Smart cities powered by HPC

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Abstract: This study analyses how High Performance Computing technology can support the development of smart cities and proposes a conceptual model relying on this technology. Smart urban development has been a research subject for many years as digital services have the potential to improve residents' quality of life. Many developments have been made throughout time but in different domains and up to this moment we cannot state that there has been developed any Smart City integrated system for a specific city on the globe. One major shortcoming in accomplishing this task is the fact that it would require a massive infrastructure with enough storage and processing power. HPC has the potential to overcome this as it combines both storage and processing power. The research paper also proposes a smart city powered by HPC infrastructure.

Keywords: Smart City, IoT, AI, Big Data, HPC.

Orașe inteligente bazate pe HPC

Rezumat: Acest studiu analizează modul în care tehnologia High Performance Computing (HPC) poate contribui la dezvoltarea orașelor inteligente și propune un model conceptual bazat pe această tehnologie. Dezvoltarea urbană inteligentă a fost un subiect de cercetare în ultimii ani, întrucât serviciile digitale au potențialul de a îmbunătăți calitatea vieții rezidenților. De-a lungul timpului au fost făcute multiple dezvoltări, în diferite domenii, dar până în acest moment nu putem afirma că a fost dezvoltat un sistem integrat Smart City pentru un oraș specific de pe glob. Un neajuns major în realizarea acestui deziderat este faptul că necesită o infrastructură masivă și sigură, cu suficientă putere de stocare și procesare. HPC are potențialul de a depăși acest neajuns întrucât combină puterea de stocare cu puterea de procesare. Studiul propune, de asemenea, un model de oraș inteligent bazat pe infrastructura HPC.

Cuvinte cheie: Smart City, IoT, AI, Big Data, HPC.

1. Introduction

The number of residents in urban areas is constantly growing and it is estimated that 68% of the population at global level will live in urban areas by 2050 (ONU, 2018). The states that will not take appropriate measures could face problems in providing basic services to the general population such as energy systems, healthcare, transportation, infrastructure, waste collection, water distribution, schools/education, etc. Integrated IT systems are required to improve the lives of urban residents, while strengthening the collaboration between urban administration units. (Gartner, 2015)

High Performance Computing (HPC) refers to the practice of aggregating computing power in order to deliver higher performance which enables the processing of large volumes of data in a few hours while a conventional system would process the same amount of data in a few weeks. HPC means dividing a task into several smaller tasks.

A smart city requires the existence of an integrated information system that includes a multitude of Internet of Things (IoT), Open Data, Big Data and mobile applications, connected to the Internet through secure networks operating on cloud computing systems and High Performance Computing Systems. These systems enable the local administration to interact directly with the citizens and the city's infrastructure.

Also, it enables the administration to supervise the events and incidents in the city, take appropriate measures and ensure a better quality of life. Data is collected, processed and analyzed via sensors and devices, installed throughout the city and integrated in real-time monitoring systems.

Smart cities based on AI, Big Data and HPC technologies can help improve the quality of life, but, a "smart" urban landscape, with many interconnected devices supported by a

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communications network, poses security challenges which can't be tackled by using traditional cybersecurity solutions.

1.1. Smart cities

A smart city is an ecosystem comprising technologies and systems working jointly to manage in an efficient and secure manner a city's resources, with the goals to improve citizen's life and community services while protecting the environment. Ideally it aggregates water distribution, traffic monitoring, public lighting, parking, urban transportation, traffic monitoring, air quality monitoring, weather monitoring, waste collection, schools, hospitals, public agencies and other community services.

Smart City concept is defined in multiple ways within the literature. Komninos states smart cities are ecosystems with an enhanced capacity for development reuniting the creativity of residents and local organisations with digital infrastructures to function in the physical, institutional and digital spaces of cities. The different definitions make it difficult to understand how the adoption of technologies impacts the development of smart cities. (Komninos, 2006), (Nasulea, 2018)

As a simple explanation, in a smart city, using digital technologies translates into an increased quality of public services for its residents, and an efficient use of resources (Mohanty et al., 2016). Collecting all the information from these domains creates premises for smart city governance resulting in better community services and resource optimization. (Gori, 2015)

Albino et al. (2015) describe a smart city as a set of paradigms spread across different areas: people, governance, mobility, environment, economy, and living:

- Smart Economy addresses entrepreneurship with a positive impact on local businesses, access to jobs, job mobility and increased work standards;
- Smart Mobility refers to local transport systems that enable commuting for citizens. A Smart City should provide environment friendly transportation facilities such as bicycle and scooters that can be used jointly with public transportation. Also, it should provide an integrated parking system which offers citizens information on parking lots availability. Smart Mobility requires implementing the latest communication technologies to ensure a fast internet connection;
- Smart Environment implies overviewing continuously the quality of the urban environment concerning air quality, garbage disposal, water treatment stations, recycling programs;
- Smart People addresses education systems, starting from public systems and extending to extracurricular programs developed to educate citizens;
- Smart Living collects indicators for an increased quality of life as good health conditions, tourist attractions, individual security, housing conditions, cultural facilities and leisure facilities, education facilities;
- Smart Governance implies developing integrated solutions which enable governments to provide efficient services to citizens while ensuring a transparent public administration. Example of services could be a tax collection system enabling the public administration to reduce bureaucracy and a platform where citizens can report incidents they notice all over the city.

A smart city is an ecosystem with integrated communication and information technologies enabling interactive spaces that bring computational capabilities to the physical world. (Steventon & Wright, 2006)

Networks and services are designed having in mind efficiency, flexibility and sustainability by using ICT technologies to improve the smart city's administration process for the benefit of its residents.

Smart City represents the future in urban development and governing by incorporating new infrastructures and applications that enable the residents to use relevant information about the city they live in. Also, it enables the communication between citizens and the public administration. (Petre et al., 2018)

Over time cities have been trying to implement a series of smart city infrastructures but the main issue is the lack of interconnection of those infrastructures. A smart city efficient application will consume a lot of processing power that cannot be provided by traditional computing systems that have certain limitations. High Performance Computing (HPC) can be used by public administration to implement an efficient information system supporting multiple interconnected services for citizens. The large amount of data that will have to be processed in such a vast environment, needs an infrastructure with high processing power to support the continuous service provisioning for citizens. They are the main beneficiaries of a smart city.

HPC, Big Data and AI technologies have a major role in the development of smart cities enabling event reporting and detection, making smart decisions, and taking appropriate actions, saving time and costs.

1.2. European landscape in HPC

HPC is defined as the practice of deploying aggregated computing power in a way that it provides high performance to solve problems in engineering, science and the business environment.

HPC is considered an emerging general-purpose technology with the potential to improve the framework for innovation by increasing efficiency and reducing development time. It also allows the use of distributed computing resources to solve complex problems involving large data sets. HPC allows the processing of massive volumes of data efficiently significantly increasing the innovation capacity of companies by shortening the product development cycle. (InnoHPC, 2019)

At EU level, the European Commission has identified the need to improve the HPC infrastructure taking into account the benefits that this technology offers. Thus, in 2018, the EUROHPC program started, which has as main objective the development of infrastructure and competencies in Europe. (European Commission, 2020)

The program aims to improve the quality of life, developments in science, stimulate industrial competitiveness, and develop a pan-European network of supercomputers, 3 pre-exascale and 5 petascale for users from public and private sectors. At the same time, it aims to support research, innovation and development activities. In September 2020, the Commission proposed a new regulation to replace the 2018 regulation and added new objectives such as expanding the supercomputer infrastructure, developing a federated European supercomputing, quantum computing infrastructure and quantum simulation integrated with HPC infrastructure. (European Commission, 2021)

There are several HPC centers of excellence in Europe reunited by Focus COEs initiative which promotes the development and use of petascale and exascale computing infrastructures within member states.

The service digitalization process within the public administration had an ascending trend in the past years, generating a vast amount of data. Adequate storage and analysis of such data has an important role in optimizing essential processes for the operation of the community. HPC systems give the ability to become more advanced in such routines.

2. HPC use cases for smart cities

A Smart City should include key components which enable the centralization of the data and these components can take several shapes starting from a simple website to more complex and context aware applications supported by specialized hardware and communication infrastructures. On the other hand, the availability and accessibility of the data should be guaranteed 24/7 and the system should be freely accessed by the citizens and should allow them to propose modifications and corrections.

Cities need to become smart to properly support the quality of life of their residents. The rapid expansion of urban communities poses new infrastructure related challenges for municipal administration. As cities continuously extend their services, the management of all these assets increases in complexity. As a result, cities have to assess the economic, social, environmental and engineering and issues associated with these transformations.

2.1. HPC for IoT devices

Nowadays, there is a tendency to design smart systems in a large variety of domains, especially in the areas where implementing this kind of systems will have a huge impact on work processes and life standards. From oil and gas pipelines sensors to smart meters on utility lines, IoT devices are used in critical domains as a reliable resource to execute daily tasks. Because IoT networks architecture became more complex, with a large number of interconnected devices, the computation power had to grow exponentially to sustain all the processes and all the collected data. Thus, new computing architectures were designed in order to satisfy the need of processing speed and quick responses. IoT devices are collecting an enormous amount of data from different sources and in most cases, it is difficult to manage and process all the information. Also, devices should have a quick response to any request and should be able to communicate and work with all the other devices from the system. Requests arrive at the same time and it must be executed as soon as possible. Here it's the part where HPC technology and infrastructure intervene. When we say High Performance Computing we think about GPUs, MICs, Peer-to-peer Computing and so on. For the integration of HPC with IoT devices was defined a minimum list of requirements that must be fulfilled (de Souza Cimino et al., 2017):

- Security and privacy – a level of security should be ensured in managing identities and encrypting communications;
- Different programming models – both technologies should use the same programming model for user applications;
- Context awareness – the system must report permanently the status of the executed processes and intercept data;
- Distributed storage – the code should be transparent for the computed tasks and for IoT devices;
- Heterogeneity – interoperability and portability should exist between devices and platforms;
- Sensing analytics – the system has to be able to process data from sensors with mathematical and intelligence instruments;
- Simple deployment – platforms that integrates IoT/HPC should be easy to deploy, without affecting other components from the computing system;
- Fault tolerance – the system should implement data loss and corruption policies;
- Task scheduling – scheduling algorithms are essential in IoT/HPC systems;
- Performance and scalability – the system has to optimize the time processes and has to be able to extend.

To better understand the connection between IoT systems and High-Performance Computing, we will concentrate on smart applications and the advantages of using more computing power.

Smart building management

In a smart building almost all the main functionalities like air conditioning and light work making use of IoT devices and interaction between them. This kind of interaction requires the solution of scheduling problems, a combinatorial problem. For example, ADREAM building, which is an autonomous building in France, has 6000 sensors that measure temperature, light, motion, etc. Besides the sensors, the building has IP cameras and specialized devices like

geothermal exchanger. The management of such large number of devices and collected data is hard and requires a great computational power. Optimal scheduling of tasks can be obtained by using GPUs and MIC coprocessors. This type of HPC solution reduces computing time by factors from 50 up to 150 and requires less energy (Baz, 2014).

Smart logistics

The main goal in logistic applications is optimization of time, quality, and cost of delivery. Because of the dynamics in the logistic process, difficult events may occur at any time, for example, cancellation of an order or traffic jam. The ALMA project proposes a real-time mobile application, based on IoT devices and HPC technology and infrastructure. Mobile devices are used to track and report the status of a delivery. Also, this application solves the loading truck issues and vehicle routing problems. For this type of situation, a cluster-based solution was used (Baz, 2014).

Smart manufacturing

Smart manufacturing is based on machine learning algorithms for prediction of a step or configuration of an instrument. The results of the ML algorithms can indicate an operator how to adjust the working machine when production conditions deviate from normal. HPC infrastructure contributes with an improvement in response time, in comparison with the results from machine learning algorithms (Office of Energy Efficiency and Renewable Energy, 2020).

2.2. HPC for AI

One of the critical enablers for AI has been the large amount of data that it generates on a daily basis and has to be stored for further analysis. The collected data represents the input from which machines learn from continuously. After collection, it needs to be processed and for this a large amount of computing power is required which can be provided by GPUs.

Their capability to execute millions of operations per second makes GPUs the best candidate to perform the computations required by machine learning algorithms.

An autonomous vehicle has the capability to sense the environment and to operate without human commands. For proper functionalities, autonomous vehicles depend on sensors, algorithms, a powerful executing infrastructure, actuators and machine learning systems. With the help of the large variety of sensors positioned in different parts of the vehicle a map of the surrounding can be generated. The detection of traffic lights, signs and pedestrians is made by video cameras and the list can go on. All the collected input is proceeded by complex algorithms to send instructions to the car's actuators, which control the speed and breaks of the car. Object recognition, predictive modelling, obstacle avoidance algorithms and others help the car's software follow the traffic rules and avoid accidents. GPUs systems are used in training machine learning algorithms, in simulations of efficient traffic flows and so on.

The city of the future has also a smart parking system which uses sensors incorporated in the parking spaces or motion detection cameras which allow the development of real-time maps showing free parking spaces for residents.

AI can also be used to interpret the data collected from cameras installed all over the city monitoring the vehicles on the road. The results are used to adjust the city's traffic light system timing to ensure an optimal flow of vehicles taking into consideration the time and location.

2.3. HPC cybersecurity

HPC systems are often distributed in different geographic location and it can be challenging to ensure cybersecurity across different platforms.

In order to detect intrusion attempts, it is necessary to monitor the legitimacy of the data traffic in HPC clusters. Though, the conventional security monitoring tools cannot cover the increased volume of data flow in HPC environments. Thus, dedicated security solutions must be implemented.

Abnormal activities within a HPC cluster might include: increased network latency, an increased number of processes running on one node, increasing CPU usage, data alteration, unauthorized jobs, etc. Dedicated tools for process monitoring and analytics are essential for early intrusion detection. These can stop or prevent a cyber-attack.

Another solution is to develop a dedicated security framework that would analyze network activity, monitor processes and provide a real-time feedback on intrusions and potential security risks within the system.

3. Smart city powered by HPC architecture

The smart city conceptual model proposed within this paper is based on an open and interoperable platform that can be extended and adapted to the changing needs of citizens and municipalities. The platform requires digital infrastructure based on fast broadband internet networks, Wi-Fi as well as applications running on the HPC infrastructure. (Stanciu, 2013)

The information collected by the sensors installed in the city (air quality monitoring, intelligent lighting management, intelligent water distribution metering, etc.) from the public data sets available at the level of local and central authorities are aggregated in the HPC platform. It allows the addition of new information from any type of sensors.

HPC technology can be implemented not only in dedicated data centers but also it can be combined with cloud services or it can be provided as a service to stakeholders as, for example, public administration, academia and research institutes. A smart city would require a federation of systems and applications connected through a fast communication system. All participating systems will be required in creating a “continuum” of computing. The figure below describes the components of a smart city, where HPC functionality is combined with cloud systems:

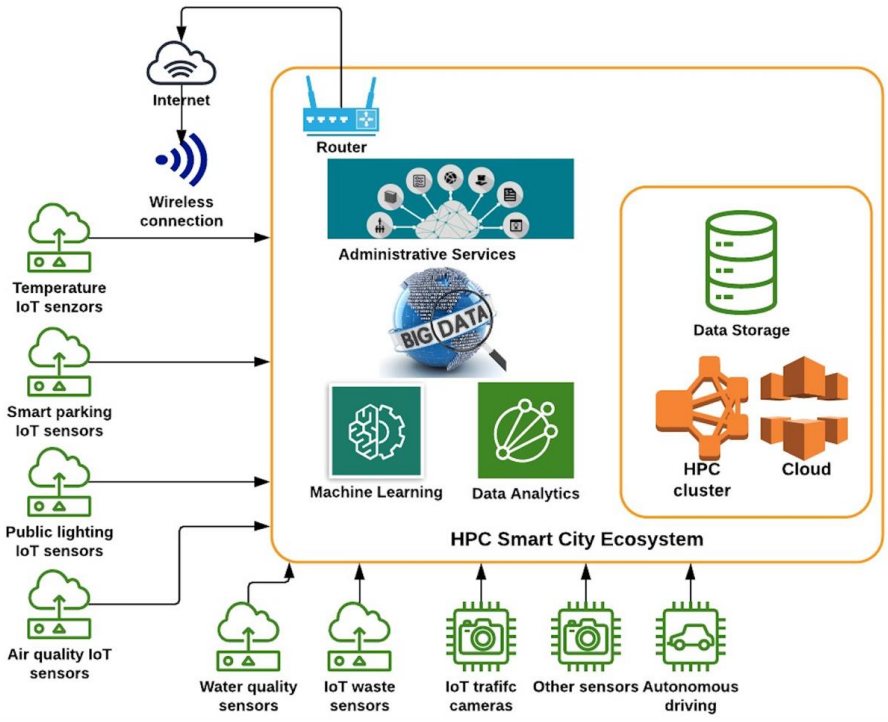

Figure 1. Smart City Ecosystem using HPC (Source: own)

4. Conclusions

In a smart city infrastructure, communication, applications and information are being used jointly to enhance the performance, speed and quality of urban services thus reducing costs and resources.

A smart city is a city of the future, which enables citizens and public administrations to interact in a safe and technology-driven environment comprising many interconnected systems which need a secure and reliable infrastructure as support. For many years cities tried to implement a series of smart city infrastructures but the main problem is that those infrastructures are not interconnected, but separate systems. High Performance Computing (HPC) infrastructures have the potential to support public administration in implementing a secure and efficient information system comprising many interconnected services for citizens. The architecture described within this research paper could be used in developing a federated smart city ecosystem powered by High Performance Computing.

Smart cities require a lot of processing power that cannot be provided by traditional computing systems that have certain limitations.

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