Smart Communities: From Sensors to Internet of Things and to a Marketplace of Services

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Abstract: Our paper was inspired by the recent Society 5.0 initiative of the Japanese Government that seeks to create a sustainable human-centric society by putting to work recent advances in technology: sensor networks, edge computing, IoT ecosystems, AI, Big Data, robotics, to name just a few. The main contribution of this work is a vision of how these technological advances can contribute, directly or indirectly, to making Society 5.0 reality. For this purpose we build on a recently-proposed concept of Marketplace of Services that, in our view, will turn out to be one of the cornerstones of Society 5.0. Instead of referring to Society 5.0 directly, throughout the paper we shall define a generic Smart Community that implements a subset of the goals of Society 5.0. We show how digital technology in conjunction with the Marketplace of services can contribute to enabling and promoting sustainable Smart Communities. Very much like Society 5.0, our Smart Community can provide a large number of diverse and evolving human-centric services offered as utilities and sold on a metered basis. The services offered by the Smart Community can be synthesized, using the latest technology (e.g. 3D printing, robotics, Big Data analytics, AI, etc.), from a hierarchy of raw resources or other services. The residents of the Smart Community can purchase as much or as little of these services as they find suitable to their needs and are billed according to a pay-as-you-go business model.

1 INTRODUCTION

In 2016, the Japanese Government issued and publicized a bold initiative and a call to action for the implementation of a "Super Smart Society" announced as *Society 5.0*. The vision and novelty of Society 5.0 is that it embodies a sustainable *human-centric* society enabled by the latest digital technologies. Society 5.0 meets the various needs of the members of society by providing goods and services to the people who require them, when they are required, and in the amount required, thus enabling its citizens to live an active and comfortable life through the provisioning of high-quality services (Shiroishi et al., 2018). Society 5.0 provides a common societal infrastructure for prosperity based on an advanced service platform which turns out to be its main workhorse. The insight behind Society 5.0 is that continued progress of ICT and digital technologies of all sorts will provide individuals and society tremendous opportunities for innovation, growth, and unprecedented prosperity and well-being through various forms of human-to-human, human-to-machine, and machine-to-machine cooperations and collaboration. Most of these forms of cooperation and collaboration between humans and machines or between autonomous machines systems have yet to be defined and understood (Horwitz and Mitchell, 2010).

Our paper was inspired and motivated by some of the challenges that will have to be overcome in order to implement Society 5.0. With this in mind, the main contribution of this work is a vision of how sensor networks, edge computing, and IoT ecosystems can contribute, directly or indirectly, to making Society 5.0 reality. For this purpose, we build on the recently-proposed concept of Marketplace of Services that, in our view, will turn out to be one of the cornerstones of Society 5.0.

Instead of referring to Society 5.0 directly, throughout the paper we define a generic Smart Community that implements a subset of the goals of Society 5.0. We show how digital technology, in conjunction with the Marketplace of Services can contribute to enabling and promoting sustainable Smart Communities.

This work is a continuation and extension of a recent paper (Eltoweissy et al., 2019) where we have defined the concept of Marketplace of Services. In

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(Eltoweissy et al., 2019) we have argued that the Marketplace of Services is, along with an IoT ecosystem, an integral part of a Smart Community infrastructure. Very much like Society 5.0, our Smart Community can provide a large number of diverse and evolving services offered as utilities and sold on a metered basis. We expect that most of the services offered by the Smart Community can be synthesized within the community itself, using the latest ICT and digital technologies (e.g. 3D printing, robotics, Big Data, AI, etc.), from a hierarchy of raw resources or other services.

The remainder of the paper is organized as follows: Section 2 reviews recent digital technologies that will be key ingredients in realizing Smart Communities. Specifically, Subsection 2.1 reviews wireless sensor networks; Subsection 2.2 surveys the recently-proposed edge computing paradigm, a modern incarnation of sensor networks; Subsection 2.3 reviews IoTs, a common extension of both sensor networks and edge computing; Subsection 2.4 reviews the Smart City concept proposed by visionaries two decades ago; Subsection 2.5 reviews the basics of utility computing; finally, Subsection 2.6 reviews he basics of crowdsourcing. Moving on, Section 3 reviews the concept of a Smart Community as an extension of the well-known Smart City concept. Section 4 illustrates our vision in the context of reviving small communities fallen onto hard times. Finally, Section 5 offers concluding remarks and highlights a number of challenges that will have to be overcome in order to implement the Smart Communities of the future.

2 THE NUTS AND BOLTS

The main goal of this section is to review known ICT and digital technologies that, in our vision, will play an important role in implementing sustainable Smart Communities. These technologies will be surveyed in chronological order since newer technologies often extend old ones, while avoiding their limitations and shortcominings. As an illustration, edge computing is a natural extension of wireless sensor networks, where individual edge devices are more powerful and have fewer limitations than the traditional sensor nodes. In turn, edge computing and sensor networks have suggested the rise of the IoT an eclectic collection of networked devices. We consider sensor networks, edge devices and IoT ecosystems as underlying the Smart Community concept.
To orient the reader, we begin by a table of acronyms that will be used throughout the paper.

Table 1: A guide to acronyms.

Acronym	Description
ICT	Information and Communications Technology
OGS	Open eGovernment Services
AI	Artificial Intelligence
IoT	Internet of Things
IoPaT	Internet of People and Things
CC	Cloud Computing
CPS	Cyber Physical System

2.1 Sensor Networks

Over the last two decades, rapid advances in inexpensive sensor technology and wireless communications have enabled the design and cost-effective deployment of large-scale wireless sensor networks. Such networks appeal to a wide range of mission-critical situations, including health and environmental monitoring, seismic monitoring, industrial process automation as well as a host of military applications ranging from situation awareness to battlefields surveillance, to tactical operations (Chen et al., 2011; Mohrehkesh et al., 2014; Olariu et al., 2007; Oliveira and Rodrigues, 2011). The common thread that unifies these applications is that the sensors are affording novel, and sometimes surprising, perspectives on phenomena at a scale that was not possible before.

Sensor networks are viewed as time-varying systems composed of autonomous mobile sensing devices (using mobile robots) that collaborate and use distributed coordination to successfully accomplish complex real-time missions under uncertainty. The major challenge in the design of these networks is attributable to their dynamic topology and architecture, caused either by sensing devices mobility or else by the limited energy budget that suggests turning off individual sensors to save energy. This state of affairs may have significant impact on the performance of sensor networks in terms of their sensing coverage and network connectivity. In such dynamic environments, sensing devices must self-organize and move purposefully to accomplish any mission in their deployment field, while extending the operational network lifetime. In particular, the design of sensor networks should account for trade-offs between several attributes, such energy consumption (due to mobility, sensing, and communication), reliability, fault-tolerance, security, and delay (Jones et al., 2003; Jones et al., 2005).

The designers of sensor networks face another challenge, namely that of reaching consensus fast in order not to delay action (Frederick et al., 2002; Nakano and Olariu, 2000; Olariu et al., 1992; Olariu et al., 2013). Indeed, it is well known that the value of information collected by sensors decays (often quite dramatically) over time and space and aggregation of sensor data needs to take this into account (Rajagopalan and Varshney, 2006; Sachidananda et al., 2010). Yet another challenge facing the designers of sensor networks is retasking sensors and re-purposing entire sensor networks in the face of changing mission parameters (Olariu et al., 2014; Ruffing et al., 2014; Wang et al., 2018).

2.2 Edge Computing

The past decade has witnessed a fundamental paradigm shift in computing as the number of smart device users (e.g., smartphone and tablet users) has exceeded 3 billion (i.e., 40% of the global population) in 2017 and is expected to exceed 4 billion by 2020. In recent years, the realization that Moore's law no longer applies has motivated an emphasis shift in computer architecture towards energy-efficient special-purpose architectures (Hennessy and Patterson, 2019). In conjunction with recent advances in nano-technology and smart materials, this has lead, quite naturally, to the development of new types of connected smart devices (e.g., smart watches, smart glasses, smart meters, smart robots, connected vehicles, among others). These pervasive and ubiquitous smart mobile devices are referred to, collectively, as *edge* devices, or the "edge" (Lopez et al., 2015).

It was reported that in 2017 the amount of data generated each month at the *edge* by smart devices, such as smartphones, vehicles, and wearables, has reached 14 exabytes and is expected to exceed 24.3 exabytes by 2019 (Systems, 2015). As a result, we are beginning to see more and more network traffic originating at these "edge" devices.

Figure 1: Illustrating the offloading path from the network edge to the cloud.

It was soon realized that the data generated at the edge is incredibly rich in contextual information and, hence, extremely valuable and should be harvested to capture and understand context (Haig, 2015). Unfortunately, because of the widening gap between bandwidth capacity and data volumes, the data generated at the edge will increasingly stay at the edge and will be thrown away for lack of adequate processing power. A good example of such contextually-rich data is the sensor data collected by the cars that criss-cross our roadways and city streets. This data is highly ephemeral as it reflects instantaneous traffic conditions that are apt to change fast. Due to latency, costs, and the risks involved in moving data to and from a cloud, cloud-based real-time processing of edge data is neither technologically feasible nor economically viable. Refer to Figure 1 for an illustration of the time delay incurred in offloading the processing of the data generated at the edge to some remote cloud for processing simply takes too long.

Given the transient nature of context and context-sensitive needs of individuals and enterprises, the highest value from edge data can be extracted only by processing it *near real-time*.

In the light of our previous discussion, there is a *critical need* for an alternative computing platform, one that allows harvesting and aggregating the huge amounts of data generated by edge devices right there – at the edge (Mach and Becvar, 2017). It is an interesting observation that the same edge devices that generate huge amounts of data, also offer, potentially, a huge compute and storage resource that at the moment is untapped (Shi et al., 2016). Indeed, it is expected that the collective computing and storage capacity of smartphones will exceed that of worldwide servers by the end of 2018 (Haig, 2015).

2.3 The Internet of Things

The Internet of Things (IoT) has been defined in myriad ways (Atzori et al., 2010). At the most basic level, an IoT is a network consisting of smart objects, commonly referred to as *things*. The things in the IoT can be sensor nodes, actuators, everyday objects endowed with some computation and communication capabilities, edge devices, such as RFID tags, smart phones, smart watches, tablets, smart meters and other similar devices. The IoT things typically communicate with each other wirelessly. However, more sophisticated devices such as, for example, various types of process controllers, may be part of an industrial IoT system and, as such, have wired Internet connection (Lade et al., 2017). The IoT devices can sense, collect, and aggregate data from the physical environment. At the same time, through the use of actuators and controllers, the IoTs have the ability to "close the loop" acting on the environment in response to the aggregated data. In this sense, IoTs can be viewed as Cyber Physical Systems (CPS).

IoT systems are expected to see a wide adoption in industrial applications (Lade et al., 2017) and (Wollschlaeger et al., 2017), healthcare (Mahmood et al., 2017), (Sinclair, 2017), (Wang et al., 2017) and (Yang et al., 2019) and, more broadly, to be incorporated in the fabric of society (Qiu et al., 2018) and (Montori et al., 2018). See (Sollins, 2019) and (Whitmore et al., 2015) for surveys of possible IoT applications.

Cisco predicted that the number of connected IoT devices will reach 50 billion by 2020 (Chase, 2018). However, the wide diversity and heterogeneity of devices that participate in IoT, often by joining and leaving dynamically, have direct consequences on workload assignment, networking interfaces, privacy and security, among many others (Hussain et al., 2018; Sfar et al., 2019; Sollins, 2019). These, and other similar challenges will have to be overcome if IoTs are to see the predicted phenomenal adoption rate. The problem of providing security and privacy of IoT system is already getting attention in the literature (Kim et al., 2019). For example, (Al-Ameedee and Lee, 2018) proposes to use deep learning strategies, (Sfar et al., 2019) proposes a game-theoretic solution, while (Zhang and Wen, 2016) and (Hui et al., 2019) advocate the use of Blockchain technology.

It has long been recognized the value of *smart devices* in synthesizing sophisticated services (Medina-Borja, 2015). We believe that one of the important dimensions of IoT is, indeed, that of providing services that are important to the community in which they operate. For example, (Krishnamachari et al., 2018) and (Ramachandran et al., 2018), have suggested that sensor data and other information produced by various IoTs is of fundamental importance in Smart Cities.

2.4 Smart Cities

As it turns out, the term *Smart City* was coined in the early 1990s to illustrate how urban development was turning towards technology, innovation, and globalization (Gibson et al., 1992). The early visionaries depicted the Smart Cities of the future as fully connected entities supported by various forms of *pre-deployed infrastructure*, including sensor networks, ubiquitous and pervasive wireless communication infrastructure, supplemented by advanced in-vehicle resources such as embedded powerful computing and storage devices, cognitive radios and multi-modal programmable sensor nodes. The visionaries anticipated that, in the near future, vehicles equipped with computing, communication and sensing capabilities will be organized into ubiquitous and pervasive networks with a significant Internet presence while parked or on the move. They predicted that this would revolutionize the driving experience making it safer, more enjoyable and more environmentally friendly.

In our view, the Smart Cities envisioned by the early visionaries differ from present-day cities in three major respects. First, the Smart Cities will be instrumented with the latest ICT, and will actively rely on, *intelligent infrastructure* – these are smart devices that can sense the environment, send and receive data and are networked together and with other networked elements in the Smart Cities. The intelligent infrastructure is apt to provide real-time traffic data on which timely management decisions can be based. Second, Smart Cities will make extensive use of strategies and techniques to incentivize and to engage its connected citizens.

While Smart Cities have been defined in myriad ways (Harrison and Donnelly, 2011; Hatch, 2013; Lakakis and Kyriakou, 2015; Litman, 2015; Townsend, 2013), it is telling that all these definitions have two explicit or implicit characteristics in common: first, the Smart Cities assume an transparent governance and management style that *anticipates* the read needs of the citizens; and, second, they assume a broad and continued *engagement* and active *participation* of the citizens. These two characteristics of Smart Cities can be viewed as "putting the citizen first", or being *human-centric*.

It is worth noting that the human-centric characteristic of Smart Cities is consistent with, and was echoed by, OGS – the *open e-government* services proposed, in a slightly different context in the past decade or so by Johansson and his coworkers (Johansson et al., 2015a; Johansson et al., 2015b) as well as by various documents originating with (European Commission, 2016).

In fact, empowering their citizens with increased access to high-quality information is one of the defining dimensions of a Smart City. And, the role played by the citizens is poised to increase since, according to recent statistics, as of the end of 2015, over 70% of the US population resided in big cities (United States Environmental Protection Agency, 2016; United States Census Bureau, 2015). In fact, (National Academies of Sciences, Engineering, and Medicine, 2017) predicts that, by 2050, more than 70% of the world population will reside in metropolitan areas. It is not surprising, therefore, that many countries are planning and deploying Smart Cities. They are "urban centers that use intelligent, connected devices and automated systems that maximize the allocation of resources and the efficiency of services" (National Academies of Sciences, Engineering, and Medicine, 2017)

The rise of IoT and adoption of Smart Cities create opportunities for creative and efficient management and utilization of the available resources. One of the characteristics of Smart Cities is the interconnectivity of the city's infrastructure, which allows data to be collected from various human-generated or machine-generated sources.

2.5 Utility Computing

Cloud Computing (CC) is a modern metaphor for *utility computing*, implemented through the provisioning of various types of hosted services over the Internet. The underlying business model of CC is the familiar pay-as-you-go model of *metered services*, where a user pays for whatever she uses and no more, and where additional demand for service can be met in real time. This powerful idea was suggested, at least in part, by pervasive low-cost high-speed Internet, a good handle on virtualization, and advances in parallel and distributed computing (Barroso et al., 2019; Hennessy and Patterson, 2019; Marinescu, 2017).

Three aspects are novel in CC: First, it gives users the illusion of infinite compute resources available to them on demand. Second, it eliminates the up-front financial commitment by cloud users, allowing them to increase hardware/software resources as needed. Third, it gives users the ability to pay for resources on a short-term basis and release them when they are no longer needed (Marinescu, 2017)

2.6 Crowdsourcing

Crowdsourcing, a term coined in 2006 by Jeff Howe (Howe, 2006), involves outsourcing tasks to an undefined group of people. The main difference between ordinary outsourcing and crowdsourcing is that in the former the problem to solve is outsourced by a requester to a specific body of people, such as paid employees, while in the latter the task is outsourced to an unstructured group of folks with no permanent relationship to the requester.

As is typical of all emerging research areas, crowdsourcing has appeared in the literature under various other names including, peer production, community systems or collaborative systems. Indeed, it has been argued by several authors that crowdsourcing can be legitimately looked at as a collaborative way of problem solving (Brabham, 2008). In the past few years crowdsourcing applications have mushroomed (Franklin et al., 2011; Li et al., 2017; Ra et al., 2012; Xu et al., 2017; Yang et al., 2012).. For example, MicroBlog (Gaonkar et al., 2008) is used to build a location-based map of videos by allowing participants to share videos to a cloud server through their cellular connectivity. Similarly, CrowdDB (Franklin et al., 2011) utilizes end user's knowledge to conduct in a distributed fashion SQL queries in a crowdsourcing approach. Medusa (Ra et al., 2012), a programmable framework to facilitate crowdsensing by allowing users to request sensing tasks (e.g. take a video), recruit volunteers, upload preliminary task results, validate them, and choose a subset of the volunteers to carry out the task. All of these approaches and others considered collecting edge-generated data and sending them to a cloud server, usually for computational convenience. Recently, Wang *et al.* (Wang et al., 2016) offered a literature review of crowdsourcing in support of ITS.

There are two important issues that have attracted attention in crowdsourcing: the use of incentives to attract a competent and motivated workforce, and the related topic of preserving the privacy and security of all parties involved. Several strategies for incentivizing participation in crowdsourcing have been reported in the literature (Hussain et al., 2018; Li et al., 2017; Yang et al., 2012). As pointed out by (Doan et al., 2011), the race is on to build general crowdsourcing platforms in various application domains. For example, *vehicular crowdsourcing* is an instance of a crowdsourcing application domain where a group of vehicles lend their on-board processing resources to an authorized user (Florin and Olariu, 2015).

A related, but quite distinct, area is that of *crowd computing* which combines mobile devices and social interactions to achieve large-scale distributed computation (Murray et al., 2010). Here, an opportunistic networks of mobile devices, including smart phones, tablets, laptops and the like, offers an aggregate compute power and communication bandwidth. Murray's seminal paper (Murray et al., 2010) points out a number of reasons crowd computing is attractive: key among them is the willingness of people to contribute to a common cause, even if no reward is offered. Typically crowd computing involves one or a series of tasks that are farmed out to a number of mobile devices. As these devices socially meet other such devices, the tasks are shared with the new devices and this process continues until the tasks are completed.

3 WHAT ARE SMART COMMUNITIES?

Recently, the U.S. National Science Foundation's " Smart and Connected Communities" solicitation (Smart and Communities, 2019) described Smart Communities as communities "*that synergistically integrates intelligent technologies with the natural and built environments, including infrastructure, to improve the social, economic, and environmental well-being of those who live, work, or travel within it.*"

Even though the NSF definition does not state explicitly that Smart Communities are human-centric, their definition is not inconsistent with the vision and stated goals of Society 5.0. Extending the NSF definition, we define a Smart Community as a community governed by the lofty goal of satisfying, through the provisioning of high quality services, most of the reasonable needs of the people, irrespective of whether these needs arise from the stomach or the mind. In our vision, one of the defining characteristics of the Smart Community is that the resources and services are valuated through a Marketplace of Services that acts as an (impartial) arbiter between producers of services and consumer of services.

Unlike a Smart City that assumes geographical co-location inside a metropolitan area, we view Smart Communities as only *logically* co-located and not necessarily geographically co-located.

Evidently, Society 5.0 is a superset of the Smart Community we just defined. At the same time, a Smart Community need not fit the description of Society 5.0. This is because a Smart Community, while human-centric, does not necessarily strive to become a welfare society. Instead, the main goal and objective of a Smart Community is to equip the members of the community with information and services that they can use to make intelligent decisions. As we discuss later, some of the information and services provided by the Smart Community come in the form of training the workforce in skills that are highly marketable and that correspond to their abilities.

As already mentioned, this paper builds on the work of (Eltoweissy et al., 2019). The main contribution of (Eltoweissy et al., 2019) was to take the idea of cloud computing to the next level. Specifically, they envisioned the Smart Communities of the future as offering services of all sorts bundled as utilities: the citizenry consumes these services of a metered basis, according to the well-known pay-as-you-go business model. According to (Eltoweissy et al., 2019), the Smart Community is synthesizing these services from urban resources produced by various sensor networks, edge devices, and IoTs. Suitably aggregated, the resources are sold as services.

The main contribution of this work is to extend the results of (Eltoweissy et al., 2019). Specifically,

a. we remove the assumption that Smart Communities are either urban areas or else are geographically collocated;

b. unlike (Eltoweissy et al., 2019) where the pillars of a Smart Community are the various IoTs deployed within the community and a centralized marketplace of services, in our vision, Smart Communities are built around IoPaTs (to be defined in Subsection 3.1) and a *distributed* Marketplace of Services (to be defined in Subsection 3.2).

In the remainder of this section we discuss IoPaTs, the Marketplace of Services and show the symbiotic relationship between them.

3.1 From IoTs to IoPaTs

For our purposes, the IoT concept discussed in Subsection 2.3 will be augmented as we are about to describe. Instead of IoTs, we look at IoPaTs as underlying the Smart Community concept. We assume that within the Smart Community, resources and services are produced by independently-owned, deployed, and operated entities that we refer to, generically, as IoPaTs (short for Internet of People and Things). At the highest level of abstraction, an IoPaT is a CPS where the various sensing devices (e.g. sensor networks and various edge devices) make up the physical component, while the *people* in the IoPaT, acting as the cyber component, "close the loop" by enabling actuation and iteration.

To the first approximation, the IoPaTs can be thought of as *startup* companies that produce and bring to the marketplace innovative goods and services. In our view, the IoPaTs are the main pillars of innovation in a Smart Community. The IoPaTs generate value added in the form of services that they expose to the community though the Marketplace of Services. These services may be purchased and consumed, in some form, by the general public or else may be further aggregated by other IoPaTs to synthesize higher-level services.

Where does this process stop? To answer this question, we need to remember that the marketplace acts as an (impartial) arbiter that will indicate what services are aligned with the needs (and wants) of the society and which others are not. Occasionally, new services will be produced that may or may not be successful in the marketplace. The new services that turn out to be successful will continue to be produced, and may spawn other related services, while those that are not will be discontinued.

The nature of the resources produced by the IoPaT and of the locally-aggregated services is largely immaterial for this discussion. However, for the sake of illustration, these services may include hiring members of the community to work within the IoPaT itself, training members of the community in skills that are in high demand, providing (on a subscription basis) personalized route guidance, etc.

While some of the services offered by IoPaTs are sold in the Marketplace of Services, some others may be offered free of charge or at discounted prices. For example, such might be the case when some IoPaTs within the community decide to offer job training services to the unemployed. The service, here, is to equip the unemployed with new, marketable job skills. His human-centric service is expected to have a very high societal value.

3.2 The Marketplace of Services

Traditionally, a marketplace serves the dual purpose of bringing together producers and consumers, and of providing valuation for the various goods and services (Bass, 1969; Gates, 1995; Hill et al., 2006). However, one can also look at the marketplace as enabling the diffusion of innovation among consumers. As pointed out by (Bass, 1969), once brought to the market in some form or another, innovation is likely to create new needs among consumers. In turn, through social interactions, these needs encourage and foster more innovation. Ideally, the marketplace plays the role of an (impartial) arbiter since it provides a valuation of services that reflects their usefulness to the community and society.

It is now widely accepted that information has value and therefore can be traded or sold (Mahajan et al., 1990; Olariu and Nickerson, 2008). There are many aspects of information that may increase or decrease its value: timeliness is an important one; accuracy is another. Assessing the value of information and understanding the dynamics of its change over time has been a topic of research in economics (Allen and March, 2003; Frederick et al., 2002). Two recent papers, (Krishnamachari et al., 2018) and (Ramachandran et al., 2018), have proposed that the sensor data and other information produced by various IoTs in a Smart City be sold and purchased in a marketplace. However, these authors were more interested in making the exchange fair, which is not our purpose. Services and their effects have been studies intensely in the past decade and most of their dynamics are now well understood (Maglio and Spohrer, 2008; Maglio et al., 2009). The Marketplace of Services can build with confidence of this basis. The Marketplace of Services plays a regulatory role in three fundamental ways: first, it will keep the price of the services offered competitive; second, it will reward quality services; and, third, it will promote innovation by rewarding new services aligned with the needs of the Smart Community. Needless to say, the Marketplace of Services will act as an indication that some existing services do not sell well and should be discontinued while new services are needed and may be synthesized by innovative IoPaTs to fill the gaps.

By using data analytics (and machine learning) the Marketplace of Services acquires the ability to predict services needed by community members. The Smart Community is synthesizing these services from IoPaT-produced resources that, suitably aggregated and synthesized, are packaged and sold as services. In our vision, most if not all the resources exist within the corresponding metropolitan community and are being acquired within a resource marketplace whose producers are various IoT systems within the confines of the community. It is to be noted while initially we expect Smart Community boundaries to be physical, we envision that the future Smart Communities will operate beyond the physical confines.

3.3 IoPaTs and Marketplace of Services – A Symbiotic Relationship

To understand the symbiotic relationship between IoPaTs and the Marketplace of Services, we note that the IoPaTs are connected by, and contribute to, a Marketplace of Services. Moreover, by sharing information, the IoPaTs create value (Chesbrough and Spohrer, 2006; Spohrer et al., 2007). One of the fundamental role played by the Marketplace of Services is to incentivize the IoPaTs to share information by contributing their services in return for payment of some form or another.

Even though independently-owned and operated, the IoPaTs find it beneficial to become integrated with other IoPaTs. The general arbiter of this integration is the above-mentioned Marketplace of Services. The marketplace will provide, based on supply and demand, a valuation of the resources and services produced by individual IoPaTs. It follows immediately that when several IoPaTs are producing the same service (say, sensor readings at a certain resolution), it becomes inefficient for both of them to continue flooding the market with resources/services for which demand may be limited.

We envision the various IoPaT subsystems to be integrated into a city-wide *IoPaT ecosystem* that will revolutionize the citizens' experience making living safer, more enjoyable and more environmentally friendly. An important challenge that needs to be overcome is the thorny issue of integrating IoTs into a harmonious *ecosystem*. While, to date, "silo" integration strategies for IoTs have been proposed (Larson, 2016), we believe that a more efficient and effective solution for both IoT and IoPaT integration into an ecosystems is a marketplace-driven, open integration based on a valuation of the services they provide.

4 A CASE STUDY: REVIVING STRUGGLING COMMUNITIES

It is a sad but well-known fact of life that in the US many small communities around the country are struggling: they are trying to come to grips with poverty, neglect, decaying infrastructure, drug addition and increasing crime rate. This predicament is encountered frequently in small communities built around a single employer or a single industry. Once that employer leaves, the community enters a slow process of stagnation and decay. All these factors have a negative effect on the perceived quality of life in the community. In turn, the perceived quality of life that keeps deteriorating induces some of the inhabitants of the small community to move away – to other communities that provide better long-term prospects. In reality, an increased out-flow de-population that is not offset by an equivalent in-flow contributes to a feeling of helplessness and motivates more folks to seek a better life elsewhere.

We believe it is time to stop this process and to enlist technological advances in an effort to revive struggling communities. The process of reviving small communities is multifaceted and involves, among others:

1. Better managing local resources. This entails optimizing the use of existing resources and identifying potential new resources that can be exploited/aggregated;
2. Providing high quality services that the population needs and is ready to pay for, either through taxes or by purchasing them from a service provider;
3. Setting up a marketplace of resources and services that provides valuation for the goods and services produced and consumed by the community
4. Policies that support and promote the better managing of resources and high quality services aligned with the needs of the local population.

The process of reviving a struggling small community is often hard to jump-start mainly because of the lack of technical expertise at the community level and reluctance to rely on external help. Besides, we are aware that the process of better managing local resources, both existing and yet to be discovered, takes time and technical skill that may not be available inside the community. The same holds true of the marketplace of goods and services. For example, providing training for the purpose of acquiring the required skills by the local population is a service that many of the folks in the community will be interested and willing to pay for.

It is evident, therefore, that a single struggling small community is very unlikely to boot-strap itself out of poverty and decay. With this in mind, we propose REASON: a REgional Alliance of Small cOmmuNities, a paradigm for reviving a group of like-minded small communities in a geographic region. These communities are very likely to share the same predicament and to benefit from the same approach to revitalize themselves. The idea is that the participating communities will set up a body in charge of producing a registry of their resources and that will monitor the production of goods and services within the participating communities. In our view, our proposed Internet of People and Things (IoPaT) is a possible platform for enabling the registry of resources and services. The valuation of the resources and services will be implemented by a Goods-and-Service Marketplace (GSM, for short).

In the US, the funds necessary to jump-start REASON could be obtained through various channels, ranging from federal appropriations, to state funds, to local lotteries, or to venture capital, among many similar ones. We surmise that it is in the best interest of the federal and state governments to ensure that the folks in those communities are back to work leading, again, normal lives.

As already mentioned, (Eltoweissy et al., 2019) have put forth the vision of a Smart Community that is largely self-sufficient in terms of producing its own resources and of aggregating sophisticated services whose valuation is regulated by a marketplace.

There are a number of implicit assumptions in (Eltoweissy et al., 2019). First, that the community has exceeded a critical mass, in terms of both population size, technical skills and buying power of its inhabitants, so that the marketplace forces can work unimpeded. The second implicit assumption is that being geographic proximity the resources and services can reach all those who are ready to pay for them without delay and that, moreover, the shipment costs of these goods are negligeable and will not adversely affect their marketability. Finally, (Eltoweissy et al., 2019) make the implicit assumption of a centralized marketplace.

These assumptions do not hold true for individual small communities and, in fact, may not hold for the conglomerate of communities in the regional alliance that we have defined. The vision and main contribution of this case study is to show how that the implicit assumptions of (Eltoweissy et al., 2019) are not essential and that, perceived as a community of communities, the regional alliance of small communities, can satisfy all these conditions.

First, concerning critical mass, we argue that the regional alliance should count a number of inhabitants that is comparable with a community that is large self-sufficient in terms of producing the basic resources it is consuming. This follows from the fact that, originally, each of the small communities in the alliance must have specialized in producing a certain resource. This "division" of work is a fundamental law of economics and applies intra- and inter-communities. The alliance can use this division of work to advantage in the process of diversifying its resource and service base. Second, for the delivery of material goods that are subject to stringent deadlines, the regional alliance can employ drones. Companies like Amazon, UPS and others are already finding drones to be a cost-effective alternative to the traditional truck delivery. We expect that, in volume, the additional expense will be amortized and will not adversely impact the marketability of goods and services.

Finally, our vision is to replace a centrally-controlled Marketplace of Services by a distributed one. A distributed marketplace can be viewed, essentially, as a distributed database of key-value pairs where the first component is a service, the second its market value. Distributed database technology is sufficiently mature and well understood and the range of its applications is tremendous. While this way of implementing (modeling) a Marketplace of Services is possible, there are numerous challenges to overcome to make it reality.

The goal of the REASON is to revive its member communities. This process involves a number of human-centric goals that we now state:

1. Improve the quality of life in each of the member communities. One significant component is to fight crime. We expect that, in a small community, the vast majority of crimes are petty crimes ranging from burglary to larceny, etc. To combat this type of crime we can rely, effectively, on drone technology to discourage would-be criminals;
2. Enhance the outside image projected by the communities. The idea here is to make the community attractive to folks who would be interested in joining the community. Of a special interest is attracting industrial partners (new IoPaTs). In this regard, inspired policies, including free land, tax rebates and other similar incentives, supported by the local governments are of a fundamental importance;
3. Enhancing the technical skills of the population. One way of implementing this idea is by using assistance from federal programs;
4. Promoting tourism and organizing fairs and open houses showcasing the natural beauty of the region,

5 CONCLUDING REMARKS AND CHALLENGES AHEAD

Motivated by the recently-proposed Society 5.0, our main contribution was to offer our vision of a sustainable human-centric Smart Community built around a Marketplace of Services. The services offered by the Smart Community can be synthesized, using the latest ICT and digital technology including 3D printing, robotics, Big Data analytics, AI, etc., from a hierarchy of raw resources or other services. The residents of the Smart Community can purchase as much or as little of these services as they find suitable to their needs and are billed according to a pay-as-you-go business model.

In our vision, the basic pillars of service provisioning and innovation in a Smart Community are the IoPaTs, cyber-physical systems, that behave very much like startup companies. Some of the IoPaTs thrive because the services they offer are aligned with the real needs of the community; other IoPaTs, whose services are less well aligned, will have to adjust or else discontinue their services. This is very similar to the survival of the fittest service providers. The arbiter, in the Smart Community is the Marketplace of Services that reflects the need and the willingness to consume services expressed by the population.

To make our vision reality, a large number of open problems and technical challenges need to be addressed. Here is a sample of challenging problems that await resolution:

- One of fundamental attributes of a Smart Community is sustainability. What safeguards, if any, need to be added to guaranteed that the civil society is sustainable?
- What is a minimal set of incentives that triggers the formation of the ecosystem of IoPaTs?

- Can the Marketplace of Services provide those incentives?
- Can the Marketplace of Service guarantee sustainable innovation in a Smart Community? What other actors are at play here?
- In the process described above, some IoPaTs may become more and more successful and powerful while others will become weaker. Can the Marketplace of Services, by itself, prevent this imbalance from having a negative effect on the community?
- What is the role of community-wide administrative policies?
- Can powerful IoPaTs manipulate the marketplace and influence the needs and wants of the community?
- What are the factors that can stifle innovation?

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