**SERBIAN JOURNAL OF ELECTRICAL ENGINEERING**
**Vol. 17, No. 3, October 2020, 337-355**

**UDC: 711.45:004.78** **DOI: https://doi.org/10.2298/SJEE2003337S**

# Big Data and Development of Smart City: System Architecture and Practical Public Safety Example

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**Abstract:** The concept of Smart City started its development path around two to three decades ago; it has been mainly influenced and driven by radical changes in technological, social and business environments. Big Data, Internet of Things and Networked Cyber-Physical Systems, together with the concepts of Cloud, Fog and Edge Computing, have tremendous impact on the development of Smart City, reforming its frame and tasks and redefining its requirements and challenges. We consider feasible architectures of the IT infrastructure and signal processing, taking into account aspects of Big Data, followed by summary of benefits and main challenges, like security of infrastructure and private data. As a practical example we present a public safety application of multi-sensor imaging system: a smart device with target detection subsystem based on artificial intelligence used for activation of target tracking. The experiments have been performed in the cities of Abu Dhabi and Belgrade, which have very different environment. The experiments have shown the effects of video-streaming compression on thermal imagers and the importance of distributed processing power that optimizes requirements for amount of transmitted data and delay.

**Keywords:** Smart City; Big Data; Internet of Things; Cloud, Fog and Edge Computing; Multi-Sensor Imaging Systems, Public Safety.

## 1 Introduction

Common definition of Smart City relates to the monitoring and integration of the critical infrastructure, optimization of resources, planning of maintenance activities, monitoring of security while maximizing services to the citizens [1]. The crucial infrastructure usually includes civil infrastructure (roads, bridges, tunnels, rails, subways, airports, seaports, water, power), IT infrastructure (broadband networks, data centers, access points, terminal devices/sensors, available IT services), social infrastructure (schools, hospitals, theatres, media,

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social clubs, social networks) and business infrastructure (companies, campuses, business clusters) [2].

The main four technological layers of Smart City architecture are: 1) sensing layer – sensors or terminal devices, 2) network layer – telecommunication medium and associated services, 3) Operation, Administration, Maintenance and Provisioning, and Security (OAM&P&S) layer - centralized processing or management platform and 4) application layer [3]. The technological layers faced dynamic changes and transformation, with recent one triggered by the appearance of Smart devices, Internet of Things ( IoT) [4], Big Data [5] and finally application of Artificial Intelligence (AI) in data analytic platforms, resource management and control systems [6, 7].

Big Data is a common tag for the exponential growth, availability, and use of information, both structured and unstructured [8]. Smart networked sensor devices, predominantly IoT as the primary source of Big Data, became well-known and affordable both for organizations and citizens. It is considered that 90% of world`s digitized data was captured (or generated) in the last two years. Per Intel and United Nations estimations, the number of connected smart devices will rise from respectable 6 billion in 2006 to astonishing 200 billion in 2020, which will be 26 devices per each human being on Earth [9].

Main characteristics of Big Data are referenced to as the Vs of Big Data management. They include the main 3 Vs (1, 2 and 3) and two additional Vs: 1) Volume: total amount of data that has been created from all the sources; 2) Velocity: speed at which the data is generated, stored, analyzed and processed, with focus on support of the real-time Big Data analysis; 3) Variety: various types of data being generated – structured or unstructured; 4) Variability: constant changes of data structure and 5) Value: possible benefits that Big Data can offer to businesses [10].

This study is the extended work of the preliminary results published in [11], where a time line of Smart City development is presented. It starts from pilot projects with SCADA-like applications in 80's, via web services, positioning services and CCTV as a main surveillance technology in 90's to modern applications like public safety smart home, smart grid, healthcare, education, smart transportation and other applications. In this paper we continue to present our research activities in order to give possible solutions for system architecture that would make mentioned application feasible, cost-effective and easy to expand per future needs.

The data generated for Smart City applications boost new requirements for handling enormous data volume, fusion/filtering, security/privacy, building appropriate ICT infrastructure and real-time performance. These requirements are beyond the traditional centralized cloud-based applications, and give rise to the notions of Fog Computing, Edge Computing and their variations [12]. The main references in literature about importance of system architecture related to Big Data are given in this paper. We have adopted some of the remarks from those references for practical implementation of surveillance systems. The practical results of tests performed in the cities of Abu Dhabi and Belgrade are presented.

The paper is structured as follows: in the second chapter we give overview of the smart-city enabling technologies from perspective of sensors, data transfer and storage and data processing. In the third chapter we address the topic of architecture, with examples of proposed architectures. In the fourth chapter we analyse application of multi-spectral cameras and related data processing based on AI, in next generation of public safety systems. Finally, in fifth chapter we make some conclusions.

## 2 Enabling Technologies

Besides obvious need for smart cities and worldwide initiative of major state level key players [7] the key stakeholders of smart cities concept are enabling technologies like smart devices and IoT, advanced broadband networking and its security, Big Data analytics methodologies and application of artificial intelligence. Understanding of the main aspects of mentioned technologies is the key driver for design of computational architectures that will be described in the next section.

### 2.1 Smart Devices and IoT

The first sight of smart devices and IoT brings the initial assumption that these are the devices of sensor or actuator type, coupled with microcomputer having capabilities for Internet connectivity.

Typical smart devices are various sensors for measurement of temperature, pressure, humidity, air pollution, and streaming devices like cameras, microphone arrays etc. All of the mentioned sensors have a common attribute: they are unidirectional - from location where the data are acquired to the location where the data are used. The other types of smart devices are various actuators that act according to commands from the command system. Open loop architectures are very rare (except for time triggered actuators), so some sort of interactivity between sensors, actuators and control systems are needed.

From data processing architecture perspective, the main attributes of smart device are: devices' control plane and interactivity level with other entities in the network, device data type: on-demand, continuous streaming, bulk mode downloading etc. and redundancy level (is device crucial for entire system or not). These attributes could be transferred to networking requirements expressed as: bandwidth, delay, delay variations and allowed packet error ratio, as given in ITU-T Rec. Y.1541 [13].

## 2.2 Networking and security

Communication between smart devices and data processing systems is the crucial part of smart city applications. Luckily in recent years a plethora of new technologies is brought from laboratories and trial project to world-wide practice, providing cost-effective networking service. In smart cities concept usage of wireless technologies is very important starting from short range communications like RFID, via medium range like Wi-Fi, ZigBee or low-energy Bluetooth (BLE) to long range like LoRa, LoRaWAN or Sigfox [6]. Of course, usage of mobile communication systems 2G/3G/LTE, public safety networks, like TETRA, or 5G is always assumed. The design of various gateways that bridge between different technologies or for Internet access is one of the very important tasks. We emphasize the advantages of usage of fiber optics technologies, especially DWDM, providing huge capacity (several Tb per optical fiber) for backbone communication.

IP-based technology, with IPv6 addressing scheme is predominant traffic routing technology that enables easy application development in Smart City arena [14]. Unfortunately Internet access brings serious security issues, so methodologies for communication protection, data protection and data privacy based on applied cryptography are very important aspect of smart cities [15]. Having in mind relatively low computational power of majority of IoT smart devices, development of special light weight cryptography schemes is a very challenging tasks, which requires innovative solutions [16][17].

## 2.3 Big Data - the main data processing challenge of Smart Cities

Big data and IoT will enable new data-driven services to upgrade processes and enable innovation of products and business models. In the era of advanced digitization of the society, the potential benefits and challenges associated with big data and IoT are important topics for decision-makers [18, 19]. Challenges related to Big Data may be grouped in the following way, as given in [5]:

1. Data sources and characteristics – related to the format of data;
2. Data and information sharing – related to the “ownership” of data and protocols of sharing;
3. Data quality – related to the heterogeneity of data and its subsequent (un)certainty;
4. Cost – related to whether the citizens should pay for deployment of advanced application based on Big Data or not;
5. Smart City population – related to growth of population and growth of generated data per capita;
6. Security and Privacy – related to security policies and mechanisms to protect the data against unauthorized use and malicious attacks. There is

a huge risk which comes from the process of exchange of digital data, particularly in Big Data environment. Small and large scale cyber-attacks are reality and the potential resulting damage is rapidly growing. Even well-planned Big Data applications, such as Cassandra and Hadoop, suffer from a lack of cyber security mechanisms.

On the other hand, IoT has emerged as a new technology with the potential to support a wide range of Multi-Agent (MA) Systems of Systems (SoS) applications in Smart Cities. The IoT can be defined as [1]: "The Internet of Things (IoT) is the network of physical objects (devices, vehicles, buildings and other items) embedded with electronics, software, sensors, and network connectivity that enables these objects to collect and exchange data." The IoT-generated data for Smart City applications gives rise to new requirements for handling enormous data volume, fusion/filtering, security/privacy and real-time performance, which require new approaches to the organization of the supporting IT infrastructure. The main challenges are [6][5]:

1. Interoperability of large-scale SoS;
2. Interfacing multiple SoS layers;
3. Real-time data processing and control;
4. Filtering data to conserve networking, storage, and processing resources;
5. Fusion of data from diverse devices and sources;
6. Ensuring security and privacy of data;
7. Monitoring, managing, and interactive interfaces with IoT systems;
8. Using large-scale analytics to improve IoT systems performance.

## 2.4 Artificial Intelligence

Obviously, for efficient big data analysis it is necessary to employ huge computational power and artificial intelligence - AI methodology for its analysis, presentation and decision making aid. A comprehensive overview of AI applications in various domains of smart cities is given in [20]. One of extreme applications is public safety which has very significant Big Data tag due to huge volume of data produced by surveillance cameras, open-source intelligence originating from social networks, legal eavesdropping systems, gas leakage inspection systems etc., which is impossible to be processed by any number of human operators. Thus, employing AI is mandatory, with much care for legal issues and privacy protection. One of the frameworks for AI incorporation into public safety systems is presented by European Emergency Number Association (EENA) [21].

## 3 Architecture: Benefits and Challenges

Data mass in Smart City arena is increasing exponentially in all areas, from individual and municipal level to global. The data will come from plethora of devices and sources present in the market and in various forms: structured, semi-structured and unstructured. We may witness the shift from the realm of traditional desktop computing to an increasingly sophisticated computing [18]. It is already critically important to understand the data sets and organize them properly. Foreseen quantity of sensor or smart devices in all Smart City applications drives the necessity of aligning with Big Data principles. Congestion management systems will not be able to operate through conditions of unprecedented sizes of cities, where dozens of millions of people live, work and commute, without using Big Data for analytics. Europe with its 240 million smart meters in 2020 will be an excellent example of networked and optimized Smart Grid which everybody will benefit from, but only in case it will be capable of digesting the Big Data created. Face recognition and tracking of the suspects via urban video surveillance is the dream of the public safety professionals – the dream that can only became reality if the challenges of Big Data are handled.

Big Data and IoT are offering and bringing immense advances to applications of urban life. Actually, they are the necessary condition for Smart City of the future.

### 3.1 Architectural issues: centralized, hierarchical and decentralized computing paradigms

In the initial development steps, typical IT infrastructure organization for Smart City was based on the centralized cloud-based architecture. At the high level, this approach provides capability for gathering, analyzing and processing massive amounts of data from heterogeneous sensors deployed in urban areas with remote computing resources. This huge amount of data requires large computational and storage facilities. One way to provide infrastructure for applications and services in various city domains is to rely on the cloud computing platform. The crucial benefit of the cloud architectural choice is hardware, software, storage and network virtualization providing cost savings, scalability, modularity and efficiency in maintenance and monitoring. This architecture is also known as Cloud of Things or CloudIoT [22]. Cloud-based infrastructure for realization of Smart City services can be designed in the form of private, public or hybrid model. Different types of services are available via cloud for users through their smart phones, tablets, PCs or laptops, as shown in Fig. 1.

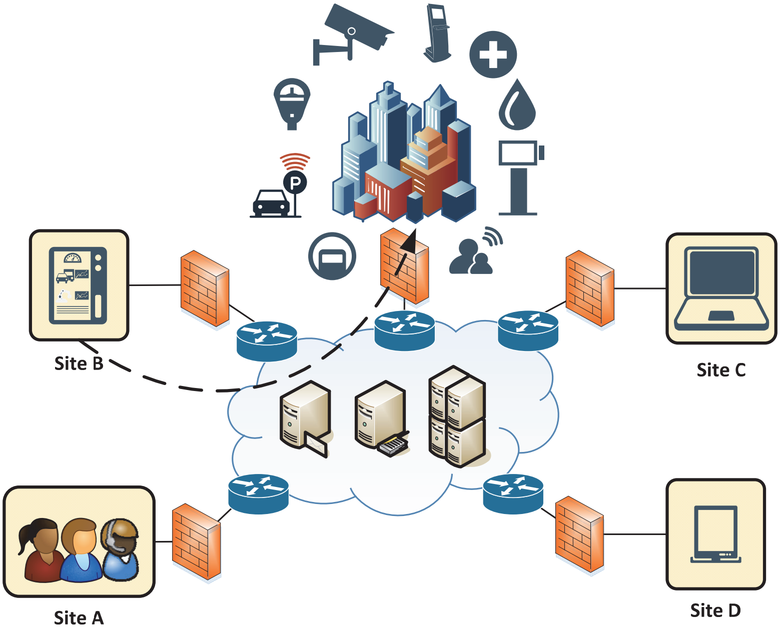

**Fig. 1 –** *Cloud-based Smart City services for different users.*

The centralized cloud-based applications typically cannot handle the constraints mentioned in the previous section [23]. In order to support large-scale SoS, typical for Smart City, data from the devices on the edge of the underlying IoT has to be transferred through and processed by many intermediate computing resources/agents (such as local devices/gateways, and intermediate nodes/servers/clouds). The supporting systems/architectures are also called Cyber-Physical Systems (CPS). CPS is defined as [24]: "a mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users. In CPS, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities and interacting with each other in a lot of ways that change with context..." A completely developed CPS typically has a hierarchical SoS organization (CPSoS), comprising networked interacting nodes/agents which may be pure "cyber" devices or may possess physical inputs and outputs. The emerging CPS applications combine traditional data, Big Data, and IoT data, introducing a novel paradigm in large-scale data processing, which is distributed at multiple time, spatial, volume, and velocity scales.

To address these issues, the so-called Fog Computing paradigm has been recently proposed by both industry and academia [24, 12], with the main idea of employing the hierarchical CPSoS organization and introducing standardized interfaces between the agents/subsystems, allowing decentralization and distribution of data processing, computing, storage, networking, management, decision making and control functions. Typically, these functions are partially transferred towards the closer vicinity of the network/system edge (IoT devices) and are executed along the path between the edge and the fusion center at the highest architectural layer (which is typically based on the cloud technology). In the next subsection we provide a more detailed description of fog computing paradigm, describe its general reference architectural framework, and argue that it provides the most appropriate basis (compared to the other mentioned computing paradigms) with sufficient generality for Smart City applications.

### 3.2 Fog computing and other related computing paradigms

Fog computing is standardly defined as a horizontal system-level architecture that distributes computing, storage, control and networking functions closer to the users along a cloud-to-thing continuum [12]. The term "horizontal" indicates that, besides the vertical distribution, the computing functions can possibly be distributed between different platforms and industries, and accounts for the interactions between multiple applications supported by different verticals. Also, fog computing provides strong support for the IoT. These aspects are of large importance of Smart City applications, which typically consists of many heterogeneous application domains.

In most fog deployments, there are typically several tiers (layers) of nodes/agents/devices. Nodes at the edge are typically focused on sensor data acquisition/collection, data normalization, and command/control using actuators. These nodes are the nearest to the network physical edge, and typically need to operate at fast (millisecond and sub-millisecond) time scales, from sensing to actuation, to avoid performance deterioration and to ensure safe functioning. In many deployment models, important for Smart City applications, large amounts of data processing, analytics and decision making is located at this level (e.g. video processing on surveillance cameras). This is because the network connection bandwidth may not be large enough to effectively carry the raw sensor data to the higher layer fog nodes for processing.

Next layer is typically focused on data filtering, compression, and transformation. However, it often provides some data analytics and decision making required for critical real-time or near real-time operation. As we move towards the higher levels of the network, the data processing, learning and analytics capabilities of the nodes increase. Nodes nearest to the central cloud are typically focused on the aggregation and turning the data into a higher-level knowledge where greater insights about the underlying system and data can be conceived. However, as the computational capabilities of the devices near the edge grow, their level of intelligence will grow, enabling the general growth of intelligence of fog deployments. It is obvious as well that communication of data between fog nodes, both horizontally and vertically, increases the overall system performance and capabilities.

Depending on a particular application, fog deployments can have different sizes (number of tiers), which is dictated by the application requirements, including:

– Amount and type of effort required by each tier,
– Number of edge devices/sensors,
– Capabilities of the nodes at each tier
– Communication latency between the nodes
– Reliability/availability of nodes

The nodes within a system may all be linked together through a mesh network providing better capabilities for real-time load balancing, resilience, data sharing, minimizing communications to the cloud. This may require capabilities to communicate both laterally (peer to peer or east-west) and/or up-down (north-south) within the fog hierarchy. The node must also be able to discover, trust, and utilize the services of other nodes "on the fly".

In general, a system with described architectural and operational organization, is able to support latency-sensitive applications (e.g. real-time control and decision making) while maintaining satisfactory quality of service (QoS). The issue of security is also substantially more complex in CPSoS systems with fog computing compared to the cloud computing. In fog computing, security must be provided in the dedicated locations of fog nodes (or edge nodes), as opposed to the centrally-developed security mechanisms in dedicated buildings for cloud data centers.

Because of all the above described conceptual differences, cloud and fog computing differ with respect to the employed hardware components. Cloud computing is typically based on computing resources with high availability and capability with relatively high power consumption. Fog computing typically provides moderate or even low availability and capability of computing resources with lower power consumption. Cloud computing is typically based on large data centers, while fog computing utilizes edge IoT devices, small servers, routers, switches, gateways, or access points, which occupies much less space so that it can be located closer to the edge and/or users. Fog computing can be accessed through local networks, while cloud computing must be accessed through the network core. Hence, continuous Internet connectivity is not essential for the fog-based services to function - they can perform needed operations locally (with low or no Internet connectivity) and asynchronously send necessary data to the cloud whenever the connection is available, which is not possible with cloud computing.

Edge, Fog and Cloud computing frameworks are shown in Fig. 2. They typically have high degree of decentralization; however, in most cases they can be considered as special cases of fog computing by removing certain architectural tiers.

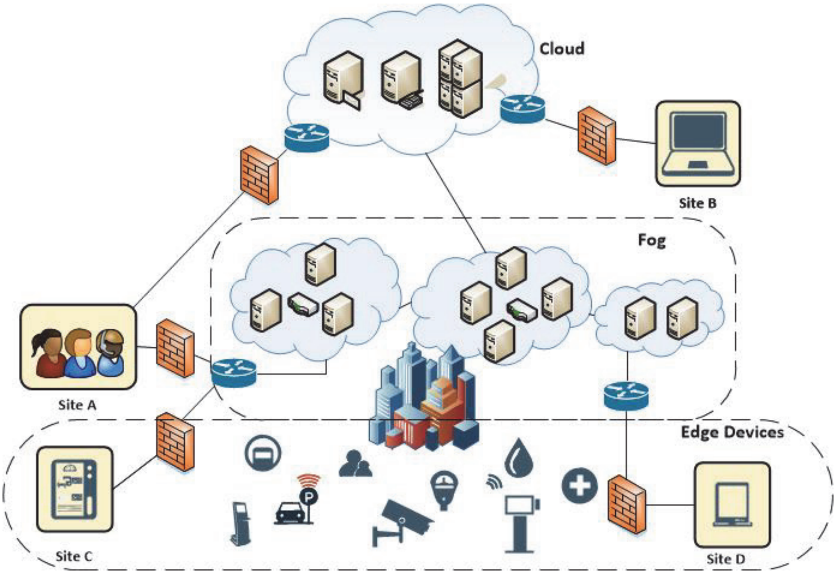

**Fig. 2** – *Edge, Fog and Cloud-based computing framework.*

## 4 Experimental Results: Usage of Multi-spectral Cameras in a Public Safety Example

As a practical example we have staged a scenario of utilization of latest (third) generation of Vlatacom Institute's multi-sensor imaging systems VMSIS3 [25]. VMSIS is powered by external EDGE computing-based AI target detection module and remote command and control (C2) software ORAO in a smart city / public safety application. The goal of the experiment is to demonstrate two aspects of this application: (1) amount of data transferred between the nodes and (2) real-time processing with conclusion how this affects the system's architecture. The experiments are performed at two locations: Belgrade, Serbia - urban street environment and Abu Dhabi, United Arab Emirates - coastline environment.

### 4.1 System setup and amount of data

Internal architecture of VMSIS3 model C825 is shown in Fig. 3. It contains three video channels: visible light, thermal and short wave infrared. Visible light channel has full HD sensor (1920 × 1080 pixels), three colors RGB (8 bits per sample each), with frame rate of 30 frames per second. It produces about 1.5 Gbps of raw video image. Similarly, the system is equipped with high-end cooled thermal imager in medium wave infrared (MWIR) spectral range (wavelengths from 3 to 5 µm). This cutting-edge sensor detects target temperature, so it is capable for vehicle target detection at distances above 20 km, in day or night conditions. More details about thermal imager performance analysis may be found in [26]. Thermal imager has lower resolution of 640×480 pixels (VGA) which are sampled by 16 bit per pixel at up to 60 fps. Thus, thermal images raw data stream rate is up to 295 Mbps. It should be noted that information value of thermal imager is much greater than that of color image, so its lower resolution is not much of an issue. The third imaging channel is short wave infrared (SWIR) with wavelengths 0.9 – 1.6 µm. The main purpose of SWIR is better target identification and observation in extreme fog conditions. Additionally, such sensor can detect laser illumination, which might indicate serious threat, e.g. from terrorists. The resolution of SWIR channel is also VGA, similarly to thermal channel, but frame rate is lower, so it generates about 140Mbps of raw image data.

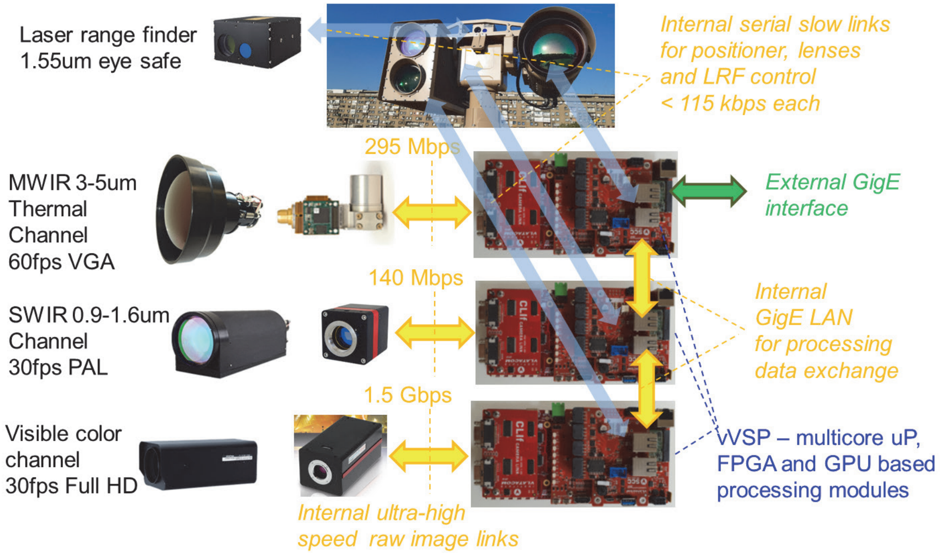

**Fig. 3** – *Smart device VMSIS3-CSD-C825T architecture.*

Each video channel transfer its raw data to signal processing unit, denoted as Vlatacom Video Signal Processing (vVSP) platform. vVSP platform has three types of processing units: 1) a field programmable gate array (FPGA) with infinite parallelization for pixel level processing, 2) a multi-core ARM-based micro-processor – µP, and 3) graphic processing unit GPU with 256 CUDA cores [27]. This unit is capable of running image processing algorithms like: image enhancement, image stabilization, target tracking (in cooperation with pan-tilt positioner platform), etc. In order to provide optimal performance, the algorithms are executed in real-time on raw image data and then video data are compressed via H.264 video compression algorithm and transferred to external GigE port towards other processing systems in smart city. We emphasize that each new signal processing instance gets its own video stream, so more than three streams are transmitted over external interface.

The system is equipped with laser range finder (LRF) enabling accurate distance measurement between sensor and target, even at distances larger than 10 km. Its data stream has negligible capacity of less than 115 kbps, but it's main attribute is necessity for interactivity between image, laser and operator.

The system is installed on pan-tilt positioner device, capable of accurate and fast positioning of the optical axis of sensors to the desired target. Besides positioning accuracy, it`s speed and acceleration capabilities, as well as latency are crucial for same application like tracking. In this particular scenario raw image processing brings minimal possible latency and highest possible quality of image. Thus, for external application it is sometimes necessary to transmit also raw images at maximum quality besides compressed video streaming, but with lower frame rate, even lower than one frame per second.

Obviously, VMSIS3-CSD-C825T is very complex and expensive smart device. But having in mind its operational range of more than 20 km according to [26], certain city may be easily covered with a relatively small number of such devices. For certain applications VMSIS may also be installed on vehicle, making it a mobile or nomadic solution.

Linking of VMSIS3 to external processing system is shown in Fig 4. A VMSIS3 is connected via LAN switch/router to EDGE AI platform which runs target detection application. The hardware of our EDGE AI platform is a server based on ten-core INTEL Xenon 1540 D, equipped with GPU with 3072 CUDA cores, which is more than tenfold increase in processing power compared to single vVSP module in VMSIS3. VMSIS3 is remotely connected via WAN to datacenter which runs cloud-based C2 application. The operator interface is web-based, so the operator may perform its task using remote workstation (usually three-screen device). The operator may setup automatic target detection by specifying patrolling parameters to VMSIS3 and target parameters together with region of interest to AI EDGE platform. After certain target detection AI EDGE platform sends target tracking command and specifies target bounding box to VMSIS, hence initiating tracking procedure. It might raise additional activities in C2 system: recording for further processing, alarming the staff, measuring the distance to target and mapping it on geographic information system of web application etc. We emphasize that all described actions are near real-time. Commands and target information typically have relatively small amount of data, while data streaming consumes from several Mbps to several tens of Mbps per video stream.

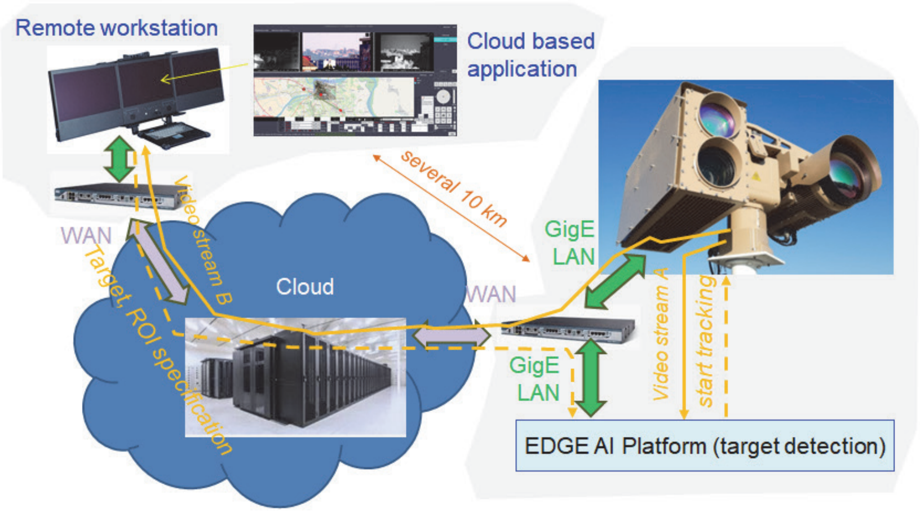

**Fig. 4** – Experiment *setup architecture.*

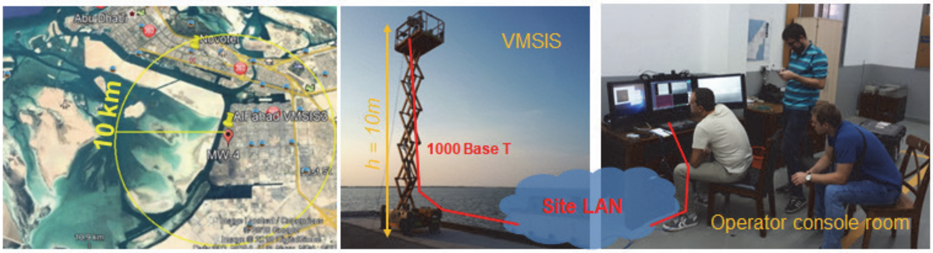

**Fig. 5** – *Experiment location 1 setup in Abu Dhabi, UAE.*

The outline of experiment setup is shown in Fig. 5. The location is chosen to have good line of sight towards city of Abu Dhabi over sea, which puts the observation sensor in very harsh environment, especially in terms of visible light. The main goal of this setup is to test not only sensor performance, but also video compression parameters necessary for proper operation of EDGE AI platform, networking influence (especially bandwidth limitation and latency) and human operator experience. Similar setup is performed at Vlatacom Institute, Belgrade, with main application of urban environment control (Fig. 6).

In the chapter that follows, we will present some experimental results just for illustration, with majority of results being beyond the scope of this paper.

**Fig. 6** – Experiment *location 2 setup in Belgrade, Serbia.*

### 4.2 Experimental results

One of the main benefits of experiment in Abu Dhabi was ability to observe entire city coastline by small movements of the sensor. The main concerns in the setup were usage of MWIR thermal sensor at its range limit and influence of compression (Fig 7.).

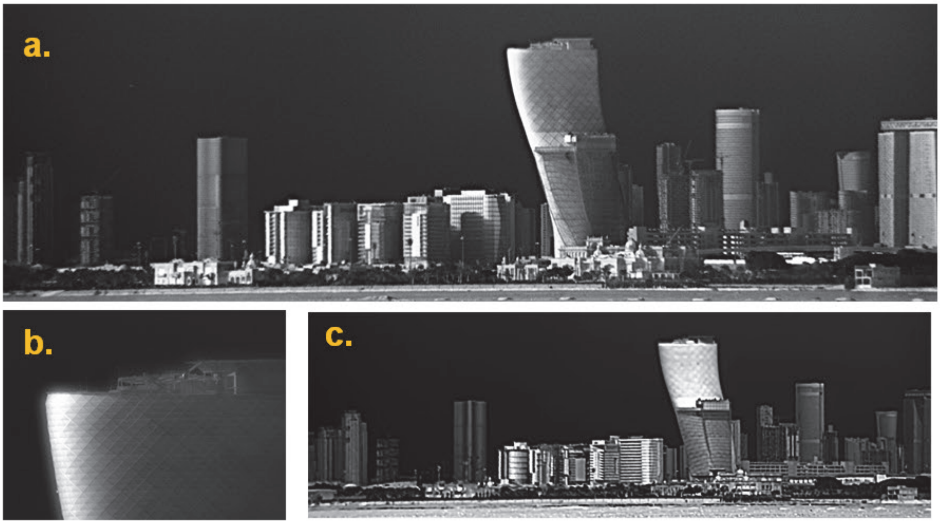

**Fig. 7** – *Thermal MWIR long distance (the city is* 8 km *away from camera) imaging:* (a) *Raw image panorama of Abu Dhabi;* (b) *Raw image optical zoom of hotel Hayat Capitol Gate rooftop,* (c) *H.264 video compression introduce artifacts.*

As expected, those effects could not be neglected, so fine tuning of the H.264 video compression algorithm was performed. The outcome is that compression effects on thermal image are not noticeable in majority scenes if VGA/30fps video stream bit rate is about 60 Mbps, which is more than order of magnitude higher than for visible light color video of similar resolution (even much bigger). This indicates the amount of data that should be supplied from sensor to EDGE AI Platform per processing task. Acceptable quality is obtained at about 10Mbps per stream for MWIR and SWIR VGA channel and 8Mbps per stream for color channel, what is supplied via cloud network. Considering all mentioned data, we conclude that LAN should have capacity of at least GbE, while WAN port communication is between 30 and 50 Mbps, depending on number of streams supplied to cloud base processing. This brings us to the necessity of deploying video management system (VMS) in smart city application. One of the required VMS functionalities is careful distribution (e.g. streaming duplication) of video material between processing platforms and human operators' workstations.

Results from described experiments also show the necessity of having raw image in near real-time for further analysis - especially for AI-based platforms, which require more details and better image quality than human operators (e.g. situation on building rooftop, Fig. 7b).

The second example from Abu Dhabi represents dynamic scenario of monitoring the bridge which is about 12.5 km away from multi-sensor system and monitoring the buildings behind which are about 17 km away (Fig. 8).

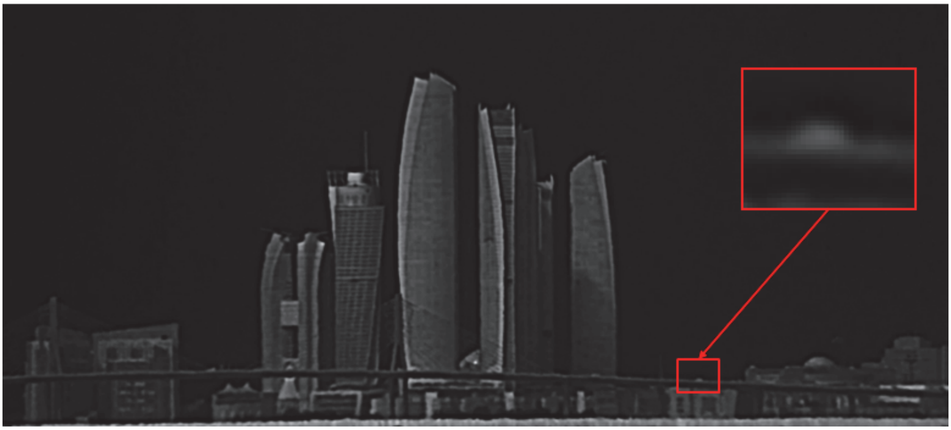

**Fig. 8** – *Cars on the bridge* 12.5 km *away from MWIR thermal camera and Etihad Towers buildings* 17 km *away from camera: ROI-based movement detection.*

Our aim was to detect cars on the bridge by motion detection algorithm running within the selected region of interest (ROI) and thus test whether criterions for thermal image detection range described in [26]. This scenario proved to work satisfactory, not exceeding traffic consumption due to cloud-based image processing on already existing video streams. Unfortunately, resolution of cars images is very low, which is not sufficient to use target detection algorithms like YOLO [28] on EDGE Platform. We emphasize that the visible color channel is completely useless in this scenario due to high level of salt water evaporation from sea. We conclude that color channel is useful in less than 20% of daytime for distances larger than 5 km in this environment.

In urban streets environment in Belgrade, we have first focused on utilization of SWIR channel which proved to be superior to the other two channels during extreme fog conditions, which are very frequent by the end of December and beginning of January. As shown in Fig. 9, the color channel, which is a reliable video sensor in day conditions providing crystal clear image (Fig 9b), becomes completely useless in fog conditions (Fig. 9a). SWIR channel proved to be very useful for traffic monitoring, so employment of EDGE platform running AI-based algorithm for cars and pedestrian detection may be upgraded also for detection of accidental situations and efficient alarming of rescue services. This is one aspect of the future work in this area.

**Fig. 9** – *Belgrade city environment* (1.1 km *away from camera*) *in:*
(a) *extreme fog conditions;* (b) *sunny day conditions.*

**Fig. 10** – *Pedestrian detection and multi-target tracking*
*on different channels, Belgrade, Serbia.*

One of the often promoted applications of AI is pedestrian detection and activation of further processing algorithms like crowd detection in prohibited area, loitering, box-dropping etc. [29]. We have also tried this application on EDGE platform running YOLO target detection algorithm [28] improved by target tracking [30] and multi-target tracking extensions [31], as shown in Fig. 10. The results of such analysis may be further processed in C2 systems for various applications like load optimization in public transportation, accident detections, even detection of improper person-to-person distance, or remote measurement of persons' body temperature in crises situation like recent one caused by pandemic of COVID 19 virus [32]. Since privacy disturbance might raise serious legal issues, usage of MWIR and SWIR sensors might also be justified, because person’s identity is protected in this case.

## 5 Conclusion

Smart city ICT architecture considerations gives strong advantage to shared data processing paradigm between local smart device, EDGE or FOG platforms and Cloud computing. Experimental data shows that the main constrains in public safety smart city applications are: real-time processing, finite signal propagation (e.g. limited by finite speed of light which is not too high: about 5μs are needed to pass only 1m) and constrained number of human operators, with limited reaction speed (limitation of human body reaction). It literally gives no other option than employment of AI-based solution. The sharing between data processing tasks is limited by available processing power on smart device, EDGE, FOG and Cloud processing platforms. The amount of data needed to be transferred for sure has Big Data as a tag, even for single sensor and limited geographical range of its usage. It is also obvious that there is a huge demand for various types of programming skills starting from ultra real-time sensitive task of processing several tens of Gbps of data in smart devices that would require register-gate logic implementation of FPGA or C/C++ implementation in real-time operation system on multi-core embedded system, via AI-based solution on EDGE processing platform to web programming of cloud-based applications. Thus system architecture is very challenging task for every application in modern smart cities that would strongly influence possibilities of solution application and its every-day utilization to make the citizens' life more comfortable. Our future work will be related to optimization of system architecture and implementation of AI-based and Big Data-related applications in high-level programing languages like Python, rather than low level programming languages like C/C++. This would enhance the engagement of pure algorithm developers, rather than professional programmers.

## 6 Acknowledgements

The authors wish to thank to the management of Vlatacom Institute of High Technologies, Belgrade, Serbia and Etimad/AlFahad, Abu Dhabi, United Arab Emirates for supporting the experimental work in this paper.

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