Smart City as an Urban Intelligent Digital System: the case of Parma

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Abstract

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.

Keywords: smart city, IoT, intelligent environment, urban services, data integration

In the last years, the concept of *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 (ICTs) 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, 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 heterogenous information flows.

A smart city is an *urban intelligent digital system* that relies on key technologies of embedded and cyber-physical 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 first discuss the applicability of the following key technologies, pictured in Figure 1: (i) secure IoT and systems of systems; (ii) edge computing and embedded AI; (iii) systems of systems integration platforms for digitalization; and (iv) 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 is crucial to make the entire urban "eco-system" more efficient and

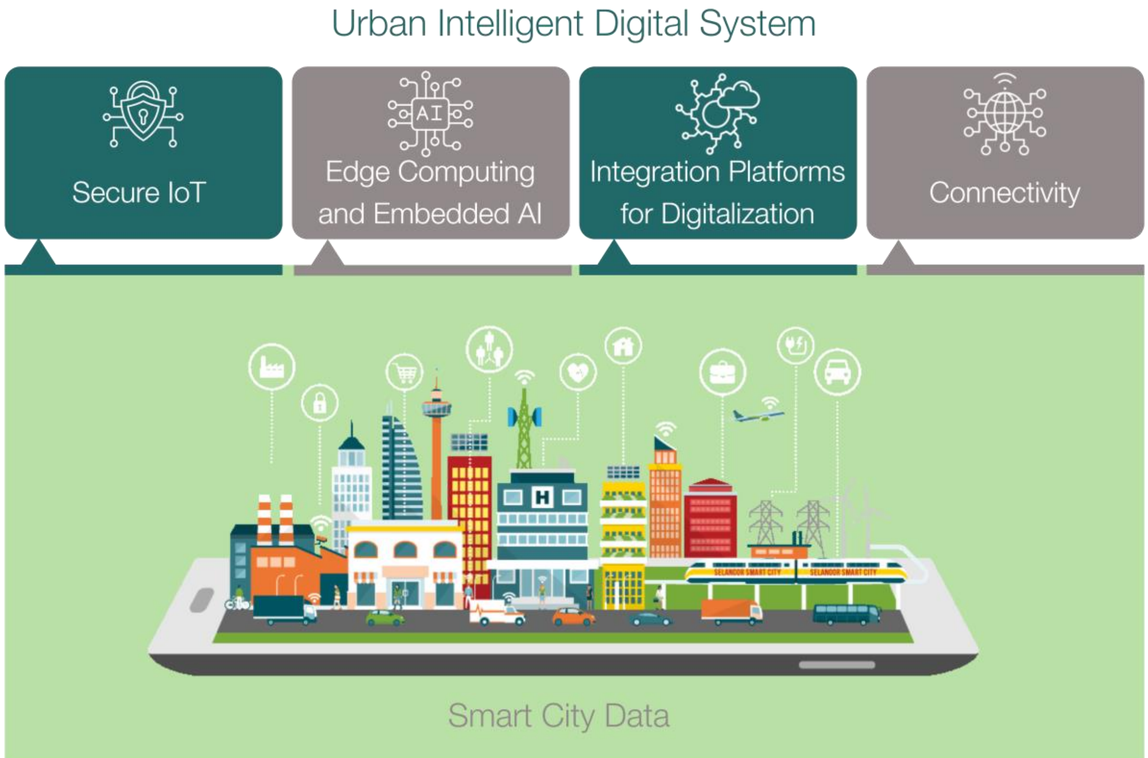

Figure 1: Key technologies of the smart city as an urban intelligent digital system.

sustainable. The availability of several Commercial Off-The-Shelf (COTS) intelligent systems supports the implementation of smart cities, allowing municipal authorities to gradually acquire and deploy innovative IoT technologies in the metropolitan area, in order to monitor and control various processes related to the city's life cycle. In the following, we show how the key technologies mentioned above 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] 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, better organized and customized, thus requiring effective privacy, safety, and security properties.

Edge Computing and Embedded Artificial Intelligence

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 back-end server which is in charge of data analysis. An alternative approach, to lower the latency and the traffic load, requires to embed lightweight AI-based mechanisms or custom processing algorithms directly inside the IoT nodes located at the edge of each sensing network.[3] This allows to process collected data close to their origins, in *near real-time*, thus avoiding redundant transmissions and moving from centralized (e.g., cloud) computing solutions towards 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 beneficial also to an increased user and data privacy.

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 IoT, collecting and processing information in heterogeneous ways. The recent growing demand of a comprehensive digitalization activity is bringing cities and public administrations to save physical space and energy, enabling data transmission, generating innovative smarter ways to manage assets and processes. This trend leads to new paradigms, such as Digital-as-a-Service (DaaS) and Virtual Digital Infrastructure (VDI), 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 aiming at improving the city governance towards goals addressed also by the UN 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: (i) Low-Power Wide Area Networks (LPWANs) with very low bit rate (on the order of b/s) and large coverage (on the order of km); (ii) cellular (e.g., 4G/5G) characterized by very low latency (below 1 ms) and very high bandwidth (over 10 Gb/s); (iii) Wireless Local Area Networks (WLANs) covering small areas (e.g., 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 Proof of Concepts (PoCs).

Edge Computing and Embedded Artificial Intelligence

Following the edge computing paradigm described above, 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 park occupancy status, and this concise information (compared to the complete park image) is transmitted to the cloud using the 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 no. 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.

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