

# A Case Study on Estimation of Sensor Data Generation in Smart Cities and the role of Opportunistic Networks in Sensor Data Collection

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## Research Article

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# A Case Study on Estimation of Sensor Data Generation in Smart Cities and the role of Opportunistic Networks in Sensor Data Collection

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## Abstract

The across-the-global diffusion of smartphones is initiating an enormous growth of data traffic. Soon, the existing cellular networks will suffer from traffic overload issues, and establishing additional infrastructure might be the costlier solution. An offloading of the traffic to different networks is considered a promising approach. Opportunistic offloading refers to diverting traffic from a cellular network to Opportunistic Networks (OppNets) by utilizing nearby devices having idle computing resources through opportunistic contacts. As a case study, we analyzed the number of sensors needed and the amount of data generated in Ahmedabad and Gandhinagar by considering the smart city scenario. The paper comprehensively reviews OppNets in data offloading for various scenarios and applications of smart cities. We further point out the important future challenges, problems, and applications.

**Keywords:** Smart City, Sensor Nodes, Data Offloading, Opportunistic Networks

## 1 Introduction

A "Smart City" is an initiative to promote the technological, political, economic, and environmental efficiency of the city [1] [2]. It enhances the performance of public services like managing traffic and transportation, crime detection, resource consumption, and other community services. Enabling these services requires the integration of

Information & Communication Technology (ICT) with the numerous physical devices connected to the network. The world population has been heavily migrating towards urban areas in the last two decades. The growth of cities forecast that by the year 2050, more than 6 billion people will reside in the urban area [1]. However, urban growth poses environmental, energy, and economic sustainability challenges.

The smart city notion heavily relies on real-time data consolidated by numerous heterogeneous sensors, the Internet of Things (IoT), and mobile devices. These devices collect opinions, emotions, thoughts, feelings, experiences, and observations about the city from millions of citizens/visitors [3]. Smart city also focuses on using the next generation technology in the routine life of people, embedding the sensors to form the IoT network. The deployed sensors in the city are used to collect data such as public infrastructure, parking availability, garbage collection, traffic monitoring, and many more [4]. The real-time collection of such data avoids the regular physical inspection by authorities. Therefore it reduces costs and can forecast the city's future needs.

The sensors and IoT devices can be integrated into cloud computing and supercomputers to analyze collected data. Collecting data to the central server requires the large number of sensors deployed in the city to be interconnected. The heavy use of mobile devices for personal interaction, along with distributed sensor networks and IoT, generates a tremendous amount of data, increasing the load of traditional infrastructure-based wireless communication. So, it poses various challenges [5]. This paper addresses two critical aspects of urban sensor networks: the daily sensor data generated by various sensors covering an entire city area and the solution for transmitting the collected data to a central server, ensuring efficient and reliable data transfer with an OppNets based approach.

This paper is organized as follows: Section 2 comprehensively reviews smart city design and architecture. Section 3 calculates sensors and data generation in smart cities for various applications. In Section 4, existing OppNets approaches for data collection in smart cities are thoroughly discussed, highlighting their features and capabilities. Section 5 examines the challenges in implementing sensing technologies in smart cities and potential future directions to overcome these constraints. Finally, the research paper concludes in Section 6, summarizing the essential findings and contributions of the study.

## 2 Smart City Design and Architecture

Several smart city designs and architectures are proposed, mostly following similar characteristics and patterns. To collect the data and monitor the smart city, we have to identify the different regions of the city, the flow of vehicles and citizens, residential area, industrial area, agriculture zone, the density of people in each zone for the various periods, types of sensors, routing protocols, and amount of data generation of the city. The main components and categories of smart city architectures are described in this section.

## 2.1 Components of Smart City

The components of a smart city can vary based on the specific goals and priorities of a city but generally include the following:

**Sensor and Actuator Nodes:** Sensor and Actuator node is the computing device with sensing capabilities having the constraint of processing power, memory, and energy [2]. From a broad perspective, there are mainly two types of sensors. Firstly, to monitor and collect the data from the city's exteriors such as parks, streets, and avenues. Second, to monitor and collect data from the interior, such as buildings, malls, water consumption, and gas leakage [1] [3] [4]. The external sensors utilize the long-range routing protocol to cover the entire city using minimum sensors. The placement of various sensors plays a vital role in acquiring the data from the city. Various factors such as light, shape, size, population, and energy are essential in data collection. The platform collects data that must be transmitted to the server for processing. For this reason, the sensor node usually sets up the Wireless Sensor Network (WSN) network.

**Wireless Sensor Network (WSN):** The WSN provides connectivity between the sensors to transmit the data from sensors to servers. The WSN consists of sensor nodes with memory, power supply, processor, and radio interfaces [6]. The WSN is a low-power and low-cost node deployed in the environment for years to sense its surroundings continuously. WSNs are characterized by various resource constraints, one being battery lifetime [7]. It is infeasible to provide power and battery replacement to each smart city deployed sensor. So, it is needed to develop a routing protocol that is energy efficient and provides an effective power management scheme. However, considerable research is also ongoing in the energy harvesting domain in WSN.

**Cloud of things:** The cloud or server used for central processing is a vital component of a smart city. The sensors generate terabytes of data daily that needs to be aggregated and processed. With recent technological advances, the cloud has become a critical resource for processing and data storage. Cloud is a collection of resources accessible through the Internet that allows the collection of the sensors' data and later used for analytics [8]. In a smart city, providing the high-level architecture to enable the interface between sensor and cloud for ubiquitous computing is crucial. The collected information from numerous sensors ensures smooth city operations and gives a massive information-sharing system to support smart city requirements [9].

## 2.2 Different Categories of Combined Architecture

The section describes the perspective of combined architecture which integrates the platforms and technologies to develop a valuable architecture for smart cities. The combined architecture is a novel trend in smart city design to facilitate the different aspects of communication. We have presented some works distinguishing it in the categories such as IoT-AL, IoT-SOA, IoT-SOA-AL, IoT-EDA, and IoT-SOA-AL-EDA [10] [11].

**IoT-AL:** The cloud-based architecture improves the applications and services offered to the citizen of the smart cities using Architectural Layers (AL). IoT provides the data through the citizen's smart devices, and after processing the collected data, they use the information as a service. The objective is to develop the platform and

technology that stores and processes the tremendous amount of data generated daily. The cloud-based architecture gives access to users with a high level of availability and scalability of the server.

**IoT-SOA:** Service Oriented Architecture (SOA) is an approach that aims to communicate, collect, and interact amongst services to the users by considering their requests and needs. The IoT-SOA architecture combines the IoT and geo-localization to improve access to smart city services. It also includes 3S technology, which incorporates Remote Sensing (RS), Geographic Information System (GIS), and Global Positioning System (GPS) to give geospatial information for accurate positioning by the 3D visualization of the city. The IoT-SOA architecture allows access to smart city services through wireless networks and the Internet.

**IoT-SOA-AL:** It is novel architecture to effectively collect and manage the heterogeneous data received from the smart city sensors. The architecture distinguishes into four layers: the storage layer, the application layer for data vitalization, the application layer for development, and the supporting layer. These layers are used for several purposes, such as collecting the sensor's data, storing data, and creating and computing services. The advantage of the architecture is its modular design and simplicity of development.

**IoT-EDA:** The IoT-EDA is the Event Driven Architecture (EDA) strategy that enables Machine-to-machine communication to improve the performance of smart city applications. The M2M approach can potentially establish the connection between computers, sensors, smart devices, and citizens. In order to utilize the maximum benefits of a smart city system, the M2M approach must be combined with sensors, networks, clouds, and the Internet. The prime advantage of EDA-based architecture is its capability to provide security and sustainability through event management in a smart city environment.

**IoT-SOA-AL-EDA:** The architecture is divided into six layers, namely the data acquisition layer, data storage, and vitalization layer, data transmitting layer, support service layer, event-driven application layer, and domain service layer. These layers are responsible for data collection for sensors, integration of wireless network technologies, data storage, and visualization, and facilitating internet access and cloud computing. The ultimate goal of the architecture is to match the smart city requirement and provide services that fulfill citizens' needs.

### 3 Calculation of Smart City sensors and estimation of data generation based on various applications

In this section, the smart city applications are discussed along with their usages, main features, advantages, sensors, and data generation. In the study, sensors requirement and data generation analysis are undertaken using the case study of Ahmedabad and Gandhinagar City. There are various types of sensors used to provide Smart City facilities. To make realistic assumptions, we have taken care of the area, population, residential land, agricultural land, the number of vehicles, and many more to calculate the number of sensors and their data generation for both cities.

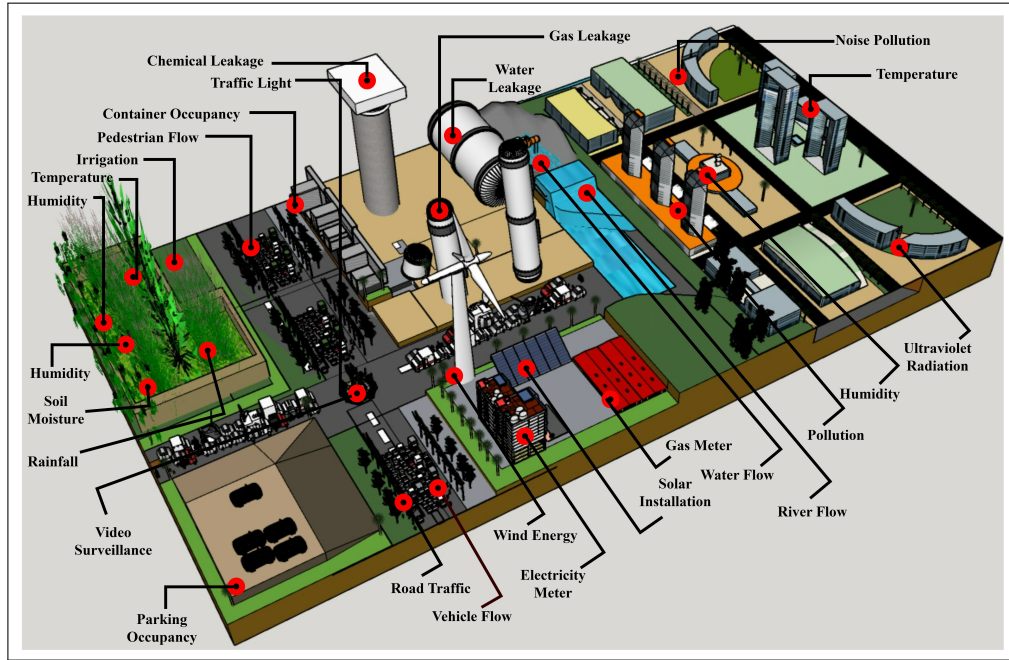
We have considered that the area of Ahmedabad and Gandhinagar is  $464 \text{ km}^2$  and  $177 \text{ km}^2$ , whereas the population is 84.1 lakh and 3.26 lakh, respectively [12]. The city sensors data are categorized as Environment Monitoring, Garbage Collection Monitoring, Agriculture Monitoring, Utility Infrastructure, Smart Parking Management, Smart Grid, Urban Traffic Monitoring, and Video Surveillance. The city's sensors and geographical distances should be managed according to smart city projects and concepts. Figure 1 visualizes the deployment of diverse sensors within a smart city. The figure provides a graphical representation of the strategic placement of sensors throughout the city's infrastructure. This visualization aids in understanding the comprehensive sensor network and highlights the distribution and arrangement of sensors for various monitoring and data collection purposes in the urban environment. We have estimated the total number of sensors required for full coverage of these cities. The amount of data generation calculation is based on the frequency and size of data transmission.

The authors referred to a specific study of Barcelona city in [13] to inform their decisions regarding deploying the number of sensors, data frequency, and data size. This reference played a crucial role in determining the appropriate number of sensors, the frequency at which data should be collected, and the size of the data to be gathered, ensuring that the chosen deployment aligns with the application requirements.

The authors have utilized various reports to accumulate information on residential areas, population demographics, agricultural zones, buildings, vehicle statistics, and video surveillance data from other smart cities, ensuring a comprehensive understanding of the context for their study. The authors obtained valuable insights and statistical data essential for their research by consulting these different reports [12] [14] [15] [16].

**Smart Environment Monitoring:** Smart Environment Monitoring can collect and process the information about the climate, pollution, and temperature that influences the citizen's quality of life [17] [18]. For example, the collected sensor data monitors the air quality and notify residents about the polluted and unsafe area. The deployment of numerous low-cost sensors in the smart city is possible with the help of IOT. The sensors located in some specific geographic region help the policy maker, like the municipality, to analyze the environment for an extended period (month or year). Environment monitoring can be performed by exploiting the smart devices of the citizens and allowing them to comment and report the environmental condition that helps the community [1] [17]. Furthermore, wireless devices, a network of sensors, cameras, and a data center create an essential infrastructure to provide environmental monitoring services efficiently, robustly, and faster. For smart environment monitoring, temperature, and humidity sensor are deployed per 20,000-22,000 sqft. pollution and ultraviolet sensors are deployed per 38000-42000 sqft, and noise pollution sensors are deployed per 48000-50000 sqft. The frequency of data generation varies between 15-20 min. The amount of data generated by the sensor is between 20-80 bytes per transaction.

**Garbage Collection Monitoring:** Garbage management is a vital issue in many cities due to storage problems and cost of service. The dustbins at various locations like colleges, parks, and hospitals are overflowing. The overflowing creates an unhygienic



**Fig. 1** Deployment of various sensors in Smart City

situation that causes diseases. The efficient solution for the issues results in significant cost savings and economic advantages [19]. The intelligent garbage collection monitoring system detects the level of garbage in the dustbin, and such information is used to optimize the route of the collector truck. It can help improve the recycling process and reduce the garbage collection cost [20]. For effective monitoring, the waste container shall connect with the center, where an optimization algorithm processes the data and take the optimal route for the collector truck. The automation in garbage collection gives benefits such as resource optimization, cost reduction, effective use of dustbins, and healthy life to citizens [19] [20]. For Garbage Collection Monitoring, sensors are needed per 50000-80000 sqft. The residential areas required more sensors than other areas of cities, so we have considered the population density of cities in the calculation. The data generation frequency is 30-40 min, and 50-60 bytes of data are generated per transaction.

**Smart Agriculture Monitoring:** The latest agricultural technique increases the productivity and efficiency of crops. The IOT-based sensors play a vital role in Smart Agriculture Monitoring. The farmers and researchers deploy various sensors at the agricultural field to collect the data such as humidity, temperature, irrigation, soil moisture, solar radiation, and rainfall. [21] [22]. To collect real-time information, the sensors must integrate and deploy that can estimate crop requirements at any given time. The data collected from the remote site helps for the analysis purpose. Satellite communication, cellular phone device, or mobility of farmers and tractors can be used to transfer the data to a central server. Smart Agriculture Monitoring gives

tremendous advantages in saving resources, cost, human resources, reducing time, and accommodating the demand for quality food in higher amounts [2]. The Smart Agriculture Monitoring calculation is based on the Potential Linked Credit Plan (PLP) report. It gives the measure of agricultural land in the cities. The sensors used for agriculture monitoring are irrigation, temperature, humidity, soil moisture, and rainfall. The data generation frequency and amount of data per transaction are 20-40 min and 25-50 bytes, respectively.

**Utility Infrastructure Monitoring:** Utility Infrastructure refers to monitoring structural health, improving structural reliability and damage detection. The maintenance of historical monuments, buildings, and bridges requires timely monitoring of the conditions such as stress, the pollution level of surroundings, temperature, and humidity to measure the structure's integrity [23]. Various IOT sensors like vibration, deformation, humidity, temperature, and pollution are utilized to collect such information. The collected information about the infrastructure makes it possible to achieve accurate and timely decision-making for maintenance and inspection requirements [24]. The proper plan can be made to replace any equipment by predicting the failure time. Although, the real-life use of the service requires installing the sensors in buildings and surrounding areas, which needs substantial initial investment to develop such infrastructure. In Utility Infrastructure Monitoring, various sensors such as water leakage, river flood, chemical leakage detection, water flaw, and explosive/-hazards gases detection are utilized [24]. The data generation frequency and amount of data per transaction are 25-40 min and 40-50 bytes, respectively.

**Smart Parking Management:** Smart Parking Management provides a solution to find unoccupied parking spaces and direct motorists to the best path for parking. The efficient management of city parking locates the parking slots faster, which reduces traffic congestion, decreases CO emission from vehicles, and increases the life of civilians [25]. Along with effective parking management, monitoring available parking slots can be used to analyze the need for parking areas in the city for the future. The data collected by the input sensors provide real-time information about the availability of parking slots [25]. The server retrieves all the data through an input sensor and provides parking information to users. The data collected by the servers of various city areas can be combined to process and analyze the new urban necessities for parking [26]. The new intelligent solution enables convenient parking management and helps to forecast the future need for parking in urban areas. For Smart Parking Management, existing vehicles and the increasing growth of vehicles are considered. The data generation frequency and amount of data per transaction are 5-15 min and 35-45 bytes, respectively.

**Smart Grid:** Smart Grid is a type of electric grid that provides various operation and energy measurements such as smart appliances, smart meters, and renewable energy sources [27]. Smart Grid enables reliable and efficient systems to meet the growing electricity demand using smart distribution and transmission. Reliability is a vital requirement of the smart grid to support business models like electric vehicles, smart cities, and energy-efficient smart communities. In Smart Grid, sensors and actuators are located in cities that are used to collect data about energy generation, consumption, and failure detection [28]. The generated data helps to make efficient



electricity transmission, reduces management costs, ultimately reduces power cost and peak hour demand, and increases the integration with the renewable energy system. Therefore, Smart Grid gives information about citizens' energy consumption, utilization, and future demand in the city. The Smart Grid consists of Electricity Meter, Gas Meter, Street Lighting, Solar Installation, and Wind Energy sensors. The data generation frequency and amount of data per transaction are 10-20 min and 20-40 bytes, respectively.

**Urban Traffic Monitoring:** The traditional traffic management approach makes managing constantly increasing vehicular traffic in urban areas challenging. The camera and sensor-based traffic monitoring system are used to monitor the traffic congestion in the city [29]. Monitoring the traffic via vehicular sensor networks using GPS-installed vehicles with sensing capabilities is also possible. The vehicles such as buses, cars, trams, or pedestrians with smartphones are sensors for sensing the city traffic [30]. The generated traffic data is sent to the traffic monitoring center to develop a report for traffic estimation. This information is vital for authorities to resolve numerous challenges in urban traffic, like finding the optimal route, travel cost, reducing pollution, and traffic congestion [1]. The collected data helps to analyze traffic mobility patterns and predict congested areas and accident zone. Furthermore, it helps to design the future transportation policy and city planning for comfortable travel for citizens. Urban Traffic Monitoring includes Road Traffic, Pedestrian Flow, Vehicle Flow, and Traffic Signal sensors. The data generation frequency and amount of data per transaction are 15-20 min and 30-45 bytes, respectively.

**Video Surveillance:** The smart city infrastructure requires having a scalable and robust video surveillance system. The video data generated from the city are used to define urban policy and to support city management. Furthermore, the citizen may contribute images, videos, and sound clips for monitoring and surveillance purpose [31]. The objectives of video surveillance are vehicle tracking, identifying their mobility and behavior, detecting anomalies, and abnormal event prediction. The smart devices carried by the citizens and public transport such as trains, buses, and taxis are utilized to carry vast amounts of data to the central server. The evolution of cloud computing enables data storage and processing to give rapid response [32]. The cloud-based storage provides scalable, reliable, and cost-efficient solutions. The video surveillance system deployed in private and public areas gives better security and trust and monitors the activities of citizens. In Video Surveillance Information, the number of cameras is calculated based on per square mile and population. We have explored on the 150 most heavily populated cities in the world. Based on the survey of the ten most surveilled cities worldwide, we have considered 350-450 cameras per mile and 100 cameras for every 1000 people. The entire city coverage requires 1,25,000 and 32,600 CCTV cameras in Ahmedabad and Gandhinagar, respectively. The data generation frequency is 10-20 min, and 100-150 Mb of data is generated per transaction.

The Table 1 highlights the distinctions between a smart city equipped with sensors and without sensors, emphasizing the associated benefits. Additionally, it provides information on the frequency of data transmission and the size of the data:

**Table 1** Feature and Benefits of Smart City with Sensor Integration

Application	Without Smart City Sensing	With Smart City Sensing	Frequency of sending the data and size per transaction
Smart Environment Monitoring	Continuous monitoring of environment is not possible, Difficult to ensure that pollution is at acceptable level	Early detection of hazardous situation can detect by sensors, Gives accurate, fast and cost effective solution, reduced carbon emission level	Frequency: 15-20 min Size: 20-80 bytes
Garbage Collection Monitoring	High cost due to unnecessary garbage collection, Overflow of container leads to the unhygienic situation	Real time monitoring of waste container's fill level, Identifies cost effective routes, Estimates garbage bin require in area	Frequency: 30-40 min Size: 50-60 bytes
Smart Agriculture Monitoring	Analyses of production and results related with treatment is difficult, Precise control of water and soil is laborious, Wastage of resource such as water, seed, electricity etc.	Reduces waste and improves productivity, monitoring by remote sensing, Real time data insight helps in decision making, Reduces operational cost and Environmental footprint	Frequency: 20-40 min Size: 25-50 bytes
Utility Infrastructure Monitoring	Periodically personnel inspection required that increases cost, Time consuming, Visual examination of structure is not much effective	Provides valuable information about the strength and behavior of structures, Gives low cost and low maintenance solution, Accurate analysis of structures avoids possible accidents	Frequency: 25-40 min Size: 40-50 bytes
Smart Parking Management	Needs to check manually about available parking slot, Wastage of flue, Increases stress and cost, Increases the search traffic on the roads	Gives more accurate notification about available parking slot, Reduced individual environment footprints, Increases the safety, Predict the future requirement of parking in city	Frequency: 5-15 min Size: 35-45 bytes
Smart Grid	Manual billing and inaccurate demand prediction, High electricity consumption, Increases the operation and management cost of utilities	More accurate consumption identifies customer's real need, Accurate billing and improves customer service, Reduces carbon emissions, Efficient electricity transmission	Frequency: 10-20 min Size: 20-40 bytes
Urban Traffic Monitoring	Inefficient traffic management scheme cause the traffic jams, Increases pollution and fuel wastage	Reduces the congestion by improving traffic flow, Prioritize traffic by adapting current situation, Improves the traffic safety	Frequency: 15-20 min Size: 30-45 bytes
Video Surveillance	Human/Manual operation is likely to distracted, Requires huge manpower that increases cost, Remote monitoring is not possible	Intelligent surveillance system automatically detects abnormal situation, Improves storage, Reduce cost and more scalable, Improves safety and security	Frequency: 10-20 min Size: 100-150 mb





breaks between nodes because the contemporaneous path is not possible [33]. Due to rapid changes in topologies and mobility of nodes, in this type of network, message transmission between source to destination happens using intermediate nodes by store-carry-forward mechanism [34]. If a node moves away from the transmission range of the communicating node, turns off its power, or has insufficient storage, the message will be dropped. The OppNets application is where the environment can tolerate long delays and lower message delivery [35]. In smart cities, nodes of OppNets can be people's Smartphones/Tablets, Vehicles, Roadside Units, and other Smart Devices. By utilizing such nodes, OppNets facilitate multi-hop communication without using fixed infrastructure or centralized control. Node movement in the city is not random, and moving from one place to another has regular hourly, daily, or weekly patterns, e.g., buses, trains, and commuters, who follow the same path to work every day. OppNets are utilized to offload the traffic from mobile infrastructure, which in turn minimizes the communication cost.

**Formation of network:** The first step is constructing a network among the participating devices and sensors. It can be accomplished using diverse networking technologies such as Wi-Fi, Bluetooth, and Zigbee. The devices can also create a mesh network, where each device acts as a relay node for forwarding data to other devices in the network.

**Data collection:** Once the network is constructed, the devices and sensors can start collecting data on different aspects of the smart city, such as traffic flow, air quality, and noise levels. The data can be stored locally on the device or sensor or transmitted to other devices in the network.

**Opportunistic communication:** In OppNets, there may not be a contemporaneous end-to-end path available between the source and destination nodes. Therefore, the devices and sensors must use opportunistic communication techniques to transmit data to their destination. It involves store-carry-forward technique, where the data is stored at intermediate nodes and forwarded when a suitable opportunity arises. The Figure 6 shows the store-carry-forward approach to deliver sensor data to a central server by utilizing mobile devices, vehicles, and trams as intermediate nodes.

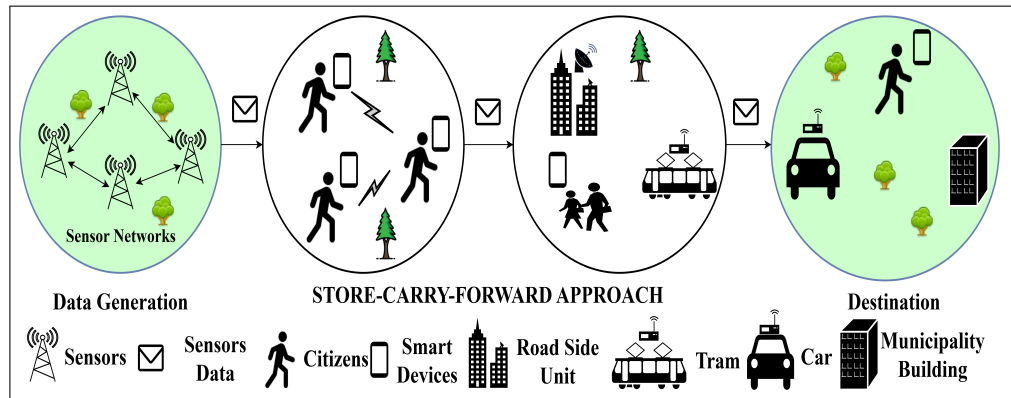


Fig. 6 Data Collection in Smart City using Opportunistic Networks

**Data processing:** Once the data is collected and transmitted to the destination nodes, it can be processed to generate insights and for decision-making in various areas of the smart city. For example, traffic flow data can be used to optimize traffic signal timings and reduce congestion. In contrast, air quality data can help informing on reducing air pollution.

Overall, OppNets in smart cities enable efficient and reliable communication among devices and sensors in a dynamic and constantly changing environment. By leveraging the power of these networks, smart cities can improve their operational efficiency, enhance citizen services, and promote sustainability.

In this paper, we have conducted an extensive ten-year survey on using OppNets in smart cities. The survey primarily focuses on data transmission, offloading, and data collection within smart cities through OppNets. Several research papers, propose protocols based on OppNets for data collection in diverse applications such as environment monitoring [36], medical monitoring [38], agriculture monitoring [42], wildlife habitat monitoring [40], and river pollution monitoring [59]. These analyses were accomplished in specific areas where smart city sensors were deployed. The generated data is opportunistically collected using modes of transportation such as trams, drones, boats, tractors and other vehicles. The authors also studied the utilization of OppNets for data collection in smart cities across different locations, including Bologna [47] [55], Agdal District-Rabat [50], Shanghai [65], Rome [53], Beijing [68], Fargo [70], Skudai, Helsinki [72] and several urban scenarios [64] [62] [56] [46]. Both real experiments and simulations were utilized to evaluate the significance of the proposed approaches in offloading data from existing infrastructure. The experiments used different simulation tools such as NS-2 [52], NS-3 [45], ONE Simulator [49], and OMNET++ [58]. The survey provides valuable insight into choosing appropriate routing protocols based on node characteristics, density, area, scenarios, simulators, and movement models. Researchers simulate the behavior of opportunistic protocols in large-scale smart city environments by leveraging these simulation tools. The authors have studied the impact of node density, movement, characteristics, area coverage, and patterns on data offloading and collection efficiency. The simulations helped assess the proposed approaches' reliability, scalability, and performance trade-offs, enabling researchers to construct informed decisions regarding selecting and optimizing routing protocols for specific smart city applications. The combination of real experiments and simulations provided a comprehensive evaluation and performance analysis of opportunistic protocols for data offloading and collection in smart cities.

Table 2 shows comparative analysis of Opportunistic Protocols utilizes for offloading sensor data in smart city.

This comprehensive survey contributes to understanding the use of OppNets for data collection in smart cities. It presents beneficial information for researchers and practitioners in choosing appropriate routing protocols and designing efficient data transmission mechanisms based on the precise requirements of the network environment. The combination of real experiments and simulations enhances the trustworthiness and applicability of the proposed approaches, further validating their effectiveness in addressing the data-offloading challenges in smart cities.

**Table 2** Comparative Analysis of Opportunistic Networks approaches for Data Offloading in Smart City Scenarios

Year	Protocol	Scenario	Objective	Used Devices	Compared to	Mobility Model	Validation Tool
2007	SeNDT [36]	Environment Monitoring-Europe	Lake Water Monitoring and Noise Monitoring using DTN	Vehicles, Boats	None	Random Movement [37]	Real Experiment
2008	P2N, N2N [38]	Medical Monitoring-UCLA Parking Area	Remote Medical Monitoring with OppNets and medical sensors	Bluetooth Devices	None	Random Walk [37]	NS-2.9 with UCBT [39]
2010	None [40]	Wildlife Habitat Monitoring-Ontario	DTN based reliable and cheaper solution to monitor the while tail deer	Car or Helicopter	None	Random Movement [37]	Planetlab [41]
2011	PEAR [42]	Agricultural-University of Tokyo	DTN based Agricultural data collection from the remote sensors	Vehicles Tractors	None	Custom	Real Experiment
2013	None [43]	Surveillance Application-Smart City	Mobility Prediction in smart city to support OppNets	Cameras, Buses	Epidemic [44]	Bus Movement Model [45]	NS-3 [45]
2013	TOOF, VOOV [46]	Smart Grid-Urban Scenario	Vehicular Networks used to carry and deliver Smart Grid	Vehicles	Best Effort (BE)	Map Based Movement Model [45]	NS-3 [45]
2016	Drone [47]	City Center-Bologna	Offload the traffic of infrastructure based network and reduce the cost	Drone, Vehicles, Smart Devices	departure time of Drone	Working Day Movement Model [48]	ONE Simulator [49]
2016	AODV [50]	Agdal District-Rabat City	Use the vehicular network for sensor data collection in smart city	Taxis, Buses, Trucks, Trams	None	CarAgent Mod (SUMO) [51]	SUMO [51], NS-2 [52]
2016	None [53]	Smart City-Rome	Collecting data from sensors and actuators using OppNets	Taxis	Different week days and Times	Real Traces Crawdad [54]	NS-2 [52]
2016	S&DA Bus [55]	City Center-Bologna	Develop the routing protocol that exploit the mobility of citizens	Vehicles, Buses	Epidemic [44]	Working Day Movement Model [48]	ONE Simulator [49]
2016	Admission Control [56]	Smart City	Improve the performance of M2M approach for Smart City	Smart Devices, IoT Devices	DNC [57]	Random Movement [37]	OMNET++ [58]
2016	DFA [59]	River Pollution Monitoring-Europe	River Pollution Monitoring by collecting sensor data using DTN	Vehicles	Epidemic [44], Spray & Wait [60], PRoPHETv2 [61]	Random Movement, MapRoute Movement [37] [49]	ONE Simulator [49]

Year	Protocol	Scenario	Objective	Used Devices	Compared to	Mobility Model	Validation Tool
2017	ECDS [62]	Smart City	Energy efficient data delivery using D2D communication in smart city	Smart Devices, Vehicles	DDA, CDA [63]	Random Movement [37]	Custom
2017	LoRa-Mac [64]	Campus-University of Aveiro	Environmental data collection of wide area using OppNets platform	Cars, Bicycles, Aerial and Drones	Different LoRa Sinks	Bicycle Movement	Real Experiment
2018	V-CCHN [65]	Smart City-Shanghai	Design the data transport network using vehicles to reduce congestion	Vehicles	GPSR [66], MDRA [67]	Road Network	NS-3 [45]
2019	DRLS [68]	Smart City-Beijing, China	Deep Reinforcement Learning based Crowd Management to balance network load	Smart Devices, IoT Devices	OSPF, EROSPF [69]	Edge Network Topology	Custom
2019	HSM, FAR, UBS [70]	Smart City-Fargo	Portion of data offloaded from cellular networks using OppNets	Buses	PRoPHET [71], Epidemic [44]	Haggle [54]	ONE Simulator [49]
2020	Poiford [72]	Skudai and Helsinki-Smart City	Obtain knowledge to take routing decision for city scale applications	Smart Devices Model	PRoPHET [71]	Working Day Movement Model [48]	ONE Simulator [49]

#### 4.1 Opportunistic Networks in Smart Cities: Applications and Scenarios

OppNets offer promising applications in the context of a smart city, as represented by the following scenarios:

**Personalized and Motivational Feedback:** Individuals interested in jogging acquire personalized messages based on their precise location, advising them about the inappropriateness of the current environment for jogging. For instance, if the air quality is poor or the area is unsafe for asthma patients, a message is sent only to those in that location, leveraging OppNets for the targeted community.

Vehicles can convey messages to nearby vehicles in traffic queues, urging them to turn off their engines to minimize CO levels. By utilizing OppNets, vehicles within communication range receive these messages, encouraging an energy-efficient solution for providing alerts and reducing emissions.

**Traffic Management:** Traffic flow can be dynamically controlled by analyzing road situations and sending messages about heavy traffic to redirect vehicles to alternate routes. OppNets facilitate the dissemination of these messages, ensuring that vehicles in the affected lanes obtain the alerts, thus enabling efficient traffic control and congestion avoidance.



Intelligent parking systems can leverage OppNets to notify citizens when parking lots are reserved. It enables adequate utilization of parking spaces and minimizes congestion caused by unnecessary searches for parking spots.

**Women’s Safety:** In urban areas where women may be vulnerable to violence or abuse, alert notifications can be disseminated opportunistically to nearby individuals, providing their precise location. This instantaneous message transmission via OppNets allows nearby individuals to respond promptly and offer assistance. Additionally, alert messages can be forwarded to the nearest police station for quick intervention.

**Entertainment and Medical Emergency:** OppNets can improve the entertainment experience for visitors by providing timely messages when they are near specific locations, such as restaurants, museums, or theaters. Visitors can also share thoughts, reviews, and recommendations, benefiting other visitors in their decision-making process.

In areas lacking centralized communication infrastructure, OppNets facilitate remote medical monitoring for patients. Patients can be monitored and receive medical assistance through OppNets, assuring continuity of care in areas with limited connectivity.

These scenarios emphasize the diverse applications of OppNets in a smart city, addressing various elements such as personalized feedback, traffic management, women’s safety, entertainment, and medical emergencies. Leveraging OppNets offers efficient and targeted communication solutions to enhance urban living experiences and citizen well-being.

## 5 Challenges

The realistic implementation of a smart city includes various sensing-related issues such as design, cost, communication protocol, heterogeneity of devices, data collection and analysis, privacy, security, and social nature. To utilize the benefits of smart city services, we need to overcome the below mention challenges.

**Coordination between heterogeneous sensor nodes:** In a smart city, sensors, and actuators, various sensing components such as smartphones, smart wearable devices, smart meters, and surveillance cameras are used to collect and transmit the data. The smart city architecture can collect data from the heterogeneous devices; still, the platform incompatibility hinders the integration of data. For seamless communication, cooperation is essential between cellular networks, wireless ad-hoc networks, OppNets, and wide area networks.

**Security and Privacy:** The smart city should prevent the unauthorized access of sensitive data from disclosure, modification, interruption, and inspection. Essential requirements such as integrity, confidentiality, availability, and privacy should be provided for the data and communication happening in the city. The authority has to identify the rightful owner of all data collection. For example, an electric utility can access an individual’s power consumption but can anyone use the data for analysis without the owner’s consent? Also, the smart city architecture should be secure from outside attacks.

**Reliable and Trustworthy Control:** The collected data is stored in the cloud as a central server for processing and analysis. The company that manages these things should be dependable so that citizens and authorities have trust in storing data. The central system in the real world is a desirable target for hackers to perform malicious activity and unauthorized third-party inspection. The available software framework to detect the attack having high latency and false detection rate does not provide a solution for rapid detection of the attacks.

**Tremendous data generation of sensors:** The numerous sensors are deployed in smart cities to provide services to the citizens. These sensors spread across the city to enable real-time monitoring. As discussed in the previous section, the amount of data the sensors generate daily is enormous. It needs to transmit to a central server to obtain the benefit of these raw data. It is a significant challenge to provide a suitable solution that offloads the data from the cellular network and transmits data to the central server on a timely basis. In addition, sensors deployed at various places require ad-hoc networks solution for sophisticated data transmission.

**Cost of sensors and upgrading infrastructure:** Several factors make it difficult to upgrade the city to a smart city, including cost. The smart city is heavily dependent on infrastructure and its support. So, how expensive will it be to upgrade the existing infrastructure? Secondly, is it feasible to install numerous sensors in the city to cover the entire area? An alternate solution is required that incorporates existing infrastructure to enable smart communication. Also, the smart devices used by citizens with sensing capabilities can be utilized to reduce the number of sensors.

**Social Affairs:** The citizens can play an essential role in improving the services of a smart city. For example, people can provide personalized and motivational feedback about the current environmental condition of this area. The people interested in jogging and currently located in a precise location receive the message that the area is not safe for jogging. The challenge is to involve the citizens to communicate to improve the quality of life actively. The collaborative initiative of people helps to enhance government and citizen engagement that expands digital services.

## 6 Conclusion

This paper surveys the existing OppNets approaches to offload the data traffic. To prove the necessity of OppNets as an alternate solution for data transmission, we have made a case study on Ahmedabad and Gandhinagar. The analysis proves that deploying sensors for various purposes generates massive data daily. OppNets provide a cheaper solution because it uses smartphones, vehicles, trams, and other nodes without infrastructure support. The paper also gives research challenges and potential futuristic applications in this field. The study efforts will provide guidance and motivation to the researchers to provide a prominent opportunistic approach for data offloading.

## 7 Declaration

**Ethical Approval:** This declaration is “not applicable”.

**Competing interests:** The authors have not received any organizational support for this work, and there are no relevant conflicts of interest declared by the authors.

**Authors' contributions:** **Jay Gandhi:** Conceptualization of this study, Methodology, Data Analysis, **Zunnun Narmawala:** Data curation, Writing-Original draft preparation. Both the Authors have reviewed the manuscript.

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## References

- [1] Hancke, G.P., Silva, B., Hancke Jr, G.P.: The role of advanced sensing in smart cities. *Sensors* **13**(1), 393–425 (2012)
- [2] Pau, G., Arena, F.: Smart city: the different uses of IoT sensors. *MDPI* (2022)
- [3] Kiritmat, A., Krejcar, O., Kertesz, A., Tasgetiren, M.F.: Future trends and current state of smart city concepts: A survey. *IEEE access* **8**, 86448–86467 (2020)
- [4] Shah, J., Kothari, J., Doshi, N.: A survey of smart city infrastructure via case study on new york. *Procedia Computer Science* **160**, 702–705 (2019)
- [5] Gandhi, J., Narmawala, Z.: Coverage, capacity and cost analysis of 4g-lte and 5g networks: A case study of ahmedabad and gandhinagar. In: *Futuristic Trends in Networks and Computing Technologies: Select Proceedings of Fourth International Conference on FTNCT 2021*, pp. 25–38 (2022). Springer
- [6] Raghavendra, C.S., Sivalingam, K.M., Znati, T.: *Wireless Sensor Networks*. Springer, ??? (2006)
- [7] Pottie, G.J.: Wireless sensor networks. In: *1998 Information Theory Workshop (Cat. No. 98EX131)*, pp. 139–140 (1998). IEEE
- [8] Petrolo, R., Loscri, V., Mitton, N.: Towards a smart city based on cloud of things. In: *Proceedings of the 2014 ACM International Workshop on Wireless and Mobile Technologies for Smart Cities*, pp. 61–66 (2014)
- [9] Petrolo, R., Loscri, V., Mitton, N.: Towards a smart city based on cloud of things, a survey on the smart city vision and paradigms. *Transactions on emerging telecommunications technologies* **28**(1), 2931 (2017)
- [10] Kyriazopoulou, C.: Smart city technologies and architectures: A literature review. In: *2015 International Conference on Smart Cities and Green ICT Systems (SMARTGREENS)*, pp. 1–12 (2015). IEEE
- [11] Gitakarma, M., Priyambodo, T., Suyanto, Y., Sumiharto, R.: Architectures, frameworks, and applications in iot-based smart environment: A review. In: *Journal of Physics: Conference Series*, vol. 1810, p. 012007 (2021). IOP Publishing

- [12] Gujarat State Portal. <https://gujaratindia.gov.in/state-profile/demography.htm>. [Online; accessed 2021-01-05]
- [13] Sinaeepourfard, A., Garcia, J., Masip-Bruin, X., Marín-Tordera, E., Cirera, J., Grau, G., Casaus, F.: Estimating smart city sensors data generation. In: 2016 Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net), pp. 1–8 (2016). IEEE
- [14] Libelium. [https://www.libelium.com/libeliumworld/top\\_50\\_iot\\_sensor\\_applications\\_ranking/](https://www.libelium.com/libeliumworld/top_50_iot_sensor_applications_ranking/). [Online; accessed 2022-02-15]
- [15] Pollution Report. <https://gpcb.gujarat.gov.in/webcontroller/page/annual-report>. [Online; accessed 2021-11-25]
- [16] Potential Linked Credit Plan (PLP). <https://www.nabard.org/default.aspx>. [Online; accessed 2022-01-02]
- [17] Bacco, M., Delmastro, F., Ferro, E., Gotta, A.: Environmental monitoring for smart cities. *IEEE Sensors Journal* **17**(23), 7767–7774 (2017)
- [18] Ranjan Senapati, B., Mohan Khilar, P., Ranjan Swain, R.: Environmental monitoring through vehicular ad hoc network: A productive application for smart cities. *International Journal of Communication Systems* **34**(18), 4988 (2021)
- [19] Medehal, A., Annaluru, A., Bandyopadhyay, S., Chandar, T.: Automated smart garbage monitoring system with optimal route generation for collection. In: 2020 IEEE International Smart Cities Conference (ISC2), pp. 1–7 (2020). IEEE
- [20] AbdElminaam, D.S., El-Ashmawi, W.H., Elsayed, S.M.: Design and fabrication smart garbage management and monitoring system using automatic unloading robot in residential area. *Int. Arab. J. e Technol* **5**(4) (2019)
- [21] Suma, N., Samson, S.R., Saranya, S., Shanmugapriya, G., Subhashri, R.: Iot based smart agriculture monitoring system. *International Journal on Recent and Innovation Trends in computing and communication* **5**(2), 177–181 (2017)
- [22] Hu, H., Chen, Z., Wu, P.W.: Internet of things-enabled crop growth monitoring system for smart agriculture. *International Journal of Agricultural and Environmental Information Systems (IJAEIS)* **12**(2), 30–48 (2021)
- [23] Kireev, V.S., Bochkaryov, P.V., Guseva, A.I., Kuznetsov, I.A., Filippov, S.A.: Monitoring system for the housing and utility services based on the digital technologies iiot, big data, data mining, edge and cloud computing. In: Big Data Innovations and Applications: 5th International Conference, Innovate-Data 2019, Istanbul, Turkey, August 26–28, 2019, Proceedings 5, pp. 193–205 (2019). Springer

- [24] Kumar, R., Khatri, K., Imran, M., Khattak, H.A.: Towards smart utility monitoring and management. In: 2019 2nd International Conference on Communication, Computing and Digital Systems (C-CODE), pp. 77–80 (2019). IEEE
- [25] Khanna, A., Anand, R.: Iot based smart parking system. In: 2016 International Conference on Internet of Things and Applications (IOTA), pp. 266–270 (2016). IEEE
- [26] Das, S.: A novel parking management system, for smart cities, to save fuel, time, and money. In: 2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC), pp. 0950–0954 (2019). IEEE
- [27] Heck, G.C., Hexsel, R., Gomes, V.B., Iantorno, L., Junior, L.L., Santana, T.: Grid-city: A framework to share smart grids communication with smart city applications. In: 2021 IEEE International Smart Cities Conference (ISC2), pp. 1–4 (2021). IEEE
- [28] Cavalieri, S., Cantali, G., Susinna, A.: Integration of iot technologies into the smart grid. *Sensors* **22**(7), 2475 (2022)
- [29] Bertolusso, M., Spanu, M., Anedda, M., Fadda, M., Giusto, D.D.: Vehicular and pedestrian traffic monitoring system in smart city scenarios. In: 2021 IEEE 7th World Forum on Internet of Things (WF-IoT), pp. 60–64 (2021). IEEE
- [30] Fadda, M., Anedda, M., Girau, R., Pau, G., Giusto, D.D.: A social internet of things smart city solution for traffic and pollution monitoring in cagliari. *IEEE Internet of Things Journal* (2022)
- [31] Tian, L., Wang, H., Zhou, Y., Peng, C.: Video big data in smart city: Background construction and optimization for surveillance video processing. *Future Generation Computer Systems* **86**, 1371–1382 (2018)
- [32] Li, H., Xiezhang, T., Yang, C., Deng, L., Yi, P.: Secure video surveillance framework in smart city. *Sensors* **21**(13), 4419 (2021)
- [33] Bharamagoudar, S., Saboji, S.: Routing in opportunistic networks: taxonomy, survey. In: 2017 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECCOT), pp. 300–305 (2017). IEEE
- [34] Jiang, J., Han, G., Lin, C.: A survey on opportunistic routing protocols in the internet of underwater things. *Computer Networks* **225**, 109658 (2023)
- [35] Gandhi, J., Narmawala, Z.: Fair comparative analysis of opportunistic routing protocols: an empirical study. In: Data Communication and Networks: Proceedings of GUCON 2019, pp. 285–294 (2020). Springer

- [36] McDonald, P., Geraghty, D., Humphreys, I., Farrell, S., Cahill, V.: Sensor network with delay tolerance (sendt). In: 2007 16th International Conference on Computer Communications and Networks, pp. 1333–1338 (2007). IEEE
- [37] Bettstetter, C.: Smooth is better than sharp: A random mobility model for simulation of wireless networks. In: Proceedings of the 4th ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp. 19–27 (2001)
- [38] Cho, D.-K., Lee, S.-H., Chang, A., Massey, T., Chang, C.-W., Tsai, M.-H., Sarrafzadeh, M., Gerla, M.: Opportunistic medical monitoring using bluetooth p2p networks. In: 2008 International Symposium on a World of Wireless, Mobile and Multimedia Networks, pp. 1–6 (2008). IEEE
- [39] Ns-2.9 with UCBT. <https://www.isi.edu/nsnam/ns/>
- [40] Tovar, A., Friesen, T., Ferens, K., McLeod, B.: A dtn wireless sensor network for wildlife habitat monitoring. In: CCECE 2010, pp. 1–5 (2010). IEEE
- [41] Carbone, M., Rizzo, L.: An emulation tool for planetlab. *Computer communications* **34**(16), 1980–1990 (2011)
- [42] Ochiai, H., Ishizuka, H., Kawakami, Y., Esaki, H.: A dtn-based sensor data gathering for agricultural applications. *IEEE Sensors Journal* **11**(11), 2861–2868 (2011)
- [43] Morelli, A., Stefanelli, C., Tortonesi, M., Suri, N.: Mobility pattern prediction to support opportunistic networking in smart cities. In: 2013 International Conference on MOBILE Wireless MiddleWARE, Operating Systems, and Applications, pp. 166–175 (2013). IEEE
- [44] Vahdat, A., Becker, D., et al.: Epidemic routing for partially connected ad hoc networks. Technical Report CS-200006, Duke University (2000)
- [45] Riley, G.F., Henderson, T.R.: The ns-3 network simulator. *Modeling and tools for network simulation*, 15–34 (2010)
- [46] Cheng, N., Lu, N., Zhang, N., Shen, X.S., Mark, J.W.: Vehicle-assisted data delivery for smart grid: An optimal stopping approach. In: 2013 IEEE International Conference on Communications (ICC), pp. 6184–6188 (2013). IEEE
- [47] Giannini, C., Shaaban, A.A., Buratti, C., Verdone, R.: Delay tolerant networking for smart city through drones. In: 2016 International Symposium on Wireless Communication Systems (ISWCS), pp. 603–607 (2016). IEEE
- [48] Ekman, F., Keränen, A., Karvo, J., Ott, J.: Working day movement model. In: Proceedings of the 1st ACM SIGMOBILE Workshop on Mobility Models, pp.

- [49] Keränen, A., Ott, J., Kärkkäinen, T.: The one simulator for dtn protocol evaluation. In: Proceedings of the 2nd International Conference on Simulation Tools and Techniques, pp. 1–10 (2009)
- [50] Bouroumine, A., Zekraoui, M., Abdelilah, M.: The influence of the opportunistic vehicular networks on smart cities management study case on agdal district in rabat city. In: 2016 4th IEEE International Colloquium on Information Science and Technology (CiSt), pp. 830–834 (2016). IEEE
- [51] Krajzewicz, D., Hertkorn, G., Rössel, C., Wagner, P.: Sumo (simulation of urban mobility)-an open-source traffic simulation. In: Proceedings of the 4th Middle East Symposium on Simulation and Modelling (MESM20002), pp. 183–187 (2002)
- [52] Rehmani, M.H., Saleem, Y.: Network simulator ns-2. In: Encyclopedia of Information Science and Technology, Third Edition, pp. 6249–6258. IGI Global, ??? (2015)
- [53] Bonola, M., Bracciale, L., Loreti, P., Amici, R., Rabuffi, A., Bianchi, G.: Opportunistic communication in smart city: Experimental insight with small-scale taxi fleets as data carriers. *Ad Hoc Networks* **43**, 43–55 (2016)
- [54] Kotz, D., Henderson, T.: Crawdad: A community resource for archiving wireless data at dartmouth. *IEEE Pervasive Computing* **4**(4), 12–14 (2005)
- [55] Giannini, C., Calegari, P., Buratti, C., Verdone, R.: Delay tolerant network for smart city: Exploiting bus mobility. In: 2016 AEIT International Annual Conference (AEIT), pp. 1–6 (2016). IEEE
- [56] Huang, J., Xing, C.-C., Shin, S.Y., Hou, F., Hsu, C.-H.: Optimizing m2m communications and quality of services in the iot for sustainable smart cities. *IEEE Transactions on Sustainable Computing* **3**(1), 4–15 (2017)
- [57] Boyer, M., Le Corronc, E., Bouillard, A.: *Deterministic Network Calculus: From Theory to Practical Implementation*. John Wiley & Sons, ??? (2018)
- [58] Varga, A.: Discrete event simulation system. In: Proc. of the European Simulation Multiconference (ESM'2001), pp. 1–7 (2001)
- [59] Velásquez-Villada, C., Donoso, Y.: Delay/disruption tolerant network-based message forwarding for a river pollution monitoring wireless sensor network application. *Sensors* **16**(4), 436 (2016)
- [60] Spyropoulos, T., Psounis, K., Raghavendra, C.S.: Spray and wait: an efficient routing scheme for intermittently connected mobile networks. In: Proceedings of

- the 2005 ACM SIGCOMM Workshop on Delay-tolerant Networking, pp. 252–259 (2005)
- [61] Grasic, S., Davies, E., Lindgren, A., Doria, A.: The evolution of a dtn routing protocol-prophetv2. In: Proceedings of the 6th ACM Workshop on Challenged Networks, pp. 27–30 (2011)
  - [62] Zhou, L., Wu, D., Chen, J., Dong, Z.: Greening the smart cities: Energy-efficient massive content delivery via d2d communications. *IEEE Transactions on Industrial Informatics* **14**(4), 1626–1634 (2017)
  - [63] Zhang, Y., Yu, R., Xie, S., Yao, W., Xiao, Y., Guizani, M.: Home m2m networks: Architectures, standards, and qos improvement. *IEEE Communications Magazine* **49**(4), 44–52 (2011)
  - [64] Almeida, R., Oliveira, R., Sousa, D., Luis, M., Senna, C., Sargento, S.: A multi-technology opportunistic platform for environmental data gathering on smart cities. In: 2017 IEEE Globecom Workshops (GC Wkshps), pp. 1–7 (2017). IEEE
  - [65] Ding, H., Li, X., Cai, Y., Lorenzo, B., Fang, Y.: Intelligent data transportation in smart cities: A spectrum-aware approach. *IEEE/ACM Transactions on Networking* **26**(6), 2598–2611 (2018)
  - [66] Tornell, S.M., Calafate, C.T., Cano, J.-C., Manzoni, P.: Dtn protocols for vehicular networks: An application oriented overview. *IEEE communications surveys & tutorials* **17**(2), 868–887 (2014)
  - [67] He, J., Cai, L., Pan, J., Cheng, P.: Delay analysis and routing for two-dimensional vanets using carry-and-forward mechanism. *IEEE Transactions on Mobile Computing* **16**(7), 1830–1841 (2016)
  - [68] Zhao, L., Wang, J., Liu, J., Kato, N.: Routing for crowd management in smart cities: A deep reinforcement learning perspective. *IEEE Communications Magazine* **57**(4), 88–93 (2019)
  - [69] Sidhu, D., Fu, T., Abdallah, S., Nair, R., Coltun, R.: Open shortest path first (ospf) routing protocol simulation. *ACM SIGCOMM Computer Communication Review* **23**(4), 53–62 (1993)
  - [70] Ghosh, A., Khalid, O., Rais, R.N., Rehman, A., Malik, S.U., Khan, I.A.: Data offloading in iot environments: modeling, analysis, and verification. *EURASIP Journal on Wireless Communications and Networking* **2019**(1), 1–23 (2019)
  - [71] Lindgren, A., Doria, A., Schelén, O.: Probabilistic routing in intermittently connected networks. *ACM SIGMOBILE mobile computing and communications review* **7**(3), 19–20 (2003)



- [72] Amah, T.E., Kamat, M., Bakar, K.A., Moreira, W., Oliveira Jr, A., Batista, M.A.: Preparing opportunistic networks for smart cities: Collecting sensed data with minimal knowledge. *Journal of Parallel and Distributed Computing* **135**, 21–55 (2020)