# The Internet of Things as Smart City Enabler: The Cases of Palo Alto, Nice and Stockholm

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**Abstract.** Due to rapid urbanization, city populations are rapidly increasing all over the world creating new problems and challenges. Solving some of these problems requires innovative approaches; one increasingly popular approach is to transform cities to Smart Cities. Smart Cities implement innovative approaches based on IoT technologies and convert many services to digital services. These services are implemented within the different components of a Smart City, helping city administrators to improve the life of the citizens, addressing different service, security and administrative challenges. The objective of this paper is to explore and determine how three well-known cities - Nice, Palo Alto and Stockholm - implemented the Smart City concept. The study indicates that a successful implementation of a Smart City model requires addressing a number of critical challenges: citizen involvement, business collaboration and strong leadership prove to be key success factors in the Smart City development process.

**Keywords:** Smart City · Smart City Strategy · Internet of Things · IoT · IoT infrastructure · E-government

## 1 Introduction

According to the United Nations [1], 55% of the world population lives in urban areas today, and this percentage is expected to increase to 68% by 2018. As a result, cities already are facing tremendous challenges related to issues like housing, mobility, logistics, energy consumption, air quality, quality of life, social inclusion, safety, public services and governance [2]. Cities are forced to search for and find solutions for these challenges in innovative and even groundbreaking ways. A strategy that is widely popular yet challenging in many ways, is to become a Smart City [3]. According to Yin et al. [4] a Smart City is a "systematic assimilation of technological infrastructures which builds on progressive data processing, with the objectives of making city governance more efficient, offer a higher quality of life for civilians, help businesses flourishing and protect the environment." Even though there is still not a city, that is universally recognized as a full-fledge Smart City, some cities are leading the way towards such a goal and provide examples of progress in this domain. It can be said that city attempts to become a real Smart City are made on a worldwide scale.

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The technologies often described as Internet of Things (IoT) could be seen as one of the key drivers behind the development of a Smart City. According to Giusto et al. [5], the IoT is a "communication paradigm which visualizes a near future, in which physical objects are equipped with microcontrollers, transceivers for digital communication and fitting protocol stacks that will make these objects able to communicate with each other and with the users". This technology develops fast with an estimated number of 20 to 50 billion devices connected in 2020 [6].

Smart Cities are seen as the future solution to urbanization problems. IoT-based infrastructures will allow cities to devise solutions addressing the earlier mentioned issues in an efficient and environmentally responsible way.

Since every city has its own unique problems and prioritizes its own city components, every city transforms into a Smart City in its own way. Research is mainly focused on implementation of IoT as a way for cities to become smart, but less attention is paid on differences of IoT implementation between cities and comparison of such strategies after implementation. The objective of this study is to contribute to better understanding of similarities and differences between cities during the Smart City implementation process using IoT. Therefore, the research question is: how do three globally leading Smart Cities implement the Internet of Things within different components of their city, in order to become a smarter city?

The study was carried out by conducting case studies in three cities, that are globally recognized as leading Smart Cities. By investigating how these cities successfully implement the IoT within their Smart City components, more insights will be gained on common success factors and common problems facing cities in the process of becoming smart.

## 2 Theoretical Framework

### 2.1 Smart Cities

Over the last few decades, the concept of a Smart City attracted wide interest and debate around the world. Part of the debate is about the extent to which technology and ICT should have a dominant role in the city to become smarter. According to Batty et al. [7], a Smart City is defined as "a city where Information and Communication Technologies (ICT) are blended with traditional infrastructures, organized and unified by using advanced digital technologies". Technology appears to be a common thread in most definitions within literature, but not the only aspect of importance. According to Hollands [8], a Smart City must be based on more than the use of ICT alone. This opinion seems to be supported by many different authors over the years, since most of the definitions found, are more integral than the one that Batty et al. [7] gave. According to Nam and Pardo [9], a Smart City consists of three core components: technology factors, human factors and institutional factors. Their vision states that "smart" can be identified as innovative and revolutionary developments, leaded by new technologies. However, it is the social aspect, rather than smart technologies that stands fundamental within a Smart City according to Nam and Pardo [9]. Even though these authors state that smart developments are leaded by new technologies, they do not

designate technology as the core component within a Smart City. According to Caragliu, Del Bo and Nijkamp [10], a city is smart when "continuous economic growth and a high quality of life, with thoughtful handling of natural resources through participatory management, is inflamed by investments in human capital, social capital, traditional (transportation) and current (ICT) communication infrastructure". While the meaning of the word "smart" is interpreted differently within this definition, the underlying core components of a Smart City are highly similar to the ones given in the previous definition. Some researchers accept an even broader definition of a Smart City. According to Neirotti et al. [11], a Smart City should be capable of optimizing the practice and exploitation of tangible assets (e.g. transportation infrastructures, natural resources), as well as intangible assets (e.g. human capital, academic capital of firms). Zanella et al. [12] argue that "the final objective of a Smart City is to make better use of the public resources, in order to raise the quality of the services which are presented to the citizens, while lowering the operational expenditures of the civic administrations". While the concept of Smart City became broader over the years, including more integral approaches, researchers acknowledge the importance of using internet technology, and in particular IoT, as one of building blocks for a smart city. The most common of the components of smart cities we have identified are displayed in Table 1.

**Table 1.** Smart city components

| Author(s)/ smart city domain | Environment | Mobility | Governance | Smart citizens | Energy | Buildings homes | Healthcare | Economy | Security |
|---|---|---|---|---|---|---|---|---|---|
| Al Nuaimi et al. [13] | x | x | x | x | x | | x | | x |
| Arasteh et al. [14] | | x | x | x | x | x | x | | x |
| Arroub et al. [2] | x | x | x | | | x | | x | |
| Habibzadeh et al. [15] | x | x | | | x | | x | | |
| Khan et al. [16] | x | x | x | x | | | | x | |
| Lombardi et al. [17] | x | | x | x | | x | | x | |
| Nam & Pardo [9] | x | x | x | x | x | | x | | x |
| Neirotti et al. [11] | x | x | x | x | x | x | | x | |
| Silva et al. [16] | | x | | x | x | | x | | |
| Talari et al. [18] | x | x | | | | x | x | | x |
| Venkat Reddy et al. [19] | x | x | | | x | x | | | |
| Yin et al. [4] | x | | x | x | | | | x | |
| Total of mentions | 10 | 10 | 8 | 8 | 7 | 6 | 6 | 5 | 4 |

### 2.2 The Internet of Things

The concept of IoT is an increasingly popular concept in the literature; there are many different opinions, views and definitions on it. Giusto et al. [5] describe the IoT as a communication paradigm which visualizes a near future, in which physical objects are equipped with microcontrollers, transceivers for digital communication and fitting protocol stacks that will make these objects able to communicate with each other and with the users. Zanella et al. [12] state that "the intention of the IoT is to make the Internet even more engaging and omnipresent, by allowing easy entrance and communication with a large variety of devices so that it can support the development of a number of applications which make use of the possibly gigantic bulk and diversity of data produced by objects to present new services to citizens, companies and public administrations". According to Miorandi et al. [20], the IoT can be seen as an application whereby the Internet is used "for connecting physical items, that interact with each other and/or with humans in order to present a service that embraces the need to rethink about a new some of the traditional pathways commonly used in networking, computing and service management". As stated by Atzori et al. [21] the IoT should indeed be considered as part of the Internet of the future, which is expected to be dramatically different from the Internet we use today. According to these authors, the objective of the IoT is to enable communications with and among smart objects. The IoT interconnects a large variety of physical objects, enabling these objects to communicate with each other, as well as with users, without any human engagement.

Effective IoT implementation in cities requires a specific IoT infrastructure, supporting the complexity of different sensors set up in urban environments. Sensor-enabled smart objects demonstrate to be the essential feature for the interconnected infrastructures of the future [22]. According to Jin et al. [23], the IoT can be seen as the key technological enabler for the infrastructure of a Smart City. Sicari et al. [24] stated that, a flexible infrastructure is necessary within a Smart City, because of the large number of interconnected devices. Corici et al. [25] mention that an infrastructure where end device connectivity is monitored and IoT communication reliability is assured, is key for a Smart City. According to Joseph et al. [26], an IoT-infrastructure should ensure that the sub-systems of a Smart City are intelligent enough to communicate and work interconnected with each other. According to Rathore et al. [27], an IoT-based infrastructure is necessary to fulfill the needs of a Smart City and Gope et al. [28] argue that in future Smart Cities, devices should be connected to IoT-based infrastructure. According to Cheng et al. [29], to enable the IoT services, deployed within a Smart City, infrastructure should form a large scale IoT system with widely deployed IoT devices. IoT in Smart City development remained a central issue in the literature over the last decade and especially in recent years; in order to implement the IoT within Smart City components, an IoT-based infrastructure is indispensable. Therefore, it can be seen as the backbone for building a Smart City.

Many authors are modeling a Smart City infrastructure in layers that start with data generation [23, 30–33]. This data generation is used by an application and results into a service or processed data that serves an end-user. Sensors and devices collecting data and a using a dispersed network for transmission is another key part of the infrastructure [23, 30–34]. Data flows allow the formation of a layered and generic IoT-based

infrastructure for Smart Cities. Berkel et al. [35] note that the baseline infrastructure for Smart Cities consists of four layers (Fig. 1). However, in practice, the entire system architecture is often more complex than shown in this layered infrastructure.

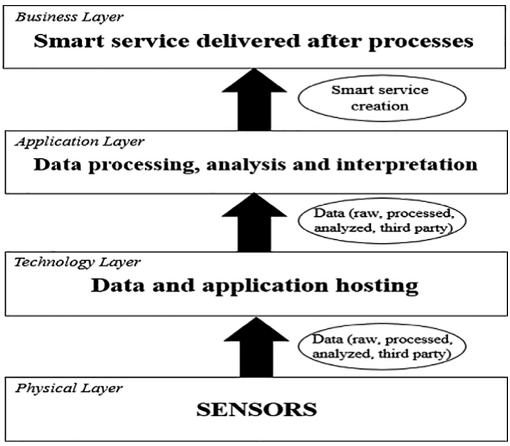


**Fig. 1.** Layers of an IoT based infrastructure

## 3 Methodology

We conducted an exploratory case study since we aim to discover underlying motivations, experiences and lessons from a few leading smart cities; professionals directly involved in prominent Smart City transformations were interviewed. We included the cases of Palo Alto, Nice and Stockholm. In the heart of Silicon Valley (US), Palo Alto is pioneering the concept of a Smart City for many people [36]. According to United Smart Cities (2017), Nice, at the Cote D'Azur in France, is recognized as a world pioneer and well-known Smart City. Stockholm is also seen as one of the top Smart Cities in the world [37–39], ranked 5th in The Top 10 Smartest Cities in the World [40]. The semi-structured interviews consisted of a total of 33 open-ended questions. The analysis included Axial coding.

## 4 Results

### 4.1 Palo Alto

"I cannot think of a single project that the city of Palo Alto is doing today, where technology is not on the table." [41] According to Palo Alto's CIO, technology is going to be one of the largest components of how to enable positive change in the future. Palo Alto stated to have over 300 distinctive systems and therefore, a whole array of services and technologies, that run everything within the city. From their record management system, to software that helps with medical information in their ambulances. "In order

to have the IoT, which seems to be one of the major trends in the Smart City space, you got to have a solid, fast, high-quality core backbone infrastructure" [41]. The IoT-based infrastructure of Palo Alto was stated to be built of several critical elements. Data flows securely across this network. This includes everything from open-data, to analytics, visualizations and data-driven decision-making. This way, the data is opened-up and an ecosystem of participants exists. According to Palo Alto, a city cannot be smart without a data strategy. On top of that, sensors are embedded in physical pieces within the city's architecture. This architecture was not necessarily formalized into specific layers.

Palo Alto focuses on mobility, energy and sustainability as primary Smart City components. Mobility is a major challenge; "In many ways, probably that is the biggest Smart City area for the city of Palo Alto right now. It is everything from initiatives, to encourage people to not drive their car" [41]. They promote electric cars, bikes and scooters and try to make different forms of non-car transport available. Palo Alto also values the support of the emergences of autonomous vehicles. The second component was stated to be energy. "One of the things that makes Palo Alto unique in the United States, is that we are one of the few cities that provides all the utilities services. Electric, gas, water, waste-water. We even provide fiber internet. So, we have a lot of control over our utility's infrastructure" [41]. The city moved away from fossils and coals years ago and is therefore entirely carbon-free on the residential front. By having a smart energy grid rolled-out, Palo Alto connects every house, to gain rich information for optimizing their energy distribution. This information is also used for operations and repairs. The third component was stated to be sustainability in the environment. "In some ways, all the things I have already shared with you, are subscenes of that. Energy, transportation and digitization are all parts of the sustainability movement" [41]. Next to that, it also means water-management technology by using sensors in the water. Also, it includes distribution of electric vehicle chargers all over the community. Other examples were, gaining a better understanding of emissions and managing city buildings more energy-efficient.

A broad area of digital transformation was identified as key component. The city has deployed over 60 different digital experiences. "All our signatures are now done digitally. We do not have a lot of paperwork anymore; we digitize all our papers. We do not print as much as we used to. So, a big push on digital transformation and just better services. More efficient, more streamlined, more accurate and more managed services" [41]. In Palo Alto there were priorities set in city governance, talent management, budget allocation and leadership in order to realize smart city goals. "Even through your best tempts to get grants and loans and all the other kinds of mechanisms, there is just not enough money to do everything you want to do" [41]. Palo Alto stated several critical requirements for an IoT-based infrastructure. "Then, you have to have the mindset, the vision, the strategy and the governance. Those will be the additional layers on top of it" [41]. Next to those factors, human capital was also mentioned as an important factor for supporting the build of a Smart City, next to the IoT. According to Palo Alto, every city must decide whether becoming a Smart City is a mission they want to take on. "The best practice is to make sure that there is a strong supportable vision for it and then execute on it" [41].

### 4.2 Nice

"If we come back to how the Smart City of Nice was born, this is from political intentions to use digital innovation for developing the local economy of Nice" [42]. According to Nice, their IoT-based infrastructure consists of specific layers. It was also mentioned that public and private partnerships exist within the IoT-based infrastructure of Nice. The city of Nice is using the IoT to digitize existing services and to create new ones. "An IoT-based infrastructure is important for a Smart City, because it is a way to improve the performance of public services. Today we are living in a digital world. It is really important for cities to use an IoT-infrastructure to develop its services" [42]. On top of that, Nice agreed that an IoT-based infrastructure can be seen as the backbone for building a Smart City.

According to Nice, their primary Smart City components are: mobility, energy and environment. Next to that, the city plans developing the healthcare component as well. "Nice aims to be a good Smart City in all these components. So, I would say that Nice wants to be an innovative Smart City in developing these components" [42]. An example of how they already used the IoT to become a smarter city, is a high-tech tramway, that makes use of IoT-services within their mobility component. By means of an IoT-based mobile application, users can organize their trip. Also, drivers of the tramway can anticipate on technical problems and resolve them, because of real-time data presented by IoT-services. An example for their energy and environment components, are sensors that collect data about the environment by measuring the air quality. "In order to help business companies to use this data for developing new innovative services, enabling consumers to transform their energy habits" [42].

"One strength of Nice is, that they build their Smart City concept on the open-data perspective" [42]. However, in practice, not all data was always accessible. This was stated to be a real problem for the development of IoT-services. Next to this problem, the privacy and acceptance of citizens regarding IoT-services were experienced as important problems. A more general problem was experienced to be the public administration services in Nice. "It is a really bad problem we have in France, the public administration. If IoT-services could improve the process of public administration services, it would be good" [42]. According to Nice, the first requirement for an IoT-based infrastructure is technology-based. "You need it, to develop the infrastructure in order to implement the IoT" [42]. Next to that, the right digital capabilities need to be developed and enough storage space should be available. Other factors that are important for building a Smart City, next to the IoT, were stated to be: management and intention, funding and collaboration. "I think for developing innovations, build on IoT-technologies, we really need to improve the management of ecosystems of these technologies and how we can implement them" [42]. Therefore, the right intentions and management of local public actors are needed to build a Smart City. Within all of the focused components of Nice, private and public partnerships services were included. Nice does not only collaborate with big companies, but also with local startups. Together with these companies, the city of Nice creates smart solution services. "I think we also have to give chance to startups" [42]. Nice recommended other cities to assess citizen needs and to include citizens as co-actors within city projects, before developing these projects and corresponding technologies. Next to that, Nice recommended cities

to care about citizen's privacy and their acceptance of the use and potential use of IoT-services. "When you use IoT-technologies, you collect a lot of personal and impersonal data and this data is sensitive" [42]. "The building of a Smart City depends on the main characteristics of its own territories and its managers. I do not think there is a universal model to build a Smart City" [42].

### 4.3 Stockholm

For Stockholm, an IoT-based infrastructure is extremely important for Smart Cities nowadays. "The reason though we are establishing this, is because we have a lot of challenges. We know that using the smart technologies can help us to be a better city, for the people that live there, work there and even the people that are visiting us" [43]. Stockholm did agree on the question whether an IoT-based infrastructure can be seen as the backbone for building a Smart City but were a bit hesitant to disclose details on how it was exactly layered. "There is no other part of our infrastructure that we can use to build a Smart City" [43]. Stockholm's main domains are: sustainability (green policies), smart locks, smart traffic and smart lighting. It was also stated that their environmental department is being active with smart technologies as well and that they are engaging in air pollution. "We need to be a fossil-free city within 2040" [43]. Several examples of how the IoT is used within Stockholm, in order to become a smarter city were given. "We have a lot of locks today that are electronic and used all over the world… a lock that you can open with an iPhone or a code for instance" [43]. For the smart traffic component, roads were equipped with sensors. Stockholm is actively using cameras in traffic, to obtain real-time data from cars, bicycles, pedestrians and public transportation and optimize the traffic lights operations. In a pilot project, next the use of LED-lighting in lampposts, these were equipped with sensors as well. These sensors are used among others for changing the light, measuring air pollution and measuring the wind temperature.

The data, generated from all the different projects described above, is shared and private companies are encouraged to establish new services using this data. "The city of Stockholm should establish the data that we can publish. The next step is to make the smart services. I hope that should be done by private companies and not by the city of Stockholm. By using the data from the sensors, we can establish new services" [43]. A new business model is a challenge: who is going to pay for it. A more important obstacle was stated to be the citizen security. "People are of course a little bit afraid when we use IoT-solutions" [43]. The development of an IoT-based infrastructure was seen as a continuous process. Stockholm stated that adaptability to a city's needs is the most important requirement for an IoT-based infrastructure. Also, technologies must meet security requirements. Apart from the IoT, citizens have a fundamental role within the Smart City development of Stockholm. It was stated that everything the city does, is for them. "When we work on the strategy, we asked a lot of citizens…, we also asked academia and the businesses" [43]. Stockholm views the Smart City development process as a democratic issue as well.

## 5 Discussion

Our findings show that there is not a single best approach for implementing IoT for creating a smart city. The approach is contingent on the specific characteristics of the city. IoT is the key enabling tool for smart cities; it can truly enrich the existing landscape of information technology in a city and deliver new open data and connections to the current information systems. Mobility and energy are the core challenges driving the smart city movement. These were shown as key fields of attention in both our literature findings and empirical results. IoT investments raise the need for additional security measures. A city can become vulnerable for hackers and terrorists as a result of connected sensors and devices that deliver a critical infrastructure. Without an underlying and fitting infrastructure, a city's desired Smart City vision is difficult to realize. Therefore, the IoT infrastructure is the backbone for a Smart City. Our cases have all reserved a major role for the IoT infrastructure. They all showed some form of layering. First, there is the use of sensors to obtain data (Physical Layer). Second, enough storage space is needed for storing and sharing data (Technology Layer). Third, in order to create new services, the data must be transformed (Application Layer). Finally, all cities spoke about the actual creation of new services, which confirms the Business Layer.

Even though the cases show how IoT can be implemented within various Smart City components, this paper emphasizes that a Smart City cannot be realized by using the IoT alone [8]. The social aspect of a city also matters [9]. Citizens and governance play a fundamental role within the Smart City development of each city. The needs, privacy, security and acceptance of citizens are seen as major challenges for every Smart City. This is because, all the Smart City objectives that are set by cities, are eventually aimed at the people that live and work there. Therefore, a strategy should be developed that includes citizens, businesses and universities and that is adaptable to their needs and those of the city. In order to create new and innovative services, collaboration with businesses is of great importance. During the Smart City development process, leadership must ensure that the needs of citizens are continuously strived for and collaborations are established. This should be done by setting the right priorities, maintaining the right intentions and aligning all parties involved.

There are some limitations that have to be taken into account for our study. During this research, semi-structured qualitative interviews were conducted. Interviews were conducted with a relatively small number of cities. There are many cities that are trying to become a Smart City worldwide. Therefore, the finding cannot easily be generalized for other smart cities (e.g. non-Western Cities). The underlying aim of our study was to describe three leading examples instead of trying to generalize findings. Smart Cities and the IoT are complex fields of expertise. Even though interest and objectivity has been demonstrated regarding these concepts, there is a lack of specific skills, knowledge, experiences and expertise compared to experts within these fields. Therefore, the quality and interpretation of the gathered data, might vary from the standpoint of specific fields (domains) of expertise. In the end, the future of a city is not dependent on IoT alone, but IoT is definitely playing a big part in innovation of the city.

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