Social Opportunistic Sensing and Social Centric Networking

Enabling technology for Smart Cities

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ABSTRACT

In recent years, with tremendous advances in areas like mobile devices, algorithms for distributed systems, communication technology or protocols, all basic technological pieces to realise a Smart City are at hand. Missing, however, is a mechanism that bridges these pieces to ease the creation of Smart Cities at a larger scale.

In this visionary paper, we discuss challenges of Smart Cities and propose enabling technologies to bridge the above mentioned pieces for their actual realisation. In particular, we introduce the concepts of Social Opportunistic Sensing (SOS) and Social Centric Networking (SCN). While the former is an enabling technology to interconnect all parties in a Smart City, the latter has the potential to enhance offline social networks in Internet of Things (IoT) enhanced Smart Cities by connecting individuals based on their automatically updated profile via context-based routing.

Categories and Subject Descriptors

H.1.2 [**User/Machine Systems**]: Human Information Processing

Keywords

Smart Cities, Environmental Sensing, Crowdsourcing, Participatory Sensing, Context Centric Networking

1. INTRODUCTION

Smart City as a concept is around for more than a decade now [41] and has been identified to cover various aspects including Smart Governance, Smart Economy, Smart Mobility, Smart Environment, Smart People and Smart Living [38]. These aspects have been discussed mainly with regard to economics (E-commerce), Life sciences (Life-long learning), Green energy or urban planning. In addition, Information and Communication Technology (ICT) has been a common theme that is featured prominently in all Smart City aspects (ICT-enabled working, ICT-enabled life-styles, ICT-enabled energy grids, ICT supported transport systems, ICT-enabled manufacturing, ICT-enabled processes).

This prominent occurrence of ICT in Smart City-related publications is justified by advances in mobile devices, sensing technology, communication techniques and protocols. The enabling technologies for Smart Cities are now at hand. What is missing though is a mechanism that bridges these technologies to provide a holistic solution for Smart Cities.

In particular, a major aspect of Smart City-related research focuses on the benefits and advances of technology [62]. However, this alone would result in a lifeless concept. Smart City is a concept of the people and for the people that live within a Smart City, utilise the technology in a Smart City and shape the view of a Smart City [41].

In this paper, we propose and discuss two enabling technologies for Smart Cities that put the human in the center. Namely, these are Social Opportunistic Sensing and Social Centric Networking. While the former provides an interaction paradigm in Smart Cities, the latter utilises Internet of Things (IoT)-enriched [58] environments to automatically link individuals.

2. RELATED WORK

We present in this paper solutions for the implementation of Smart Cities. The concept of a smart City has been first introduced by Gibson in 1992 [22]. Originally, the term Smart City was loosely coined to express how urban development was turning towards technology, innovation and globalisation [46]. Over defining aspects of a Smart City such as Economy, Infrastructure and Governance [46], the discussion, utilising various diverse definitions of Smart Cities [23, 25, 7, 63], gradually matured to cover six main axes, namely Smart Economy, Smart Governance, Smart Mobility, Smart Environment, Smart People and Smart Living [38, 10] which are woven around an omnipresent ICT.

This ICT is seldom discussed in great detail but should generally cover sensors and real-time awareness [41]. Objects, services and people in a smart city are linked together by a networked infrastructure so that the IoT, the Internet of Services (IoS) and the Internet of People (IoP) and in general the Future Internet are mere sub-topics of Smart Cities [27].

An architecture for Smart Cities therefore needs to connect all parties in a city, in particular, objects, services, people and environmental sensors [52, 55] and place the individual at the nerve center and in control of this orchestration of the enormous amount of incoming information flows and actuation and communication opportunities.

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A number of frameworks and architectures has been proposed for Smart Cities [2, 13, 19]. A good overview and comparison is given in [14]. The authors survey 17 Smart City architectures and compare them with respect to 11 requirements identified for Smart Cities. Among others, these requirements cover *interoperability between objects*, *real-time monitoring*, *Mobility*, *Privacy*, and also *Social aspects*. One result of that study is that most architectures for Smart Cities are indeed developed with technical challenges in mind but only few also consider social aspects [4, 33] or privacy. This is surprising for a concept like Smart Cities that places the human at its center and which is designed for humans. Interestingly, the architectures which cover these social aspects do not fulfil the technological requirements.

We therefore conclude that there is not a single architecture for Smart Cities to-date that fulfils both social and technological requirements.

We propose to connect people, sensors, objects and services in a Smart City with a Social Opportunistic Sensing concept. This is related to Opportunistic and Participatory sensing as well as to Mobile Crowdsourcing but exceeds all these concepts.

To start with, Opportunistic Sensing, in contrast to Participatory sensing, describes a paradigm in which applications are enabled to access sensor data from mobile devices without explicit interaction of the users of those devices [31, 36]. Distributed devices provide their sensing capabilities to neighbouring devices, that are then empowered to access the remotely sensed information or to generate tasks for remote devices to acquire and share this information [36, 31]. This is a very promising concept which greatly exceeds the perception of a mobile device into the reach of neighbouring devices and environment [9]. In the frame of the OPPORTUNITY project [1], an architecture for opportunistic sensing, in particular activity recognition was developed [45, 35]. Opportunistic Sensing rises a lot of issues not only regarding the mere technical implementation, protocols, mobility and timing. It also touches aspects of privacy and security when alien devices are allowed to access potentially privacy-related personalised information in an uncontrolled manner [31, 51]. In particular, the concept envisions that arbitrary sensors can be accessed. Apart from the also tremendous challenge to enable the seamless interaction technically, the design of a privacy or security preserving scheme is a nightmare. The sheer infinite possibilities for privacy exploits and security threats posed by all the sensors can hardly be solved.

On the other hand, in Participatory Sensing [8], the privacy issues of Opportunistic sensing are solved pragmatically. In this sensing principle, remote sensing is restricted to user-controlled mobile devices. Other devices are still expected to task neighbouring devices for sensed information, but human interaction is required in order to allow such request [36]. Consequently, not only is the range of devices restricted to explicitly user-controlled devices with an interactive interface but also the important principle of calmness and unobtrusiveness in Pervasive Computing is disregarded. Instead, the mental load for a user with a Participatory Sensing Device is likely significantly increased as she might be frequently interrupted for interaction.

In our proposal for a Social Opportunistic Sensing framework we incorporate aspects of Participatory and Opportunistic Sensing and combine these with Mobile Crowdsourcing and Crowdsensing concepts.

Crowdsourcing has become a popular approach to many problems that cannot be easily addressed by automated methods and algorithms, or problems that explicitly require significant amount of human intelligence or human feedback. Humans are confronted with queries which they can decide to answer and thereby manually solve the crowdsourcing task. It can often be found in knowledge processing tasks such as data or media classification [26], data acquisition tasks such as data completion [20] or information extraction [37], as well as in providing training data for machine-learning-based approaches [48]. Furthermore, crowdsourcing has proven to be useful to the research community for performing large-scale user studies for evaluating new prototype implementations [32], or performing surveys with a large and diverse number of participants for investigating general human behaviour or preferences [6]. These tasks mostly rely on general purpose crowdsourcing platforms such as Amazon Mechanical Turk, CrowdFlower, or ClickWorker. Recently, crowdsourcing platforms have also been implemented for mobile platforms [17, 67, 42, 24]. In these approaches, common crowdsourcing functions are made available on a mobile device but no additional value is created through the migration to a mobile platform. In particular, answers to queries inherently require human interaction.

On the other hand, in Mobile Crowdsensing, information available from sensors of mobile devices is acquired. Mobile Crowdsensing is related to Participatory and Opportunistic Sensing since the sensing task can require various amounts of manual user interaction on mobile phones but, in addition, necessitates a common server that coordinates the sensing tasks on all mobile devices [21]. A number of crowdsensing architectures have been proposed in the literature [49, 43, 59, 15]. In Mobile Crowdsensing, the mobile client runs an application that is connected to a server component in the cloud. Example implementations are the *CrowdSense@Place* framework [12], *Common Sense* for pollution monitoring [16], sensing of traffic congestion levels by *CarTel* or *Nericell* [28, 40], *ParkNet* for the detection of available parking lots [39] as well as installations that track daily exercise routines such as BikeNet or DietSense [18, 44].

We propose the concept of Social Opportunistic Sensing as a combination of Opportunistic Sensing, Participatory Sensing, Mobile Crowdsourcing and Mobile Crowdsensing for the use as an interaction platform in Smart Cities.

3. SOCIAL OPPORTUNISTIC SENSING

We envision a Social Opportunistic Sensing platform that can be used in a desktop as well as in a mobile setting. It consists of a client that implements the mobile and desktop interface and a server component which manages the distribution of requests and which connects user clients. The platform places the human in the center to interact with all parties in a Smart city as depicted in figure 1. In Social Opportunistic Sensing, the human is in the center, enabled through the platform (e.g. on her mobile device) to interact with the diverse parties in a Smart City. The mobile platform serves as an information hub and also for interaction. Social Opportunistic Sensing is a non-hierarchical concept in the sense that each participant finds herself in the exact situation depicted in figure 1. The architecture does not distinguish between content providers or content con-

[1]Opportunity Project website: http://www.opportunity-project.eu/ (May 2014)

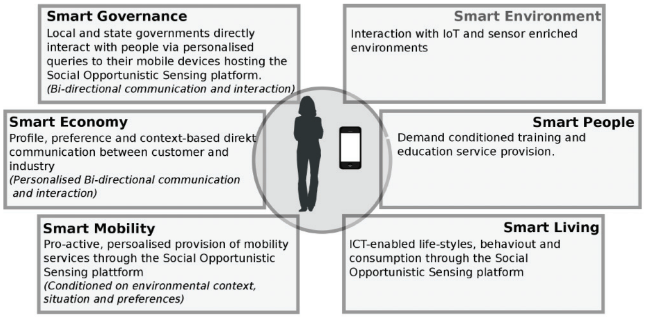

Figure 1: Interaction through a Social Opportunistic Sensing platform with entities in a smart city

sumers. Every participant is consumer and provider alike with identical possibilities and her role is not defined by the architecture but by her actions and interactions.

For instance, a mobility provider, such as a cab company could announce its serveice through requests. In these requests, the company would, for instance, specify a region of operation and also announce special offers for groups, or at different times of day. The Social Opportunistic Sensing platform would in turn distribute the offers to participants with context properties that match the specified conditions (e.g. region, age, need of transportation). These conditions are derived from sensors in the environment, on the device or body of the person as well as from the user profile or manual preferences set. For instance, having just missed a bus, the platform might offer services of that cab company as an alternative way to reach the destination while it would offer, for instance, local news services when the person had catched the bus. In this sense, the platform can take advantage of the fluctuation in context since services can be provided exactly when they are required.

Another example is the interaction with a smart environment. The environment, for instance a smart home, itself is just another player in the Smart City that can provide information on its sensor readings or status and in turn react on requests from authenticated users through the Social Opportunistic Sensing platform. Away from home, a user might monitor heating and light conditions or also, for instance, a washing machine and control these devices remotely by stating requests to change their status which are then reacted on by the smart environment.

The interaction in the Social Opportunistic Sensing platform basically follows Crowdsourcing interaction patterns. Queries are replied to by entities in the system. In contrast to Crowdsourcing, however, any entity is entitled to issue a query at any time. Entities are not only human users but, like in Opportunistic/Participatory Sensing or Mobile Crowdsensing can also be services or sensing systems. In this sense, Social Opportunistic Sensing democratizes Big Data. Each client has, via queries, access to enormous amounts of data from other clients, services or sensor streams. However, the greatest potential of Social Opportunistic Sensing does not lie in the simple flooding with queries but in the possibility to choose a desired audience for each single query in a fine-grained manner. We utilise sensor and profile information on mobile clients to this end. For instance, queries can be restricted to be forwarded to users in a limited geographical region by utilising, for instance, GPS. A query can also

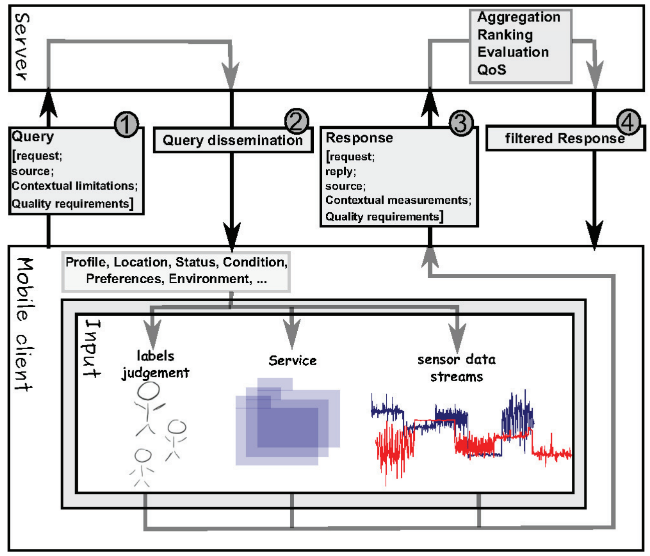

Figure 2: Sketch of a Social Opportunistic Sensing platform

be restricted to people of a specific age, with particular interests or to users currently conducting a particular activity. Social Opportunistic Sensing is a convenient way for users to interact with citizens, Government, industry, environment or services in a Smart City. It interconnects all parties in a Smart City and creates an interface for seamless interaction that bridges existing communication gabs on an underlying Future Internet and Internet of Things infrastructure.

Figure 2 sketches this Social Opportunistic Sensing scheme. The mobile client is the local application installed on the mobile device. Through their clients, individuals and services are enabled to formulate new queries which are then forwarded to the server component. Queries also contain restrictions that limit the audience of this query (for instance, location, age, interest, ...) [47]. The server then forwards this query to a set of clients that match the requirement specified in the query.

At the same time, the server is responsible to ensure privacy requirements of the individual parties in the system and to guarantee a good quality of replies [34]. This is taken into account in the server's choice of addresses (see section 3.1) and in the processing of replies (see section 3.2). Responses to queries which are of sufficient quality are then forwarded to the mobile client which had stated the corresponding query.

3.1 Establishing privacy

Security and privacy are of utmost importance for any large scale social platform. In Social Opportunistic Sensing, this especially means protecting the privacy rights of individuals, protecting the the query requesters and the integrity of their tasks, and protecting the platform infrastructure itself.

3.1.1 Protecting individuals

A Social Opportunistic Sensing platform has access to a tremendous amount of personalised information (profile, sensors, habits, ...). Therefore, it is most important for the acceptance of such platform to protect and secure such information against malicious use and access from third parties. Here, the central question are:

- How to retain the full value of a Social Opportunistic Sensing platform without sacrificing the privacy of its users?
- Which level of transparency is required to foster trust between the platform and the users?
- How can transparency of the platforms' design deter malicious parties?

One of the main concerns is the actual identity of individuals. The query requester should be ignorant of and unable to obtain any hints towards the real identity of the individuals that provided replies. Otherwise, she might be in the position to create profiles over time. Fortunately, when faced with big data, even small parts of the overall available information might already be sufficient to reliably sample global properties in the data. An intelligent set of different but sufficiently large populations of individuals confronted with each new request might therefore prevent the creation of person specific profiles while at the same time providing generalisable results. Contextual information, obtained from sensors attached to the mobile device, might help in order to obscure the identity of an information provider. In particular, with knowledge on the distribution of values for a specific sensor over a population of individuals, the system might obscure or omit data that would likely disclose the identity of a person.

3.1.2 Protecting query Requesters and queries

Also the query requesters and the integrity of their queries need protection. In particular, fraud detection is a central concern. This covers malicious users which provide large quantities of low quality or even fake data to quickly gain potential benefit attached to the task, but also users assuming multiple identities in order to circumvent user limits, or fake profiles with fake contextual information in order to be included into more tasks they should not be eligible for.

3.1.3 Protecting the Platform Infrastructure

Finally, also the platform infrastructure itself needs protection to harden it against malicious attacks, and especially for securing it against the theft of the valuable user data stored on it. This especially raises the following questions:

- Where does the system store information, which information is stored and who has access to it?
- Can stored information be effectively anonymised or encrypted while still allowing the platform to work without restrictions?
- Which and how much information shall be made accessible to a single individual?

For these questions, it is important to distinguish between the information that is required and available by the system and the information that is available to individual requesters and also to other users in the system. In order to eliminate a single point of failure, the platform should be designed with minimum requirements on centrally stored information.

3.2 Guaranteeing good quality of replies

Social Opportunistic Sensing combines Participatory and Opportunistic Sensing which are based on sensor-generated output, but also employs manually generated feedback as it is employed in crowdsourcing applications [30]. A central problem in crowdsourcing applications is the low quality of replies. Replies from human participants are impacted by their condition (fatigue, concentration,...), environmental situation (loudness, crowdedness, subject's movement,...), a subject's education and also her intention (malicious intent, ...). In a typical crowdsourcing process, the task of filtering the replies from such low quality answers requires a significant amount of the overall workload. Clearly, this is not feasible in the context of a Smart City where all parties are required to seamlessly interact through the Social Opportunistic Sensing platform. In order to achieve a good quality of replies at low manual load, we propose to employ sensor outputs from mobile devices and in the environment. In particular, these inputs are provided alongside any manual input in order to judge on the quality of the manual part.

For example, analysing the eye-gaze movement one is able estimate fatigue. Reasoning from the loudness level or amount of other people around, it might is possible to judge whether the user might be impaired in answering questions that require considerable concentration [57, 53]. Analysing movement and body gesture and pose it is possible to reason on a user's emotional state [3, 11, 61, 60, 5] for instance via accelerometer devices or also, for instance, utilising environmental device-free sources [56, 65, 64, 66]. Attention can be estimated also by environmental sensors [50] These developments potentially provide tremendous additions to traditional crowdsourcing quality management, which have never been tapped before in this setting. This information can be used to judge whether the user is impaired in answering questions that require considerable concentration.

3.3 Smart-City related Opportunities

Social Opportunistic Sensing provides further opportunities especially for Smart Cities. A Social Opportunistic Sensing platform connects people, Government, Industry and the environment as all can state queries or provide input to queries. It can therefore serve as an interaction principle in such environments and constitute the backbone of a Smart City, interconnecting all major parties. In addition, with sufficient data at hand, prediction techniques might be applied in order to further boost the confidence on a result reached [54]. Such a platform can have various advantages in a Smart City Context.

For instance, Social Opportunistic Sensing can be utilised for life-feedback on everyday questions. A wide utilisation by people in a City will result in a low latency from stating a query to the reception of responses. As a result, responses can be very up-to-date and may include real-time assistance, for instance, in searching/ recommendation for point-of-interest locations/ navigation or spontaneous translation of foreign sentences (e.g. while ordering a menu at a restaurant).

A Social Opportunistic Sensing platform integrates environmental sensors and services. Humans and services acquire maintenance information from infrastructure and surrounding sensors via queries limited by proximity or belonging to a specific entity (building, room, etc.). In addition, services can serve as actuators, completing queries designed to control smart buildings and automation. In particular, the controlled entity might change relative to the location of the requester.

4. SOCIAL CENTRIC NETWORKING

In an IoT-enriched Smart City, how do queries actually reach the anticipated recipients? In the Social Opportunistic Sensing discussed above, we have proposed a client-server architecture in which the server takes care of the proper dissemination of queries. However, this concept also contains a number of disadvantages. Most critically, the server is a single point of failure. If the server becomes unreachable for whichever reason, the whole Social Opportunistic Sensing platform ceases to work. In addition, in order to be able to quickly forward queries to a proper subset of clients, the server would either have to broadcast requests to all clients with each query in order to obtain their contextual and profile information or, else the server would cache part of this information for all clients. While the former solution is highly inefficient and causes high network traffic, both possibilities pose considerable threats to privacy and security of clients as personalised information of all nodes is either stored in a single location or is repeatedly and continuously transmitted over the network.

In order to mitigate these issues we propose to abstract from a central server and instead utilise an ad-hoc communication scheme via the ubiquitously deployed IoT hardware in a Smart City.

In particular, we propose a Social Centric Networking in which queries are routed not according to addresses or content but according to context. This is necessitated by the observation that, due to quickly changing context at all nodes, a destination address with a matching contextual state is not known at the sender. Similarly, the routing can not follow a specific content like in Content Centric Networking [29] since queries are not expected to produce already generated fixed content, but instead replies which are generated spontaneously. In particular, a specific query might produce a completely different reply (e.g. sample from sensor data) when stated at a different point in time.

4.1 SCN infrastructure

Social Centric Networking requires a dense network of sensing and communicating nodes like this is provided by the upcoming Internet of Things. These nodes are equipped with sensing, communication and computational capabilities as well as storage so that environmental situation and context can be captured and reasoned from the observed environmental stimuli.

This contextual information is (under the consideration of privacy constraints) partly shared with neighbouring nodes that in turn may share it with their neighbours. In this way, a contextual map is generated in the network via which a routing may be conducted.

Each query is accompanied by a contextual description of the situation in which the query was stated (e.g. interaction with which devices, environmental conditions). This query is forwarded in the network of interconnected IoT nodes hop-by-hop while the direction of next hop is decided by contextual similarity. A node that has higher similarities between the context items cached and the context items in the query is more likely chosen as a next hop.

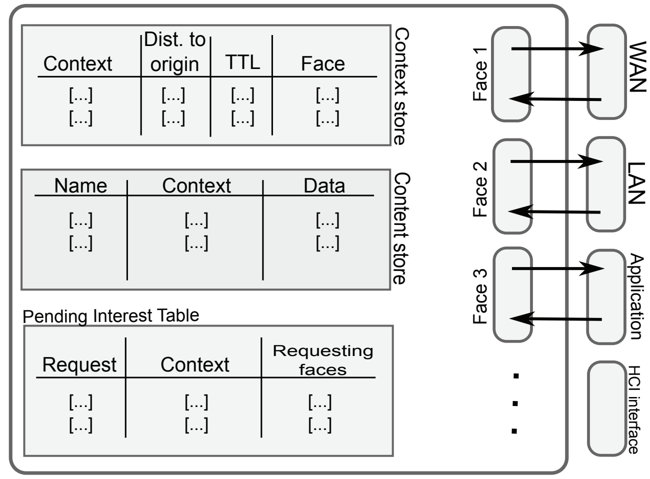

Figure 3: Sketch of a node in a Social-Centric Network

In this manner, the query arrives at nodes with high contextual similarity.

Consequently, the people interacting with these nodes are likely in a similar context as the one required in the query and therefore might provide a proper reply. Like in Content Centric Networking (CCN), the response is routed the same path backwards by which the query arrived and is cached at all intermediate nodes. This caching further disseminates responses in the network and thus improves the routing capabilities also to more distant locations. Cached responses might also be re-used for similar requests. A response might not necessarily be information or data but also just link requester and requesting person and thus implicitly link individuals in an automatically maintained offline social network within a Smart City.

4.2 SCN nodes

Routing in a Social Centric Network is based on contextual information. This is, in particular, represented by the design of SCN nodes. Figure 3 sketches the design of a generic SCN node.

A SCN node is connected via Faces to the physical world (e.g. via an Human-Computer-Interface (HCI) interface or a sensor), to applications or to further nodes in wireless or wired networks.

Each node implements a Context store, a Content store and a Pending Interest Table. The Context store combines the task of a Forwarding Information Base in CCN [1] and adds Context specific information.

When a query arrives at a node, this node compares the similarity of contexts stored in the Context store with the requested contexts in the query. The probability to forward a query to a specific interface is then proportional to the number of similar or matching contexts in the entries of the Context store. This random routing paradigm ensures that queries are routed via the most promising route with highest probability. However, there is also the chance to deviate from this route, which might then result in the discovery of a new, possibly faster path.

Since Context is a time-varying concept, the information in this Context store is periodically updated. When the Time-To-Live (TTL) for a specific item expires, the item is deleted from the Context store and a new item is requested from neighbouring nodes. At such request for an item from the Context store, a node randomly forwards an item from its Context store, where the probability to forward an item is inversely proportional to the distance of this item's context information to its origin. In this way, nodes will hold context information from nearby nodes with higher probability while still providing some information on nodes that are farther away.

When a query can be answered by a node, the corresponding content is routed backwards the same path as the query was routed. This is done with the help of the Pending Interest Table. Here, requests that arrive are stored together with their context information and the information on the face from where the interest arrived. With this information, a reply to a query arriving back at this node can be matched with the query in the Pending Interest Table and thus forwarded back one further hop via the respective face. The content of this reply is sorted in the Content store so that the network caches replies on a path between the requester and the answering node. The context from replies stored in the Content store will also be considered for the forwarding to neighbouring nodes. In addition, in order to support mobility among nodes, other routing concepts are required as the return path might be broken.

With this concept, Social Opportunistic Sensing in an IoT-enriched Smart City can be realised without the necessity of a central server. In addition, Social Centric Networking implicitly generates and maintains an offline social network within a Smart City via which individuals with common contexts and interests are linked.

5. CONCLUSION

We have presented the concepts of Social Opportunistic Sensing and Social Centric Networking as enabling technologies for Smart Cities. Most Smart City architectures proposed to-date focuses on the technical aspects of its implementation but do not design the system for the actual individual that inhabits a Smart City. Social Opportunistic Sensing and Social Centric Networking put the human in control. Through the incorporation of Mobile Crowdsourcing, Mobile Crowdsensing, Opportunistic Sensing, Participatory Sensing and Content Centric Networking concepts, a novel interaction scheme for Smart Cities can be generated that also enables automatically maintained, network-enhanced offline social networks.

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