An Apache Spark Framework for IoT-enabled Waste Management in Smart Cities

Gerasimos Vonitsanos
University of Patras
Computer Engineering and Informatics Department
Patras, Greece
mvonitsanos@ceid.upatras.gr

Theodor Panagiotakopoulos
Hellenic Open University
School of Technology and Science
Patras, Greece
panagiotakopoulos@eap.gr

Andreas Kanavos
Ionian University
Department of Digital Media and Communication
Kefalonia, Greece
akanavos@ionio.gr

Achilles Kameas
Hellenic Open University
School of Technology and Science
Patras, Greece
kameas@eap.gr

ABSTRACT

The diffusion of small low cost sensors has opened new opportunities in terms of designing real-time monitoring systems in several application fields. Internet of Things (IoT) is a new branch of Information and Communication Technologies that connects vast amounts of heterogeneous sensing devices and other smart objects through different network protocols in order to provide large scale interoperability and underpin the development of novel applications. A fundamental application domain regarding IoT refers to smart cities, which offer a fertile ground for implementing technological advances to enhance urban management, ensure environmental sustainability and improve the quality of living. In this paper, we propose an innovative framework aiming at collecting, monitoring and processing streams of data received in real-time by IoT sensor devices while measuring the waste level of waste bins in a distributed environment.

KEYWORDS

Apache Spark; Classification; Internet of Things (IoT); Machine Learning; Smart Cities; Urban Waste

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1 INTRODUCTION

The technological developments of recent years have greatly helped raise the human standard of living and optimize the living conditions of a large portion of the human population. Technology is now present in almost every aspect of everyday life, from communicating with other people and moving around to personal information and medical care.

All of the above aspects have been made possible through applications created with the help of smart devices as well as the internet, which are flooding the humanity on a regular basis. Efforts are constantly being implemented for transferring this technological development to a more significant level, i.e. the level of the city, in which it will be called for coordinating various daily activities aimed at improving the quality of living of citizens. The efforts to integrate technologies in urban governance underpin the smart city concept.

Consequently, the term smart city refers to the optimization of urban functions and the improvement of city services offered to the general public mainly by means of technology with the ultimate objective of improving the living conditions of metropolitan areas. Such services include waste management, energy savings (shared lighting, public buildings), remote medical monitoring, transport management, water distribution, traffic management, and direct transmission of information.

On the other hand, urbanization, overpopulation, economic growth and the urban lifestyle are major drivers of the steep rise in municipal solid waste pollution. Cities generate 1.3 billion tons of solid waste per year worldwide and it is expected that municipal solid waste will climb to 2.2 billion tons per year by 2025 [10]. In addition, the accumulation of considerable populations in cities regarding developing countries, such as China and India, has led to the creation of vast amounts of waste, combined with deplorable sanitation. As urbanization gallops, the waste management challenge is becoming more and more acute and municipal authorities along with IT companies are trying to exploit advanced technologies for efficiently and effectively sorting and distributing waste. In this context, innovative technologies such as the Internet of

Things offer integrated waste management solutions, aiming at zero residual waste [8].

In this paper, we examine and present the contribution of technology to integrated municipal waste management. Through the study of various examples of cities and applications, an effort is made to disclose different proposed solutions to the major and always crucial issue of waste, which are either already commercially applicable or under research.

Through an in-depth bibliographic research, this work aims to disseminate up-to-date information due to the rapid development of advances in the field of information technology, recent social products in the technological world, as well as long-term social trends, particularly regarding the issue of municipal waste. The concept of smart cities has attracted particular attention in the context of urban development policies. After all, the idea of the smart city has much in common with the sustainable urban movement. Still, it is characterized by a particular emphasis on technological innovation, which constitutes the primary means of achieving sustainability [27]. Internet and broadband technologies, which enable e-services, are increasingly becoming important for urban development, and cities are progressively playing a critical role as drivers of innovation in areas like health, environment and businesses [3]. Therefore, the question arises as to how cities, suburbs, and rural areas can evolve into sustainable, open, and user-led innovation ecosystems in order to stimulate future internet-driven research and experimentation and how they can accelerate the research cycle in real-life environments.

A complex combination of technology, social and economic aspects, governance systems, and policy and business objectives determine the emergence of the smart city concept. As a result, depending on the policies, goals, funds, and scope of each city, the implementation of this concept follows quite varied routes. After all, the term "smart" has only recently been used in urban planning to denote the development of a city from its traditional spread to a more efficient unit [19].

2 RELATED WORK

All over the world, smart waste management systems are now part of everyday life. Therefore, smart waste management is an area where seemingly endless opportunities exist to create smart management solutions in smart cities. A review of common waste management models was presented in [1] along with the proposal of an enhanced waste management design. The design accommodated population and urban expansion by employing various truck sizes based on waste type and IoT devices that facilitate communication between system entities such as smart bins, waste source locations, waste collection vehicles, and waste management centers.

The authors in [11] presented a waste collection solution based on providing intelligence to trashcans using an IoT prototype embedded with sensors, which can read, collect, and transmit trash volume data, processed by graph theory optimization algorithms, to manage waste collection in an efficient way. Also, an architecture was presented in [24] which simulates an IoT streaming scenario in a persistent way and a batch analytics engine to process the data inputs for producing higher-order, granular insights in traffic scenarios in terms of smart cities. Because the number of passengers and flights is rising all the time, a technological solution for optimizing management procedures could also include IoT systems connected to other platforms to implement the concept of smart airports [31].

In the proposed system of [25], cloud and mobile app-based monitoring are used to link with a municipality web server in the concept of a dynamic waste management system for a smart city. The maximum waste level of the bin is measured along with checks about various stinky gases, and the waste bins are tracked by a unique number that represents their location. Regarding the development of a system for household waste management, machine learning techniques such as KNN were used to generate alert messages for combinations of three sensor values like the level of bio and non-biodegradable waste and the concentration of poisonous gas in [7].

Several methods were introduced in [4] to solve the problem of efficient smart municipal waste management using IOT and effective algorithms. In [21], a multilevel IoT-based smart cities infrastructure management architecture is proposed, and the waste management problem is used as a case study to evaluate the performance of the proposed solution. Furthermore, authors in [17] used machine learning and graph theory to optimize the probability prediction of the amount of waste in trash bins as well as to collect waste with the shortest path.

Moreover in [12], authors proposed a system for online prediction using spark streaming framework. They focused on applying streaming machine learning models on streaming health data events ingested to spark streaming through Apache Kafka topics. The authors in [13] through their suggested framework, analyzed Apache Kafka's data transmission performance as well as efficient cluster setups and parameter settings, using Apache Kafka and the Spark Streaming Engine.

Smart contracts and access control technology can be used to improve state-of-the-art healthcare services in a smart city. Each patient's EHR can be safely preserved without compromising their privacy. In most of these circumstances, multiple departments need access to information contained in patients' medical histories, [18]. Counterfeiting can be avoided by using blockchain to manage the supply chain of medical supplies, as medical products are discovered and tested for their origin, [23]. As indicated in [29, 30] blockchain technologies can be integrated into smart cities and smart homes.

3 RECENT ADVANCES OF ICT IN SMART CITIES

The concept of Smart City is still emerging and the process of demarcating and integrating it is ongoing as it is easy to use and also reusable with the same ease [14]. Some recognize the use of the smart city as a phenomenon of urban signage or even as a concept and thus, it is used in ways that are not always consistent [6]. Others define a smart city as the integration of the physical into the virtual world [2]. Because of the above, several definitions have been proposed for both practical and academic use [6].

A technical definition of a smart city states that "it is an urban space that combines Information and Communication Technologies

(ICTs) along with Web 2.0 technologies and includes other organizational, planning and scheduling efforts to dematerialize and expedite bureaucratic processes and assist in identifying innovative solutions for better city management for increased living standards" [19].

At its core, the idea of smart city has its roots in the creation and connection of human capital, social capital and ICT infrastructure with the aim of creating greater and sustainable economic growth and better quality of life. Moreover, the concept of a smart city arose as a result of the objectives set by the Kyoto Protocol since 1997, which identified the development of cities as smart. Of course, initiatives for smart cities are not the same worldwide and depend to a large extent on local governments and cultures. Thus, the development of smart cities has remained heterogeneous and, to date, there is no dominant planning process. Instead, economic growth and other structural variables are more important in determining the smart development and planning of a city [19].

According to [5, 14, 20], the relevant goals for a smart city are:

(1) Intelligent mobility (traffic management, bicycle/car/truck sharing, multimodal transport, road condition monitoring, parking system, route planning, electric vehicle services).
(2) Smart grid/energy (power generation/distribution/storage, power management, smart metering, street lighting optimization).
(3) Public safety (video/radar/satellite surveillance, environmental and territorial surveillance, child protection - e.g. safer movement of children to school, emergency solutions, waste management, smart air quality, weather data for snow removal) [15, 16].
(4) Smart governance (transparent decision-making process, greater citizen participation in legislative initiatives, partnerships in public and private sector, online tax systems).
(5) Smart economy (high quality jobs, competitiveness, entrepreneurship, innovation and research in the field).
(6) Smart life (cultural and educational facilities, important events, entertainment and guided tours, access to cultural sites and historical monuments, good health conditions).

Therefore, one of the basic nuances of the term smart city is given by the integration of ICT in urban infrastructure, with solutions such as city operating systems, central control areas, urban control systems (dashboards), smart transport systems, single tickets, bike-sharing programs, real-time passenger information screens, supply chain management systems, smart grids, controlled lighting, smart meters, sensor grids, building management systems, various applications smartphones (smartphones) and sharing economy platforms, etc. [9]. This intensive use of ICT involves the mass development of all types of sensors, actuators and machine-to-machine communication infrastructure to process the vast amount of data collected for the provision of additional services and applications of value [2]. In addition, data activation and application analysis are essential in smart cities [32].

According to the existing smart city structures and future plans in this area, six key features that govern smart cities can be proposed [14, 22]:

- **Smart Governance**: Smart governance refers to governance in and out of the city - including the services and interactions that connect and, where appropriate, integrate public, private, civil, and European organizations; so that the city can effectively and efficiently function as an organization. The primary tool for achieving this goal is with use of ICT technologies (infrastructure, hardware, and software), implemented by smart processes as well as interoperability and are powered by data. International and national connections are also critical, as a smart city could be described as a global web hub. This involves public, private, and urban partnerships along with cooperation with various bodies working together to pursue smart goals at the city level. Regarding smart goals, they include transparency and open data using ICT and e-government in participatory decision-making processes and co-creation of e-services, such as smartphone applications. As a transversal factor, smart governance can also orchestrate and incorporate some or all of the other smart features.
- **Smart Economy**: The term "smart economy" means e-business and e-commerce increased productivity, advanced production, and provision of ICT services and new products, new services, and business models. This term also constructs intelligent clusters and ecosystems (e.g., digital business and entrepreneurship). The smart economy also involves local and global interconnection and international integration with natural and virtual goods, services, and knowledge flows.
- **Smart Mobility**: "Smart mobility" deals with ICT-supported and integrated transport and supply systems. For example, sustainable, secure, and interconnected transport systems may include trams, buses, trains, subways, cars, bicycles, and pedestrians, which use one or more modes of transport. Smart mobility also prioritizes clean and often non-motorized options. Those interested can access the relevant information in real-time to save time and improve the efficiency of transportation, save costs and reduce CO2 emissions. Another feature consists of contacting the transport managers to improve services and provide feedback to citizens. Mobility users may further provide their real-time data or contribute to long-term planning.
- **Smart Environment**: The term "smart environment" mainly means the term "smart energy", which includes renewable energy sources, energy networks, energy waste, pollution measurement, control and monitoring, building renovation, green buildings, green urban planning as well as the efficiency of the use of resources that serve the above objectives. Municipal services such as street lighting, waste management, drainage systems, and water resources monitored to evaluate the system, reduce pollution and improve water quality are also representative examples [26].
- **Smart People**: By "smart people", we denote those having e-skills and working using ICT technology. They have access to education, training, human resources and skills management in an inclusive society that enhances creativity and promotes innovation. As a feature, it can also allows people and communities to enter, use, manipulate, and personalize

data through appropriate data analysis tools and dashboards, make decisions, and finally create products and services.
- **Smart Living**: The term "smart living" deals with lifestyle, behavior, and consumption that allows ICT use. Smart living also includes a healthy and safe lifestyle in a culturally vibrant city with diverse cultural facilities and high-quality accommodation and lodging. "Smart living" is also associated with high social cohesion and social capital levels.

Based on the many, but completely different, conceptual definitions of a smart city presented above, a number of factors are proposed for the understanding of smart city initiatives and projects by various scientists. These factors, grouped in a context of smart cities, can be used to study and identify success factors in terms of smart city frameworks. In addition to sustainability and reliability, this structure addresses a number of internal and external factors that influence the design, implementation and use of smart city initiatives. The eight sets of factors include [6]:

(1) Management and organization
(2) Technology
(3) Governance
(4) Politics
(5) Individuals and communities
(6) Economy
(7) Structured environment
(8) Natural environment

3.1 IoT in Smart Cities

IoT is a recent example of communication that foresees a future in which everyday objects will be equipped with microcontrollers, digital communication transceivers, and appropriate stacks of protocols that will allow them to communicate not only among themselves but also with users, thereby becoming an integral part of the Internet. Therefore, IoT is essentially an umbrella keyword for many different aspects as long as the current Internet is expanding with physical objects and sensors.

The International Telecommunication Union advocates defining IoT as a network that is "available anywhere, anytime, from anything and anyone" and consists of three levels, namely a detection layer, a networking and data communications layer, and an application layer [32]. Therefore, its meaning aims to make the Internet even more impressive and widespread. In addition, with the allowance of easy access and interaction with a wide variety of devices, such as home appliances, surveillance cameras, surveillance sensors, actuators, monitors, vehicles, etc., IoT can promote the development of many applications that take advantage of the potentially vast amount and variety of data generated by such items to provide new services to citizens, businesses and public administrations. This standard is indeed applicable in many different fields, such as home automation, industrial automation, medical devices, mobile healthcare, assistance for the elderly, intelligent energy management and smart grids, automotive industry, traffic management [2, 3, 28, 33].

The majority of smart city services is based on a central architecture, where a dense and heterogeneous set of peripherals, developed in the urban area, produce different types of data. These types of data are in following provided through appropriate communication technologies in a control center where data is stored, analyzed and processed.

The ability of an urban IoT infrastructure to integrate diverse technologies with existing communication infrastructures, to support the IoT's progressive development by networking other devices, and to deploy new features and services is a critical aspect. Another fundamental aspect is the need for authorities and citizens to have easy access to some of the data collected by the urban IoT, to increase the authorities' response to urban problems, and to promote public awareness and participation in public affairs [33].

4 PROPOSED ARCHITECTURE

Initially, the system is analyzed and the architecture of the proposed framework is depicted in Figure 1. In following, a pre-processing procedure is applied, and as a next step, the classification process follows.

The novel framework proposed in this work consists mainly of data collection and processing sub-systems. The data collection unit has been developed to deliver data from different IoT sensors measuring the waste level in the bins and in following to store it in Cassandra, a NoSQL database. Furthermore, the framework performs a real-time update with use of Apache Spark Streaming following this data collection process. In more detail, the flow pipe can be considered by the following aspects:

- Waste level IoT sensors: The data are given as input to our system in terms of the level of waste. More to the point, features contain, among others, the distance from the top of the waste bin to the waste and other values such as weight or humidity.
- Apache Kafka: This framework is a distributed messaging system designed to collect and send massive amounts of data with low latency and high throughput. It runs as a Kafka Cluster on several servers and maintains streams of keys, values, and timestamps in topic categories. The first is a push-type model, in which the transmitting side initiates data transmission, while the second is a pull-type model, in which the receiving side initiates data transfer by sending a data request. Finally, there are producers, brokers (Kafka Cluster), and consumers in Kafka.
- Apache Spark Streaming is a module that streams and processes data from sensors. To execute Streaming Analytics, Spark Streaming makes use of Spark Core's swift scheduling capabilities. It also ingests data in scaled-down clusters and executes RDD modifications on those small groupings of data.
- MLlib (Machine Learning Library): This library provides a machine learning framework for Spark, including regression, classification, and neural network processing, among other machine learning methods. This library is built on the RDD API and works with both R and Python. The library is designed to scale out in a cluster, avoiding large memory constraints, because Apache Spark can take advantage of several computer nodes in a cluster. A DataFrame-based machine learning API called SparkML is included with Apache Spark, in addition to MLlib. In order to achieve the greatest

speed, programmers can select which library to use based on their dataset and data size.

- Cassandra: The data collected by the sensors is stored in the specific NoSQL database without any special formatting, and then if required, the necessary transformations will be executed.
- Classification Process: This procedure concerns the prediction of the level of waste and the dynamically selection of bins collected daily, based on historical data.

5 IMPLEMENTATION

Waste management encompasses all practices and actions, as well as advanced smart technology given by IT firms, that are used to manage and minimize waste in a way that ensures their long-term viability. Recycling and smart resource management may significantly reduce the amount of trash produced, paving the path for a green economy in its purest form. Waste management uniformity is currently being pursued in every country on the planet. Citizens all across the world collaborate with IT firms and smart technologies to find a solution that ensures our global sustainability.

The intelligent systems devised by major IT companies combined with the IoT offer many advanced technological features that have perfected waste management solutions. Intelligent systems can also analyze a situation through data and sensors with the aim of controlling and classifying forecast data, that is the most efficient way of waste management.

The key feature of this system is that it is designed to learn from experience and make decisions not only about the daily state of waste but also about future situations related to it, as well as traffic congestion, balanced cost-effectiveness functions and other factors that people cannot predict. For example, the rate at which a rubbish bin fills can be analyzed based on historical data, and as a result, overflow can be predicted before it occurs. Depending on predefined financial requirements, optimizing the selection of bins to be collected is expected to reduce costs and improve collection efficiency, or both.

A fast but flexible database system was required to store the waste bins critical data and the Machine Learning library's final results. Furthermore, the risk that the number of waste bins can exponentially grow created the additional need for scale-out, which dictated that we would swiftly move away from the traditional RDBMS and seek a NoSQL alternative. As no join operations were compulsory for our analysis, a document-based database was the best-suited solution. More specifically, we opted to use the Cassandra NoSQL database because of its maturity level and its robustness.

Three different algorithms have been chosen in the present system for extracting the optimal result. In particular, the key characteristics of these algorithms are given as follows:

(1) Decision Trees: Decision Trees algorithm is one of the most popular supervised machine learning algorithms. The "divide and conquer rule" technique divides the search space into sub-sets. In a decision tree, there are nodes, edges, and leaves; the nodes represent the characteristics of the problem, while the edges are assigned a predicate that can be applied to the parent node attribute. Finally, the leaves give the names of the available classes to which the comments should be categorized.
A specific methodology is followed for the construction of the tree. Firstly, the initial node contains all the records. This node is then divided based on a separation condition on one of the attributes. In this way, the entries are shared on both nodes. This procedure is repeated on each node until all the entries on a leaf belong to a single class.

(2) Random Forest: The second utilized machine learning algorithm is the Random Forest, which creates multiple decision trees by randomly selecting sub-sets of the original training dataset. Finally, the classifier takes all results into account, and the final result is the class obtained from the majority of the decision trees.
The performance of this algorithm is based on the randomness with which the individual trees are constructed, as decision trees are susceptible to changes. A small change in the training set can lead to creating a different tree. The Random Forest classifier also takes advantage of this method to create many other trees.

(3) Naive Bayes: The Naive Bayes classification algorithm aims to categorize a sample into one of the available classes, using a probability model defined according to Bayes theory. It is based on the Bayes probability theorem and produces probability tables for each independent variable separately.

6 CONCLUSIONS AND FUTURE WORK

Operational efficiency and waste reduction play an essential role in the innovative features of smart waste management. Generally, the smart waste management system aims at reducing the amount of waste, time, and energy required to manage it through smart technology. Controlling the amount of waste generated daily consists a vital aspect of waste management. Intelligent waste management benefits both private consumers and municipalities.

The aim of the current study is the design of a new schema based on Big Data frameworks and NoSQL technology for the manipulation of the level of waste in bins. We propose a novel architecture utilizing the benefits of machine learning algorithms so that it can be used in an effective way in smart waste management.

For further work, we would like to evaluate the effectiveness of our architecture in real datasets. In addition, new classifiers can be considered in order to be compared with the current ones, such as neural networks.

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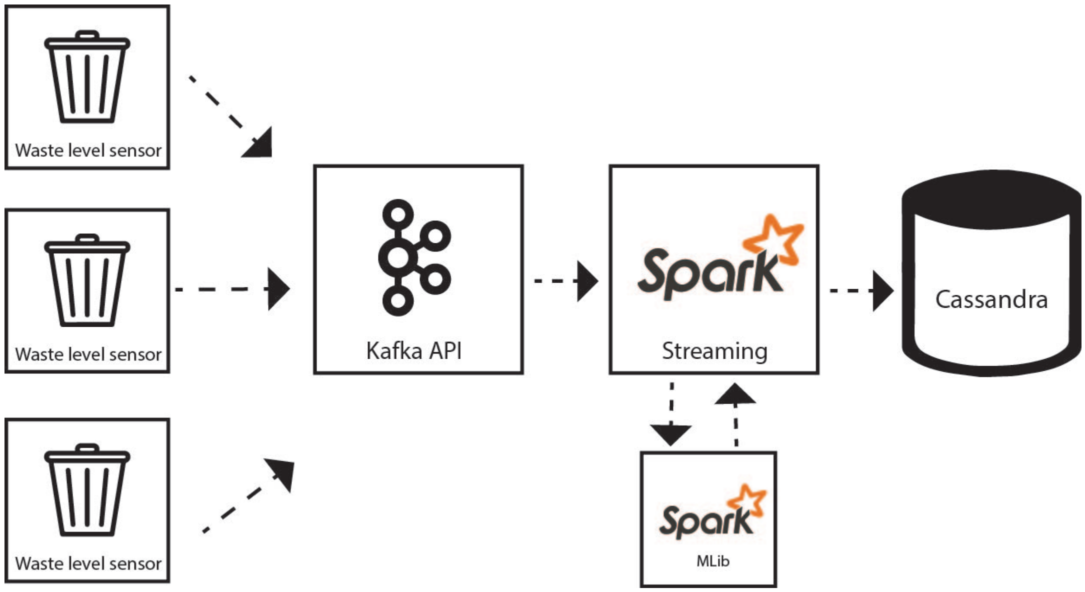

Figure 1: Overall Architecture of the Proposed System

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