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SUSTAINABLE SMART CITIES: A FOG COMPUTING FRAMEWORK FOR A SMART URBAN TRANSPORT NETWORK

Ioan-Mădălin NEAGU, Ph.D
Technical University of Cluj Napoca, Romania
E-mail: madalin.neagu@cs.utcluj.ro

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Abstract: In the present paper, a fog computing framework for smart urban transport is developed. The proposed framework is adapted to the smart city concept. It uses a collaborative multitude of end-user clients to carry out a substantial amount of communication and computation. It can be adapted for specific situations of smart cities in Romania, such as: Cluj-Napoca, Timișoara, Iași or Bucharest. Economic and social implications as well as available European funding sources are presented.

Keywords: smart city, ICT, fog computing, transportation

JEL Codes: O14, O33, C61, R42

1. Introduction

In the vision of European Commission, a ”smart city is a place where traditional services and networks are more efficient by using digital technologies for the benefit of its inhabitants and business. A smart city means the use of ICT for an efficient resources use and less emission, smart urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings, as well as an interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population”. (https://europa.eu). In the implementation of the smart cities concept, the European Union developed a large process of smart cities concept implementation. Considering that societal change, globalisation and Informational and Communication Technologies (ICT) affects growth, the Europe 2020 Strategy launched in 2010, established three priorities for growth and seven flagship initiatives: *smart growth* (effective investments in education, innovation, ICT and research) with *Innovation Union, Digital Agenda for Europe* and *Youth on the move* as flagships; *sustainable growth* (low-carbon economy) with Resources Efficient Europe, an *Industrial Policy for the Globalisation Era* as flagship initiatives and *inclusive growth* (creating jobs and reducing poverty) with an *Agenda for New Skills and Jobs* and *European Platform Against Poverty* as flagship initiatives (European Commission, 2010).

Later, the European Innovation Partnership Initiatives for Smart Cities and Communities, conceived a strategic plan on how the concept of smart cities would be put into practice. For example, The European Innovation Partnership for Smart Cities and Communities (EIPSCC) and its Platform (2011) proposes a better planning, higher energy efficiency, better transport sollutions and intelligent use of ICT (European Commission, 2013).

The "people" component and the role of its involvement in the smart city development in a participatory approach is introduced by the European Parliament in 2014.

Recently, the concept of smart city was completed by adding the feature of sustainability. Smartness in terms of energy sustainability is one of the Horizon 2020 targets (European Parliament, 2012) and represents an evolution of the definition itself of Smart Cities. In fact, initial analyses revolved around the concept of "sustainable cities" (Ahvenniemi et al., 2017), with specific attention to environmental issues and on ICT as the main driver of smartness (Caragliu and Del Bo, 2018b).

Network is the basic component of nowadays living environments where smart objects are interconnected. Vehicle, machine components, domestic consumables durable and cloths are communicating, defining the so called Internet of Things (Iot). In a such network, with self configuring capabilities based on standard and interoperable communication protocols, physical and virtual "things" have virtual personalities and are integrated into the information network (Vermesan, 2009). The emergence of Internet of Things (IoT) has enabled the interconnection and intercommunication among massive things, generating a huge and heterogeneous amount of data.

Cloud and fog computing are paradigms used by specialists in smart environment in order to design information systems processing data in an efficient way due to their high computation power and storage capability. The fog computing is an extension of cloud services, by making computation, communication and storage closer to end-users, which aims to enhance low-latency, mobility, network bandwidth, security and privacy.

In the present paper a framework of a urban transportation model using fog computing is developed in a smart city. Economic and social implications are presented as well as possible funding sources are identified.

The present paper is organised as follows: after the introduction, conceptual aspects related to smart city concept and fog computing are exposed. In the third section the proposed framework for a smart transportation network is described. The fourth section is dedicated to discussion and the last section includes the conclusions.

2. Conceptual issues

2.1. The smart city concept

The meaning of a smart city is a multi-faceted and it is used in multidisciplinary topics. An analyis of the relevant literature reveals these considerations, as follows.
The term of "smart city" was adopted since 2005 by technology companies (i.e. IBM, 2009) in order to use information systems in the operation of urban infrastructures and public services in metropolitan areas. But the vision of a smart city was earlier present in the focus of scientists. A smart city integrates conditions of all of its critical infrastructures (roads, bridges, tunnels, rails, subways, airports, etc) and optimizes its resources, plan its preventive activities and monitor security activities while maximizing services to its citizens (Hall, 2000).
Smart cities are associated with innovation process and policies to manage it. Cities are playing a key role in facilitating the production, diffusion and accumulation of knowledge (Duranton and Puga, 2004).
Smart city is built on a smart combination of endowments and activities of aware citizens and it refers also, to intelligent solutions allowing the enhancement of the services provided to the citizens (Giffinger et al., 2007), or a network infrastructure improving economic and political efficiency and allowing the social, cultural and urban development (Hollands, 2008).
Caragliu et al. (2011, p. 70) define a city as smart "when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure lead to sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance".
Lombardi et al. (2012) identified six components of the smart cities: economy, people, governance, mobility, environment and living integrating the following aspects of urban life: industry, education, e-democracy, logistics&infrastructures, efficiency&sustainability, security&quality.
In a smart city, physical (roads, buildings, bikes lanes, sewage system, distric heating and cooling, energy grids) digital (sensors, smart phones, mobile networks, broadband, cloud computing, fibre optic cables, databases) and communication (open interfaces, open source technology, standardized coding languages, citizen inclusion through ICTs) infrastructure are integrated (Copenhagen Cleantech Cluster, 2012).
In a systemic approach, smart cities are emerging opportunities to introduce digital nervous system, optimization at every level of system integration and intelligent responsiveness (MIT, 2013).
A smart city builds livability, workability and sustainability for its inhabitants by using ICT for collecting information (through sensors and devices), for

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communicating data using wireless network and analyses data to understand what intervention is needed (Smart Cities Council, 2013).

The mechanisms through which smart city policies can foster urban innovation and economic performance were investigated in several studies (i.e.Caragliu and Del Bo, 2018a).

2.2. Fog computing: key concepts and use

Network is the basic component of smart living environments where smart objects and processors, sensors, controlles and inter-connectors are used to monitor, control and communicate in the network,.In a smart environment (e.g., smart city, smart home), cloud computing allows the coordination and collaboration among smart objects. The recent fog computing paradigm further enables real-time interaction and location-based services.

Fog Computing was first introduced by Cisco in 2012, to describe a compute, storage and network framework for supporting Internet of Things (Iot) applications. The term highlights that computing resources are close to the ground (that is, proximate to the data sources), in contrast to cloud computing, where computing resources are centralized and remote.

The main characteristic of fog computing is its ability to support applications requiring low latency, location awareness and mobility, due to the fact that it is deployed very close to the end users in a widely distributed manner.

Fog computing has the potential to be applied in: health care, augmented reality, brain machine interface and gaming, smart environments, vehicular fog computing, smart energy grid, Internet of Things (IoT), urgent computing and other applications (Pengfei et al., 2017).

Fog computing applications in health care may include: monitoring, detection, diagnosis and visualization of health maladies, stroke mitigation (i.e. Stantchev et al., 2015; Shi et al., 2015; Cao et al., 2015).

Zao et al. (2014) developed augmented brain computer interaction game based on fog computing and Ha et al. (2013) have designed a wearable cognitive assistance based on Google Glass and Cloudlet, which can offer social interaction through real-time scene analysis.

Li et al. (2015) developed a data-centered fog platform to support smart living (smart energy, smart health, smart office, smart protection, smart entertainment and smart surroundings.

Intelligent Transportation Systems needs to monitor and ensure traffic efficiency, driving safety, and convenience by exchanging valuable information, content-sharing applications (i.e. advertisements and entertainments) information-spreading services, leading to an increase in demand of computational capability and data communication. Thus, a new paradigm known as Vehicular Fog Computing has been proposed (Hou et al., 2016; Kang et al., 2016; Bonomi, 2011).

3. Framework proposal for a smart transportation network

A common fog framework architecture or ecosystem consists of three prime layers:

- **Layer 1**: contains data generated by end user devices and IoT devices;
- **Layer 2**: contains monitoring and control logic, aggregated in fog clusters and fog nodes: switches, access points, gateways, routers, PCs, smartphones, etc.;
- **Layer 3**: contains Cloud Computing services used for storing and analyzing the data and usually employs services such as: Software as a Service (SaaS), Platform as a Service (PaaS), Infrastructure as a Service (IaaS), Anything as a Service (XaaS). Regarding the deployment method, the services are delivered as private, public, hybrid and community.

Besides the framework architecture, there are other elements that need to be considered:

- **Big data**: represented by data sensitive to characteristics and/or dimension requirements: velocity, volume, variety, veracity, valence and value;
- **Analytics models**: diagnostic, descriptive, preventive, prescriptive and autonomous requirements;
- **Other elements**: governance, regulatory, legal, compliance, policies, strategies and tactics requirements; design, deployment, execution, control, maintenance and management of fog framework elements.

In the context of smart cities and urban transport management, a fog framework implementation is feasible and nonetheless, achievable. A fog framework can sustain such types of networks in smart cities due to its characteristics and architecture.

However, when designing such a framework, one must take into consideration the design requirements and constraints, such as: Who are the end users and what IoT devices are connected? How many fog clusters are needed and what types of components do the fog nodes contain? What kind of Cloud Computing services is needed? The deployment methods are strictly public or based on communities?

Considering the above, we propose a fog-based framework that can be employed in smart cities, to sustain them and to manage the urban transportation network.

The ecosystem of the fog framework is as follows:

- **Layer 1** – data producers
    - Every end user connected to the framework that uses its services and generates data.

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    - IoT devices: any type of vehicle travelling in the city, traffic signs/lights sensors, weather monitoring sensors, energy efficiency sensors, surveillance systems, road safety systems.
- **Layer 2** – fog cluster containing fog nodes for monitoring and control logic
    - Monitors the data generated by the devices in Layer 1 and generates control and command signals and notifications based on the data analysis outcome: alarms, events and information for end users, vehicles and traffic signs LCD/LED displays. These signals and notifications might need human intervention or they can be intended for machine-to-machine communication.
    - Fog devices in this layer are set up at critical waypoints through the city (access points, routers, gateways, smart grid, traffic signs LCD/LED displays, information LCD/LED displays), in urban transportation vehicles (information LCD/LED displays for drivers and passengers, smartphones) and in ordinary vehicles (information LCD/LED displays, navigation systems, smartphones).
- **Layer 3** – Cloud Computing services
    - Responsible for storing and analyzing the entire data generated by Layer 2.
    - Based on the data analysis, it computes: optimal routes/navigation through the city based on history, energy efficient scheduling and travel assistance based on weather and energy sensors history, unsafe zones/areas based on history from surveillance systems and police reports, traffic reduction and travel scheduling based on traffic reports history.
    - All types of services are required: SaaS, PaaS, IaaS, XaaS; while the needed deployment methods are the following: public (for everyone), community (for urban transportation drivers, specific components/waypoints), private (local authorities, police, firemen, hospitals).

The big data for the proposed framework is collected from the data producers (Layer 1 of the architecture) and from the monitoring and control logic (Layer 2), hence it can be divided into data coming from sensors and commands and control signals and notifications. Furthermore, the data can be further divided into categories such as: sensitive biometric data, vehicle data, traffic signs data, weather data, energy data, surveillance data, road safety data, alarms, events, general information, notifications etc.

Based on the characteristics defined in the beginning of this section, the data stored in the proposed framework has the following features:

- large **volume** due to the high number of devices connected;
- **variety** is also high, as explained above;
- the data **velocity** is related to each type of data (e.g. weather data is collected slower than data acquired from surveillance systems, while commands or notifications must be sent as fast as possible, they are critical);
- **veracity** is related to the quality of data and reliable data can be obtained by using redundancy of components and by using secure communication (e.g. identity-based network, end-to-end encryption, SSL/TLS, public/private key, etc.);
- **valence** is also high, the data collected is highly interconnected;
- **value** is medium, some data might have high monetary value, such as biometric data.

Essential for a big data system to work in a fog framework is to classify each type of data or information collected and stored in the Cloud. Moreover, appropriate connections or relationships between categories or types of data must be defined before collecting or storing data. For example, road safety and travel assistance are related to weather conditions, traffic congestion, roadworks and/or road accidents, and they produce information and notifications for traffic signs LCD/LED displays, vehicles navigation displays, etc.

All the analytics models enumerated earlier can be employed more or less in the proposed framework. These models are described, explained and discussed below, based on the relevance to our proposed framework.

- **Descriptive analytics** use data aggregation and data mining to provide insight into the past, basically to answer "What has happened?". In other words, it used to summarize raw data and make it readable by humans. It is useful because they allow to learn from past behaviors and events, and to understand how they influenced future outcomes. Applied to our proposed framework, this model can be used to understand the collected data, to create statistics and to be used in future actions. For example, by analyzing past traffic congestion at specific time and date intervals, traffic reduction and scheduling, as well as traffic assistance can be provided to the end users in the future.
- **Predictive analytics** has the ability to predict what might happen and it uses statistical models and forecasts techniques to understand the future ("What could happen?"). While understanding the future is difficult due to

a large variety of factors, predictive analytics provide estimates about the likelihood of a future outcome, but keep in mind that no statistical algorithm can predict the future with 100% certainty. This model uses the collected/historical data to identify patterns and fill in the missing data with best guesses, based on statistical models and algorithms that capture relationships between various data sets. This analytic model can be used in our proposed framework because data interconnection is high in the collected data and, due to the large amount of information, pattern identification is also easy to achieve. With respect to our proposed framework, an example would be identifying patterns in traffic congestion in combination with weather forecasts, a specialized algorithm can predict future traffic based on time, date and weather.

- **Prescriptive analytics** is a relatively new field and more complex than the previous two. In short, the model uses optimization and simulation algorithms to advise on possible outcomes. It can predict multiple futures and allows to assess a number of possible outcomes based upon the previous actions. Prescriptive analytics use a combination of techniques such as: machine learning, computational modelling procedures, optimization and simulation algorithms. The input to this type of model is historical data, real-time data feeds and big data. While relatively complex to employ, this model can have a large impact on decision making, urban transportation optimization and scheduling in our proposed framework.
- **Diagnostic analytics** is focused on why something happened; it examines the data with techniques such as drill-down, data discovery, data mining and correlations. This model is centered on the processes and causes and can prove to be useful in smart city transportation network. For example, based on past data, by increasing the green time at specific traffic lights when a traffic jam occurs, it creates traffic reduction.
- **Preventive analytics** is triggered by time, events or meter events and it can be associated with scheduled maintenance. This model can be employed in fog framework with respect to the IoT devices and fog nodes in the smart city. In other words, having the fog components regularly checked can provide a fail-safe system and can assure that the sensor readings are accurate, further sustaining the veracity of the framework devices.
- **Autonomous analytics** is the application of machine learning to human judgement. Self-learning algorithms are a must and they are implemented to modify themselves as data grows and more decisions and actions are

evaluated. It is the most complex analytic model that can be employed in a fog framework due to its complex algorithms.

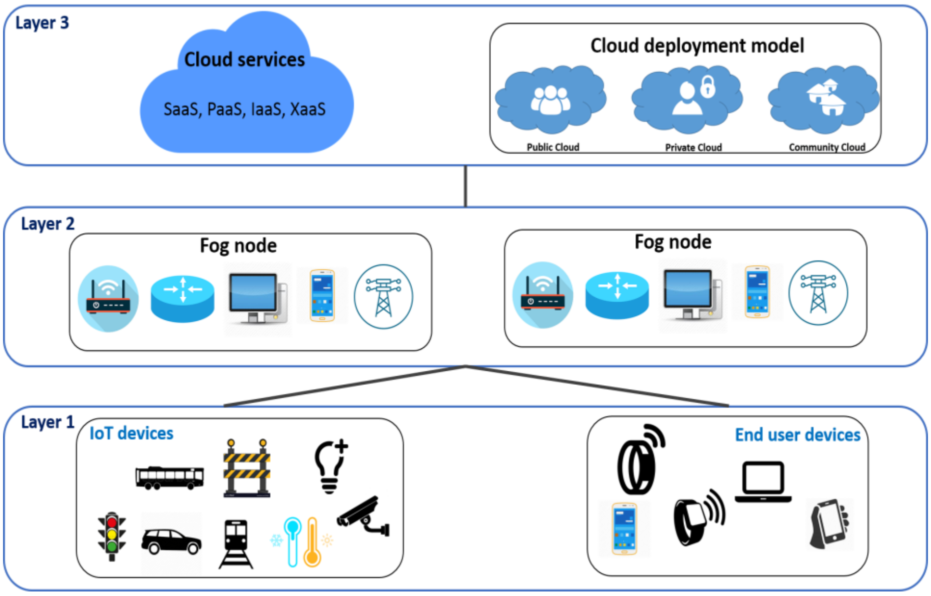

Figure 1 The fog framework architecture for an urban transport network
Source: the author's own view

Based on the above, we considered the descriptive, predictive and diagnostic model for our proposed framework because these analytics models can provide a good insight about the collected data, can predict future outcomes and can advise and guide towards a solution. However, the ultimate goal is an autonomous analytics model because it's the most advanced and complex of them all, it can eliminate the human bias and self-adapt to new conditions and constrains based on learned experience.

The other elements of the fog framework, such as governance, policies, strategies and tactics can be assigned to the local administration office, as well as maintenance, management and control.

Given the above explanations, the fog framework architecture is illustrated in Figure 1.

4. Discussion

4.1. Economic and social implications

The proposed framework for urban transportation network in a smart city could have the following economic and social benefits:

- reducing resources consumption (notably, fuel) and contributing to the air quality improving;
- improving the use of existent transport capacity, hence improving the quality life of citizens;
- alleviating traffic congestions;
-improving safety and security measures for passangers and pedestrians;
- reducing the waiting time of passengers in bus stations;
- making new services available online for citizens (i.e. online application for guidance on the urban transport or how best exploit the transport modalities);
- creating opportunities for new business (i.e. publication of real-time data on public city services);
- boosting urban innovation and attracting investments in innovation;
-enabling the adoption of smart city policies on urban innovation performance and increase of the city's stock of knowledge (recognized as driver of economic growth).

4.2. European funding sources

The proposed model can be implemented through several type funding sources of European Union, such as: EU funds (EU Cohesion Policy funds, EU Competitiveness and Innovation funds), European Investment Bank's Financial Instruments and private instruments (European Commission, 2013).

There are two types of funding initiatives available for development of smart cities and relevant for the proposed model: Horizon 2020 Programme and other financial instruments.

The Horizon 2020 Programme includes three main priorities: Excellent Science, Societal Challenges and Industrial Leadership. Under the Societal Challenges, areas as Secure, Clean and Efficient Energy and Smart, Green and Integrated Transport are financially supported for smart cities development.

In the group of other financial instruments are included: JESSICA (Joint European Support for Investment in City Areas), a policy initiative of European Commisssion developed jointly with European Investment Bank; Risk Sharing Financing Facility (RSFF), a Joint Financial Instrument created between European Commission and European Investment Bank; ELENA (European Local Energy

Assistance), consisting of a technical assistance facility financed through the Intelligent Energy Europe (IEE).

5. Conclusions

The framework developed in the present working paper uses a collaborative multitude of end-user clients to carry out a substantial amount of communication and computation. It can be adapted for specific situations of smart cities in Romania, such as: Cluj-Napoca, Timișoara, Iași or Bucharest, with specific features related to management, maintenance and control.

Based on the proposed framework, other transportation applications or management tools can be developed (road management, parking anagement, renting and tracking taxis, predicting the passengers' demand in bust stations, traffic lights control, etc).

Integrating smart transportation systems into smart cities improves operational efficiency of cities and ensures its sustainability, by optimizing time, cost and reliability, as well as it leverages the quality life of urban citizens and ensures the sustainability of the city.

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