

Article

A Survey of Enabling Technologies for Smart Communities

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Abstract: In 2016, the Japanese Government publicized an initiative and a call to action for the implementation of a “Super Smart Society” announced as Society 5.0. The stated goal of Society 5.0 is to meet the various needs of the members of society through the provisioning of goods and services to those who require them, when they are required and in the amount required, thus enabling the citizens to live an active and comfortable life. In spite of its genuine appeal, details of a feasible path to Society 5.0 are conspicuously missing. The first main goal of this survey is to suggest such an implementation path. Specifically, we define a Smart Community as a human-centric entity where technology is used to equip the citizenry with information and services that they can use to inform their decisions. The arbiter of this ecosystem of services is a Marketplace of Services that will reward services aligned with the wants and needs of the citizens, while discouraging the proliferation of those that are not. In the limit, the Smart Community we defined will morph into Society 5.0. At that point, the Marketplace of Services will become a platform for the co-creation of services by a close cooperation between the citizens and their government. The second objective and contribution of this survey paper is to review known technologies that, in our opinion, will play a significant role in the transition to Society 5.0. These technologies will be surveyed in chronological order, as newer technologies often extend old technologies while avoiding their limitations.

Keywords: Smart Cities; Smart Communities; Society 5.0; enabling technologies; cloud computing; vehicular clouds; sensor networks; edge computing; IoT, crowdsourcing; Big Data analytics; Marketplace of Services



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1. Introduction

In 2016, the Japanese Government publicized a call to action for the implementation of a “Super Smart Society” announced as Society 5.0. The goal of Society 5.0 is to meet the needs of all members of the society by providing goods and services to the people who require them, when they required, and in the amount required—thus enabling its citizens to live an active and comfortable life through the provisioning of high-quality services [1].

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 Information and Communications Technology (ICT) and digital technologies of all sorts will provide individuals and society tremendous opportunities for innovation, growth, and unprecedented prosperity. All this will be provided through various forms of human-to-human, human-to-machine, and machine-to-machine cooperation and services [2,3]. Most of these forms of cooperation and services developed between humans and machines or between autonomous machine systems have yet to be defined and understood [4–6].

The unmistakable appeal of Society 5.0 is that it provides the blueprint for a sustainable human-centric society enabled by the latest digital technologies. At the same time, a feasible path to realizing Society 5.0 is conspicuously missing. Our survey paper was inspired and motivated by providing such a path. For this purpose, we define a Smart Community as a human-centric entity where technology is used to equip the citizenry with information

and services that they can use to inform their decisions. The key idea is that the citizens of the Smart Community will consume these services on a metered basis according to the well-known pay-as-you-go business model. The arbiter of this ecosystem of services is a Marketplace of Services that will reward, in the obvious way, services aligned with the wants and needs of the citizens, while discouraging the proliferation of those that are not. In the limit, the Smart Community we defined will morph into Society 5.0. At that point, the Marketplace of Services will become a platform for the co-creation of services by a close cooperation between the citizens and their government. The second objective and contribution of this survey paper is to review known technologies that, in our opinion, will play a significant role in the transition to Society 5.0. These technologies will be surveyed in chronological order, as newer technologies often extend old technologies while avoiding their limitations.

These enabling technologies include cloud computing and its variants (e.g., vehicular clouds, cloudlets, and fog computing), crowdsourcing, Big Data analytics, sensors and sensor networks, edge computing, IoT ecosystems, and Marketplaces of Services, among many similar ones.

We feel that we owe the readers an explanation concerning the enabling technologies surveyed. While the stated goal of the manuscript is to survey the most relevant enabling technologies, we are fully aware that the choice of these technologies is somewhat subjective. Indeed, other authors may have included other technologies, while dropping some that we have surveyed. The truth of the matter is that the choice of technologies is informed and guided, to a large extent, by intuition and personal experience. Indeed, short of looking into the proverbial crystal ball, nobody can tell, with any degree of confidence, what enabling technologies will turn out to be the most relevant ones. Our choice of enabling technologies to survey also reflects our belief that these technologies will serve both Smart Cities and Smart Communities.

On the methodological side, the enabling technologies will be surveyed in chronological order, as newer technologies often considerably extend old ones, while avoiding some of their shortcomings and limitations. As an illustration, edge computing is a natural extension of wireless sensor networks, where individual edge devices are more powerful than the traditional sensor nodes [7]. In turn, edge computing and sensor networks have propelled the rise of the Internet of Things (IoT) as an eclectic collection of networked devices. We consider sensor networks, edge devices, and IoT ecosystems as foundations of the Smart Community concept.

We note that this survey paper is an enhanced and substantially expanded journal version of our recent conference paper [8].

The remainder of this survey paper is organized as follows: To set the stage for our discussion, in Sections 2 and 3, we define two basic concepts, namely, Smart Cities and Smart Communities. The main goal of the next several sections is to review known ICT and digital technologies that will play an important role in implementing sustainable Smart Communities. Specifically, in Section 4, we discuss Cloud Computing, a modern incarnation of utility computing, the first of the key enabling technologies that we review; in Section 5, we present Vehicular Clouds a recent extension, along several dimensions, of conventional clouds. Further, Section 6 discusses crowdsourcing and its applications. Section 7 provides a review of sensors and sensor networks. Section 8 reviews the recently proposed edge computing paradigm, a natural extension of sensor networks. Section 9 reviews Big Data analytics and its important role in supporting the needs of Smart Cities and Smart Communities. Next, Section 10 discusses the Internet of Things and its fundamental role in implementing Smart Cities and Smart Communities. Section 11 introduces our proposed Internet of People and Things, a non-trivial extension of IoTs. Further, Section 12 presents our vision of ecosystems of IoTs and IoPaTs. Section 13 introduces the Marketplace of Services and the fundamental role it plays in the valuation of services in Smart Communities. Next, Section 14 surveys two possible services that can be synthesized by putting to work various enabling technologies. Indeed, Section 14.1 discusses enhancing

community economic resilience in the face of natural disasters by strengthening the resilience of microbusinesses in the community; Section 14.2 discusses revitalizing struggling small communities. Finally, Section 15 offers concluding remarks and identifies several challenges ahead.

To help the reader along, the following table, Table 1, provides the definitions of all acronyms used in the paper.

Table 1. A guide to the acronyms used in the survey paper.

Acronym	Description
AEO	Association for Enterprise Opportunity
BD	Big Data analytics
CC	Cloud Computing
CPS	Cyber-Physical System
ICT	Information and Communications Technology
IoT	Internet of Things
IoPaT	Internet of People and Things
ITS	Intelligent Transportation Systems
MoS	Marketplace of Services
SBA	Small Business Administration
SC	Smart Community
TMC	Traffic Management Center
VC	Vehicular Cloud
VCS	Vehicular Crowdsourcing

2. Smart Cities—How It All Started

Nowadays, many countries around the world are developing detailed blueprints for the implementation of Smart Cities. To make the transition to Smart Cities, and to address the challenges involved in this transition, present-day urban communities must harness and put to work their most creative ideas and initiatives. Part of the challenge is to understand and demonstrate how advanced data and ICT technologies can be used to empower their citizens, reduce traffic congestion, protect the environment, respond to climate change, better attend to the needs of underserved communities, support economic vitality, among many similar ones.

By some accounts, the term Smart City was coined in the early 1990s as an illustration of how urban development was turning towards technology, innovation, and globalization [9,10]. The early visionaries [11–15] depicted the Smart Cities of the future as fully connected urban communities supported by various forms of pre-deployed infrastructure, such as sensor networks, ubiquitous and pervasive wireless communication infrastructure, powerful computing and storage devices, and multi-modal programmable sensor nodes. As depicted in Figure 1, the Smart City will leverage this infrastructure to deliver numerous “smart services” including smart healthcare [16–18], smart homes [19,20], smart transportation [21,22], smart workplaces [23], smart government [24,25], among many others.

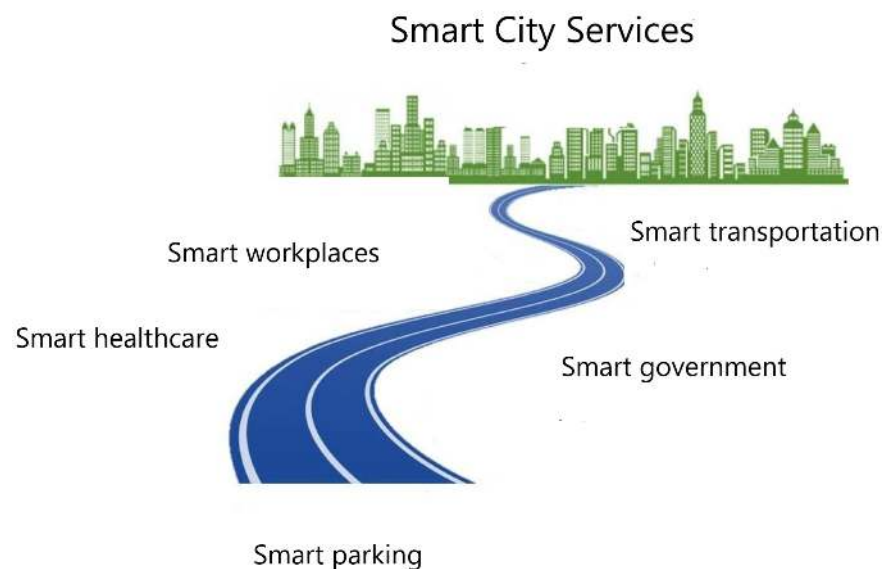


Figure 1. Illustrating some of the key Smart City services.

In modern terminology, the Smart Cities are all instances of Cyber-Physical Systems (CPS) wherein the cyber and physical components feed, condition, and learn from each other. The deployed urban infrastructure represents the physical component of the CPS while the citizens and the local government represent the cyber component. These two components closely interact with each other and progress and innovation occur at the nexus of the two.

While Smart Cities have been defined in myriad ways [11–15], it is telling that all these definitions have two explicit or implicit characteristics in common: first, the Smart Cities assume a transparent governance and management style that *anticipates* the real 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 summarized as “putting the citizen first”, or being *human-centric*, or *citizen-centric*.

It is worth noting that the human-centric characteristic of Smart Cities is consistent with, and was echoed by the *open e-government* services proposed, in a slightly different context in the past decade or so by [24,26] as well as by various documents originating with the European Union [25].

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 U.S. population resided in big cities [27,28]. In fact, the authors of [29] predict 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” [29].

The rise of Smart Cities creates opportunities for creative and efficient management and utilization of the available or planned municipal resources. Yet another characteristic 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.

In summary, then, Smart Cities differ from the cities we have inherited from our ancestors in four major respects:

- First, the Smart Cities will be massively instrumented by the ubiquitous and pervasive deployment of *intelligent platforms* equipped with smart modules that can sense and interact with the environment, store, send and receive massive quantities of data, and that can interact with other networked infrastructure elements in the Smart City. The intelligent platform is apt to provide real-time data that will be shared with all

interested parties (including the citizens) and on which timely management decisions can be based;

- Second, the Smart Cities will make extensive use of strategies and techniques to incentivize and engage its connected and well-informed citizens. These strategies and techniques will influence both short- and long-term behavior;
- Third, the Smart Cities will continually innovate and enhance their service offerings to the citizens based on community intelligence. This behavior will lead to the evolution of diverse Smart Cities based on their own characteristics and the needs of their citizens;
- Fourth, the Smart Cities will be *human-centric* as opposed to present-day cities where the citizens' needs are secondary to other considerations. As a well-known example, pedestrians have long been treated as second-class citizens in the design of urban traffic infrastructure. Existing designs for transportation networks were centered entirely around the needs of vehicles, with little or no regard to accommodating pedestrians. The challenge, as we see it, lies in integrating pedestrians into the transportation network design. Lack of timely support for pedestrians to cross the streets encourages many pedestrians to jaywalk, a well-documented source of accidents [21,22]. It is, therefore, of fundamental importance to provide *pedestrian-centric* services, particularly for *vulnerable pedestrians* such as the kids, the elderly, and the disabled. To realize this vision, it is critical to devise and implement in Smart Cities collaboration strategies that will provide pedestrians with the safety they need at intersections.

3. Smart Communities

Recently, in its “Smart and Connected Communities” solicitation [30], the U.S. National Science Foundation (NSF) described a Smart Community as a community

“...that synergistically integrates intelligent technologies with the natural and built environments, including infrastructure, to improve the social, economic, and environmental wellbeing of those who live, work, or travel within it.”

Even though the above definition does not state explicitly that Smart Communities are human-centric, the NSF 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 noble 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 evaluated through a Marketplace of Services that acts as an impartial arbiter between producers of services and consumer of services. Unlike the Smart City discussed in Section 2 that typically assumes a metropolitan area and, thus, geographic co-location, we define Smart Communities as only *logically* co-located and not necessarily geographically co-located.

Visibly, the Smart Community we just defined 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 the Smart Community, as we define it, is to equip its members with information and services that they can use, on a daily basis, to make intelligent decisions. As we discuss later, see Sections 11, 14.1 and 14.2, some of the information and services provided by the Smart Community come in the form of (re)training the workforce in skills that are highly marketable and that correspond to their abilities.

We view Smart Cities as instances of Smart Communities. Two characteristics tell Smart Communities apart from Smart Cities; first, the Smart Communities are only logically co-located, and not necessarily geographically co-located; second, the Smart Communities are likely to see *emergent behavior* that, because of scale, is not evident in Smart Cities.

However, we believe that the same enabling technologies will serve both Smart Cities and Smart Communities.

This survey paper subscribes to the view of a Smart Community expressed recently in [4]. The vision and main contribution of [4] is to take the idea of utility computing to the next level of generality. Specifically, they envisioned the Smart Communities of the near future as offering services of all sorts bundled as utilities: the citizens consume these services on a metered basis, according to the well-known *pay-as-you-go* business model. According to [4], the Smart Community is synthesizing these services from resources produced by various sensor networks, edge devices, and IoTs. Suitably aggregated, the resources are sold as services. Specifically, [4] envisioned future Smart Communities as offering a large variety of evolving services packaged, valued, and sold as utilities—all these managed by a marketplace of services. In this vision, the community members will contribute resources by choice, and consume services from the marketplace on a metered basis, according to the *pay-as-you-go* business model. We refer the reader to Figure 2 where some of the enabling technologies are illustrated.

Therefore, one way to look at the Smart Community is as a by-product of the Marketplace of Services (MoS) synthesized from inter-connected hierarchies of resources available or produced within the Smart Community itself. Our core tenet is that the empowerment of citizens of Smart Communities by unrestricted access to timely and high-quality information is one of the defining dimensions of a Smart Community [4]. This high-quality information, made available in a timely manner, allows the citizens to make informed choices when consuming or contributing services in the marketplace.

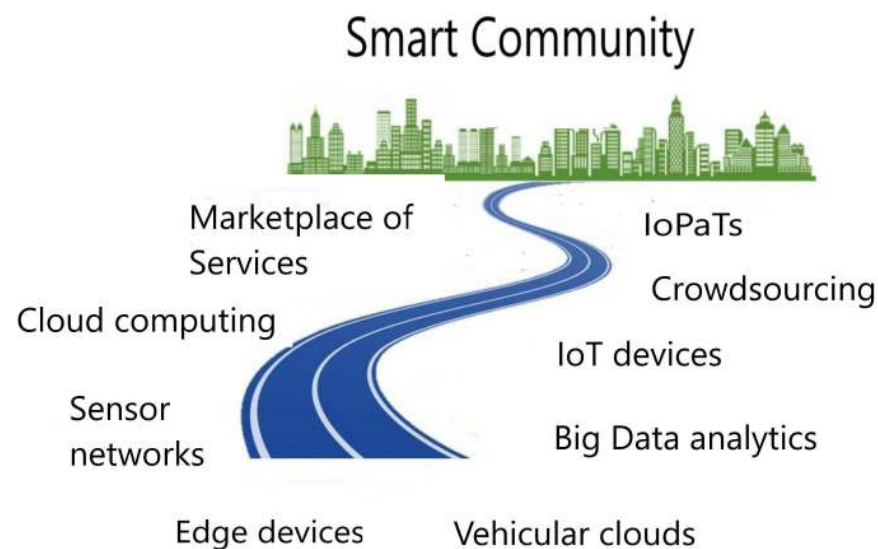


Figure 2. Illustrating some of the key enabling technologies for Smart Communities.

It is worth pointing out that when talking about Smart Communities we have in mind an extension of the results of [4]. Specifically, unlike [4] 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 Section 11) and a *distributed* Marketplace of Services (to be defined in Section 13). As noted before, due to globalization and increased technical skill level of the population, the role played by Smart Cities and, more broadly, by Smart Communities is poised to increase dramatically in the near future.

4. Cloud Computing and Utility Computing

In his 1961 MIT Centennial Celebration speech Professor McCarthy predicted that in the future, compute power and applications may be organized as public utilities and may be sold through a utility business model, like water or electricity. He said:

“If computers of the kind I have advocated become the computers of the future, then computing may someday be organized as a public utility just as the telephone system is a public utility ...The computer utility could become the basis of a new and important industry.”

Even though Professor McCarthy had *time-sharing* in mind, his prediction that computing, in some form or another, will become a utility, was accurate. However, in 1961 his bold vision was way ahead of its time: It took mankind the better of five decades to catch up with his vision.

Cloud computing (CC), a modern incarnation of utility computing, has itself arisen at the confluence of several enabling technologies, of the availability of a chronic excess of compute resources, and of the need for on-demand scalable, cheap and secure computational power that can be provided in real time.

It is fair to say that utility computing, perceived through the prism of CC, is a paradigm shift adopted by a large number of infrastructure providers whose large installed infrastructure often goes under-utilized. The main appeal of utility computing is that it provides scalable access to seemingly unbounded computing resources and to a multitude of IT services that anyone with a valid credit card can use.

Similarly, a very attractive feature of CC is that instead of investing in infrastructure, many businesses and individual entrepreneurs find it useful to rent the infrastructure and, oftentimes, the software required to run their applications [31,32]. In this context, a user may purchase the amount of services they need at the moment. As their IT needs grow and as their services and customer base expand, the users will be in the market for more and more cloud services and more diversified computational and storage resources. As a result, developers with innovative ideas for new applications are no longer required to immobilize capital in hardware and software to test their ideas. They also need not be concerned with over-provisioning for services in which popularity does not meet their predictions, or with under-provisioning for those that become immensely popular. Not surprisingly, CC and cloud IT services have seen and continue to see a phenomenal adoption rate around the world [33,34].

To summarize, three aspects are novel in CC:

- First, it gives users the illusion of having at their disposal infinite computing resources available on demand, thus eliminating the need for them to plan far ahead for resource provisioning;
- Second, it eliminates the up-front financial commitment by cloud users, allowing companies to start small and to increase hardware resources only when there is an increase in their needs because of their applications increasing in popularity;
- Third, it gives users the ability to pay for computing resources on a short-term basis (e.g., processors by the hour and storage by the day) and release them when they are no longer needed, thereby rewarding conservation [33].

In the past decade, cloud resources have expanded beyond cloud service providers to include contributory resources by individuals that may wish to share their spare computing resources and benefit from sharing. Cloud resources can help address everyday needs and challenges that people are facing in their communities. Similarly, several variants of conventional clouds were proposed in the literature. These include, among others, vehicular cloud (to be discussed in the next section), cloudlets [35], as well as fog computing [36,37].

5. Vehicular Clouds

In August 2010, inspired by the success and unmistakable promise of conventional CC, [38] introduced Autonomous Vehicular Clouds, a precursor of vehicular clouds, as:

“A group of vehicles whose corporate computing, sensing, communication and physical resources can be coordinated and dynamically allocated to authorized users.”

Later the same year, the authors of [39] introduced Vehicular Clouds (VC) and called upon the vehicular networks community to “Take VANET to the Clouds” [39], giving explicit expression to the idea that present-day vehicles, endowed with powerful on-board computers, ample storage, sophisticated transceivers and an impressive array of sensing devices, can act as servers in a vehicular datacenter. The authors of [39] hinted at an entire array of possible applications of VCs. They have shown that VCs can provide efficient solutions to problems in security and privacy, reliability and availability, intelligent transportation systems, and the like [39]. In addition to numerous interesting applications of VCs, these early papers have identified an entire series of research challenges.

Early on, a number of researchers have pointed out that even under the current state of the practice, many implementations of VCs are both technologically feasible and economically viable. Given their large array of applications, it is reasonable to expect that, once adopted, the VCs will be the next paradigm shift, with a lasting technological and societal impact. In fact, it has been argued that VCs may well be the “killer app”, taking vehicular networks to the next level of relevance and innovation [40].

One of the defining ways in which VCs differ from CCs is in the ownership of compute resources. While in the case of CCs the compute resources have a single owner, in VCs the ownership of these resources is distributed over a large driver population. As a consequence of the distributed ownership of the compute and storage resources, the VC are highly dynamic. As vehicles enter the VC, fresh compute resources become available; when vehicles leave, often unexpectedly, their resources depart with them, creating a highly dynamic environment. In turn, the dynamically changing availability of compute resources due to vehicles joining and leaving the VC unexpectedly leads to a volatile computing environment where reasoning about system performance becomes challenging [41,42].

Recent years have seen the emergence of VCs as an active topic of research. Various VC architectures and services were outlined, in terms of desirable qualitative characteristics without any regard to, or credible study of, their feasibility and quantitative performance characteristics. All this is changing now as more and more researchers are turning their attention to quantitative aspects of VCs and of the services they contemplate especially in support of Smart Cities and Smart Communities [7,43,44].

It is interesting to recall that the visionaries anticipated that in the Smart Cities of the near future, vehicles equipped with computing, communication and sensing capabilities would be organized into ubiquitous and pervasive networks with a significant Internet presence. Furthermore, these visionaries expected this phenomenon to revolutionize the citizens’ quality of experience via greater safety, enjoyment, and increased environmental friendliness [45]. Vehicular Clouds go one step further: they harness the excess compute power and storage capabilities of the vehicles in the Smart City to enable services that otherwise would not be possible,

The way we see it, the main challenge for VCs in the context of Smart Cities should be aligned with the 2015-2019 strategic priorities recently spelled out by US-DOT [46]. To show the relevance of VCs to Smart Cities, we propose to achieve the following objectives:

1. *Enhance urban mobility by exploring methods and management strategies that increase system efficiency and improve individual mobility through information sharing:* VCs should combine detailed knowledge of real-time traffic flow data with stochastic predictions within a given time horizon to help (1) the formation of urban platoons containing vehicles with a similar destination and trajectory; (2) adjust traffic signal timing in order to reduce unnecessary platoon idling at traffic light; and (3) present the driving public with high-quality information that will allow them to reduce their trip time and its variability, eliminate the conditions that lead to congestion or reduce its effect.
2. *Avoid congestion of key transportation corridors through cooperative navigation systems:* Congestion-avoidance techniques that become possible in SC environments will be supplemented by route guidance strategies to reduce unnecessary idling and will limit environmental impact of urban transportation.

3. *Handling non-recurring congestion:* VCs will explore strategies to efficiently dissipate congestion, by a combination of traffic light re-timing and route guidance to avoid more traffic buildup in congested areas.

6. Crowdsourcing and Crowd Computing

By some accounts, the term *crowdsourcing* was coined by [47] and 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. It has been argued by several authors that crowdsourcing can be legitimately looked at as a collaborative way of problem solving and that it will turn out to be one of the pillars of Smart Cities and Smart Communities [10–12].

Lately, there has been a surge in crowdsourcing applications [48,49]. As an example, MicroBlog [50] is used to build a location-based map of videos by allowing participants to share videos to a cloud server through their cellular connectivity. Other examples include, Medusa [48], a programmable framework for facilitating crowdsensing via users requesting sensing tasks (e.g., take a video), recruiting volunteers, uploading and validating preliminary task results, and choosing a subset of the volunteers to carry out the task. These approaches and others considered collecting edge-generated data and sending them to a cloud server, usually for computational convenience. Recently, the author of [51] offered a literature review of crowdsourcing in support of Intelligent Transportation Systems (ITS). Two important issues have attracted attention in crowdsourcing: the use of incentives to attract a competent and honest workforce, and the related topic of universal privacy and security [47,52]. Several strategies for incentivizing participation in crowdsourcing have been reported in the literature [53–55].

As pointed out by [52], the race is on to build general crowdsourcing platforms in various application domains. For example, Vehicular Crowdsourcing (VCS) is an instance of a crowdsourcing application domain where a group of vehicles lend their on-board processing resources to an authorized user. While the authorized user may be limited to the city's Traffic Management Center (TMC) for the express purpose of mitigating congestion through signal re-timing, the concept is more general. The usage of vehicles as computation resources in the context of crowdsourcing opens a new area of research. In support of preventing congestion or mitigating its effects, VCS involves tasking a pool of vehicles to perform parallel versions of complex optimizations that can lead to efficient signal re-timing.

Two related, but quite distinct areas are *crowd sensing* and *crowd computing*, which combine mobile devices and social interactions to achieve large-scale distributed sensing and computation [56,57]. Within this context, an opportunistic network of mobile devices, including smartphones, tablets, laptops, etc., offer an aggregate compute power and communication bandwidth.

The authors of [57] made a strong case for crowd computing and pointed to various 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 several mobile devices. As these devices socially interact with similar devices, the tasks are shared with the new devices and this process continues until the tasks are completed.

7. Sensors and Sensor Networks

Over the past three 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 applications of direct relevance to Smart Cities and Smart Communities [58,59]. Interestingly, 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 [60,61].

Sensor networks are viewed as time-varying systems composed of autonomous mobile sensing devices (e.g., 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 as energy consumption (due to mobility, sensing, and communication), reliability, fault-tolerance, security, and delay [62,63].

The designers of sensor networks face another challenge, namely that of reaching consensus fast in order not to delay action [64–67]. 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 [68,69]. Yet another challenge facing the designers of sensor networks in Smart Cities and Smart Communities is that of re-tasking sensors and re-purposing entire sensor networks in the face of changing applications of relevance to the community [70–72].

8. Edge Computing

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 [32,73]. In conjunction with recent advances in nano-technology and smart materials, this lead, quite naturally, to the development of new types of connected smart devices, including smart watches, smart glasses, smart meters, smart robots, connected vehicles, among many other household items that deserve to be called "smart" (e.g., smart coffee makers, smart refrigerators, smart vacuum-cleaners, among many others).

These pervasive and ubiquitous smart mobile devices are referred to, collectively, as *edge* devices, or *the edge* [74]. It was reported back in 2017 that the amount of data generated each month at the edge by smart devices, such as smartphones, vehicles, and all sorts of wearables, has reached 14 exabytes and that is expected to exceed 24.3 exabytes by 2020 [75]. As a result, we are beginning to see more and more network traffic originating at these edge devices. 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 [76–78]. 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 vehicles that crisscross 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. Indeed, as shown in Figure 3, the time delay incurred in offloading the task of processing 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, more broadly, the community, the highest value from edge data can be extracted only by processing it

in 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 [78].



Figure 3. Illustrating the offloading path from the edge to the cloud.

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 [79]. Indeed, it is expected that the collective computing and storage capacity of smartphones will exceed that of worldwide servers by the end of 2020 [76]. In Smart Cities and Smart Communities where the smart devices generate huge amounts of contextually rich data, harvesting this source of information to enhance the citizens' quality of experience will have very important ramifications. As another example, the large number of vehicles in our driveways, parking lots, and city streets can be seen as important edge devices with significant compute power. Their on-board capabilities can be harvested and put to good use in Smart Cities and Smart Communities [80,81].

9. Big Data Analytics

The volume of data that has to be collected and analyzed daily in a Smart City or Smart Community is growing rapidly, in fact exponentially, because data is collected by all sorts of sensing devices embedded in our smartphones, smart glasses, smart cars, various RFID readers, and so on [82]. Similarly, huge amounts of raw data are produced in a Smart City every minute by social networks, various flavors of vehicular networks, and IoT devices [4,83].

Arguably, we are approaching a fundamental paradigm shift in computing as the number of smart devices (e.g., smartphone and tablet) users has exceeded three billion (i.e., 40% of the global population) in 2017 and is expected to swell to more than four billion in 2020. In addition, given the recent advances in microprocessors and the development of more types of connected smart devices, we are seeing the next phase of the Internet, populated by traffic originating primarily from IoT devices [73].

Until new data processing technologies are developed, the processing of huge volumes of data with stringent time constraints is neither technologically feasible nor economically viable. As an example of large data sets that need to be processed not only fast but also reliably is provided by the type of processing dealing with customer experience in e-commerce applications. In this context, the most prevalent workloads are searches

and many other services that support and enhance a customer's experience. Managing the contents of a shopping cart and various queries launched by a prospective customer require the ability to store and recover efficiently customer preferences, a history of previous purchases, returns, personal data and so on. This information must be maintained reliably and must be made available in a fraction of a second. The common wisdom is that unhappy customers will not be return customers [84].

Another type of workload is associated with queries launched by a customer and involves composite services. For example, a customer may be interested in restaurants in a hypothetical Smart City. The search algorithm must traverse all available postings of each such item and must return the answers in a given, often customer-aware, way. A successful such service presupposes that the data is stored reliably and that it is accessible in a fraction of a second, irrespective of how many servers are down at the moment [31,33].

Importantly, in the examples above, the total user-perceived latency needs to be a fraction of a second. Consequently, any file system in support of such applications must support latency reduction. However, high throughput is also an important performance metric because a highly popular service needs to support many thousands of simultaneous queries. The high availability requirements in such a system can only be supported through redundancy of storage (in addition to execution redundancy, where each user query may be executed by two or more servers). Storage redundancy implies that virtually each data item must be stored at several locations in the network. More generally, Big Data is a buzzword term for describing data collections, both structured and unstructured (as discussed above), that are so large and so complex that traditional data processing applications are inadequate for handling them effectively [85]. Yet, this data needs to be analyzed to inform decision-making in such relevant areas as identifying trends in customer behavior, weather patterns, computer vision, medical sciences, terror attack prevention, nano-technology, microbiology, robotics, massively parallel processing to name just a few [65,66,86–91]. The challenges involved in handling these large amounts of data in a timely and secure and privacy-preserving fashion range from data collection, to data transfer, to data storage, to data analysis, to data visualization, to many others.

As it turns out, emerging Big Data applications involve sophisticated multi-phase data processing [31]. Many of these applications rely on MapReduce [92] and on its open-source twin Hadoop [93–95].

We now provide a succinct review of how MapReduce works. MapReduce was introduced by Google in 2004 and is suitable for processing semi-structured and unstructured data [96]. MapReduce was inspired by the Lisp functions with the same name and same functionality. The processing performed by MapReduce has two sequential stages Map and Reduce. In the Map phase, a user-defined function is applied to every logical input record to produce an intermediate result of *key-value* pairs; the Reduce phase collects all the key-value pairs produced by the Map phase and collapses them using yet another user-supplied function [31,32].

10. The Internet of Things

The Internet of Things (IoT) has been defined in myriad ways [97,98]. IoT is generally viewed through the lens of Smart Cities [99,100]. At the definitional level, an IoT is a network consisting of smart objects, commonly referred to as *things*, endowed with wireless communication capabilities. The things in the IoT can be sensor nodes, actuators, everyday objects endowed with some computation and communication capabilities (such as smart coffee makers, smart vacuum cleaners, smart refrigerators, and the like), edge devices, such as RFID tags, smartphones, smart watches, tablets, smart meters and other similar devices. As already mentioned, the IoT things communicate with each other wirelessly. There can be instances where more sophisticated devices like some types of process controllers, may constitute an industrial IoT system [101].

It is important to realize that many IoT devices, such as a smart coffee maker, for example, only contain an embedded processor and, as a rule, do not have general-purpose

compute capabilities. Being ubiquitous and pervasive, IoT systems are expected to see a wide adoption in industrial applications [101,102], healthcare [103–106] and, more broadly, to be incorporated in the fabric of a Smart City or Smart Community [59,98,107–109].

Cisco predicted that the number of connected IoT devices will reach 50 billion by the end of 2020 [96]. However, the diversity and heterogeneity of devices participating in IoT through dynamic joining and leaving can have direct consequences on workload assignment, networking interfaces, privacy and security [53,110,111]. These challenges need to be addressed before IoTs are to see the predicted phenomenal adoption rate. For example, the problem of IoT system security and privacy is becoming significant in the context of Smart Cities and Smart Communities [103,110–112].

It has long been recognized there is value of IoT devices in synthesis of sophisticated services [113–115]. For example, the authors of [116,117] have suggested that sensor data and other information produced by various IoTs is of fundamental importance in Smart Cities. We believe that one of the important dimensions of IoT is, indeed, that of providing services that are important to the wellbeing of the Smart Community in which they operate.

11. From IoTs to IoPaTs

For our purposes, the IoT concept discussed in Section 10 will be naturally 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 IoT 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.

Just like the IoTs, the IoPaTs are connected by, and contribute to, a Marketplace of Services (in our view, resources are also services) that will be used by the Community Management to aggregate the various services offered by the Smart Community. The MoS will provide mechanisms to incentivize the IoPaTs to contribute their services in return for payment of some form or another.

The nature of the resources and services produced by the IoPaT 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.

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 through 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.

The question then arises: Where does this process end? To answer this question, we need to remember that the marketplace acts as an impartial arbiter that will indicate the services that are aligned with the needs and wants of the society. Occasionally, new services will be produced that may or may not be successful in the marketplace. The continual production of services is dependent on the success level of these services. For example, a coop may be an IoPaT that serves the interest of a local group of citizens and that, at the same time, finds it attractive to sell its surplus production (or services) on a community-wide marketplace. Similarly, some of the IoPaTs may offer services for the Smart Community in the form of training the unemployed in skills that are highly marketable and that are aligned with their abilities. Such services will certainly appeal to folks who lost their jobs in mid-career and wish to acquire marketable skills to support a more promising career path. This human-centric service is expected to have a very high societal value.

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, proposal-writing workshops for starting micro-businesses and entrepreneurs, especially from the under-served minorities could be offered either free of charge or at a reduced cost to those who qualify.

12. Towards IoT and IoPaT Ecosystems

We expect that, in the near future, smart IoT devices ranging from smartphones, to tablets, to smart glasses, to vehicles, to myriad other devices equipped with computing, communication and sensing capabilities will be organized into ubiquitous and pervasive IoT subsystems with a significant Internet presence while in motion. We envision various IoT subsystems to be integrated into a Smart City-wide or Smart Community-wide IoT ecosystem that will revolutionize the citizens' experience making living safer, more enjoyable and more environmentally friendly [4].

The challenge arises with the integration of IoTs and IoPaTs into a harmonious ecosystem. While, to date, mainly stove-pipe integration strategies have been proposed [118], we believe that a more efficient and effective solution for IoT integration into an ecosystem is a marketplace-driven, open integration of IoTs based on a valuation of the services provided.

We anticipate that the collection of IoTs within the boundaries of a Smart Community will be tightly integrated and will form a smart IoT ecosystem. The IoTs in the ecosystem are offering production of resources and intermediate-level services obtained via preliminary aggregation of their resources. In addition to other roles, the marketplace serves to incentivize the IoTs and IoPaTs to contribute their resources in return for payments of various sorts.

As discussed in [4], the integration of independently owned and deployed IoTs is a major challenge of Smart Community research. The same still holds for integrating IoPaTs into a harmonious ecosystem. The ecosystem is, by definition, an integrated system where each IoT or IoPaT member may produce sensor data of a quality (e.g., resolution) commensurate with the devices that constitute that IoT. To maximize the common good the various IoPaTs may find it useful to engage in social division' of their work. The production of services is inclusive of internal use of the ecosystem or, perhaps, destined to be sold in the resource and services marketplace. The evolution of such a massive integration of, both structurally and semantically, heterogeneous IoT subsystems with the need for continuous analysis, high degree of resilience and reliability where lives and economic vitality are at stake would require building customized Smart Community platforms.

Moreover, by sharing information, the IoPaTs create value [3,114]. One of the fundamental roles 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.

Just as in the case of IoTs, an important challenge that needs to be overcome is the thorny issue of integrating IoPaTs into a harmonious *ecosystem*. Indeed, we expect that for various reasons, the IoPaTs will find it beneficial to become integrated with other IoPaTs. We envision the various IoPaT subsystems to be integrated into a Community-wide *IoPaT ecosystem* that will revolutionize the citizens' experience and will provide many opportunities for creativity and innovation, making a substantial contribution to enhancing the citizens' quality of experience.

In our view, the general arbiter of this IoPaT 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.

13. The Marketplace of Services (MoS)

It is now widely accepted that data have value and therefore can be traded or sold in a data marketplace [119–121]. 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 active research in economics [64,122].

Traditionally, a marketplace serves the dual purpose of bringing together producers and consumers, and of providing valuation for the various goods and services traded [9,123,124]. The data marketplace is no exception.

Interestingly, one can also look at the data marketplace as enabling the diffusion of innovation among consumers. As pointed out by [123], 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. Moreover, as pointed out by [9] (p. 45), “De facto standards often evolve in the marketplace through an economic mechanism very similar to the concept of the positive spiral that drives successful businesses, in which success reinforces success”. In addition, the author of [9] (p. 61) points out that “The marketplace ... adopts standards because customers insist on standards. Standards are to ensure interoperability, minimize user training, ...”.

The idea of IoTs being the key producers of resources in Smart Cities is not new and was discussed in the literature [108]. Two recent papers, [116,117], have suggested that sensor data and other information produced by various IoTs in a Smart City could be sold and purchased in a marketplace. However, these authors were more interested in making the exchange fair, which is not our purpose. Instead, we perceive the Marketplace of Services as an arbiter playing a regulatory role as we are about to explain.

Services and their effects have been studied intensely in the past decade and most of their dynamics are now well understood [2,6]. 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 Big Data analytics 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.

14. Possible Services That Can Be Offered in Smart Cities and Smart Communities

There is vast potential for synthesizing valuable services within Smart Cities and Smart Communities. The main goal of this section is to review a number of such services that can be offered by judiciously employing the enabling technologies discussed in the previous sections of this survey paper.

14.1. Enhancing the Economic Resilience of Communities in the Face of Natural Disasters

In the broadest sense of the term, *community resilience* is the capacity of a community to prepare for, withstand, and recover from the disruptions caused by an event or a series of planned or unplanned events. It goes without saying that enhancing community resilience in the face of natural disasters is a national priority [125,126].

As it turns out, the resilience of communities is multifaceted and depends on the performance of a multitude of contributing factors including: the built environment, the resilience of its social fabric, the resilience of its economic structure, as well as the resilience of its public institutions and governance mechanisms on which the welfare of the community depends [127,128].

The damage inflicted to communities and the speed of their recovery from natural (and/or man-made) disasters is characterized by significant uncertainties operating in the spatial, temporal, and socio-economic domains. In recent years, we have witnessed an increased interest of the research community in assessing and quantifying the vulnerability of communities to the occurrence of various sorts of natural disasters [129–132]. In a series of papers, specific factors that impact community readiness and resilience in the face of natural disasters have been identified and analyzed [131,133–136].

In this subsection, we only focus on one aspect of enhancing the economic resilience of a community. Specifically, following [137], we subscribe to the idea that business resilience is one of the key components of the economic resilience of a community. In turn, given the prevalence of *microbusinesses* (to be defined below) we propose to show how the enabling technologies discussed in this survey can help enhance the business resilience of microbusinesses.

The U.S. Small Business Administration (SBA) [138,139] and the Association for Enterprise Opportunity (AEO) [140] define microbusinesses as enterprises with fewer than five employees, including the owner. As it turns out, microbusinesses represent 92% of all U. S. businesses and employ directly around 26 million people [140–142]. Microbusinesses include hairdressers, dry-cleaners, financial consultants, babysitters, among myriad others. In fact, in a recent publication, to give an idea of the economic impact of microbusinesses, the AEO pointed out that if one in three microbusinesses hired one additional employee, the U.S. would be at full employment [143].

In spite of all this apparent economic clout, it is well documented that microbusinesses are among the hardest hit businesses in the case of natural disasters [144]. This is due to a combination of contributing factors:

- The vast majority of the microbusinesses do not have monetary reserves that could help them survive the disaster;
- Banks are often reluctant to offer loans;
- The owners of microbusinesses are not aware of federal or state programs set up specifically to help microbusinesses in the case of a disaster. A good example is the federal CARES Act that provides assistance (in the form of micro-loans) to small businesses in order to ensure employee retention. Unfortunately, many micro-businesses in the U.S. did not take advantage of the CARES Act because they were not aware of the various conditions, deadlines, or were not able to do the paperwork correctly and on time.

We believe that most of the impediments to microbusiness resilience can be addressed, or mitigated, by the enabling technologies discussed in the previous sections of this survey. For example, IoPaTs set up in the community can provide workshops and open fora specifically designed to inform the owners of local microbusinesses concerning the proven best practices that will enhance their readiness and speed up the post-disaster recovery path. These IoPaTs will also train the owners of microbusinesses in the use of the latest ICT technologies that could help accelerate recovery and enhance resilience.

It was pointed out by the AEO in [145] that Big Data analytics could be used by microbusiness owners to help them navigate the intricacies of

- Assessing their vulnerability to natural disasters;
- Assessing the risk of natural disasters and improve their readiness to survive natural disasters;
- Devise a multi-level post-disaster recovery plan;

- Identifying federal and state programs that provide financial assistance to struggling microbusinesses;
- Identify local interest groups that can help them with pathways to a successful recovery from natural disasters.

Similarly, cloud computing can offer microbusinesses the possibility to simulate various scenarios and help them identify the best strategies specifically tailored to their own circumstances. Vehicular clouds, edge computing, or various forms of crowdsourcing are “closer to home” in the sense that cars belonging to the employees can provide sufficient compute power to conduct sophisticated simulations that will inform the microbusiness owners about the best strategies to adopt.

14.2. Revitalizing Struggling Small Communities

It is a sad but well-known fact of life that in the U.S. many small communities around the country are struggling: they are trying to come to grips with poverty, neglect, decaying infrastructure, drug addiction 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 [146].

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. Furthermore, 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 bootstrap 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 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 U.S., 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, [4] 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 in which the valuation is regulated by a marketplace.

There are a number of implicit assumptions in [4]. 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 negligible and will not adversely affect their marketability. Finally, the author of [4] makes 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.

We show that the implicit assumptions of [4] 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 largely 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 its 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 a reality.

The goal of the REASON is to revive its member communities. This process involves the following human-centric goals:

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 workforce. 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,

15. Concluding Remarks and Challenges Ahead

Motivated by the challenges of implementing 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, in which the 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 Society 5.0 a 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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