Smart City as an Urban Intelligent Digital System: The Case of Parma

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A smart city is an intelligent digital system that implements an effective smart urban environment able to integrate information from heterogeneous data sources and to provide efficient high-level services to citizens and municipal authorities.

In the last years, the concept of the *smart city* has attracted significant interest as it has been applied to numerous urban contexts and represents a relevant opportunity for the utilization of information and communication technologies in support of the sustainability and attractivity of a city. In general, a smart city-like approach is becoming an important strategy to make cities desirable places to live and to make them attractive and business friendly, improving multiple aspects of city life for citizens and potential visitors, such as collecting and streamlining useful data.

In a smart city context, Internet of Things (IoT) technologies have emerged as key enablers, allowing the collection of very large amounts of data, which need to be processed by relying on different techniques, such as artificial intelligence (AI) and, in general, (big) data analytics.[1] The communication and networking infrastructure is crucial to support the collection of heterogeneous information flows.

A smart city is an urban intelligent digital system that relies on key technologies of embedded and cyberphysical systems, as they have been identified by the INSIDE Industrial Association, which represents the European Technology Platform for research, design, and innovation on Intelligent Digital Systems and their applications (https://www.inside-association.eu/). In this article, we

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first discuss the applicability of the following key technologies, pictured in Figure 1: 1) secure IoT and systems of systems; 2) edge computing and embedded AI; 3) systems of systems integration platforms for digitalization; and 4) connectivity. Then, we focus on the real smart city case given by the city of Parma, Italy, showing specific instances of these key technologies.

KEY TECHNOLOGIES

The use of intelligent digital systems is shaping our everyday life in general. This applies especially to a smart city environment, where information collection, processing, and dissemination are crucial to make the entire urban "ecosystem" more efficient and sustainable. The availability of several commercial off-the-shelf intelligent systems supports the implementation of smart cities, allowing municipal authorities to gradually acquire and deploy innovative IoT technologies in the metropolitan area to monitor and control various processes related to the city's lifecycle. In the following, we show how the key technologies mentioned previously instantiate in a smart city context.

Secure IoT and systems of systems

Due to the heterogeneity of IoT systems, different types of smart devices are nowadays available, each with specific communication paradigms, with specific information being sensed and transmitted, and with heterogeneous resources and configurations. All these aspects contribute to the challenge of effectively secure IoT systems. Moreover, the enormous number of interconnected devices provides a new challenge when considering operational functions, resilience, and security as well.[2] The IoT is revolutionizing the ways in which individuals interact with the physical world as well as among themselves. Traffic monitoring, waste management, and environmental monitoring as well as health- and cultural heritage-related services will be carried out in novel ways and better organized and customized, thus requiring effective privacy, safety, and security properties.

We focus on the real smart city case given by the city of Parma, Italy, showing specific instances of these key technologies.

Edge computing and embedded AI

Regardless of its specific parameters, an application for a smart city relies on data acquisition and processing, with IoT-based sensor networks sensing, collecting, storing, inferring, and transmitting information. For delay-critical applications, it is important to lower the processing delay considering where data analysis is performed. A common approach is to send all the raw data to a cloud backend server that is in charge of data analysis. An alternative approach, to lower the latency and the traffic load, requires embedding lightweight AI-based mechanisms or custom processing algorithms directly inside the IoT nodes located at the edge of each sensing network.[3] This allows processing collected data close to their origins, in near real time, thus avoiding redundant transmissions and moving from centralized (for example, cloud) computing solutions toward distributed intelligent edge systems, characterized by very low latency (in the order of milliseconds) and suitable for distributed applications. Moreover, this processing paradigm transition is also beneficial to increased user and data privacy.

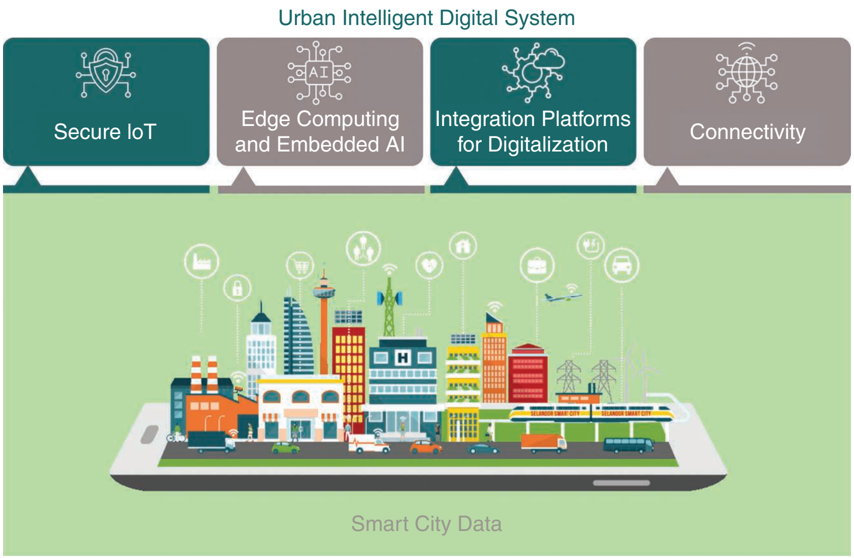

FIGURE 1. Key technologies of the smart city as an urban intelligent digital system.

Systems of systems integration platforms for digitalization

It becomes clear, considering the previous observations, that a smart city should rely on the integration of multiple digital systems, especially the IoT, collecting and processing information in heterogeneous ways. The recent growing demand for comprehensive digitalization activity is helping cities and public administrations to save physical space and energy, enabling data transmission, and generating innovative smarter ways to manage assets and processes. This trend leads to new paradigms, such as digital-as-a-service and virtual digital infrastructure, in which any complete digitalization can be implemented regardless of its associated physical infrastructure. Moreover, since enterprises and stakeholders target the development of pervasive systems as "vertical" applications to provide digital services to end users, cities will increasingly face the challenge of achieving system "pluggability" and integration in support of a sustainable smart urban transformation. More complex approaches, for example, based on digital twins,[4] must be considered as parts of such a system service integration platform,[5] steering the city's evolution toward an urban intelligence paradigm based on an ecosystem of combined digital technologies aimed at improving the city governance toward goals also addressed by the United Nations Agenda 2030 (https://sdgs.un.org/2030agenda).

Connectivity

Finally, the complexity of an urban scenario, involving several services and areas to be monitored with different characteristics, prevents the use of a single connectivity solution and leads to the design of a hybrid networking infrastructure.[6] To this end, the most relevant communication technologies for a smart city can be summarized considering the transmission range and the data rate as follows:

1. low-power wide area networks (WANs) with very low bit rates (on the order of bits/second) and large coverage (on the order of kilometers)
2. cellular (for example, 4G/5G) characterized by very low latency (below 1 ms) and very high bandwidth (more than 10 Gb/s)
3. wireless local area networks (LANs) covering small areas (for example, apartments or buildings).

Therefore, the combination of technologies in the city's communication architecture needs to be carefully designed, aiming at maximizing data collection.

THE CASE OF PARMA

The city of Parma, Italy, is investigating new services for municipal authorities and citizens through the deployment of various IoT systems organized in thematic proofs of concepts (PoCs).

Edge computing and embedded AI

Following the edge computing paradigm described previously, in Parma's smart mobility PoC, optical IoT nodes (denoted as *park2i*) are being deployed to monitor the occupancy of large parking areas. These IoT nodes, using embedded imaging AI algorithms, evaluate the parking occupancy status, and this concise information (compared to the complete parking image) is transmitted to the cloud using the Long Range Wide Area Network (LoRaWAN) protocol. Given the modularity of the solution, the same approach can be applied to other smart city-related applications as well, such as AI-based air quality monitoring and prediction. For instance, edge computing IoT air quality prediction devices are deployed in two different scenarios in Italy, specifically public transport buses in the city of Modena and in the Brindisi civil airport—these pilot cases are part of the Intelligent Secure Trustable Things (InSecTT) ECSEL Joint Undertaking project, under Grant Agreement 876038.

Systems of systems integration platforms for digitalization

This key technology is at the basis of the modular smart city software platform, denoted as *city2i*, which the municipality of Parma is integrating. This platform embodies a "middleware" to integrate the information generated by all possible data sources that are available in the city context, such as heterogeneous IoT systems or external software services used by the municipality. The information integration is performed through the implementation of specific "connectors" that collect, normalize, and process data streams, aiming at providing the municipality with a high-level tool useful to monitor the entire city from different perspectives, thus highlighting "hidden" correlations among (IoT) data collected by different (IoT) "verticals" that are not designed to be natively interoperable.

Therefore, it can be claimed that IoT technologies are becoming pervasive in the urban context, leading to sustainable smart cities. Collected data analysis, typically based on AI techniques, leads to improving the citizen's quality of life and the city's administrative processes. The urban intelligent digital system perspective for a smart city, which we describe, relies on four specific key technologies as fundamental "ingredients" for a successful and effective implementation, such as the one taking place in the city of Parma, Italy. C

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