2016 Fourth IEEE Workshop on Hot Topics in Web Systems and Technologies

A Novel Vision of Cyber-Human Smart City

Schahram Dustdar, Stefan Nastic, Ognjen Scekic
Distributed Systems Group, TU Wien, Austria
Email: *dustdar, nastic, oscekic@dsg.tuwien.ac.at*

***Abstract*—Contemporary view on Smart City is very much static and infrastructure-centric, focusing on installation and subsequent management of Edge devices and analytics of data provided by these devices. While this still allows a more efficient management of city's infrastructure, optimizations and savings in different domains, the existing architectures are currently designed as single-purpose, vertically-siloed solutions. This effectively hinders an active involvement of a variety of stakeholders (e.g., citizens and businesses) who naturally form part of the city's ecosystem and have an inherent interest in jointly coordinating and influencing city- level activities towards a common benefit. This paper presents a value-driven architecture and the defining properties of the envisioned Smart City, characterized by complex coordinated activities involving the City's services, stakeholders and their devices. We look at existing foundational technologies for provisioning, coordination and controllability of said activities and discuss the required alignment steps towards the fulfillment of the stated vision.**

***Index Terms*—smart city, IoT, social computing, socio-technical, cyber-human, incentives, governance, controllability.**

I. Introduction

While there is no a single accepted definition, the common contemporary understanding of a Smart City [1], [2] assumes a coherent urban development strategy developed and managed by city governments seeking to plan and align in long-term the management of various city's infrastructural assets and municipal services with the sole objective of improving the quality of life for the citizens [3], [4]. The ICT role in the current Smart City vision is passive – related to collecting and analyzing data, predicting and optimizing, as well as facilitating communication between different city services and automated management management of infrastructure. More importantly, the citizen is also put into a passive role. While the citizens are undeniable winners in this process as the beneficiaries of a more optimized and cheaper infrastructure they are not taking an active role in the development and daily management of the city. We denominate the current stage in Smart City development as 'representative-smart', as opposed to 'collective-smart' – one of the terms we propose for describing the future vision of cyber-human smart cities involving a rich and active interplay of different stakeholders (primarily citizens, local businesses and authorities), effectively transforming the currently passive stakeholders into active ecosystem actors. Realizing such complex interplay requires a paradigm shift how the physical infrastructure and people will be integrated and how they will interact.

At the heart of this paradigm shift lies the merging of two technology/research domains – the Cyber-physical Systems and the Socio-technical Systems – into a *value-driven* context of a Smart City. The presented Smart City vision diverges from the traditional relationship between the society and ICT, in which the stakeholders are seen as passive users which exclusively capitalize on the technological advancements. Rather, the architecture we propose puts the value generation at the top of the pyramid and relies on the "city capital" to fuel the generation of novel values and enhancement of traditional ones. This effectively transforms the role and broadens the involvement and opportunities of citizens-stakeholders, but also promotes the ICT from the passive infrastructure to an active participant shaping the ecosystem.

The paper is organized as follows: In Section II we describe the novel value architecture of the future cyber-human Smart City. In Section III we present its defining characteristics and enablers, and consider existing technologies and promising research outcomes and related work that can be used to support those characteristics. We discuss how these technologies can be aligned together to achieve the presented vision. Finally, Section IV concludes the paper.

II. Architecture of Values

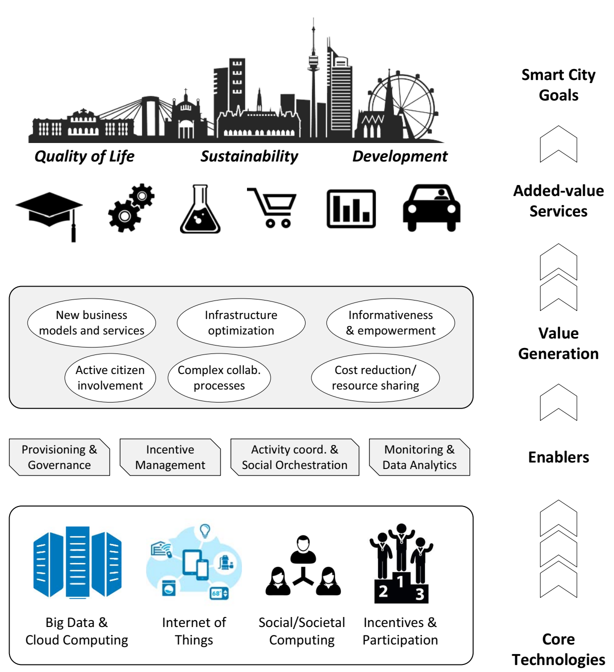

Fig. 1. Smart City 2.0 Architecture of values.

978-1-5090-5409-1/16 $31.00 © 2016 IEEE
DOI 10.1109/HotWeb.2016.16

The fundamental idea behind a collective-smart city is the inclusion of all its stakeholders (authorities, businesses, citizens and organizations) into the active management of the city. This includes not only the management of city's infrastructure, but additionally the management of different societal and business aspects of everyday life. The scale and complexity of managing diverging individual stakeholder interests in the past was the principal reason for adopting a centralized city management model where elected representatives are managing all aspects of city's life and development. However, we believe that the recent technology advances will enable us to share the so-far centralized decision-making and planning responsibilities directly with various stakeholders, allowing faster and better-tailored responses of the city to various stakeholder needs.

The key technological enabler for this process is the active and wide scale use and interleaving of technologies and principles from the IoT and Social Computing domains in the urban city domain. These technologies form the basis level of the proposed architecture of values (Fig. 1). They allow the city to interact bi-directionally with the citizens in their everyday living, working and transport environments using various IoT edge devices and sensors, but also to actively engage citizens and other stakeholders to perform concrete tasks in the physical world, express opinions, preferences, take decisions. The 'city' does not need to be an active party in this interaction. It can serve as a trustworthy mediator providing the physical and digital infrastructure and accepted coordination mechanisms facilitating self-organization of citizens into transient, ad-hoc teams with common goals. This synergy in turn enables creation of novel societal and business values.

Infrastructural values – This category includes and extends the benefits conventionally associated with the existing notion of Smart City – those related to the optimized management of shared (city-wide) infrastructure and resources. Traditionally, the management of such resources (e.g., transportation network and signalization, internet infrastructure, electricity grid) has been static and highly centralized. The new vision of Smart City relies on the interplay of humans and the IoT-enabled infrastructure, enabling additional, dynamic, locally-scoped infrastructural optimizations and interventions, e.g., optimization of physical and IT/digital infrastructure in domains such as computational resources, traffic or building management. Apart from static/planned optimizations (e.g., static synchronization of traffic lights), the dynamic optimizations of the infrastructure might include temporary traffic lights regime changes when a car accident is detected.

Societal values – This novel value category arises through the direct inclusion and empowerment of citizens as key stakeholders of the city. The fact that through the use of technology citizens can be informed, educated, consulted and ultimately incentivized/paid to perform specific tasks in the both digital and physical environments is a powerful concept bringing along a plethora of socially significant changes. For example, while most cities function as representative democracies, significant local changes are often decided upon through direct democracy (referendums, initiatives). While undeniably fair in principle, one of the biggest obstacles to a more frequent use of direct democracy is the underinformedness of voters [5]. It has been shown [6] that informing the citizens enables them to make more judicial and responsible decisions. The pervasiveness of IoT devices enables interacting with citizens directly and opens up possibility of informing the citizens better, or even simulating in practice, the outcomes of different election choices. In such cases, the citizens of the new Smart City can be included in the evaluation of the proposal and the decision process directly. The city can incentivize (see Sec. III-C) citizens to get informed about the pro et contra before making a decision; simple games and tests can raise awareness of a specific problematics. Interested parties can locate and engage same-minded neighbors and set-up citizen collectives standing for their views. Finally, citizens can sign up for participating in cyber-physical/augmented reality simulations of the effects of different outcomes. For example: For turning a traffic street into a pedestrian zone, the IoT-enabled cars can be prevented from entering the street; For raising awareness of the global warming, the citizens can be incentivized to have their apartments warmer/colder for a couple of degrees; To help people realize the low share of green energy, the citizens can be incentivized to use for a couple of days only the "green" percentage of the electricity they normally use. While simple, these simulations are affecting the citizens in their private environment through everyday (IoT) objects they interact with, and thus represent a strong motivational factor raising interest and informedness.

Business values – Apart from citizen empowerment and better inclusion into political processes, the existing research on decision making [7], social orchestration and negotiation [8], incentivization [9] provide a number of solutions for facilitating formation of collectives (groups, teams, task forces) of citizens, provisioning of necessary software support tools and digital infrastructure, algorithms for reaching agreement and compiling execution plans for different classes of tasks, as well as incentive models for both monetary and non-monetary compensation. Combined together in the context of a Smart City, this allows establishing of novel labor models where humans can engage in one-off or repeated activities within stationary or ad-hoc created collectives, motivated by a personal interest or the offered compensation. These collaborative activities can range from simplest on-demand crowdsourcing tasks such as deciding the color of the new subway line[1]) to the complex activities involving experts, such as IT incident management [10] or use of humans as sensing agents for predictive maintenance of non-IoT infrastructure, allowing an effective and cheap inspection of local infrastructure.

Apart from offering their physical and cognitive abilities, citizens can be actively involved in enriching the Smart City infrastructure with their smart devices. The augmented infrastructure, access to the huge amounts of data and active user involvement in its maintenance can be exploited in a

[1]http://qz.com/242360/stockholm-is-crowdsourcing-the-color-of-its-new-subway-line/

variety of ways, e.g., to optimize existing business models, reduce operational costs and create novel business opportunities. To be able to fully benefit from this inclusion we need novel ways to incentivize the citizens to "open source" their infrastructure, but also enable them to reap the benefits of doing so. The solution we propose lies in combination of novel incentive mechanisms and micro-payment technologies, which can enable fine-grained leasing and use of equipment, services and resources, as well as novel infrastructure provisioning and governance models and frameworks, which can support city-scale infrastructure management (cf. Sec. III-D).

III. Defining Cyber-Human Smart Cities

In this section we list and describe the defining characteristics of the Cyber-Human Smart City vision. Moreover, we discuss concrete technological enablers that enable generation of the aforementioned values in Smart Cities of the future.

A. Smart City Platform

Contemporary Smart City development and investment strategies focus on improving the efficiency of traditional services and utilities. The focus on the "historical verticals" [11] is limiting the innovation and business potential of the city. Opening up of this siloed view of Smart City will allow more horizontal integration and creation of added values. Figure 2 illustrates the high-level architecture of future Smart City Platform. The platform is a rich, self-sustaining ecosystem that facilitates both production and consumption of added values for all the involved participants, ranging from humans to smart devices. It enables horizontal integration across different architecture layers and among different stakeholders. The main components comprising the platform include: *i) Smart City Infrastructure, ii) Core Platform Facilities, and iii) Value-added services.* In continuation, we describe these components in more detail.

Starting from the *Smart City Infrastructure*, contrary to the traditionally monolithic view on city's infrastructure, in our vision of the cyber-human Smart City, we identify different integral infrastructure constituents, which are inherently entangled and interdependent. *The Physical Infrastructure* consists of the union of all stakeholders' physical assets of direct interest to other stakeholders. This can include city's transport infrastructure, electricity system, but also devices (e.g., vehicles or PV panels) owned by an individual. *The Administrative Infrastructure* consists of the political and legal organizations governing the city's ecosystem. Collectively they act as the trusted entity determining and enforcing governance policies, guaranteeing legal and privacy protection. *The Social Infrastructure* consists of all the individual citizen and business stakeholders, i.e., of their intellectual, social and physical capabilities, as well as personal assets and resources, offered indirectly as services, individually or collectively. Examples include providing labor on a given task, or offering a ride service a personal vehicle (as opposed to sharing the vehicle). *The ICT Infrastructure* is the cornerstone for efficient horizontal integration of different infrastructural layers and interoperability among stakeholders. It consists of all the physical and software (virtual) components for data gathering, processing, enactment of business logic, communication, and actuation of physical devices, such as sensors, IoT gateways, actuator, cloud processing and storage infrastructure and analytics software services.

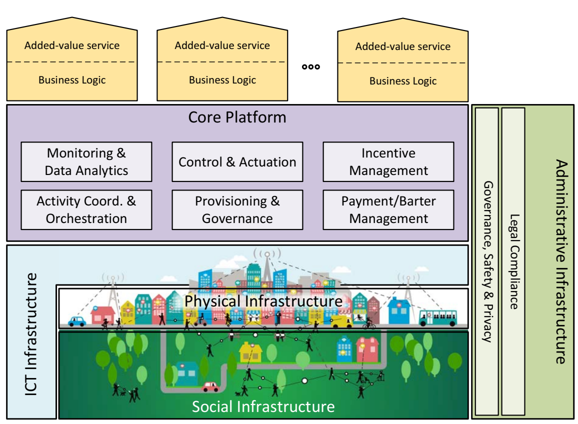

Fig. 2. Cyber-human Smart City platform.

Whereas the Infrastructure components resemble the vital organs of the Smart City, the *Core Platform* resembles its bloodstream, linking all the Smart City functionalities and enabling their seamless functioning. Most important functionalities of the Core Platform include: Orchestration functionalities for the *Complex Coordinated Activities* (Section III-B), *Incentive Management* (Section III-C), *Provisioning & Governance* (Section III-D), Monitoring & Data Analytics, as well as Control & and Actuation mechanisms. Since the last two components are also present in the Smart City of today, we will not discuss them here.

The *Value-added Services* act as the brain of the Smart City. They rely on the core platform to enable management of the Infrastructure and facilitate the value-generation process. Generally, the added value services are largely task and use-case specific and we do not impose any rules or requirements on their design or functionality. They are envisioned as a playground of disruptive innovation and value generation. For example, they can be optimizations of existing business models or incubators for novel business opportunities. The value-added services are meant to follow natural lifecycle of city's evolution and can appear and disappear in accordance with stakeholders needs.

B. Complex Coordinated Activities

One of the principal defining characteristics of the envisioned Smart City is the existence and support for rich set of interactions embodied in the concept of complex, collaborative *coordinated activities*. These activities are fundamental to the generation of societal and business values described in the previous section. Whether initialized by the municipality, local businesses or the citizens themselves, a Smart City platform acts as the legal, trust and coordination enabler of such activities. On the 'physical layer', the activities comprise the following interaction types:

1) M2M – interactions between IoT devices and software services (e.g., sensing, actuation, data analytics, service compositions, micro-transactions).
2) H2H – interactions between humans/citizens (negotiation, joint planning, collaborative task execution, learning, direct democracy).
3) M2H – interactions between humans and (their) devices (notifications, personalized use, context sensing, augmented reality).

Since the machines (devices, services) are practically used on human behalf, on the more abstract level the activities are representing the interactions among the various city stakeholders. In fact, the main objective of such coordinated activities is to actively facilitate the various stakeholders to (self-)organize and reach a common goal, both on a personal (micro), as well as on a city (macro) scale. The facilitation is performed through various coordination and communication mechanisms delivered by the Smart City platform III-A. These mechanisms serve both as direct and indirect controllability methods – either enforcing specific constraints and policies (e.g., negotiation protocols, SLAs), or indirectly influencing behavioral responses of humans through incentives and peer influence. Examples of complex coordinated activities can range from collectively-organized transportation [12], private infrastructure sharing[2], collective learning [13], game-based learning[3] to gainful activities, such as collaborative software development [14]. While the size of the heterogeneous collectives participating in these activities need not be large-scale, the potential and reach is global, allowing most citizens to participate, thus actively shaping the society, city and the business environment they share.

C. Incentives as a Soft Controllability Principle

Managing humans in various socio-technical systems has often been criticized as neglectful of the true human nature [15]. Humans are often used as role enactors in human workflows [16]–[18] or executors of instructions [19]. While such approaches allow overcoming the difficulties related to human-understandable context interpretation, the human intelligence is harnessed in a passive way, since the execution is machine-driven and deterministic. This means that the collaborative and social capital of humans is not fully used, despite the prospective of delivering a profound positive impact on the society we live in [20]. Crowdsourcing [21] and various other platforms for collaborative consumption have partially tapped into this potential, allowing for human-driven, albeit tightly structured, collaborations.

A distinguishing characteristic of human participation in socio-technical processes is the need for motivation. Differently than software services or devices whose usage can be requested for a compensation and whose outputs are deterministic, human participation is driven by personal motives which vary from person to person, vary individually in time, and also depend on the (social) environment. Furthermore, diverging individual motives and interests make team assembly and coordination of collective activities inherently complex.

Incentives are a means for inducing motivation and aligning disjoint individual interests in a group [22]. They include not only monetary/material rewards, but more often rely on intrinsic motivational factors, such as altruism, curiosity, competitiveness, social status. Compared to the listed role-based workflow systems where humans are issued concrete actions to perform, incentives serve as a powerful mechanism for "soft controllability" inducing wanted behavioral responses, setting psychological engagement constraints but leaving the liberty of action to the humans.

A cyber-human Smart City wishing to engage citizens into collaborative actions should offer the incentive management services, such as [9], through its platform (Fig. 2), offering different stakeholders the tools to motivate and engage other stakeholders into collaborative activities. The incentive management service allows the provider of the incentives to compose and tweak incentive schemes optimal for a particular purpose and a given target population. It also allows the monitoring of the incentive application and effectiveness, and subsequent adaptations. The city can incentivize the citizens to engage in decision making or to get better informed, or to change their habits (share infrastructure, promote a healthier lifestyle). Businesses aligned with such goals can provide for the costs of incentivization. Finally, where mutual resources and devices can be shared, individual citizens can set up incentive schemes to encourage bartering and partially substitute the use of money with alternative/local currencies (see Ithaca HOURS[4]) in micro-transactions having positive effects on local businesses [23] (cf. Sec. III-D). The incentives can be delivered through different channels, using personalized messages, to different hand-held or IoT devices. Serious games are also an attractive environment for engaging people and delivering incentives, especially for learning purposes, as suggested by the recent global success of the augmented-reality game Pokemon Go[5]. As the timing and the perception of the incentive, as well as the trust in the incentive provider, are the key factors of its effectiveness, we argue that the described Smart City context is a well-suited environment for the implementation of such incentive management systems. The Smart City platform provides the trusted third party technically managing the application of the incentives, while not taking an active provider role. Thanks to their pervasive distribution IoT/Edge devices are used to deliver incentive messages and provide raw data for automated monitoring of incentivized activities.

[2] https://switcher.ie/broadband/news/upc-ireland-rolls-out-horizon-wi-free-service/
[3] http://www.nobelprize.org/educational/medicine/ecg/
[4] http://ithacahours.com/
[5] http://www.bbc.com/news/technology-36763504

D. Provisioning and Governing Infrastructure as a Utility

At its core Smart City assumes an interplay between cities and technology. From the ICT point of view, smart cities are ever stronger developing and evolving Cyber-Physical Systems that blend in Internet of Things (IoT) [24], network elements Cloud services and humans. This results in complex IoT Cloud infrastructures that need to be provisioned dynamically on-demand and governed throughout their entire lifecycle. Moreover, Smart City stakeholders engage in utility generation and consumption, as well as its distribution (e.g., sale), generally in a regulated market. However, to date Smart City ICT infrastructure is hardly delivered and consumed as a utility. To enable this vision in the Smart City of the future, we identify a set of design principles that serve as a road-map towards realizing the utility-based delivery and consumption of Smart City infrastructure. These include: *Everything as code* – All the concerns, i.e., application business logic, but also Smart City infrastructure resources provisioning and runtime governance, should be expressed programmatically in a unified manner, as a part of the application's logic (code). *API Encapsulation* – Smart City infrastructure resources and capabilities are encapsulated in well-defined APIs, to provide a uniform view on accessing functionality and configurations of IoT cloud infrastructure. *Central point of operation* – Enable conceptually centralized (API) interaction with to allow for a unified view on the infrastructure's provisioning and governance capabilities, without worrying about low-level infrastructure details. *Automation* – Main provisioning and governance processes need to be automated in order to enable dynamic, on-demand configuring and operating the Smart City infrastructure without manually interacting with Edge devices.

In our previous work, we have addressed some of the aforementioned challenges by introducing models and frameworks that implement and enforce some of these principles in order to facilitate utility-based provisioning and city-scale governance. In [25], [26], we have introduced a unified provisioning model and a framework support for logically centralized provisioning large-scale, geo-distributed Smart City ICT infrastructure. This work was mainly intended to address a stringent need: To enable refactoring the Smart City ICT infrastructure into finer-grained resource components whose behavior can be defined in software; To provide conceptually unified representation of both Edge and Cloud resources; As well as to enable automated and scalable management of IoT Cloud resources, application components and their configuration models in a logically centralized fashion. Furthermore, in [27], [28] we introduced GovOps, which is a novel governance methodology and runtime framework for governing the Smart City infrastructure and services. The main aim of GovOps is: To bridge a currently wide gap between stakeholders involved in governing Smart City systems; To enable enforcing governance strategies in a large-scale, geographically distributed setup and; To enable dynamic, on-demand deployment and invocation of governance capabilities via cloud-based APIs. However, although this works lays a cornerstone for realizing our vision of the Smart City, additional work needs to be done in order develop a full fledged tool suit that is capable to facilitate the value generation chain (cf. Section II).

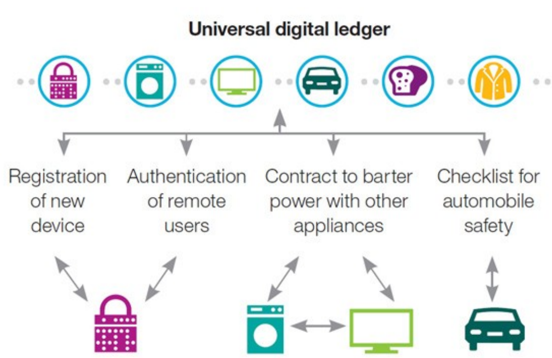

Fig. 3. Blockchain micro-transactions processing.

One of the key enablers is to provide novel support for realizing the delivery-consumption-compensation model for the previously-introduced smart city capital. Traditional public utilities exclusively rely on existing markets, business models and monetary institutions to realize this model. However, to realize broader participation in the previously presented architecture of values Smart Cities largely lack suitable business models for exchanging the resources and services among the stakeholders. Moreover, infrastructure owners and infrastructure brokers require an ecosystem to support trading Smart City services and assets. Traditional models, e.g., banking/-payment processing systems, fall short regarding the speed, scale and agility required to support trading in our Smart City ecosystem: i) They mainly rely on invoicing as the only mean to perform a monetary transaction. ii) Banks only do business with people, not smart devices (which are active participants in Smart City platform). iii) Privacy issues when trading with sensitive information due to involvement of a third party e.g., a bank. iv) Limited lower boundary of a transaction amount, e.g, 0.01 EUR. v) Duration of assets transfer or legal boundaries.

Therefore, to realize the utility-oriented delivery and consumption of Smart City infrastructure resources we need to extend the aforementioned set of principles to include: *Smart City trader units* – Devices and services/applications autonomously decide with whom to trade and do business; *Automated cash-handling* – It is difficult to manage and oversee individual devices in the large-scale hyper-distributed environments, thus devices need to have higher degree of autonomy; *Micro-transactions* (time- and size-wise) – Enabling pay-as-you-go consumption of IoT infrastructure (e.g., per data instance) with small/no transaction fees across regions with different location; and compliance criteria; *Scalable transaction processing* – Supporting the large number of devices, e.g., gateways capable to provide resources/capabilities and perform business transactions; *No central authority* – Brings considerable benefits for the privacy requirements, but keeps the whole process highly transparent.

One of the promising technologies which can be used as a base for the solutions that can support these principles is Blockchain [29]–[31]. Generally, a Blockchain is a distributed database that maintains a continuously-growing list of data records (cf. Fig. 3). Each block holds a batch of transactions and since it is based on P2P consensus and strong encryption it is very resilient against tampering and revision. This makes it a good solution for any kind of transactions within inherently untrusted IoT networks. For example, it could be used by the smart devices to autonomously trade resource, e.g., sensory data, storage and network among themselves, but also for secure file transfer or different kinds of user-defined smart contracts. However, one of the limitations of the current Blockchain solutions is a lack of scalability and although there are partial solutions, e.g., side chains a more scalable approach is required to accommodate number and frequency of transactions envisioned in our future Smart City.

IV. Conclusion and future work

In this paper we have introduced a novel vision of the Cyber-human Smart City, which is based on the architecture of values. This value-driven architecture is characterized by complex coordinated activities involving the City's services, stakeholders and their smart devices. It puts the citizens into the first plan and promotes them to the active stakeholders as opposed to passive users. We presented a set of key enablers to realize the vision of cyber-human Smart City, which include: i) Complex Coordinated Activities, ii) Incentives as soft controllability mechanisms, and iii) Utility-based provisioning and governance of Smart City Infrastructure. We presented a concrete set of design principles and requirements that serve as a manifesto of cyber-human cities of the future and lay down a road map toward realizing a comprehensive Smart City Platform. Finally, we discussed how current technologies can be used to support the introduced platform and we have identified potential research directions to advance the platform beyond current technological advances. In the future, we plan to continue developing the concept of cyber-human Smart City and the Smart City Platform.

References

[1] R. G. Hollands, "Will the real smart city please stand up? intelligent, progressive or entrepreneurial?," *City*, vol. 12, no. 3, pp. 303–320, 2008.

[2] B. Bowerman, J. Braverman, J. Taylor, H. Todosow, and U. Von Wimmersperg, "The vision of a smart city," in *2nd International Life Extension Technology Workshop, Paris*, vol. 28, 2000.

[3] G. Galdon-Clavell, "(not so) smart cities?: The drivers, impact and risks of surveillance-enabled smart environments," *Science and Public Policy*, vol. 40, no. 6, pp. 717–723, 2013.

[4] H. Schaffers, A. Sällström, M. Pallot, J. M. Hernández-Muñoz, R. Santoro, and B. Trousse, "Integrating living labs with future internet experimental platforms for co-creating services within smart cities," in *Concurrent Enterprising (ICE), 2011 17th International Conference on*, pp. 1–11, IEEE, 2011.

[5] B. Manin, *The Principles of Representative Government*. Cambridge University Press, 1997.

[6] R. Pande, A. V. Banerjee, S. Kumar, and F. Su, "Do informed voters make better choices? experimental evidence from urban india," 2011.

[7] M. Mendonca and D. Cowan, "Decision-making coordination and efficient reasoning techniques for feature-based configuration," *Sci. Comput. Program.*, vol. 75, pp. 311–332, May 2010.

[8] M. Rovatsos, "Multiagent systems for social computation," in *Proceedings of the 2014 International Conference on Autonomous Agents and Multi-agent Systems*, AAMAS '14, pp. 1165–1168, International Foundation for Autonomous Agents and Multiagent Systems, 2014.

[9] O. Scekic, H.-L. Truong, and S. Dustdar, "Pringl a domain-specific language for incentive management in crowdsourcing," *Computer Networks*, 9 July 2015.

[10] B. Sengupta, A. Jain, K. Bhattacharya, H.-L. Truong, and S. Dustdar, *Who Do You Call? Problem Resolution through Social Compute Units*, pp. 48–62. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012.

[11] International Electrotechnical Commission, "Orchestrating infrastructure for sustainable Smart Cities." URL: http://www.iec.ch/whitepaper/smartcities/, 2016. [Online; accessed Jun-'16].

[12] "Smartsociety consortium, deliverable 5.3 - specification of advanced incentive design and decision-assisting algorithms for cas." http://www.smart-society-project.eu/publications/deliverables/D_5_3, 2015.

[13] T. N. Garavan and R. Carbery, *Collective Learning*, pp. 646–649. Boston, MA: Springer US, 2012.

[14] D. Murray-Rust, O. Scekic, P. Papapanagiotou, H. L. Truong, D. Robertson, and S. Dustdar, "A collaboration model for community-based software development with social machines," *EAI Endorsed Trans. Collaborative Computing*, vol. 1, no. 5, p. e6, 2015.

[15] L. C. Irani and M. S. Silberman, "Turkopticon: Interrupting worker invisibility in amazon mechanical turk," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, (New York, NY, USA), pp. 611–620, ACM, 2013.

[16] D. W. Barowy, C. Curtsinger, E. D. Berger, and A. McGregor, "Automan: A platform for integrating human-based and digital computation," *SIGPLAN Not.*, vol. 47, pp. 639–654, Oct. 2012.

[17] P. Minder and A. Bernstein, "Crowdlang: A programming language for the systematic exploration of human computation systems," in *Social Informatics* (K. Aberer, A. Flache, W. Jager, L. Liu, J. Tang, and C. Guret, eds.), vol. 7710 of *LNCS*, pp. 124–137, Springer, 2012.

[18] S. Ahmad, A. Battle, Z. Malkani, and S. Kamvar, "The jabberwocky programming environment for structured social computing," in *Proc. 24th Annual ACM Symposium on User Interface Software and Technology*, UIST '11, pp. 53–64, ACM, 2011.

[19] M. J. Franklin, D. Kossmann, T. Kraska, S. Ramesh, and R. Xin, "Crowddb: Answering queries with crowdsourcing," in *Proc. 2011 ACM SIGMOD Intl. Conf. on Management of Data*, SIGMOD '11, pp. 61–72, ACM, 2011.

[20] US President's Council of Advisors on Science and Technology, "Report to the President and Congress ensuring leadership in federally funded research and development in information technology." URL: https://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/nitrd_report_aug_2015.pdf, 2015.

[21] A. Doan, R. Ramakrishnan, and A. Y. Halevy, "Crowdsourcing systems on the World-Wide Web," *Communications of the ACM*, vol. 54, p. 86, Apr. 2011.

[22] O. Scekic, H.-L. Truong, and S. Dustdar, "Incentives and rewarding in social computing," *Commun. ACM*, vol. 56, pp. 72–82, June 2013.

[23] L. Solomon, *Rethinking Our Centralized Monetary System: The Case for a System of Local Currencies*. Bibliographies and Indexes in Law and, Praeger, 1996.

[24] G. Fortino, A. Guerrieri, W. Russo, and C. Savaglio, *Middlewares for Smart Objects and Smart Environments: Overview and Comparison*, pp. 1–27. Springer, 2014.

[25] S. Nastic, S. Sehic, D.-H. Le, H.-L. Truong, and S. Dustdar, "Provisioning Software-defined IoT Cloud Systems," in *FiCloud'14*.

[26] S. Nastic, H.-L. Truong, and S. Dustdar, "Sdg-pro: a programming framework for software-defined iot cloud gateways," *Journal of Internet Services and Applications*, vol. 6, no. 1, pp. 1–17, 2015.

[27] S. Nastic, C. Inziger, H.-L. Truong, and S. Dustdar, "GovOps: The Missing Link for Governance in Software-defined IoT Cloud Systems," in *WESOA14*, 2014.

[28] S. Nastic, M. Voegler, C. Inziger, H.-L. Truong, and S. Dustdar, "rtGovOps: A Runtime Framework for Governance in Large-scale Software-defined IoT Cloud Systems," in *Mobile Cloud 2015*, 2015.

[29] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," 2008.

[30] F. Reid and M. Harrigan, "An analysis of anonymity in the bitcoin system," in *Security and privacy in social networks*, pp. 197–223, Springer, 2013.

[31] D. Ron and A. Shamir, "Quantitative analysis of the full bitcoin transaction graph," in *International Conference on Financial Cryptography and Data Security*, pp. 6–24, Springer, 2013.