# Smart City: The State of the Art, Datasets, and Evaluation Platforms

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*Abstract*—While smart city concept holds great promise of boosting living standards through effective management and utilization of scarce resources in cities, the unavailability of real-world datasets and test environments to evaluate designed models and techniques have slowed research progress. In this paper, we review existing research endeavors and develop a tool for extracting real-time smart city related data. We also conduct some simulations and evaluations in smart energy, which will be an important application in smart cities.

*Index Terms*—smart city, datasets, simulation and evaluation

## I. INTRODUCTION

In cities, the burgeoning population places high demand on social amenities, while the existing resources and services do not increase proportionally to match the high demand. For example, in major cities, forecast estimates world's population to reach 9 billion in the coming years, with the United Nations predicting the increasing urbanization to rise to 66 % by 2050 [24]. Thus, coordinating such a population boom and effectively managing the limited resources in cities to serve the increasing population becomes an urgent and challenging issue.

For a sustainable and improved ecosystem, ways in which these limited resources could be managed and used to afford the citizenry optimum living standard have become a necessity. To this end, the concept of "smart city" has attracted great attention from many researchers and governments of cities around the world. The idea behind this concept does not necessarily imply the increased reproduction of social amenities and infrastructure and services, but focuses on the design of techniques for waste reduction, resource re-use, and efficiency in the management and utilization of scarce resources in cities.

The vision of smart city is to integrate information communications technology (ICT) with physical infrastructures (power distribution [21], [20], transportation [13], [22], etc.) for a more effective resource management geared towards improving living standard. Nonetheless, various challenges have hindered the fast development of this concept for large-scale applications in cities. First, one of those is the lack of reliable real-world dataset for modeling, analysis and techniques for improving operations that can aid decision-making for improved services. Second, processing and analyzing the heterogeneous massive data generated by different sensors remain a challenging issue, as most analytics platforms and tools are unable to handle compatibility and interoperability issues posed by these diverse datasets. Third, designing platforms

and solutions with features that can coordinate functions across various dimensions of smart city under one integrated platform has been the goal of researchers, in both the academia and industry.

As our contributions, in this paper we review research efforts in smart cities to create adequate insight on the development, challenges and future research directions. We develop a tool using Java for real-time extraction of real-world data that can be useful in research and development for advancing the concept. We also review existing tools and conduct a case study on smart energy and communication networks using simulation tools. Our evaluation results show that the renewable energy resources (e.g., solar energy) could greatly reduce the load from the main grid and network protocol (e.g., AODV - Ad hoc On-Demand Distance Vector Routing) could be used to support smart city communications.

The remainder of this paper is organized as follows. In Section II, we review existing research endeavors related to smart city. In Section III, we present the tool that we have developed for pulling data from online sources. In Section IV, we discuss some existing simulation platforms. In Section V, we present the case study. Finally, we conclude this paper in Section VI.

## II. TAXONOMY AND REVIEW OF SMART CITIES

In this section, we first give an overview of smart city, then present the dimension of smart cities, and finally review some research projects.

### A. Smart City Overview

A smart city integrates the information and communications technology with physical infrastructures in a strategic effort to support efficient services and guarantee sustainable high living standard for the citizenry [17]. Tao *et al.* in [30] conducted survey on smart cities, and extensively reviewed existing literatures on smart city definitions to come up with a taxonomy from four different perspectives: technical infrastructure, application domain, system integration, and data processing.

From the layer aspect, the smart city will consist of three layers. At the bottom, physical infrastructures include all physical amenities (sensors, controllers, etc.) already existing as part of an ecosystem in a city. The middle is the cyber infrastructure, which involves all computer and communication techniques to interconnect different components. At the top,

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services involving processes and relevant activities aimed at providing services to societal needs are included.

## B. Areas of Smart City

In view of the active research works being undertaken on this topic, one should yet expect evolution in the definition of the "smart city" term, and also the classification of its various dimensions. Smart economy involves effective social, political, entrepreneurial, etc. strategies to foster economic growth. For example, the objectives of smart governance are on transparent and effective governance, whereby citizens participate in decision-making. Smart mobility encompasses strategies for safe intelligent transportation system, which includes active monitoring during transit, reduction of carbon emission, and effective parking lots management. Smart environment is another key area that aims at improving our living ecosystem from the perspective of efficient energy management [20], [29], water management to smart building, waste management and carbon emission reduction, and traffic management [22], [23]. Similarly, smart living focuses on providing good living standard via quality health care, education, and provisioning of social amenities. In addition, the level of educational exposure of a society's citizenry, the intelligence and synergy of human capital and abilities for bettering the economy is what smart people focuses on.

The classification of these dimensions can take different forms and compositions across research and development efforts, but only few elements within those dimensions are currently receiving serious research attention. A number of projects have been carried out towards the actualization of the smart city concept, while a manifold of them are ongoing and yet to unfold. In the next section, we take a brief look, while summarizing some of these major projects across cities of the world.

## C. Smart City Projects

Several small and mega projects have been carried out in various smart cities geared towards efficiency. For instance, Corotinschi *et al.* in [10] tried to provide solution for monitoring and managing the heating and electricity systems of a campus, which consists of 11 buildings, for energy efficiency. The Barcelona Intelligent City, BCI project is another, which proposes a solution that adopts open standards and flexible platforms for integrating multivendor systems (e.g., wireless sensor networks) to ensure the interoperability necessary for the smart city concept [16]. The ICeWater project [19] investigated the connectivity concerns with water monitoring and management infrastructures.

Pellicer *et al.* in [26] summarized the various smart city works or projects across world cities under different smart city areas: smart governance, smart mobility, smart environment, and smart living. The cities and the smart city projects that they have investigated are listed as follows: Malaga (automated meter reading, electric vehicles and charging stations, energy efficiency for public facilities, smart grid, etc.), Paris (electric charging stations, bicycles, exchange plans,

e-Health: records integration software), Amsterdam(e-citizen participation, electric vehicle and charging stations, energy efficiency for buildings, smart grid, e-Heath, etc.), Vienna (efficient buildings, smart grid, urban energy systems, CO2 emissions reduction), Toronto (efficient metropolitan urban mobility, green construction policy, community broadband network), New York (open government - open data, improving public transportation, ICT-enabled services and pedestrian spaces for citizens, start-up development for social web), Copenhagen (efficient public transport, natural resources optimization and waste management, renewable energy, energy efficiency), Hong Kong (online services for citizens, RFID in airports, smart cards), Barcelona (project iCity-APP to serve, electric vehicle, urban traffic management, efficient transport, heating/cooling networks, smart containers for wastes Wi-Fi project, smart homes), Stockholm (smart water, waste management system, smart biogas production), London (online portal, smart card, networked public service, undergrounds optimization and management, Wi-Fi for metropolitan areas), Rio De Janeiro (traffic management, security system, smart health systems), and Vancouver (electric vehicles, green transport, greenhouse has reduction, water and waste management, green areas developments).

## III. DATASETS

In this section, we first give the motivation for data collection and present challenges associated with available datasets in the smart city research area. We then introduce a tool that we have developed for extracting real time data from online web servers.

## A. Motivation and Challenges

For efforts in the smart city area to progress into meaningful developments, which will provide sustainable solutions to the society, existing data from societal infrastructures and operations will be required to validate techniques and algorithms. To this end, we embark on collecting and analyzing real-world data from active sources to help researchers build models that will improve smart city planning and deployment. We also consider effective communication network to be core to actualizing efficient smart city solutions; hence, our simulation study aimed at ascertaining the suitability of some communication protocols for smart city applications.

Challenges in smart city research need to deal with the heterogeneous data, which arise from different collection sources. Various sensors, network infrastructures, and devices from different vendors generate these data. Thus, harmonizing and consolidating them in a uniform, usable format, which can be applied to a research endeavor or simulation, is critical.

In the following, we further discuss some of the major challenges with smart city research data.

**Quality of Information (QoI):** Ensuring quality of information collected depends on the accuracy of the device or equipment used to capture the data. By this, we mean that if the data collection infrastructure is ineffective or error-prone, we cannot boast high fidelity of data to the original source.

There may be other external factors at the point of collection that might affect and distort the originality of the data.

**Data Characteristics:** Due to the enormous amount of data generated, detecting outlier and possibility of error-inducing effects during pre-processing and transmission of these data are high. With the proliferation of devices and sensors, which continuously generate huge, multiplatform data, the scalability of information systems to accommodate this expansion will be an issue. Other concerns bother on whether the format of those data are flexible enough to allow series of manipulation tasks on them across various mediums they may pass during processing. The data related questions remain unresolved.

**Constraints:** We claim that the sensors network in smart city is a constraint network because most of the wireless sensors and devices have limited resources and abilities [28], [12]. Those constraints (power, memory, processor, bandwidth, etc.) affect the data collection. Massive datasets generated require effective and reliable communication network to transfer them from their generating sources to operations stations, and across to third parties that need them for various purposes. Guaranteeing this, amongst other constraints, is critical to the advancement of this concept.

Another major challenge is how to collect real world data and more so distinguishing between data that is usable from the extremely large amount of data being generated on a daily basis. Thus, how can we mine and categorize these data, from data mining and big data perspectives?

There are some potential solutions, which are discussed from two the following aspects: (i) **Network Protocols:** One solution to enhance the data collection performance is to improve the network transmission capability. There are a number of research efforts designing protocols, including the Constrained Application Protocol (CoAP), MQ Telemetry Transport (MQTT), Extensible Messaging and Presence Protocol (XMPP), and Data Distribution Service (DDS), which can enhance the data collection and transmission performance. In addition, new architecture is needed to interconnect small-scale domain-specific NeTs into a globally connected Internet-of-Things for smart cities [27]. (ii) **Data Processing and Mining:** Un-analyzed data is valueless because those data cannot help human to improve life quality. To increase the efficiency of data collection, data process, and data analysis, some data mining techniques could be applied. If the data can be collected by interest, request, and associate, the cost for processing of data collected can be reduced and the data can become more valuable. To deal with big data processed in smart city, the fog and edge computing can be leveraged so that data can be stored and processed locally before transmitting the massive data to the centralized data center [23].

### B. Data Extraction Tool

We have developed an online data collection tool for pulling real-time data from online web servers. These web servers at intervals refresh, updating their information. Our developed tool has the capability of synchronizing with these servers as to collect the real-time datasets over time. Some of the features of the tool include: (i) enabling users to set a time during which the tool automatically activates and pulls data from online servers, (ii) synchronizing with the server to collect the latest refreshed data, the flexibility of creating and storing data collected in multiple file formats.

We have designed and implemented the tool using java. Figure 1 below illustrates an example of the layout of the data collected by our tool. The designed tool consists of three components: (i) the time management component that allows the user or administrator to set a time frame for the application to conduct data collection; (ii) the data collection component that synchronizes with the web server and ensures the changing data is pulled at regular intervals; (iii) the file management component that ensures the original nature, fields, and format of the data collected is maintained; it conducts the data processing, including file renaming and enabling users store the file in required format.

| Location | Air | RH | Dwp | Precip Type | Wind Speed | Wind Gust | Direction | Pavement Temperature | Date/Time |
|---|---|---|---|---|---|---|---|---|---|
| Hatem Bridg | 70 | 80 | 64 | None | - | 9 mph | SE | 86 - 86 | 9/23/16 11:13 |
| I-270 AT I-37 | 77 | 62 | 63 | None | Calm | | N | 94 - 95 | 9/23/16 11:10 |
| I-270 AT MD | 78 | 64 | 65 | None | Calm | 5 mph | W | 91 - 92 | 9/23/16 11:10 |
| I-495 AT Am | 78 | 69 | 67 | None | Calm | 7 mph | SW | 93 - 94 | 9/23/16 11:10 |
| I-68 AT MD-2 | 72 | 67 | 61 | None | 6 mph | 11 mph | W | 90 - 93 | 9/23/16 11:10 |
| I-68 AT Savag | 77 | 55 | 60 | None | Calm | 7 mph | NW | 92 - 95 | 9/23/16 11:10 |
| I-68 AT Sidell | 74 | 68 | 63 | None | 4 mph | 7 mph | SE | 93 - 95 | 9/23/16 11:10 |
| I-68 AT WV L | 75 | 62 | 61 | None | 6 mph | 13 mph | NW | 87 - 91 | 9/23/16 11:10 |
| I-695 AT I-83 | 80 | 56 | 63 | None | Calm | 8 mph | N | 92 - 94 | 9/23/16 11:10 |
| I-70 AT Fred- | 75 | 66 | 63 | None | Calm | 6 mph | NW | - | 9/23/16 11:10 |
| I-70 AT I-695 | 80 | 54 | 63 | None | 4 mph | 9 mph | SW | 93 - 99 | 9/23/16 11:10 |
| I-70 AT I-81 | 74 | 63 | 61 | None | Calm | 6 mph | N | 98 - 98 | 9/23/16 11:10 |
| I-70 AT MD-2 | 80 | 57 | 61 | None | Calm | 7 mph | SW | 97 - 99 | 9/23/16 11:10 |
| I-70 AT MD-5 | 77 | 64 | 64 | None | Calm | 8 mph | W | 100 - 100 | 9/23/16 11:10 |
| I-83 AT MD-1 | 78 | 69 | 68 | None | Calm | 5 mph | S | 93 - 93 | 9/23/16 11:10 |
| I-895 AT I-95 | - | - | - | No Data Avail | - | - | No Data Avail | - | |

Fig. 1. Example of Data Collected

We have collected several datasets in regard to smart city. Via analyzing data of traffic flow of GPS locations collected, we could deduce the mobility pattern of road users. An understanding of the roads' mobility pattern can help in the development of more efficient algorithms for traffic coordination and management. For example, understanding peak and non-peak hours for different road networks can aid effective traffic re-routing and management. The location dataset related to mobiles that we used is from the Microsoft Research Lab, Asia. The dataset recorded a trajectory location, which traces 182 mobile users over three years from April 2007 to October 2011 in Beijing, China. The overall distance is about 1.2 million kilo-meters and a total duration over 48,000 hours [2]. In the data, latitude and longitude in decimal degrees and altitude in feet (-777 if not valid) that allow the location of the mobile users at a specific time based on the date and time of the data field to be located. Another data collected, which is T-Drive, was also done by Microsoft Research Lab, Asia [31]. The dataset records the movement of 10357 taxis in one week in Beijing from Feb. 2 to Feb. 8, 2008. This data shows the location of a taxis continually at different time period by using longitude and latitude.

Home sensors data might be very useful in smart home and smart health care research. By learning human activities and operations in homes through sensors, designing and implementation of self-learning algorithms can be improved. The Activity Recognition in the Home Setting Using Simple and Ubiquitous Sensors Project [6] is an experiment developed by MIT in 2003. They installed 77 and 84 sensors in two

apartments on different home appliances, which monitored human related activities for two weeks starting from 3/27/2003 to 4/19/2003. The data shows the activities in those two apartments for a period of time.

In addition, the University of Massachusetts Amherst (UMass) Dataset is the power consumption or usage from 400 homes; and for each home, collected at one-minute granularity for an entire day on April 4, 2011. The locations of those homes are also not available due to privacy reasons. The data fields of this dataset are: time stamp in local time and the usage in watts. As detailed in the next section, we have conducted experiments using data from 100 buildings.



Fig. 2. Power Grid Simulation Model

## IV. EVALUATION PLATFORMS

Although smart city concept is still developing, a number of efforts have come up with useful tools for simulating scenarios in the different dimensions of the field. In the following, we review some existing simulation and evaluation platforms. We choose to focus and discuss a number of useful tools from the three aspects: smart grid, smart transportation, and smart city.

**Smart Grid:** In this area, a number of simulation platforms are available, and most of them are open source. Examples include: (i) Gridlab-D [7] is a power distribution system simulation and analysis tool. (ii) GridMat [8] is a co-simulation platform, which integrates the features of GridLab-D (physical power grid) and the capabilities of Matlab (working as the control engine) to model and simulate the physical energy system. (iii) OpenDSS [14] is a comprehensive electric power system simulation tool, primarily for utilities power distribution systems of EPRI.

**Smart Transportation:** Examples of platforms include: (i) Quadstone PARAMICS [25] is a pedestrian simulation software, which offers operational assessment of current and future year traffic conditions, with detailed reporting of key movements. It also provides user friendly interface to non-technical users. (ii) Vissim [9] is used to simulate traffic patterns; it displays all road users, from motorists, cyclist, public transports to pedestrians, etc. and how they interact in its model. Some of the software's operations include junction geometries comparison, public transport priority schemes analysis, and so on. (iii) MATSim [4] is a great agent-based transport simulator, which implements an open-source framework. (iv) Simulation of Urban Mobility (SUMO) [18] is an open source, very wearable, developed microscopic and continuous traffic simulation package that can handle large road networks. SUMO is licensed under the GPL. (v) MAINSIM [11] is a traffic simulation system for urban multi-modal transport. The simulation graph is generated by cartographic material in a completely automatic manner. MAINSIM is able to simulate the transport of entire cities with cars, bicycles and pedestrians.

**Smart City:** Having discussed simulation platforms with each addressing specific area of smart city as discussed above, efforts are being made to develop a single platform for modeling and creating smart city solutions. Some of these platforms, as discussed belo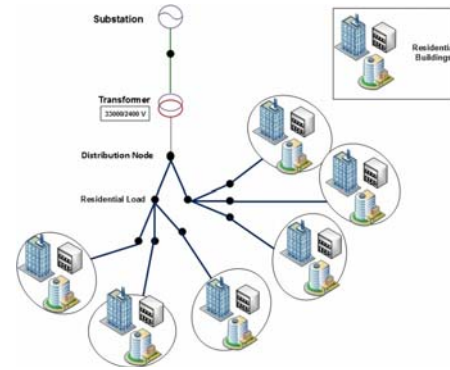w, aim to offer features that incorporate, and address concerns across various dimensions of smartness in one single solution below.

(i) Kaa project is an open-source, multiplatform middleware for building and managing Internet of Things (IoT) solutions [3]. Besides acting as an intermediary between the connected devices (using embedded SDKs) and backend infrastructures, it features other capabilities, including real-time device monitoring, sensor data analysis, behavior analysis, remote device provisioning and configuration, and management of unlimited connected devices. It employs Apache Cassandra and Apache Zeppelin for its data analytics and visualization. Kaa holds great promise as an all-in-one platform for IoT (smart city) solutions, although its features/capabilities are still work-in-progress.

(ii) B-Scada's CitiWorx is another smart city solution, which prides on its combination of technology, expertise and partners pool for delivering quality solutions [1]. It is a cloud-based solution for monitoring large connected devices, sensors, etc., while collating and presenting a powerful visualization of the data for decision-making. Built on Microsoft Azure, it has the capability of supporting massive assets through information modeling using OPC UA. With world-leading OEM suppliers and system-integration engineers constituting its partner ecosystems, B-Scada also boasts of its rich set of development tools, APIs and utilities for building complete, resourceful solutions.

(iii) ThingWorx, like other IoT platforms, is developed with smart city (and Internet of Things) in mind. Rapid creation and deployment of smart city solutions with capabilities of connecting, monitoring, managing and optimizing interconnected IoT entities (sensors, devices, infrastructures, people, etc.) is the core offer of ThingWox [5]. Like its competitors, ThingWork strives to expand its current features and capabilities in key smart city areas, including smart traffic, smart transportation, smart rail, smart infrastructure, smart water, etc.

## V. CASE STUDY

In the following, we show case study. We conduct two different simulations using some simulation tools discussed in Section IV. The first is the smart city simulation in smart

grid environment, and the second is a simulation study on communication networks to support smart city applications.
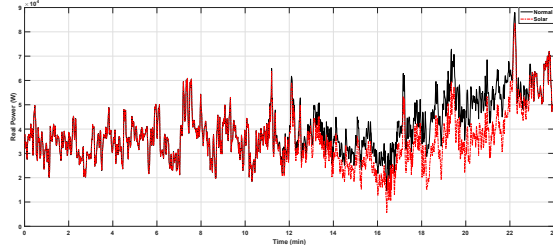


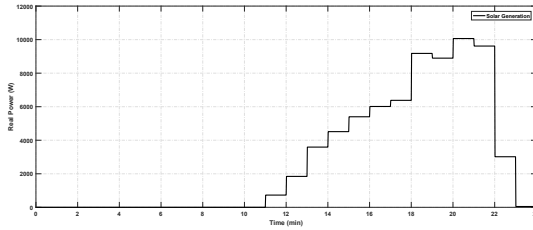Fig. 3. Total Power Generation With and Without Renewable Energy Supply



Fig. 4. Solar Power Generation



Fig. 5. Communication Network Model



Fig. 6. Network Configuration

## A. Smart Grid Simulation

In our simulation, we use GridLAB-D as the simulation tool. Figure 2 shows the simulation model. The power grid that we choose comprises a substation and residential buildings as load. The substation supplies a nominal voltage of 33000V. Using a step-down transformer connected between the generating source and the distribution components, the voltage is stepped down to 2401.7V for a city block, which consist of residential load. The residential load is made up of 100 residential buildings, which are distributed into six neighborhoods connected to the power line through meters. The data input for buildings' usage was retrieved from the UMassTraceRepository [15] from a community whose details are kept anonymous for security reasons.

Microgrid dataset represents usage data in Watts for 443 buildings from time period of 2011-04-01 19:00:00 to 2011-04-02 18:59:00. We used data from 100 buildings in our simulation. In the first simulation scenario, we assume a normal operation whereby the simulation is performed with optimal settings for comparison. The second scenario involves additional supply from the solar power plant to the grid that is commonly deployed in smart city.

Figure 3 depicts the variation in total power generation for 24 hours for the system under normal operation and solar energy supply. The curve in black represents the total power generation from the grid under normal conditions, while the curve in the red shows the grid performance when the solar plant is connected. As seen in Figure 3, from 2011-04-01 07:00 PM till 2011-04-02 06:00 AM, there is no difference in power generations for both the scenarios because the solar plant is in
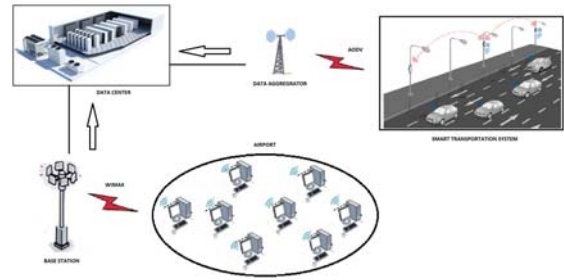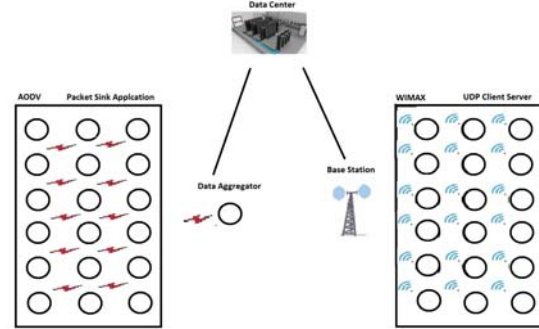
disable mode and power generated is zero due to night time. From the time period 06:00 AM till 07:00 PM, we observe the difference in the power generation because the sun radiance increases, resulting in solar generation increase. We can also see that during the time period from 05:00 PM till 07:00 PM, the power generation (with renewable energy) is almost imitating the normal operation, because during this period the solar power generation is decreasing. Figure 4 shows the solar power generation during the simulations time. Overall, we conclude that when a solar plant energy is used in the smart city, the burden for power generation is being reduced on the substation.

## B. Communication Network Simulation

We now present the performance evaluation of communication network in smart city. As shown in Figure 5, we aim to depict a smart city environment, in which two clusters of devices forward data packets to a data center for processing via their individual aggregators/ base stations.

The first cluster is simulated to be smart transportation sensors located at various stationary intersections, while the second cluster is considered to be an airline's workstations. For the experiment as an example, we use AODV protocol for data packets transmission from the first cluster to the data center, while WiMax protocol is deployed on the second cluster. In this simulation, the objective is to measure and compare the performance of both protocols with respect to delay and packet delivery ratio as to be able to infer ideal protocols and settings for specific applications in smart city. Fifty nodes are deployed for both clusters in the scenario in a 5 X 10 grid topology.

451

While the MAC protocol for the AODV is 802.11 and WiMax uses 802.16.

Figure 6 illustrates the network configuration for the simulation. As shown in the figure, packet sink application is deployed on the AODV cluster, whereby packets will continuously be sent to the aggregator, from which they are transported to the data center for processing. Likewise, the UDP client-server application is deployed on the WiMax cluster, with a base station that serves to connect the wireless transmissions from the WiMax cluster to the data center via a point-to-point connection. The simulation ran for 60 seconds to generate network parameters. In the simulation exercise, the networks performance related data was recorded when the two aggregators/base stations were re-positioned at different points around the clusters so that we could examine the various effect of the change on throughput, delay and delivery ratio.

Using ns-3, we evaluated the performance of two different re-positioning of the aggregators/base stations for both protocols. We observe that when the aggregators or base stations are in location 1, the packet transmission delay for WiMax is a bit higher than that of the AODV protocol. Nonetheless, with the change to location 2, there is a sharp difference in the delay between the two protocols, with AODV exhibiting far lower transmission delay compared to the WiMax protocol. Furthermore, our experiments shows that AODV protocol achieves a higher packet delivery ratio at both location 1 and location 2, when compared with that of WiMax protocol. These results, from the perspectives of transmission delay and packet delivery ratio, suggest that AODV protocol could be used to serve smart city applications.

## VI. FINAL REMARKS

In this paper, we addressed the issue of inadequate real-world dataset for fostering smart city research. Particularly, we first reviewed existing research efforts and relevant projects relevant to smart cities. We then presented a tool designed using Java for extracting real-world data from online sources thereby offering means of acquiring reliable data for smart city research. We further reviewed tools and platforms to conduct performance evaluation and conducted two simulation studies; one on smart grid for understanding the effect of renewable energy resources on the grid, and the other on communications protocols that could efficiently support smart city applications.

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