold. For applications that are extremely sensitive to delay or loss (e.g., VoIP), Wiffler quickly switches to 3G if WiFi is unable to successfully transmit the packet within a small time window. They also implemented and deployed Wiffler in a vehicular testbed. Their experiments showed that Wiffler significantly reduces 3G usage. For a realistic workload, the reduction is 45% for a delay tolerance of 60 seconds.

5 Conclusions

This document tries to discuss the current state of the art and open challenges in the emerging field of crowdsourcing systems, with special focus on mobile crowdsourcing applications and services. We observe that the primary obstacle to this new field is not a lack of infrastructure; billions of people have already had access to the Web (for web-based crowdsourcing systems) and millions of people already carry (mobile/smart) phones with rich sensing capabilities. Rather, the technical barriers are related to performing privacy-sensitive and resource-sensitive reasoning with noisy data and noisy labels, and providing useful and effective feedback to users. We have also identified the unique characteristics of crowdsourcing systems in general and mobile croudsystems in particular. The technical challenges include, but not limited to, sensing capabilities and preciseness, localized analytics capabilities, resource limitations, privacy, trust, security and data integrity, aggregate analytics and architecture for such a system to be materialized. Once these technical barriers are overcome, this nascent field will advance quickly, acting as a disruptive technology across many domains including social networking, health, and energy, and public transportation management, and many others to come. Crowdsourcing systems in general and mobile crowdsourcing systems in particular will ultimately provide both micro- and macroscopic views of cities, communities, and individuals, and help improve how society functions as a whole.

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