Towards Smart City Innovation

ILLUSTRATED TECHNICAL PAPER

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Abstract

This "**ILLUSTRATED TECHNICAL PAPER**" presents the slides describing the contents of the paper "Towards Smart City Innovation".

The talk was presented at **VIII National Conference on Communication, Computer Networks and Information Security - ENCOM 2018**, 19, 20 and 21 of October 2018 at Federal University of Bahia - UFBA, Salvador, Brazil.

The "illustrated technical paper format" is intended to complement, enrich and subsidize the technical paper content and contains slides, complementary text and additional and/or focused bibliographic references.

Index Terms

Smart City, Innovation, Software-Defined Networking, Openflow, Artificial Intelligence, Machine Learning, Big Data, Cognitive Management, Resource Allocation.

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1 PAPER ABSTRACT

Smart city projects address many of the current problems afflicting high populated areas and cities and, as such, are a target for government, institutions and private organizations that plan to explore its foreseen advantages. In technical terms, smart city projects present a complex set of requirements including a large number users with highly different and heterogeneous requirements. In this scenario, this paper proposes and analyses the impact and perspectives on adopting software-defined networking and artificial intelligence as innovative approaches for smart city project development and deployment. Big data is also considered as an inherent element of most smart city project that must be tackled. A framework layered view is proposed with a discussion about software-defined networking and machine learning impacts on innovation followed by a use case that demonstrates the potential benefits of cognitive learning for smart cities. It is argued that the complexity of smart city projects do require new innovative approaches that potentially result in more efficient and intelligent systems.

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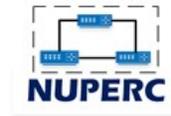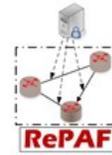
2 PAPER SLIDES

Fig. 1.

−−>　**PAPER TEXT EXTRACT**:
"This article presents a perspective towards **Smart City Innovation** addressing Software-defined Networking, Machine Learning and Big Data issues in smart city projects context [1]."

"Authors argue that smart city projects present a complex new set of requirements with multiple objectives that involve multiple layers using heterogeneous network technologies for a huge number of users. Efficient solutions for smart city scenario are not easily achievable by current approaches typically based on heuristics and meta-heuristics."

"Innovation based on new paradigm and technologies like SDN/Openflow and machine learning provides a new perspective to these projects by allowing the computation of solutions towards the cognitive management of complex network infrastructures coupled with the efficient processing of huge volume of data."

−− > **Paper to read:**

 – The full paper text describing smart city innovation is **"Towards Smart City Innovation Under the Perspective of Software-Defined Networking, Artificial Intelligence and Big Data"** and is available at:

 ∗ **ZENODO** at https://zenodo.org/record/1467771#.W8x9smhKjIU
 ∗ **Research Gate** at https://www.researchgate.net/publication/328410597_Towards_Smart_City_Innovation_Under_the_Perspective_of_Software-Defined_Networking_Artificial_Intelligence_and_Big_Data
 ∗ **ACADEMIA** at https://www.academia.edu/37618281/Towards_Smart_City_Innovation_Under_the_Perspective_of_Software-Defined_Networking_Artificial_Intelligence_and_Big_Data

−− > **Complementary papers on BAM configuration, operation and management**:

 – A summary of Bandwidth Allocation Models (BAMs) is presented in [2]
 – A summary of BAM management switching alternatives is discussed and evaluated in [3]
 – An overview (in Portuguese) of Bandwidth Allocation Models (BAMs) is presented in [4].
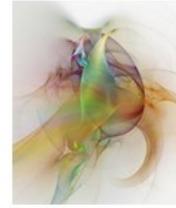
Fig. 2.

−− > **PAPER TEXT EXTRACT**:
"The paper [1] is organized as follows. It initially discusses smart city projects requirements, challenges and proposes a simplified smart city deployment model to support the discussion. Following that, software-defined networking (SDN), artificial intelligence and big data are analyzed under the perspective of contributing to smart city innovation.".

Fig. 3.

−− > **PAPER TEXT EXTRACT**:
"Cities present a clear trend to concentrate the majority of world's population in the years coming. The forecast is that about 65% of world population will live in urban spaces by 2040 [5]. City numbers are impressive: 30 cities will have more than 10 million inhabitants and largest cities will consume 85% of world's energy and produce 80% of the planet's waste [6]."

−− > Papers to read:

  – The requirements for smart city infrastructure are discussed in [6]

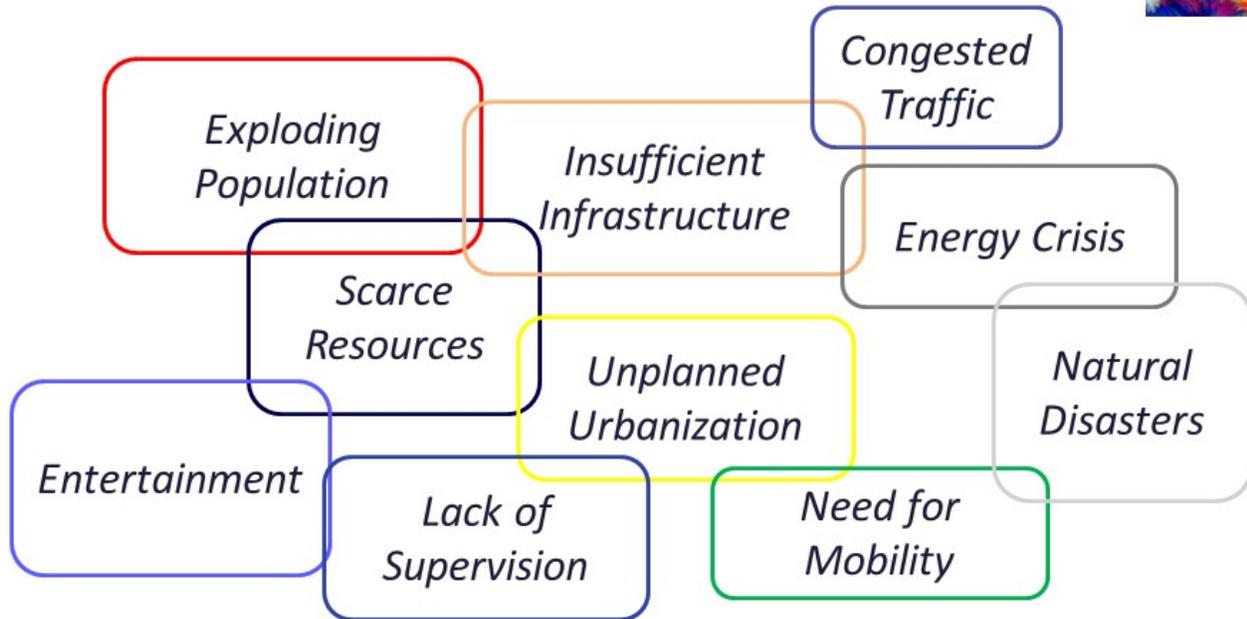## Some (not all) Perceivable Problems in Cities

Fig. 4.

−− >   **PAPER TEXT EXTRACT**:
"Easily perceivable problems in cities include congested traffic, unplanned urbanization, need for mobility, exploding population, scarce resources, waste management and energy distribution among others."

"A Smart City (SC), by definition, addresses the aforementioned urban problems looking for citizen quality of live improvement, promoting sustainability and engaging citizens through transparent government decisions [7]."

Fig. 5.

- **PAPER TEXT EXTRACT**:
  "There are various definitions for smart cities. Theolyre in [8], suggests that a smart city uses Information and Communication Technologies (ICT) very intensively "to provide the ability to gather, analyze and distribute information so as to transform services, improve operational efficiency and entail better decisions."

Smart City – Application Areas & Innovation

- Smart Traffic
- Smart Street
- Smart Parking
- Smart Health (e-health)
- Smart Grid
- Smart Utilities
- Smart Transportation
- Smart Security
- Smart Infrastructure
- Smart Education (e-Education)
- Smart Water Management
- E-government

- Smart Environment
- Smart Government
- Smart Building
- Smart Home
- Smart Living
- Smart Mobility
- Smart Public Services
- Smart Economy
- Smart Waste Management
- Other

Smart City = Smart-*

Fig. 6.

Fig. 7.

−−>   **PAPER TEXT EXTRACT**:
"IEEE Smart City Committee suggests the basic set of smart city areas to explore"

Fig. 8.

−− >   **PAPER TEXT EXTRACT**:
"Smart city projects need to innovate [7]."

Fig. 9.

−− > **PAPER TEXT EXTRACT**:
"Innovation must be present due to the complexity, multidimensional characteristic, size and multidisciplinary nature of the problems involved."

Fig. 10.

−− > **PAPER TEXT EXTRACT**:
"As such, innovation for the purpose of this discussion focused on city's smartness evolution can be understood as to evaluate and use a new set of emerging technologies that could effectively address in a efficient way the requirements and complexity of smart city's projects."

"More recently, a new set of network and computer paradigms and technologies have emerged. Software-defined networking (SDN), internet of things (IoT), network function virtualization (NFV), LTE/5G high speed wireless technologies, cloud computing, big data, cognitive management, machine learning and blockchain are examples of new elements that can bring a new perspective to smart city project developments."

Smart City over the Innovation Path

◆ Number and type of potentially internet-connected devices:

- IoT (Internet of Things) devices
- Sensors or actuators in some form (RFID tags, mobile phones, body sensors, ITS monitoring devices, others)

[Source: Cisco Internet Business Solutions Group (IBSG)]

- World population (in billions)
- Internet-connected devices (in billions)
- Internet-connected devices per person
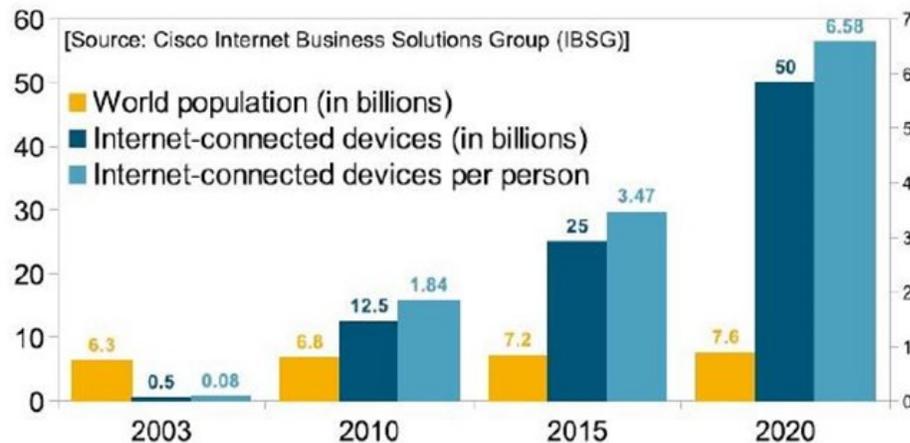
(Source: adapted from F. Javed, M. K. Afzal, M. Sharif, and B. Kim. Internet of Things (IoT) Operating Systems Support, Networking Technologies, Applications, and Challenges: A Comparative Review. IEEE Communications Surveys Tutorials, 20(3):2062–2100, 2018 and Cisco Internet Business Solutions Group)

Fig. 11.

−− > **PAPER TEXT EXTRACT**:
"On the innovation path, another relevant aspect of smart city is the number of potentially internet-connected devices. In effect, most of the connected devices in smart cities are IoT sensors or actuators in some form (RFID tags, mobile phones, body sensors, ITS monitoring devices, others). In terms of numbers, it is expected to deal with millions or billions of sensors and actuators with multiple type of equipment by user (Fig. 11)."

−− > Paper to read:

– Potentially Internet-connected devices and objects by user [9] and Cisco Internet Business Solutions Group.

Fig. 12.

−−> **PAPER TEXT EXTRACT**:
"A smart city project basically looks for improving the smartness of city's systems and applications and some of its requirements and characteristics include [6] [7] [10]:

- A robust and scalable framework combined with secure and open access;
- A user-centric or citizen-oriented architectural approach;
- A huge volume of storable, findable, sharable, tagged, mobile and wearable public and private data enabling citizens to access information from anywhere and when needed;
- An application level with analytically and integrated capabilities; and
- An smart physical and network infrastructure allowing the transfer of huge volume of heterogeneous data and the support of complex and distributed services and applications."
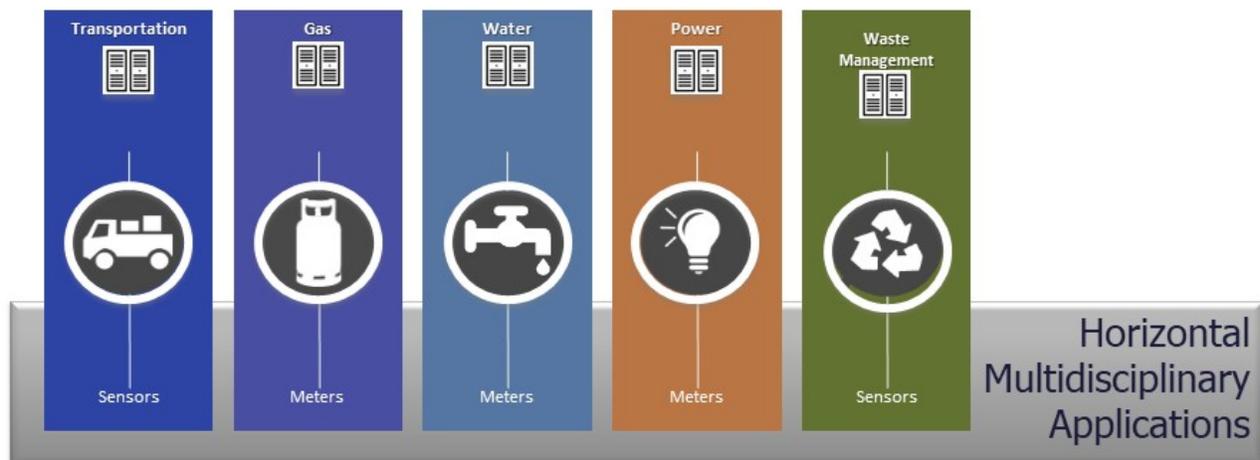
Fig. 13.

−− > **PAPER TEXT EXTRACT**:
"Most of current legacy smart city solutions do not present the set of required capabilities or are not capable to cope with the ever increasing functionality complexity required by huge, efficiently managed and multipurpose urban spaces."

"Government, institutions and private organizations need to plan their strategy towards a new smart city concept where innovation emerges as a fundamental requirement for both technical and managerial perspectives. It is expect that networks and computer technologies will keep playing a key role on this innovation process."

"Smart city challenges are both technical and managerial. Managerial solutions are not discussed in this paper but do influence the technical perspectives discussed. For example, new business model and governmental strategies are required since smart city projects will bring, by definition, more effectiveness and transparency to most of current city legacy processes."

"Another managerial aspect of smart city developments concerns the legacy "siloed" fashion in which projects are still developed by municipalities. In effect, the inherent complexity of smart city projects requires more integrated and systemic solutions. A multidisciplinary approach is most often the best one and this is a real challenge for most actual city administrations."

Fig. 14.

−− > **PAPER TEXT EXTRACT**:
"Smart city projects with a multidisciplinary perspective require a framework capable of structuring and modelling its basic components, its interactions and flow of data. The smart city's project deployment framework proposed for this discussion has a layered structure composed by three levels (Fig. 15):

– A physical components level;
– A communications level; and
– An application level."
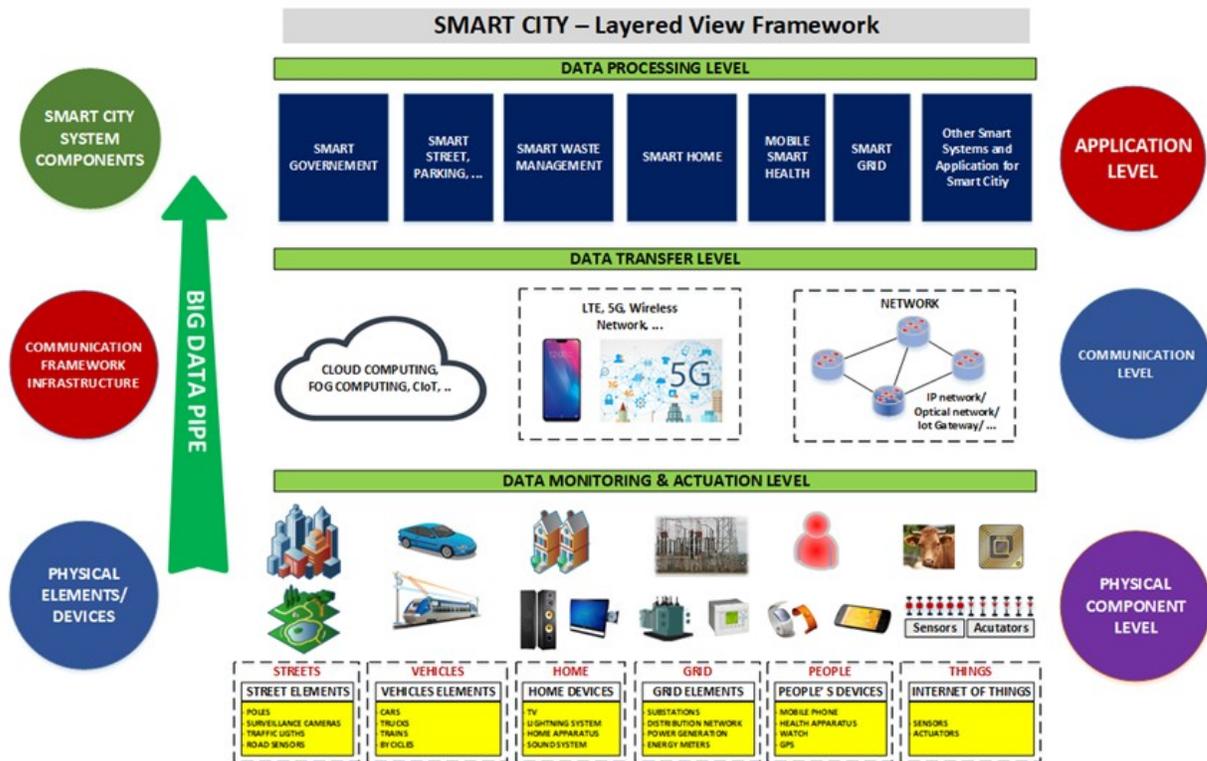
Reference: J. S. B. Martins, "Towards Smart City Innovation," ENCOM 2018 - VII Conferência Nacional em Comunicações, Redes e Segurança da Informação, pp. 1–7, 2018.

Fig. 15.

−−> **PAPER TEXT EXTRACT**:
"The physical components level hosts all devices, sensors, equipment, apparatus and components belonging to the various "smart" systems, services and applications."

"The communications level comprises all network technological alternatives for providing communication facilities among physical elements and applications."

"The application level includes all "smart" systems and developments conceived for the city. These systems are fed by and process a huge volume of data that uses the communication level to flow among the entities involved in the application process."

Fig. 16.

−−> **PAPER TEXT EXTRACT**:
"Each framework level presents a specific set of characteristics and requirements where innovation and new computer paradigms are being currently applied and researched."

"At physical level the main issues are:

– huge volume of devices;
– heterogeneity; and
– low-processing capabilities and energy limited resources."

"At "application level" innovation also plays a significant role that is not addressed by this paper. In effect, it is at the application level where the integration provided by the physical and communication levels will produce the multidisciplinary effect that will impact the citizens quality of life. Authors in [11] [12] and [5] present and discuss examples on how new multidisciplinary and integrated smart city applications can benefit citizens."

Communication Infrastructure with Innovation

◆ Urban context has some unique characteristics and attributes:

- **High density** of devices used by humans or automated systems and processes
- A **large and heterogeneous** variety of networking technologies (HetNet) supporting sensors, actuators and devices
- A highly **dynamic traffic pattern** to and from the physical elements and IoT devices
  - ◆ This is different of traffic patterns generated by human beings with computers and, as such, is a new aspect to explore in terms of planning and dimensioning of **resource allocation**
- Various **physical topologies** including unstructured and meshed ones
- An **interoperability** inherent requirement since devices and applications must communicate.

Fig. 17.

−− > **PAPER TEXT EXTRACT**:
"The communication level is the main focus of this paper and its characteristics are highlighted and discussed."

"The communication framework infrastructure is a fundamental architectural element in any smart city project. It has to address the urban context requirements with some unique characteristics and attributes like [8] [13]:

- High density of devices resulting mainly from the aforementioned trend on potentially internet-connected devices used by humans or automated systems and processes.
- A large and heterogeneous variety of networking technologies (HetNet) supporting sensors, actuators and devices that are present on the smart city deployment.
- A highly dynamic pattern of traffic to and from the physical elements, devices and applications. Traffic patterns generated by smart devices (IoT, sensors, other) can be either correlated or bursty. This is different of common traffic patterns generated by human beings with computers and, as such, is a new aspect to explore in terms of planning and dimensioning of resource allocation.
- A variety of physical topologies including unstructured and meshed ones.
- An interoperability inherent requirement since devices and applications must communicate."
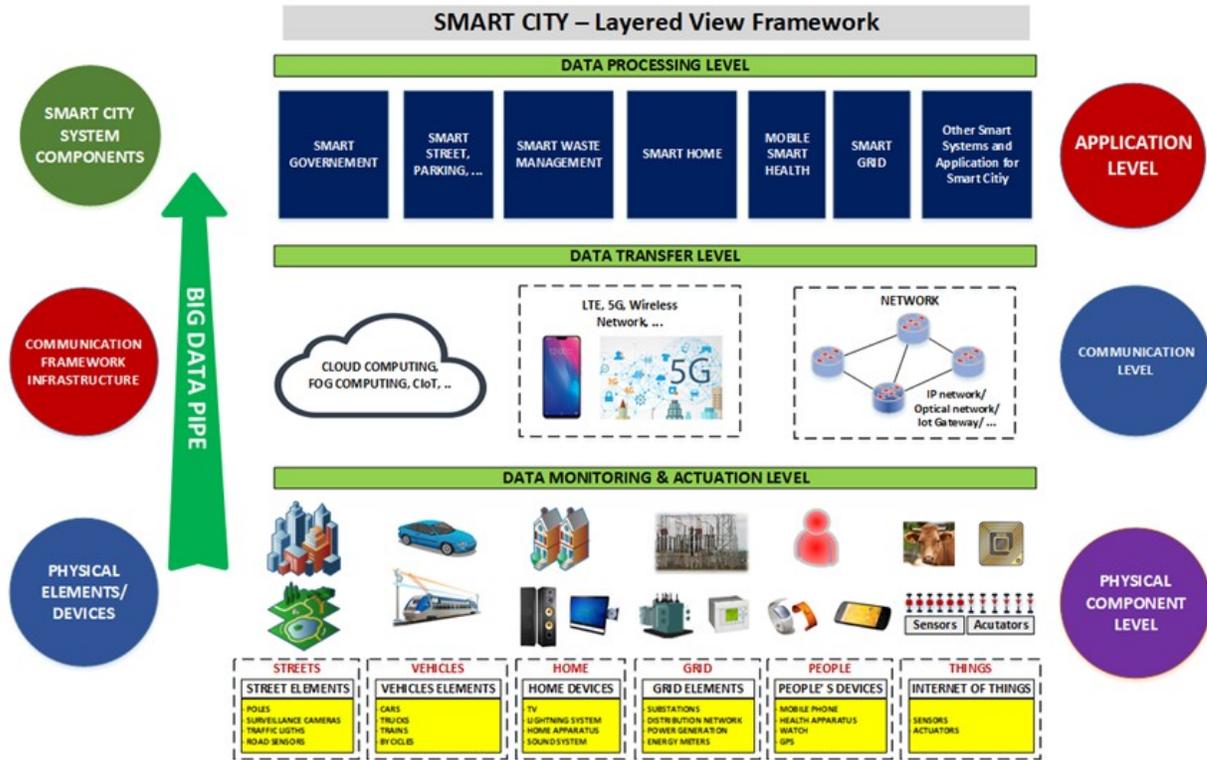
Reference: J. S. B. Martins, "Towards Smart City Innovation," ENCOM 2018 - VII Conferência Nacional em Comunicações, Redes e Segurança da Informação, pp. 1–7, 2018.

Fig. 18.

−− >   **PAPER TEXT EXTRACT**:
"In general the aforementioned characteristics and requirements make smart city projects "unique" requiring new approaches and, as such, is a potential field for innovation."
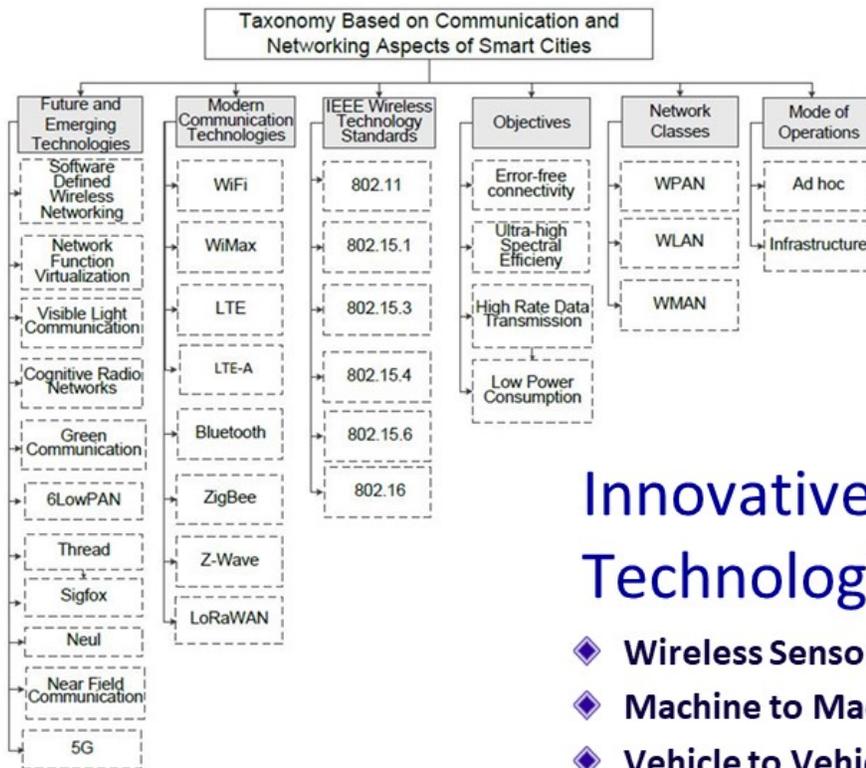
Reference: I. Yaqoob, I. A. T. Hashem, Y. Mehmood, A. Gani, S. Mokhtar, and S. Guizani, "Enabling Communication Technologies for Smart Cities," *IEEE Communications Magazine*, vol. 55, no. 1, pp. 112–120, Jan. 2017.

Fig. 19.

−− >   **PAPER TEXT EXTRACT**:
"There is a variety of networking technologies, some innovative, that are currently being explored for use in smart city projects. Technologies like wireless sensor networks (WSN), machine to machine communication (M2M), vehicle to vehicle communication (V2V), cognitive radio networks (CRN), visible light communication (VLC) and near field communication (NFC) are examples of innovative solutions being currently explored by researchers and developers [13]."

Fig. 20.

−− >   **PAPER TEXT EXTRACT**:
"Having the smart city challenges, characteristics, basic requirements and deployment model in mind, the next question is how software-defined networking, artificial intelligence and big data capabilities may contribute and foster smart city innovative projects."

Why Software-defined Networking for Smart City Developments

◆ Allows a logically centralized view and control of network equipment and resources

◆ Allows a **dynamically configurable network infrastructure** in terms of:

- Routing
- Traffic profile adaptation
- Allows very specific programming approaches
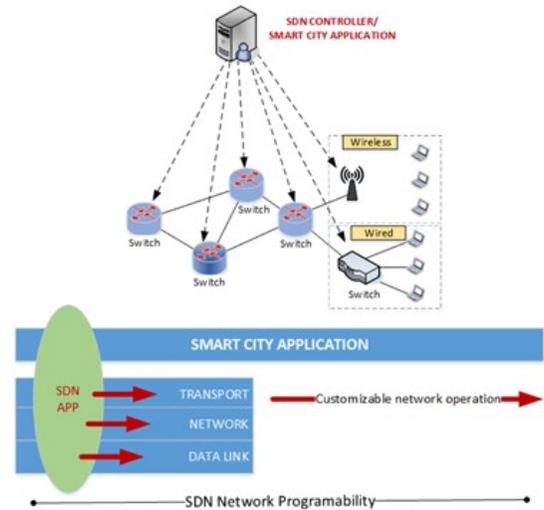
➡ Our point is that network infrastructures have to evolve to a more dynamic and flexible operation and management approach and, for that, SDN is a suitable solution that brings various benefits for the deployed network.

Fig. 21.

−− > **PAPER TEXT EXTRACT**:

"Software-defined networking (SDN) allows, in summary, the creation and deployment of programmable networks and systems [14]. In technical terms, SDN uses a logically centralized controller to program network equipment using a well know interface and protocol like Openflow (Fig. 21). As a result, we can control network state transitions by monitoring network operational parameters and programming any modification of its operational behavior in terms of packet handling and manipulation [7]."

"SDN can fit and support smart city project developments in all three deployment levels:

- at physical components level;
- at communications level; and
- at big data/ application level."

"At communication level, smart city projects require the transfer of huge volume of data captured by heterogeneous sensors over large distributed areas. In this scenario, the communication infrastructure has to cope with heterogeneous communications requirements that are difficult to realize with a single or not dynamically configurable network infrastructure. Another important issue at the communication level is routing and traffic patterns variability. Routes have to be defined between data source and destinations and the network infrastructure has to adjust itself to the variability of communication resources demanded. Due to the variety of objectives and requirements involved in these communications such as QoS (Quality of Service), QoE (Quality of Experience) and SLA

(Service Level Agreement) compliance, a flexible and programmable network infrastructure is the best possible approach."

"SDN with Openflow, P4 or other deployment approach responds very positively to these difficult to achieve objectives and requirements. In effect, SDN adoption by smart city projects brings the following benefits:"

  – Allows a logically centralized view and control of network equipment and resources; and
  – Allows a dynamically configurable network infrastructure in terms of routing, where routing here means the definition and setup of a path between data source and destinations."

"It is important to remark that SDN deployment in smart city projects do presents some important challenges. The most important one is the level of acceptance and maturity of the technology. Today's SDN deployment is prevalent in specific areas like private controlled networks, like Google's B4 approach for routing [15], and the technology has not yet achieved a full consensus about its widespread utilization in all communication areas. Anyhow, our point is that network infrastructures have to evolve to a more dynamic and flexible operation and management approach and, for that, SDN is a suitable solution that brings various benefits for the deployed network. Beyond all this, SDN with virtualization has the capability and merit to keep legacy operation or, optionally, to virtualize its operation keeping both legacy an innovative networks operating simultaneously over the same equipment substrate."

"Until very recently, most solutions based on SDN paradigm and its protocols (Openflow, P4, other) have been designed for wired infrastructures [16]."

"Nowadays, SDN-based solutions for wireless do prevail and have been extensively researched. This comes from the fact that wireless in cities do support mobility and SDN allows a more accurate and centralized view and control of network states with mobile users."

"As examples of wireless SDN-based solutions, Hakiri in [17] explains why current protocols for mesh cloud do not fit new smart city requirements and SDN-based wireless solutions are presented. Rametta in [18], exploits SDN with the perspective of more easily deployment of services. This is achieved by merging SDN with network function virtualization (NFV) for a smart city video-surveillance system. The innovative results, according to authors is that "the video stream generated by each IP camera is automatically rerouted directly to the "interested receivers" in a point-to-multipoint fashion"."

"Another challenging research issue for the communication level in smart city projects is how to distribute the collected data among producers and consumers. Data will be mainly produced by IoT sensors and as such will be highly distributed, in large volume and with distinct requirements (QoS, QoE, SLA, other). Two technical aspects are involved in this discussion:

  – How semantically discover and distribute data; and
  – How to allocate efficiently resources to the communication channels (communication level) necessary for data distribution."

"One possible approach for the first challenge is currently being addressed by using Publish/Subscribe approaches [19]. SDN plays again an innovative role with these approaches since it allows a more efficient control and deployment of network resources. Jalali in [5] and Mazhar in [20] present two distinct uses of SDN to foster resource allocation for IoT based smart city projects."

Fig. 22.
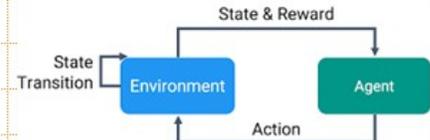
−− > **PAPER TEXT EXTRACT**:
"Artificial intelligence using machine learning techniques applied to smart city has drawn a lot of attention from research. It has a tremendous application potential by exploring, for instance, a cognitive processing and management approach for networks, IoT and data."

"The effective contribution that machine learning brings to smart city application and systems comes from the fact that:

- A cognitive approach allows the computation of solutions for highly complex problems with multiple requirements and objectives.
- Cognitive solutions have the capability to extract "knowledge" and "learn" from huge and dynamic volume of data and this is an actual requirement to allow more "intelligent" and easy to use applications.
- Cognitive-based application and systems have the capability to substitute, at least in part, some human tasks (like management tasks), which turn out to be difficult to realize and subject to errors when a large and sometimes unrelated volume of information is involved."

Fig. 23.

−−> **PAPER TEXT EXTRACT**:
"In relation to the smart city problem complexity, the computation of solutions under multiple requirements and objectives using an heuristic or meta-heuristic approach is difficult due to the NP-hard nature of the computation. Machine learning provides a new possible approach to solve the multiple requirement and objectives keeping computation on a reasonable level of difficulty and required computational capacity. This allows, for instance, the possibility to develop "on-the-fly" solutions for problems with a large number of decisions variables."

"In smart city a large volume of data has to be captured, aggregated, smoothed, clustered and processed. Machine learning techniques do apply in this specific context mainly for clustering and knowledge extraction [21] [22]."

"In summary, artificial intelligence and machine learning are techniques known for decades that, nowadays, are capable to assist in the development of new solutions to many common problems found in smart cities for network infrastructure and IoT data. Machine learning allows intelligent network infrastructures with smarter data management and cognitive applications in general [22]."

Smart City
Paradigms & Communications Technology (non exhaustive list)

◆ <u>New paradigms</u> for architectures and technologies that can be involved in Smart City projects:

- Machine Learning (ML), CBR - Case-based Reasoning, RL – Reinforcement Learning, Deep learning, Fuzzy, Genetic Algorithms, other
- OpenFlow/ SDN – Software Defined Networks, P4 and Network Function Virtualization (NFV)
- Virtualization
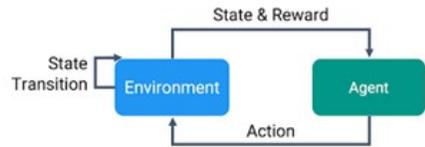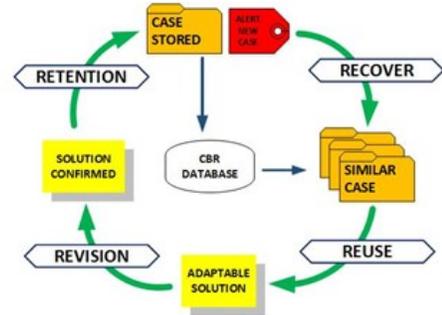
Fig. 24.

Fig. 25.

−− > **PAPER TEXT EXTRACT**:
"The big data innovation perspective for smart city projects under the technological point of view involves minimally the following aspects:

– Big data analytics; and
– Big data processing, transfer and storage."

"First, it is important to highlight that the main target pursued by big data innovation in smart city is to extract information and knowledge efficiently to be used on behalf of the citizens."

"Extract information and knowledge is certainly well accomplish by machine learning methods like reinforcement learning, case-based reasoning, deep learning, deep reinforcement learning (DRL) and unsupervised learning among other possibilities [23] [22]."

"One challenging issue concerning big data within smart city projects is to decide "where" to process and store the big data chunk. The possibilities involved include:

– To adopt an edge computing approach like used by fog computing [24]; and/or
– To adopt either user-centric or content-centric approaches for data processing, communication and storage [25] [23]."

"In all cases, introduce some "intelligence" is innovative in processing the big data flow from the physical components level to the application level through the communication level."

"The technical aspects of big data processing, communication and storage are far extensive. Innovation perspectives for the purpose of this specific discussion of big data issues in smart cities often converges to the adoption of edge computing or not for either user-centric or content-centric data processing approaches with big data analytics. In this specific context, both SDN and machine learning play a fundamental role."

"Big data analytics is, by definition, well supported by machine learning with various alternative techniques (CBR, RL, deep learning, other) [21]."

"Big data processing with SDN is discussed by Khan concerning its communication and processing aspects in [26]. Smart city big data processing and analytics by using different machine learning techniques is discussed by Mohammadi in [22] and Khan in [12]. Finally, edge computing has been extensively adopts in IoT scenarios with big data as discussed in [22]."

Smart City & Big Data

◈ Aspects of the "**big data**" issue:

- Large volume of collected/gathered data (distributed)
- Requires large and low cost storage
- Requires ontologies:
  - ◆ How systems interoperate among themselves and among various physical components (sensors, actuators, ...)
- Requires aggregation
- Geo-referencing (GIS – Geographical Information Systems approach) might be associated to the collected data
- Statistics and analytics
- Data sharing
- Decision-support systems

- Uses various machine learning and data-science techniques to mining knowledge and information
- E-health has a great potential

Fig. 26.
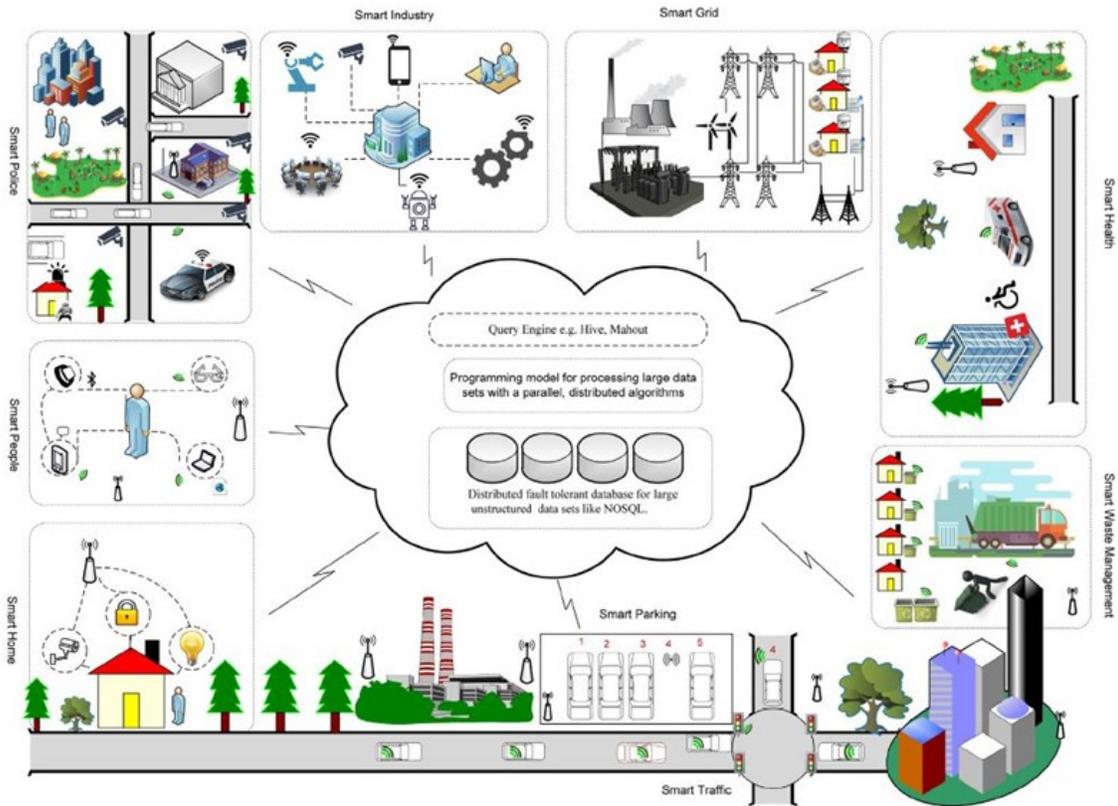
Reference: From I. A. T. Hashem *et al.*, "The Role of Big Data in Smart City," *International Journal of Information Management*, vol. 36, no. 5, pp. 748–758, Oct. 2016.
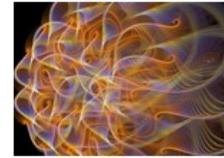
Fig. 27.

Fig. 28.

−− >   **PAPER TEXT EXTRACT**:
"A case study that highlights how innovation plays an important role in current cognitive management developments is presented in [27]."

−− >   Complementary paper to read:

– The **RePAF Project** illustrates the general strategy for cognitive resource allocation in various contexts including the smart city one [28].

Cognitive BAM-based Resource Allocation
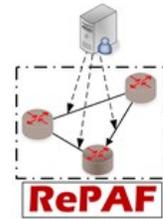
◆ The development aims to "enhance management" by adopting cognitive tools to support the overall management process (OAM - Operation, Administration and Management).
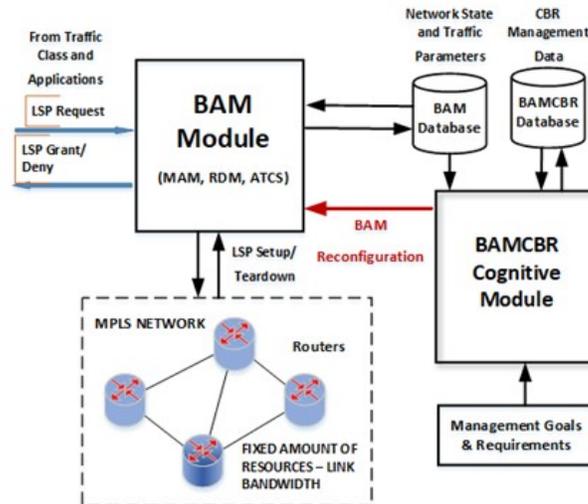
Reference: E. Oliveira, R. Reale, and J. Martins, "Cognitive Management of Bandwidth Allocation Models with Case-Based Reasoning - Evidences Towards Dynamic BAM Reconfiguration," in *IEEE International Symposium on Computers and Communications - ISCC 2018*, Natal, Brazil, 2018, pp. 1–7.

Fig. 29.

−− >   **PAPER TEXT EXTRACT**:
"The development aims to "enhance management" by adopting cognitive tools to support the overall management process (OAM - Operation, Administration and Management). The focus of this preliminary work is to control the allocation of bandwidth based on bandwidth allocation models (BAMs) operation for an MPLS network."

"The main components of the BAM-based cognitive approach are illustrated in Figure 29."

Cognitive BAM-based Resource Allocation

◆ Overall operation:

- The **BAM model** controls bandwidth allocation per group of users in **Traffic Classes (TCs)**

- User request bandwidth to the BAM module that behaves as **bandwidth broker** granting or denying requests

- The **BAM model** used is **dynamically configured** (MAM or RDM or ATCS) as a function of traffic demand which are variable both in time and in terms of its bandwidth requirements (reflecting application QoS/ QoE)

Fig. 30.

−− >   **PAPER TEXT EXTRACT**:
"The overall operation, in summary, is as follows:

- The BAM model controls bandwidth allocation per group of users in Traffic Classes (TCs);
- User request bandwidth to the BAM module that behaves as bandwidth broker granting or denying requests; and
- The BAM model used is dynamically configured as a function of input demands which are variable both in time and in terms of its bandwidth requirements (reflecting users QoS/ QoE)."

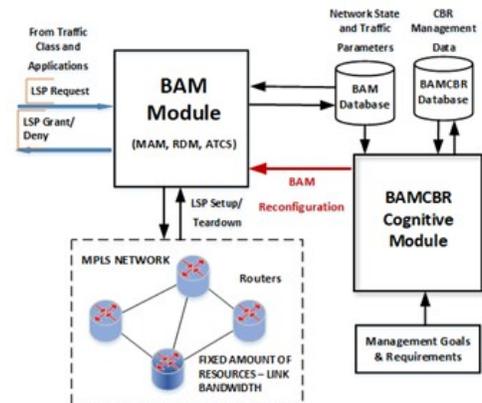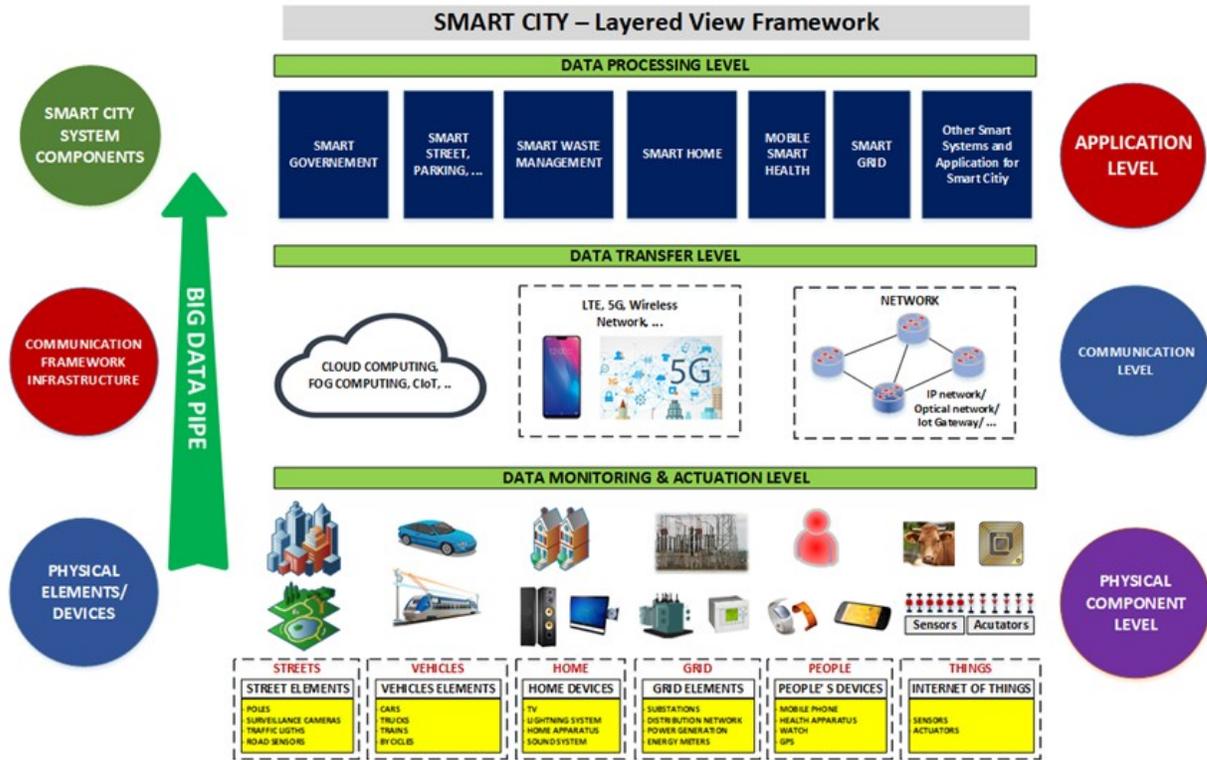Reference: J. S. B. Martins, "Towards Smart City Innovation," ENCOM 2018 - VII Conferência Nacional em Comunicações, Redes e Segurança da Informação, pp. 1–7, 2018.

Fig. 31.

Cognitive BAM-based Resource Allocation

◈ Implementation details:

- BAMCBR uses **Case-based Reasoning (CBR)** for infer and learn BAM configuration

- BAM module uses **OpenFlow** to:
  - Monitor network path information
  - Configure ethernet switches
  - Emulate a MPLS network view for external users

- Operation dynamic and is on-the-fly
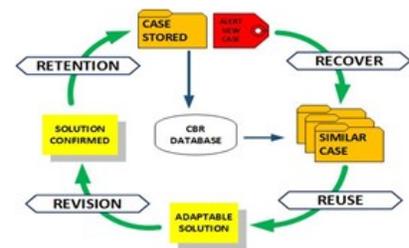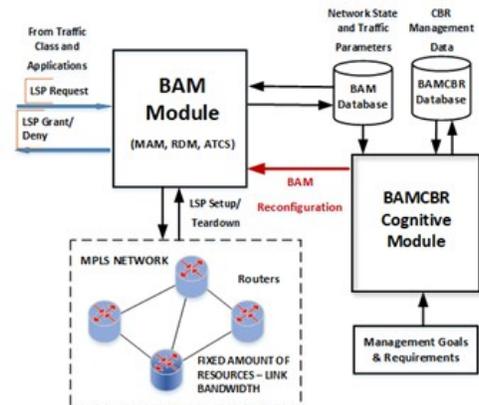
Reference: E. Torres, R. F. Reale, L. N. Sampaio, and J. Martins, "BAMSDN: Uma Ferramenta para a Exploração Dinâmica e Flexível de Recursos Baseada em Modelo de Alocação de Banda e SDN/OpenFlow," in *Proceedings of the Brazilian Symposium on Computer Networks and Distributed Systems - SBRC 2018*, Campos do Jordão, Brazil, 2018, pp. 1–8.

Fig. 32.

−− > **PAPER TEXT EXTRACT**:
"The result demonstrated by Reale in [3] is that, depending on the input traffic pattern (profile of bandwidth demands) the BAM model must be reconfigured between distinct models (MAM, RDM or ATCS) to optimize network operation like, for instance, to achieve the best possible link utilization. This reconfiguration is often mentioned as "BAM switching"."

"From the management point of view, BAM switching must be executed "on-the-fly" and the decision either to maintain actual configuration or reconfigure the BAM model has multiple requirements and possibly various objectives. Some possible management objectives include to increase link utilization, to reduce blocking or to reduce packet loss among others."

"The option for using machine learning addresses the difficulty and challenge that we have to learn about network status and decide on reconfigure it or not. In effect, having multiple requirements and multiple objectives, as is the case, leads to a rather complex solution that are difficult to handle with heuristic or meta-heuristic based solutions. The machine learning approach presents effectively some difficulties in the modelling process but has the advantage of acquire knowledge and, as such, is capable to deal with much more complex scenarios reacting to them."

"The adoption of SDN/Openflow is somehow disruptive, as the paradigm itself, and addresses the difficult we still have to dynamically configure networks. In effect, dynamic reconfiguration, like

setting up and tearing down LSPs under dynamic requests is not evident on classical IP networks."

"The main challenges involved in providing an efficient management solution for this bandwidth allocation setup are:

- The MPLS network has a highly dynamic traffic pattern;
- MPLS users have, as often happens in actual networks, various quality of service (QoS) and quality of experience (QoE) requirements; and
- The set of requirements for optimizing the configuration parameters of the BAM-based MPLS operation (bandwidth available per class, packet loss, delays, link utilization, other) is highly complex with multiple objectives."

Cognitive BAM-based Resource Allocation

◆ Lessons learned:

- Machine learning cognitive management using CBR did learn from policies and current performance metrics whether the current configuration is adequate and, subsequently, was able to dynamically reconfigure BAM models to achieve the specified manager's goal

- Network performance was improved in alignment with manager's predefined policy

Fig. 33.

−−> **PAPER TEXT EXTRACT**:
"Lessons learned from the adoption of machine learning and Openflow innovative techniques for the cognitive management of a BAM-based bandwidth allocation tool were [27]:

- The machine learning cognitive management using CBR did learn from policies defined for the network and current performance metrics whether the current configuration is adequate and, subsequently, was able to dynamically and autonomically reconfigure BAM models to achieve the specified manager's goal.
- Network performance was improved in alignment with manager's predefined policy."
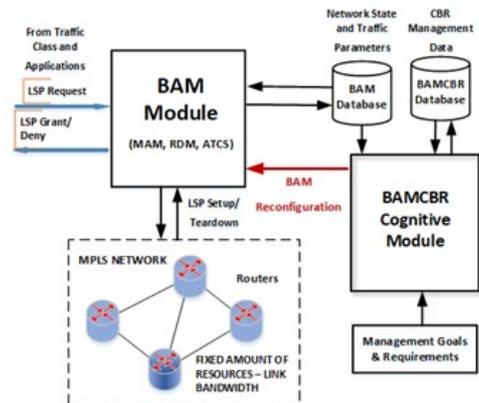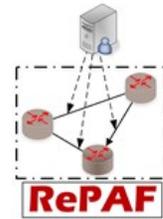
Cognitive BAM-based Resource Allocation

◆ Innovation was explored in distinct ways:

- Allowing the cognitive management of a system using a huge number of parameters that are difficult, if not impossible, to handle by humans (managers)

- Obtaining a "on-the-fly" solution that adapts the network configuration dynamically (by "dynamic" it is meant according with current user's traffic profile and load over the network)

- Deploying a new configuration "on-the-fly" which is not easily implementable by typical IP networks

Fig. 34.

−− > **PAPER TEXT EXTRACT**:
"In summary, innovation was explored in two distinct ways:

- Allowing the cognitive management of a system using a huge number of parameters that are difficult, if not impossible, to handle by humans (managers);
- Obtaining a "on-the-fly" solution that adapts the network configuration dynamically. By "dynamic" it is meant according with current user's traffic load over the network; and
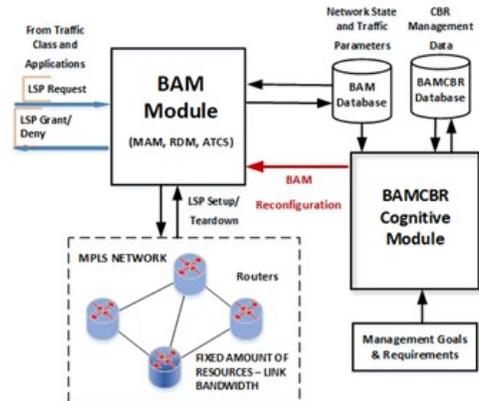- Deploying a new configuration "on-the-fly" which is not easily implementable by typical IP networks."

"The first and second gains result from innovating with machine learning and the last one (network deployment) by using SDN/Openflow."

Fig. 35.

Joberto Martins

◆ Current position: Professor at Salvador University - UNIFACS and visiting professor at Hochshule Für Technik und Wirstchaft Des Saarlandes, HTW – Saarbrucken, in Germany.

◆ PhD in Computer Science, UPMC, Paris – France, 1986; M.Sc. in Electronic Engineering, PII, Eindhoven – Netherlands, 1979

◆ Worked as visiting scientist at ICSI – California University at Berkeley (USA) in 1995; PosDoc at Évry University – Paris – 2016

◆ Member of IEEE Research Committee on Smart Grid and IEEE Technical Activities Committee on Smart Cities

◆ Additional information: see "Joberto Martins" on Google

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Fig. 36.

PPGCOMP

https://www.unifacs.br/mestrado/mestrado
-em-sistemas-e-computacao/

**Computer Science
Research at UNIFACS**

UNIFACS
UNIVERSIDADE SALVADOR
LAUREATE INTERNATIONAL UNIVERSITIES'

Fig. 37.

$-->$ **PAPER TEXT EXTRACT**:
"Computer science research at Salvador University - UNIFACS"

Fig. 38.

−− > **PAPER TEXT EXTRACT**:
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Computer Science at Unifacs

◆ **PPGCOMP** – Masters Program on Computer Science
  - http://www.unifacs.br/mestrado/mestrado-em-sistemas-e-computacao/

◆ Computer Science:
  - Machine Learning, e-science, big data, IoT, data monitoring and smart city applications

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Fig. 39.

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Fig. 40.

−− > **PAPER TEXT EXTRACT**:
"Computer science research at Salvador University - UNIFACS"

Computer Networks (04 profs)
Research Topics

- ◆ Machine Learning
- ◆ Smart City
- ◆ E-Health
- ◆ Internet of Things (IoT)
- ◆ Computational Intelligence
- ◆ SDN/ OpenFlow
- ◆ Cognitive and Autonomic Management
- ◆ Context Awareness
- ◆ Modeling and Simulation
- ◆ Smart Grid

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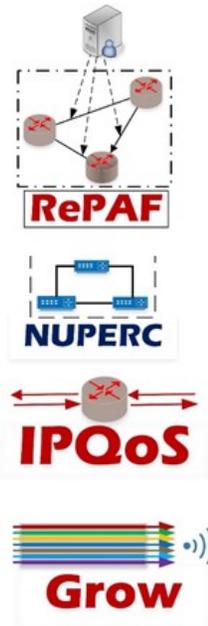
42

Fig. 41.

−− >   **PAPER TEXT EXTRACT**:
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Software Engineering (06 profs)
Research Topics

- Big Data
- Machine Learning Application
- E-Science
- Software Maintenance and Technical Debt
- Ubiquitous Computing and Software Engineering
- Information Technology Management
- Business Intelligence
- XBRL SPED, Data Quality, GIS and Security
- XBRL and Mobile Computing
- SOA, Web Services and XBRL
- Data Visualization and Software Visualization
- Software Quality
- Software Process Modelling

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Fig. 42.

−− > **PAPER TEXT EXTRACT**:
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Web/Multimedia Applications and GIS (03 profs)
Research Topics

- ◆ Geographic Information Systems (SIG)
- ◆ Multimedia, Hypermedia and Web Technologies
- ◆ Virtual and Augmented Reality
- ◆ Mobile Objects and Trajectory Semantics
- ◆ Knowledge Mining in Space-Temporal database
- ◆ Crowdsourcing
- ◆ Mobile SIG and WEB SIG
- ◆ Embedded Systems

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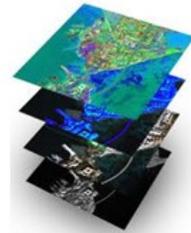
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Fig. 43.

−− > **PAPER TEXT EXTRACT**:
"Computer science research at Salvador University - UNIFACS"

PPGCOMP TEAM 2018

Professor	
Artur Henrique Kronbauer	Dr – UNIFACS/UFBA - BR – 2013
Ana Patrícia Magalhães	Dr – UNIFACS/UFBA – BR - 2015
Ernesto de Souza Massa Neto	Dr – UNIFACS/UFBA – BR - 2014
Eldman Nunes	Dr – UFF – BR - 2003
Glauco de Figueiredo Carneiro	Dr – UNIFACS/UFBA - BR – 2011
Joberto Sérgio Barbosa Martins	Dr – UPMC (Paris VI) – França – 1986
Jorge Alberto Prado de Campos	PhD – UMO (Maine at Orono) – US - 2004
Paulo Caetano da Silva	Dr – UFPE - BR - 2010
Paulo Nazareno Sampaio	Dr – Univ. Paul Sabatier / LAAS-CNRS – França - 2003
Rodrigo Spínola	Dr - COPPE/UFRJ - BR - 2010
Sergio Martins Fernandes	Dr. – USP – BR - 2013

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Fig. 44.

−− >   **PAPER TEXT EXTRACT**:
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Fig. 45.

−− > **PAPER TEXT EXTRACT**:
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Fig. 46.

−− >　**PROJECT RESEARCH GRANTS**:
This work was partially supported by the following institutions and research projects:

1)　RePAF Research Project: Dynamic and Cognitive Resource Allocation Model and Framework for MPLS, Elastic Optical Network (EON), Internet of Things (IoT) and Network Function Virtualization (NFV)

Access: https://osf.io/bgqnh/
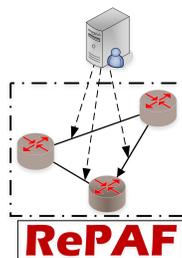
Fig. 47.

2) CNPQ Research Grant - Project "Transporte de Tráfego Multisrviço através de Redes Óoticas Elásticas sob Restrições de Camada Física":

Fig. 48.

3) Salvador University - UNIFACS - PPGCOMP Research Fund Allocation

Fig. 49.

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