Adaptive Smart Cities In Pandemics And Natural Disasters

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***Abstract*—Rapid technological developments in smart cities have unveiled new dimensions of research, one of which is the adaptive capabilities of smart cities. In this paper, we introduce the "adaptive smart city" concept. We discuss adaptive smart city components, parameters, processes and mechanisms. Furthermore, we propose a detailed procedure for smart city adaptation in cases of pandemics and natural disasters.**

***Index Terms*—Internet of things; smart cities; adaptation algorithms.**

I. Introduction

A. Vision of Smart Cities

Population in cities and urban areas worldwide is growing at alarming rates. Providing quality services to citizens using the limited available resources is, therefore, becoming increasingly challenging. The smart city vision is mainly to exploit advanced communication and computing technologies that enable providing sustained smart services to administer the city and to improve the lives of its citizens [1]. Throughout this process, the operational costs of public administration must be minimized [2]. Health care, education, environment and transportation, among others, are example domains of smart services. Currently, the internet of things (IoT), big data and cloud/edge computing provide a majority of the needed solutions to achieve the smart city vision [3].

Environmental, economic, and social sustainability in the implementation of smart cities is an integral part of the smart city vision [4]. In general, sustainability of a smart city is critically dependent on the flexibility of legislation and policies, availability of funding, infrastructure, and technological advancements [5].

B. Smart City Enabling Technologies

In order to facilitate adaptation in the services of smart cities, it is important to understand what enabling technologies are needed, and to explore how they can be adaptable. Several technologies related to communications, computing, and networking in general are included in the notion of smart city. Researchers are increasingly interested in sixth generation (6G) mobile networks; since fifth generation (5G) networks are unable to meet the requirements of real-time and data-intensive applications [6]. For example, IoT-enabled smart city applications require massive connectivity [7] that is very difficult to achieve in 5G. 6G communication networks will support data-intensive applications through features like reduced end-to-end delay, extremely high data rates up to 1 Tbps, improved mobility and higher reliability, among others [8].

IoT enables devices of everyday life to communicate with one another and with the users, ultimately making them an integral part of the Internet [9]. Device categories that can fit naturally in the IoT include home appliances, monitoring sensors, displays, vehicles, as well as many others [1]. Smart cities can benefit from the IoT paradigm in many application domains, including home and industrial automation, medical aids and smart health care, assisted living for the elderly, energy management, transportation and traffic management, and so on [10].

Cloud computing (CC) is based on the convergence of a group of technologies (e.g., networking, processing, and storage) to enable on-demand computing and storage services [11]. These services are provided in an efficient and scalable manner. The most important difference between CC and traditional computing is that the former does not necessitate investments in communication and information technologies (CIT) infrastructures and support. The widespread use of IoT in delay-aware and real-time smart city applications requires quick responses, in combination with reduced energy consumption in IoT devices. As a result, an intermediate computing paradigm that complements cloud computing was required. Edge computing (EC) and fog computing (FC) have emerged as strong candidates to play this role [2], [11], [12].

EC is a computing system that puts computations near the source data, at the edge of the network. EC evolved from the problems that arose in traditional CC as the number of IoT devices grew rapidly. These problems include high energy use [13], unacceptable latency [14], poor support for mobility [15], and poor security and privacy [13]. EC provides secure real-time CC services without the need for extensive network communication with the cloud [13], [16].

FC is a paradigm that emerged in response to IoT applications that require real-time and delay-sensitive responses [17]. The idea behind fog computing is to put

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processing and storage capabilities close to IoT environments and their users. Hence, at the network edge, fog computing delivers the same capabilities as the cloud, but it is constrained. This proximity to the IoT environment has numerous benefits for sustainable smart cities, including immediate reaction, reduced energy usage, mobility support, and improved security [18], [19].

The evolution of smart cities needs more enablers than just those in the communications and computing fields. Many new trends have emerged as smart city enabling technologies. Following are a few examples of such technologies.

- Smartphones are the perfect interface between the user and the data due to them being an essential part of everyone's lives, enabling them to generate data, as well as to access processed ones. The increased usage of smartphones make them a great generator of raw data using the various tiny sensors integrated within them [20], which in turn serves the purpose of the smart city that is to produce, process, and manage data.
- Smart dust, which refers to miniaturized devices made of microelectromechanical systems (MEMS), are small devices within the range of a few millimeters. They are able to sense and detect various things such as vibrations, temperature, wind shear, and light while being connected in a network of other devices to process the data. They found usage in a lot of fields such as medicine, agriculture, security, making them suitable enablers for smart cities [21].
- Smart cities are meant to be energy efficient, which naturally leads to the realization of the importance of the smart grid. The smart grid is an intelligent bidirectional network, that can exchange information and make decisions about energy usage and other related issues. The smart grid is, therefore, a key enabler in the smart city energy sector [22], [23].
- An intelligent transportation system (ITS) relies on a wide variety of technologies that serve the purpose of providing safe, reliable, and energy-efficient transportation. Some of the key involved technologies are the global positioning system (GPS), dedicated short range communications (DSRC), roadside camera recognition, among others [24]. No doubt, ITSs cannot be overlooked while designing a smart city.
- Smart health care technologies and services are of great help in developing smart cities. Eaxmple technologies include automated health care systems, mobile health care, telemedicine and smart hospital management [25].

C. Research Motivation and Goals

With the above in mind, smart cities are no doubt the wave of the future. As a matter of fact, many cities around the globe have shown clear evidence that the smart city concept is more than a mere research curiosity [26]–[28]. The idea of writing this paper came from realizing that being adaptive is an essential part of being smart. Motivated by this simple understanding, the adaptive smart city concept is introduced and discussed. The goal is to steer future research efforts in the direction of making cities no only smart, but also adaptive to changes arising from imaginable, and very often unimaginable, sources.

D. Problem Statement

We investigate how to equip the smart city with adaptation mechanisms and algorithms in cases of pandemics and natural disasters.

E. Paper Contributions

- Introduction of the adaptive smart city concept.
- Outlining the general smart city adaptation procedures and mechanisms.
- Detailing the behavior of an adaptive smart city in conditions of pandemics and natural disasters.

F. Paper Organization

The rest of this paper is organized as follows. In section II, we introduce the adaptive smart city concept. In section III, we discuss the possible adaptive smart city components, parameters, processes and mechanisms. In section IV, we describe the adaptive behavior in a smart city, taking the situation of a pandemic or a natural disaster as an example. Finally, in section V we conclude the paper and present a few future research recommendations.

II. What is an Adaptive Smart City?

An adaptive smart city is meant to be one where the configuration and services are self-upgrading, following any subset of the following triggers:

- Changes in user numbers, characteristics and demands. In a typical smart city, the population size is continuously varying (mostly upwards). Users themselves are increasingly changing from being traditionally all-human to mixed societies of humans and machines. Meanwhile, it has become a proven fact that user needs and demands keep changing in nature and growing in terms of technological requirements.
- Changes in city infrastructure, both to cope with the natural development of the city, and in response to emergencies. For example, major changes can take place in regard to streets and buildings, energy supply networks, sports and recreation facilities, and to many other elements of the city infrastructure.
- Technological developments in
  - electronic devices and systems
  - communication systems and networks (e.g., 5G-6G wireless)
  - computing systems and networks
  - energy, health care and transportation systems and networks

– etc.

Such developments open opportunities for running the smart city in more effective and more efficient ways. For example, new sensing features allow generating, communicating and processing new types of data that can lead to improving existing services, and even creating new services.

- Pandemics and natural disasters. This is the main focus of this article, in the context of the smart city being able to reconfigure itself and scale its operation features in terms of both type and quantity. The objective is to limit the potential consequent losses of all types, and to maintain acceptable levels of service delivery to citizens.
- Changes in governmental laws, policies and regulations. Such changes can involve taxes, health care, education, many kinds of application and licensing procedures and fees, and so on. The smart city system should able to accommodate these changes in a way that is as accurate and as transparent as possible.
- Emergence of new applications and use cases. Citizens and businesses alike are always seeking to receive/provide new and improved digital services. This has been lately becoming more and more of an established fact as times goes on. The smart city system should be flexible enough to allow seamless integration of new services that prove to be essential to achieving the goals of the smart city.

III. Adaptive Smart City Components, Parameters, Processes and Mechanisms

A. Adaptable Components and Parameters

In order to determine the elements that can be adapted in a smart city, it is essential to conduct a study of the services and technologies involved. This investigation helps identify the elements that are amenable to adaptation. Adaptable components of a smart city are those that can be enhanced or optimized by considering trade-offs related to costs and utilization of resources.

As an example, components that can be adapted in cases of pandemics or natural disasters include, but are not limited to

- traffic management all over the city or in severely affected areas,
- numbers and capabilities of ambulances, as well as procedures for distributing and moving them,
- numbers and capabilities of support and surveillance and unmanned aerial vehicles (UAVs), as well as procedures for distributing and moving them,
- deployments, capacity, networking and priorities of communication systems,
- deployments, programming, networking and priorities of computing systems,

By adapting and optimizing these components, alongside other relevant factors determined in the specific use case algorithm, a smart city can improve its ability to effectively respond to and manage pandemics and natural disasters.

B. Adaptation Processes and Mechanisms

To facilitate seamless adaptation with real-time monitoring, we propose the algorithm illustrated in Fig. 1. This algorithm serves as a general procedure for adaptive smart cities, providing a systematic approach for effective adaptation in response to changing data patterns and anomalies.

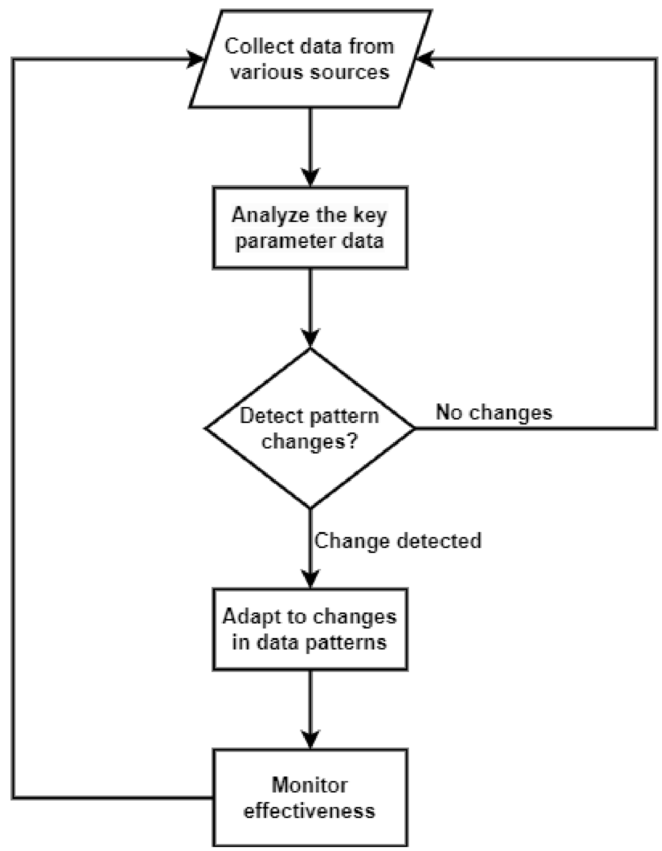

Fig. 1. General smart city adaptation algorithm

The operation of the adaptation algirthms can be described as follows.

1) Collecting data from various sources such as sensors, activity logs, documented records, and cameras, depending on the specific use case. These data are key parameters defining the system elements, such as temperature, number of users, wind speed, traffic volume, energy consumption, etc.
2) Analyzing the key parameter data to establish models for the system elements, in the form of public health status, traffic status, weather status, energy usage status, etc. Pattern detection techniques need to be used to characterize the parameters. For example, to establish a weather status model, we collect data on

temperature, wind speed, humidity, precipitation, and other relevant weather parameters. Following this, we use pattern detection techniques to identify patterns in the data.

3) Detecting pattern changes in the system using deep learning anomaly detection methods [29], or responding to direct changes in the system model.
4) Adapting to changes in the data patterns or anomalies. Adaptation methods are different in different cases, and building well-suited algorithms is essential for effective adaptation. In order to develop effective adaptation algorithms for smart cities, it is essential to follow certain rules and considerations. These rules include
   - Ensuring that adaptation methods protect the privacy and security of the citizens. This requires embedding security and privacy measures within the algorithms to safeguard sensitive information.
   - Iterative tests, simulations, and pilot projects to validate and optimize the algorithms that have to be done before large-scale implementation.
   - Implementing mechanisms for real-time monitoring of the adaptation process. Continuously analyzing data patterns and anomalies to trigger timely and appropriate adaptive processes.
   - Recognizing that each scenario may require a tailored adaptation algorithm. Considering the unique characteristics, requirements, and constraints of the scenario to design algorithms that address its specific needs.
   - Monitoring the effectiveness of the adaptation. This part is discussed in sub-section D below.

C. Adaptation Costs and Limitations

The development of adaptive smart cities brings forth a plethora of opportunities for innovation, efficiency, and improved quality of life. However, it is crucial to assess and address the costs and limitations associated with these adaptive procedures.

The main limitation to how well a smart city can adapt is the cost that adaptivity comes with. Exploiting sensors for data collection is the first step for good adaptation, which essentially requires a good infrastructure that often comes with a big cost. Moreover, the adaptation process itself can be resource-intensive and can entail additional expenses.

Another critical consideration pertains to privacy and security concerns. As adaptive smart cities rely on extensive data collection and analysis, safeguarding privacy and ensuring data security becomes paramount. Striking a balance between effective adaptation and preserving individual privacy can limit the extent to which adaptive measures can be implemented.

Finally, integrating diverse systems within a smart city is inherently complex. This integration challenge is further amplified when attempting to adapt to changes occurring across multiple systems simultaneously.

D. Assessment of the Adaptation Process

The evaluation of the adaptation process is achieved through having a closed-loop algorithm, where the data is fed back again for analysis. The system checks if the adaptation has made significant changes in the key parameters and tries to re-adapt if needed.

By leveraging the closed-loop algorithm, adaptive smart cities can enhance their ability to respond and adapt effectively to evolving conditions. This iterative evaluation and re-adaptation process helps ensure that the adaptive measures are continuously assessed, refined, and optimized for maximum efficiency and desired outcomes.

IV. Adaptive Smart Cities in Pandemics and Natural Disasters

In this section, and as an example of adaptive behavior in a smart city, we focus on adapting the communications and computing features. We discuss an adaptation procedure that is proposed to work in cases of pandemics and natural disasters.

A. Performance/Cost Tradeoff

The adaptive behavior depends on the infrastructure of the smart city, as some solutions might require advanced technologies like UAVs. That being said, there are many less advanced IoT-based services that can be utilized efficiently to reduce the damage caused and to help maintain the situation.

In emergency situations, it is essential to have high-performance communication technologies in place, even if they come at higher costs. However, the feasibility of switching to new technologies is often limited due to differences in the infrastructure and the protocols that are used.

In this context, a dual-mode communication technology that can switch between medium performance with low cost and high performance with high cost could be an effective solution. Such a technology would offer greater flexibility and adaptability, allowing it to be adjusted to the specific needs and constraints of the situation.

B. Adaptation Process

1) Increase communication capacity in affected areas to avoid any type of congestion. This can be done by allocating more channels to severely affected cells of the cellular communication network. Additionally, implementing temporary mobile cell towers can provide additional coverage and capacity where existing infrastructure is dacmaged or overwhelmed.
2) Change the internet protocol to a more suitable one for emergency situations, such as quick UDP internet connection (QUIC) protocol. Such a change can improve the resilience and efficiency of data transmission during disruptions. QUIC's ability to handle packet

loss and provide faster connectivity can be greatly advantageous in emergency scenarios.

3) Prioritize communication for emergency services or implement alternative communication channels that are less affected by the disruption, such as satellite communications.
4) Maximize edge computing for real-time processing to ensure that accurate data is timely available during disruptions.
5) Utilize multiple location technologies, such as GPS, map matching, or beacon-based location systems to ensure that accurate location data is available even in the event of disruptions.
6) Provide real-time information to commuters to help them navigate the disruption and avoid congested areas.
7) Implement adaptive routing algorithms to adjust traffic flow and reduce congestion in affected areas.

V. Conclusion and Future Research Horizons

We have introduced the concept of an adaptive smart city. We have discussed the adaptive smart city components, parameters, processes and mechanisms. Building on the above concepts and ideas, we have proposed a detailed smart city adaptation algorithm in cases of pandemics and natural disasters.

This work can be easily extended in many dimensions, including but not limited to the following:

- Smart city models, communications and computing features and infrastructures, device and system technologies, security and privacy measures, and so on.
- Specific adaptation procedures and mechanisms in the context of domains like health care, energy systems, transportation, and others.

References

[1] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of things for smart cities," *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 22–32, 2014.

[2] M. A. Ahad, S. Paiva, G. Tripathi, and N. Feroz, "Enabling technologies and sustainable smart cities," *Sustainable Cities and Society*, vol. 61, p. 102301, 2020.

[3] A. Kirimtat, O. Krejcar, A. Kertesz, and M. F. Tasgetiren, "Future trends and current state of smart city concepts: A survey," *IEEE Access*, vol. 8, pp. 86 448–86 467, 2020.

[4] A. M. Toli and N. Murtagh, "The concept of sustainability in smart city definitions," *Frontiers in Built Environment*, vol. 6, p. 77, 2020.

[5] H. H. Khan, M. N. Malik, R. Zafar, F. A. Goni, A. G. Chofreh, J. J. Klemeš, and Y. Alotaibi, "Challenges for sustainable smart city development: A conceptual framework," *Sustainable Development*, vol. 28, no. 5, pp. 1507–1518, 2020.

[6] M. Adhikari and A. Hazra, "6G-enabled ultra-reliable low-latency communication in edge networks," *IEEE Communications Standards Magazine*, vol. 6, no. 1, pp. 67–74, 2022.

[7] F. Guo, F. R. Yu, H. Zhang, X. Li, H. Ji, and V. C. M. Leung, "Enabling massive IoT toward 6G: A comprehensive survey," *IEEE Internet of Things Journal*, vol. 8, no. 15, pp. 11 891–11 915, 2021.

[8] A. Kumari, R. Gupta, and S. Tanwar, "Amalgamation of blockchain and IoT for smart cities underlying 6G communication: A comprehensive review," *Computer Communications*, vol. 172, pp. 102–118, 2021.

[9] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010.

[10] P. Bellavista, G. Cardone, A. Corradi, and L. Foschini, "Convergence of MANET and WSN in IoT urban scenarios," *IEEE Sensors Journal*, vol. 13, no. 10, pp. 3558–3567, 2013.

[11] A. Iqbal and S. Olariu, "A survey of enabling technologies for smart communities," *Smart Cities*, vol. 4, no. 1, pp. 54–77, 2020.

[12] M. M. E. Mahmoud, J. J. P. C. Rodrigues, S. H. Ahmed, S. C. Shah, J. F. Al-Muhtadi, V. V. Korotaev, and V. H. C. De Albuquerque, "Enabling technologies on cloud of things for smart healthcare," *IEEE Access*, vol. 6, pp. 31 950–31 967, 2018.

[13] K. Cao, Y. Liu, G. Meng, and Q. Sun, "An overview on edge computing research," *IEEE Access*, vol. 8, pp. 85 714–85 728, 2020.

[14] N. Hassan, K.-L. A. Yau, and C. Wu, "Edge computing in 5G: A review," *IEEE Access*, vol. 7, pp. 127 276–127 289, 2019.

[15] G. Carvalho, B. Cabral, V. Pereira, and J. Bernardino, "Edge computing: current trends, research challenges and future directions," *Computing*, vol. 103, pp. 993–1023, 2021.

[16] W. Z. Khan, E. Ahmed, S. Hakak, I. Yaqoob, and A. Ahmed, "Edge computing: A survey," *Future Generation Computer Systems*, vol. 97, pp. 219–235, 2019.

[17] Q. Wu, H. Liu, R. Wang, P. Fan, Q. Fan, and Z. Li, "Delay-sensitive task offloading in the 802.11p-based vehicular fog computing systems," *IEEE Internet of Things Journal*, vol. 7, no. 1, pp. 773–785, 2020.

[18] H. Zahmatkesh and F. Al-Turjman, "Fog computing for sustainable smart cities in the IoT era: Caching techniques and enabling technologies-an overview," *Sustainable Cities and Society*, vol. 59, p. 102139, 2020.

[19] M. M. Mahmoud, J. J. Rodrigues, K. Saleem, J. Al-Muhtadi, N. Kumar, and V. Korotaev, "Towards energy-aware fog-enabled cloud of things for healthcare," *Computers & Electrical Engineering*, vol. 67, pp. 58–69, 2018.

[20] T. Guelzim, M. Obaidat, and B. Sadoun, "Introduction and overview of key enabling technologies for smart cities and homes," in *Smart Cities and Homes*. Elsevier, 2016, pp. 1–16.

[21] B. Warneke, M. Last, B. Liebowitz, and K. Pister, "Smart dust: communicating with a cubic-millimeter computer," *Computer*, vol. 34, no. 1, pp. 44–51, 2001.

[22] M. L. Tuballa and M. L. Abundo, "A review of the development of smart grid technologies," *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 710–725, 2016.

[23] M. Farmanbar, K. Parham, Ø. Arild, and C. Rong, "A widespread review of smart grids towards smart cities," *Energies*, vol. 12, no. 23, p. 4484, 2019.

[24] S.-h. An, B.-H. Lee, and D.-R. Shin, "A survey of intelligent transportation systems," in *2011 Third International Conference on Computational Intelligence, Communication Systems and Networks*, 2011, pp. 332–337.

[25] P. Sundaravadivel, E. Kougianos, S. P. Mohanty, and M. K. Ganapathiraju, "Everything you wanted to know about smart health care: Evaluating the different technologies and components of the internet of things for better health," *IEEE Consumer Electronics Magazine*, vol. 7, no. 1, pp. 18–28, 2018.

[26] T. Bakıcı, E. Almirall, and J. Wareham, "A smart city initiative: the case of Barcelona," *Journal of the Knowledge Economy*, vol. 4, pp. 135–148, 2013.

[27] K. E. Calder, *Singapore: Smart city, smart state*. Brookings Institution Press, 2016.

[28] U. Gretzel, J. Ham, and C. Koo, "Creating the city destination of the future: The case of smart Seoul," *Managing Asian Destinations*, pp. 199–214, 2018.

[29] G. Pang, C. Shen, L. Cao, and A. V. D. Hengel, "Deep learning for anomaly detection: A review," *ACM Computing Surveys (CSUR)*, vol. 54, no. 2, pp. 1–38, 2021.