Proposal of a Mobile Ecosystem for Efficient Collection of Municipal Solid Waste

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***Abstract*: In smart cities, communication and information sharing among various smart devices is performed using ubiquitous sensor networks (USN). In this paper, we propose a novel concept of Mobile Ecosystem (MES) for municipal solid waste (MSW) collection over a wireless sensor network (WSN), which utilizes mobile communication networks (MCN). This MES identifies MSW components such as bins/skips and garbage collection points, etc. through Internet Protocols (IPs) and shares real-time information with municipal authority (MA) on a platform of Information and Communication Technology (ICT). ICT enables the IPs to share the waste-related data with main server (MS) where it is analyzed and processed and is send to the Mobile Ecosystem- Database (MES-DB). Subsequently, the aggregated information is shared with the end-users on their smart mobiles. Our proposed platform develops ubiquitous computing for municipal waste collection and uses ICT to connect MA to the main server through assigned IPs. From a communication standpoint, information sharing among smart devices is an important aspect of smart cities, therefore, our proposed MES platform is expected to be a major development in smart waste collection from urban cities.**

***Keywords*: Solid Waste Smart Space, Real-time data sharing, Information and Communication Technology**

I. INTRODUCTION

Every metropolitan city municipal corporation has different types of facilities for collecting Municipal Solid Waste (MSW), as well as resources used to link skips/bins, garbage collection points, garbage trucks, manpower, and transfer stations [19; 23]. However, roughly half of MSW remains uncollected in urban cities in developing countries such as Lahore in Pakistan [19], Padang in Indonesia [31], Isfahan in Iran [33], and in different states of India due to inadequate communication among these facilities [34]. The amount of scattered MSW increases every year, causing an increase in the use of open dumps throughout many urban cities in developing countries [20]. Apart from this, insufficient funds, poor communication, inadequate technology, and insufficient facilities for MSW in developing countries exacerbate the problem [1]. Indeed, inadequate communication and information sharing among various components such as house hold bins/skips, garbage collection points, waste collectors, and dump trucks are manually operated in urban cities, which hinders the process of MSW collection [14]. Given that roughly 60% of the world population will be living in urban cities by 2030 [26; 27], we put emphasis on the application of a ubiquitous sensor networks (USN) [12]. One possible solution for this problem is the use of information and communication technology (ICT) in urban cities, which allows for the use of USNs at waste collection facilities, waste collection points, and bins/skips [2; 7]. From a communications standpoint, the use of autonomous sensors is the key to developing a Mobile Ecosystem (MES) [14]. The MES is based every MSW-related component in the urban area sharing information with the municipality authority and its end-users/residents.

The collection of MSW uses approximately 70% of the municipal budget, whereas it utilizes 80-90% of the resources of municipalities [4; 18]. In fact, only 60% of the urban population receives collection services from municipal authorities [8]. In order to overcome these problems, some researchers have proposed the use of advanced technologies, such as global positioning system (GPS) [32], geographic information system (GIS) technology [30], and barcodes and tagging radio-frequency identification (RFID) [1], for waste collection and disposal. However, these works have various limitations, such as GPS signal dropout in urban cities, GIS availability of user input data, and the barcode and RFID efficiency of the system not taking into account which measurements are invalid [22; 25]. Yet, an efficient, cost-effective, real-time information sharing, and interactive platform has not been adequately invested in regarding the collection of MSW. Therefore, we propose a platform in which smart devices of different operative domains can be connected in various ways to extract the required information and share data amongst themselves. According to K. Doppler [10], device pairing and device-to-device communication is feasible. Components with embedded sensors for MSW can share their real-time information and communicate with MAs through either wired or Wireless Sensor Networks (WSNs) [35]. This platform bridges the physical world of real-time information with the virtual world using ICT. Presently, in both developed and developing countries, experiments are being performed with new methods/techniques to collect waste efficiently, as this is the foremost requirement for a sustainable environment. To date, the identification of waste identified via technology with unchecked mobility has not played an efficient role in the collection of scattered waste [6;11;28]. Therefore, one possible way to enhance the performance of a municipal authority (MA) is to merge Internet of Things (IoT) with MSW through the ICT. This collaboration between ICT and IoT leads to the concept of an MES, which is used to improve the efficiency of MSW collection and enhance information sharing for MSW from urban cities. In this paper, we propose an MES where the components can share information in order to link end-users with MAs in smart cities. We focus on MSW collection, data storage, processing, and real-time information sharing using a USN. This inter-sensor communication was developed in mobile ad hoc networking [16]. The proposed networking system is based on a mobile communication network (MCN), such as 4G/5G or LTE, supporting Internet Protocol (IP) while enabling internet services [3; 9; 24]. In this proposed platform for MSW, IoT makes use of a routing protocol for sharing waste-related information to the MA. This platform, can lead to cost-effective and efficient MSW collection. Furthermore, the MES permits data transmission, synchronization, and sharing between smart devices such as smartphones; this is accomplished using variable message signs (VMS) and short message service (SMS) in order to help facilitate end-users. Basically, the MES integrates these smart devices, facilities, and authority into a single platform through IoT. The scheme proposed in this paper is to build waste bins with real-time information sharing, online monitoring, location finding, and comprehensive volume estimation. Consequently, cost-effective waste collection results in an improved overall efficiency for MA. Thus, the basic concept behind the development of an MES for smart cities is to enable communication using a web 2.0 platform for the ease of stakeholders and shareholders.

II. MATERIALS & METHODS

A. Layout of the Mobile Ecosystem

The term natural ecosystem refers to all non-living elements and living species in a specific local environment. Components of the natural ecosystem include water, air, sunlight, and soil NLT as well as plants, microorganisms, insects, and animals (living organisms) [5; 13; 21]. In an ecosystem, the interaction between living organisms and non-living things (NLT) is substantial for the sustainability of any environment [21]. The MES for solid waste collection is based on the same analogy as that of a natural ecosystem. The MES components include house hold bins/skips, garbage collection points, scavengers, transfer stations, dump trucks, and autonomous sensors. The components of the MES function together as a single unit and communicate with each other via wired or wireless network technology (Wi-Fi, Bluetooth, LTE, or RFID) [15]. The foremost assumption for the development of MES on MSW in urban cities is that the end-users using smart devices are a part of the ecosystem. The end-users are connected with all of the components of the IP-space and IP-facility of the network by using mobile applications on their smartphone, as shown in Figure 1. When an event occurs, such as a component being related or critical, these updates are shared with the end-users on their smartphone based on their individual IP-addresses. Table 1 shows a description of a natural ecosystem compared to a mobile ecosystem based on their interest activities regarding MSW.

B. Architecture of a Mobile Ecosystem

The MES for solid waste includes real-time data collection, monitoring, and promotes bi-directional (two-way) information sharing between the MS with waste facilities and end-users. Each component of the MES has a unique IP that enables the system to obtain information and share the real-time data with the MA [36]. These protocols are connected to the end-user through a WSNs, as shown in Figure 3. Moreover, the IP interface with the MS, thus enabling the system to collect real-time bin data, including the volume, zone location, location of waste dump trucks, and subsequently sends this data to the gateway. Furthermore, this real-time data is sent to the data-logger through a gateway via a coordinator node. It is then transmitted to the MS through the modem. Additionally, the modem shares the data via unique IP addresses allotted to the components of MSW, the end-users, and the MS by using a bridge mode. The bridge mode also shares the data with end-users via a mobile communication network (MCN) using specific cloud computing security IDs with the MS. The accumulated data for all IPs are analyzed by the MA in a central processing room and the results are shared with the MES database (MES-DB). This information is then shared with end-users on their smart devices after passing through a security interface, depending on the filtered data in the MES-DB.

The MS applies an algorithm to find the waste bin, as illustrated in Figure 4. This flow pattern is based on five-steps approach to locate and find solid waste bins status. In the first step, the authority fixes the monthly schedule regarding waste collection from the bin. In the second step, the MS manages the daily consumer services. In the third step, technical support shares information such as the location, status of the bin, and the schedule for waste collection. In the fourth step, requests an additional trip to collect the waste from the bins/skips. In the fifth step, completion of the task is accomplished.

C. Function of the Mobile Ecosystem

The MSW operations are performed using the protocol of MES components integrated with IPs. The function of the IPs is to specify the target destination for data transmission [17; 29]. Subsequently, control protocols (CP) are assigned to any event activity (Critical) occurring in the MES and issues related to it (Related), which are referred to as CP-Critical and CP-Related, respectively [36]. Descriptions of the IPs and CPs are assigned and are given in Table 2. The objective of IP-Space is to trace the overfilled bin; the IP-Facility suggests the most suitable type of method for waste collection. CP-Related communicates with the smart waste devices and end-users in order to share information via the internet. CP-Critical identifies when an unexpected, rare event occurs in the MES. Table 3 describes the inner-workings of the IPs and CPs. As an event occurs, the real-time data from these protocols are sent to a BS via the gateway using MCN (2/3/4G or LTE). The protocols enable all MSW components to be identified on the MS. The MA accesses all the components via an address resolution protocol (ARP). At the same time, this real-time data form the components are received by the reverse address resolution protocol (RARP). This method pinpoints the location and status of the waste components in a zone.

A step-by-step approach of MES for MSW flow-pattern diagram is shown in Fig. 5. From the figure, it is observed that the process is composed of six phases, viz., inputs, application services, communication, processing, output and goals. The first phase is the input phase, in which information is collected from IPs and CPs. In the second phase, the application servers provide a platform for assessing the protocols and send accumulated data to the next phase. In the third phase, communication sharing of IP and CP data takes place via the mobile communication network or gateways. In the fourth phase, the collected information is processed and analyzed, and an algorithm is run to assess the event. This event information is shared via a web-based application for the end-users. This information is looped in the second phase and run again until this loop is completed, and this level of information is used for the next phase. In the fifth phase, all activities appear on smart devices as an output. In the sixth and final phase, the objectives of MSW, such as efficient waste collection, zero scattered solid waste, minimization of CO2 emission, and reduction of the use of open dumps, are accomplished.

D. Response to a Triggering Event

The response to any event is based on the three-steps shown in the MES schematic diagram in Fig. 6. The first step is remote access of MSW by the MA to install IP-based sensors for monitoring the MSW data. This data is sent to the database (DB) via a gateway. The second step is comprised of collecting of solid waste and locating the dump truck, along with continually monitoring the bins/skip. This real-time data is monitored through GPS/LBS while it sends the data to a central processing room. In the third step, the data is shared with end-users on their smartphones through short message services (SMS). Moreover, end-user can send their feedback to MA using a secured MCN. The inputs are received by the end-users via their smartphones, autonomous sensors, CCTV, and environmental sensors. The accumulated data is synchronized and analyzed in the MS. This data is then shared with concerned stakeholders through the Web server.

III. RESULTS

A. Event Evaluation by the Main Server

Whenever an event (CP-Critical) takes place, the WSN notifies the MS. The MS processes the bin file data as a CP event occurs, such as user uploads an image onto MES platform or a garbage truck passes through for collection of waste. The daily schedule is also analyzed for a second trip, if necessary. This flow pattern is illustrated in Fig. 4. Fig. 7 demonstrates the aggregated data of waste facilities and space is synchronized and evaluated in three-phase process viz. the responses of the sensors, data analysis, and real-time communication. In the first phase, the solid waste data received from individual IP is shared with the control room and with the MA. In the second phase, IP data analysis is performed in the MS. This analysis is based on specific IP threshold values. The threshold index is fixed by the MA. This data is send to big data for further short and long term data analyses. In the third phase, communication is developed between IPs and the central processing room using the WSNs, specifically through ZigBee, WiFi, and LTE. The IPs also communicate with specific end-users through a mobile communication network or broadband convergence network (BcN).

B. Performance Outcome of the Mobile Ecosystem

The performance of MES is based on four-key approach, as shown in Figure 8. The first approach is related to sensor alerts; the embedded network sensors installed on the bins/skips, and waste collection points etc. share real-time data with other domain IPs. This IP based events of IP-facility and IP-space is send to VMS, SMS, or smart speakers installed on waste facilities. The second approach is relevant to MCN where IPs share their data via smartphones and SMS and generates waste collection schedule. This communication of IPs with smart mobiles/devices use LTE/3G or 4G. The third approach is based on efficient household IP bin waste collection, door-to-door facility, and indication of the bin hygiene level. The smart operation IPs data is shares with each other using RFID, and NFC while notifies the MA. Based on these IPs, smart wallet bills and waste collection schedule are updated. The fourth approach deals with the bi-directional (two-way) communication among all end-user, bins/skips, waste collectors, waste dump trucks, and also with control center, which are linked with each other via web browser Web 2.0. This IPs data output is analyzed to assist the metropolitan authorities based on policies, public awareness and quality control to keep the city environment clean and green for future generations.

IV. CONCLUSIONS

In this paper, we proposed a Mobile Ecosystem for efficient collection of municipal solid waste in smart cities of developed and developing countries. This MES identifies the components of municipal solid waste by assigning them IPs on the domain of the internet. This framework extends to ubiquitous communication, real-time information sharing with the main server and municipal authorities using mobile networks. It is well known that adoption of proposed platform of communication through ICT plays a key role in aspects of our everyday life. Hence, the generation of municipal solid waste is associated with the size of the population and the lifestyle of urban dwellers, also poses a health risk and impacts the environment. It is presumed that if municipal authorities continue using the conventional methods of waste collection, they would have to increase their expenses, and many problems associated with current waste collection would get worse. The proposed, structure of MES can be implemented in few systematic steps based on the event occurred. It has also been shown that this approach could be enabled on many sensor networks through IP addresses. Moreover, communication have been developed among smart waste-related devices. Thus, this communication brings the end-users with municipal authorities via main server. Although this approach predicts efficient solid waste collection, cost-effective operation, and real-time information sharing, however, there are further development points for the disposal of solid waste that need to be addressed. It is well known that mass balance of solid waste without smart devices for recovery of scattered waste could not be established. Hence, the use of MES for MSW is proposed to tag products with a USN which can communicate through ICT embedded on smart bins/skips. Another possible research direction is to develop self-reporting bins using apps to enhance scattered waste collection and recovery by garbage trucks.

V. RECOMMENDATIONS

Table 1: The Description of MES interest activities of the Natural of the Ecosystem and Mobile Ecosystem

Natural Ecosystem	Mobile Ecosystem
Sustaining process	Sharing information
Energy flow	Activity flow
Decomposition	Pyramid network
Nutrient cycling	Energy cycling
Function and biodiversity	Function and physical diversity
Ecosystem goods and services	Mobile goods and services
Ecosystem management	Smart management

Table 2: IP- Component and CP-Component Relationship Services

IP-Component (Space)

House/Flats

Daily, solid waste is generated after the use of many products.

Polythene Bags

The waste is put in a polythene bag or segregated bags.

Garbage bins

All or some of the polythene bags are placed in bins outside of the house, which is collected by some authority.

Garbage Fixed or

Open Points

The majority of residences throw their garbage out directly at fixed points.

IP-Component (Facility)

Scavengers

Many residences have fixed scavengers to pick up their garbage from their doorsteps.

Garbage Point Containers

In some big cities, an authority provides mobile container points to facilitate scavengers.

Garbage Trucks

These trucks collect the solid waste from fixed points and from these containers.

Route Plan

The route plan should be planned in order to maximize the reduction of

CO_2.

CP-Component (Related)

Weighing Facilities

This component provides the exact date when the capacity of the dumping site is filled.

Sampling Analysis

This facility analyzes the waste.

Segregation &

Reclamation Units

This unit reduces the capacity of the dumping quantity.

CP-Component (Critical)

Event can be acquired randomly, abruptly, or fixed in a year.

Table 3: Relevant Functions of the Components of the Mobile Ecosystem

Services	Application	Function
Waste Bins and Skips	Data Assess Layer & Tagged RFID	IP-Space
Transfer Stations	Onsite/Offsite Waste Recovery	IP-Space
Collection Schedule	Synchronize Daily Notification	IP-Facility
Route Plan/Road	Real Time Traffic Information	IP-Facility
Waste Assessment	Valuable Waste Segregated Information	CP-Related
Garbage Fixed Points	Fixed Coordinates & Tagged RFID	IP-Related
Scattered Waste	Randomly Cluttered Information	CP-Critical

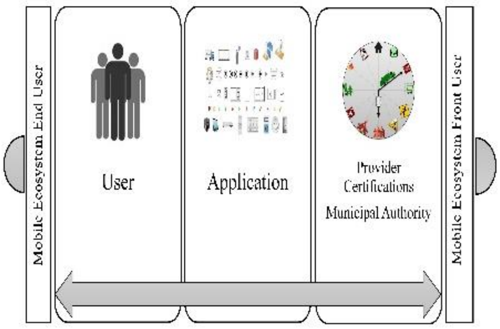

Fig. 1: Integration of end-user, Municipal Authority (provider), and all components of municipal solid waste collection setup are staging part of Mobile Ecosystem Application.

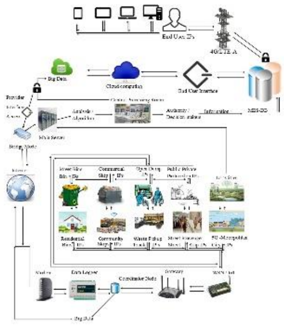

Fig. 2: The architecture of the Mobile Ecosystem (MES) is demonstrated here; as an event occurs, the municipal authority (MA) and end-users communicate with the unique IPs of the waste components and are linked via a mobile communication network (MCN) and share their data with the central processing room

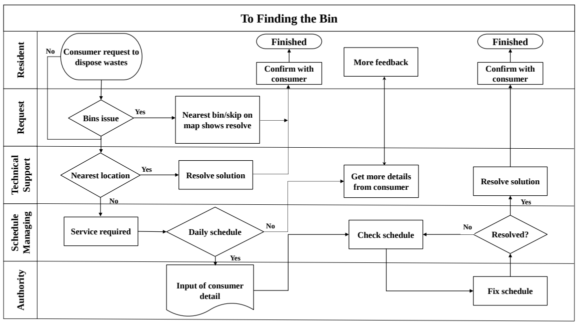

Fig. 3: Five-step approach to establish flow pattern for locating and finding solid waste bins

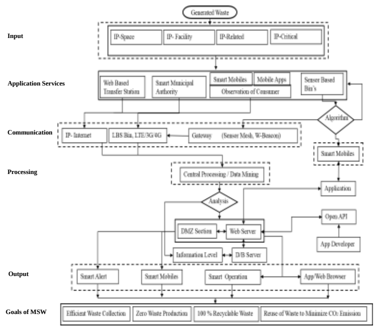

Fig. 4: A step-by-step approach of Mobile Ecosystem for municipal solid waste data flow pattern, real-time information sharing and real-time data process and analysis.

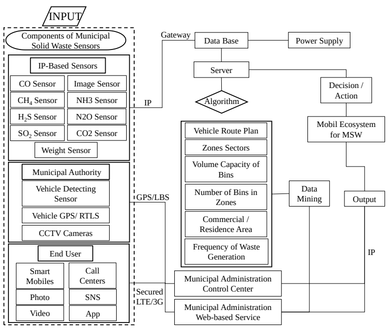

Fig. 5: A comprehensive Mobile Ecosystem input data analysis flowchart for efficient collection of municipal solid waste

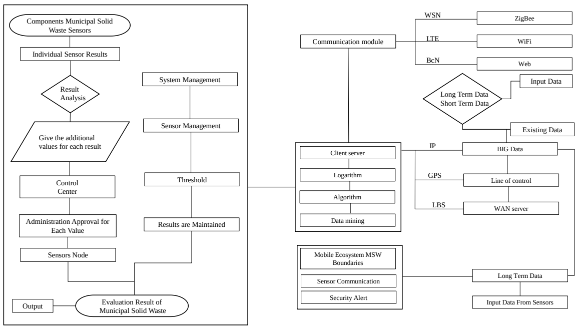

Fig. 6: Municipal solid waste data analysis process flowchart of main server

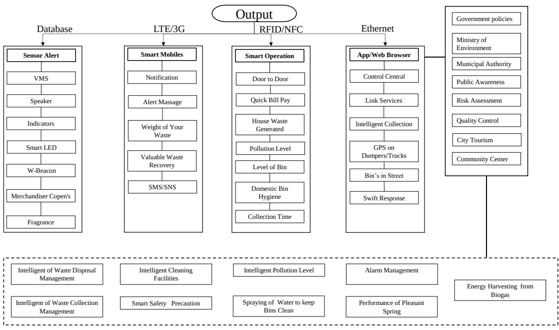

Fig. 7: Flowchart of Mobile Ecosystem output system for Municipal Solid Waste.

REFERENCES

[1]. S. Abdoli, RFID Application in Municipal Solid Waste Management System, International Journal of Environmental Research 3 (2009), 447-454.
[2]. Aleke, U. Ojiako, and D.W. Wainwright, ICT adoption in developing countries: perspectives from small-scale agribusinesses, Journal of Enterprise Information Management 24 (2011), 68-84 %@ 1741-0398.
[3]. L. Atzori, A. Iera, and G. Morabito, The Internet of Things: A survey, Computer networks 54 (2010), 2787-2805.
[4]. S.A. Batool and M.N. Ch, Municipal solid waste management in Lahore City District, Pakistan, Waste Manag 29 (2009), 1971- 1981.
[5]. P. Bolund and S. Hunhammar, Ecosystem services in urban areas, Ecological Economics 29 (1999), 293-301.
A. Boustani, L. Girod, D. Offenhuber, R. Britter, M.I. Wolf, D. Lee, S. Miles, A. Biderman, and C. Ratti, Investigation of the waste-removal chain through pervasive computing, IBM Journal of Research and Development 55 (2011), 11: 11-11: 11.
[6]. Caragliu, C. Del Bo, and P. Nijkamp, Smart Cities in Europe, Journal of Urban Technology 18 (2011), 65-82.
[7]. S. Cointreau-Levine, Private sector participation in municipal solid waste services in developing countries, World Bank Washington DC, 1994.
[8]. M. Conti and S. Giordano, Mobile Ad Hoc Networking: Milestones, Challenges, and New Research Directions, IEEE Communications Magazine 52 (2014), 85-96.
[9]. K. Doppler, M. Rinne, C. Wijting, C.B. Ribeiro, and K. Hugl, Device-to-Device Communication as an Underlay to LTE-Advanced Networks, IEEE Communications Magazine 47 (2009), 42-49.
[10]. Y. Glouche and P. Couderc, A smart waste management with self-describing objects, in, 2013.
[11]. S. Graham, Bridging Urban Digital Divides? Urban Polarisation and Information and Communications Technologies (ICTs), Urban Studies 39 (2002), 33-56.
[12]. R.E. Grumbine, What Is Ecosystem Management?, Conservation Biology 8 (1994), 27-38.
[13]. M.A. Hannan, M. Abdulla Al Mamun, A. Hussain, H. Basri, and R.A. Begum, A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges, Waste Manag 43 (2015), 509-523.
[14]. Hong, S. Park, B. Lee, J. Lee, D. Jeong, and S. Park, IoT-based smart garbage system for efficient food waste management, Scientific WorldJournal 2014 (2014), 646953.
[15]. C.F. Huang and Y.C. Tseng, The coverage problem in a wireless sensor network, Mobile Networks & Applications 10 (2005), 519-528.
[16]. J.Postel, RFC: 791 Internet protocol, in: DOD, ed., Information Sciences Institute University of Southern California 4676 Admiralty Way Marina del Rey, California 90291, Arlington, Virginia 22209, 1981 September.
[17]. R. Jacobsen, J. Buysse, and X. Gellynck, Cost comparison between private and public collection of residual household waste: multiple case studies in the Flemish region of Belgium, Waste Manag 33 (2013), 3-11.
A. Jadoon, S.A. Batool, and M.N. Chaudhry, Assessment of factors affecting household solid waste generation and its composition in Gulberg Town, Lahore, Pakistan, Journal of material cycles and waste management 16 (2014), 73-81.
[18]. H.S. Joeng and K.W. Kim, KOICA-World Bank joint study on solid waste management in Punjab, Pakistan, in: Waste Management, Pakistan, 2007.
[19]. C.G. Jones, J.H. Lawton, and M. Shachak, Organisms as ecosystem engineers, in: Ecosystem management, Springer, 1994, pp. 130-147 %@ 0387946675.
[20]. M. Kaur, M. Sandhu, N. Mohan, and P.S. Sandhu, RFID technology principles, advantages, limitations & its applications, International Journal of Computer and Electrical Engineering 3 (2011), 151.
[21]. Kawai and T. Tasaki, Revisiting estimates of municipal solid waste generation per capita and their reliability, Journal of material cycles and waste management 18 (2016), 1-13.
[22]. A.H. Khan, M.A. Qadeer, J.A. Ansari, and S. Waheed, 4G as a next generation wireless network, in, IEEE, 2009, pp. 334-338
[23]. %@ 0769535917.
[24]. P.J. Krenn, S. Titze, P. Oja, A. Jones, and D. Ogilvie, Use of global positioning systems to study physical activity and the
[25]. environment: a systematic review, Am J Prev Med 41 (2011), 508-515.
[26]. U. Nations, World Population Prospects: The 2015 Revision, World Population 2015 Wallchart, in: World Population 2015
[27]. Wallchart, Department of Economic and Social Affairs, Population Division (2015), 2015.
[28]. U. Nations, World Population Prospects: The 2015 Revision, Key Findings and Advance Tables in: Key Findings and Advance

[29]. Tables ESA/P/WP.242, ed., Department of Economic and Social Affairs/ Population Division New York, 2015.
[30]. Offenhuber, M.I. Wolf, and C. Ratti, Trash track--active location sensing for evaluating e-waste transportation, WasteManag Res 31 (2013), 150-159.
[31]. Postel, RFC: 768 User Datagram Protocol, in, 1980 August 28th
[32]. E.C. Rada, M. Ragazzi, and P. Fedrizzi, Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies, Waste Manag 33 (2013), 785-792.
[33]. S. Raharjo, T. Matsumoto, T. Ihsan, I. Rachman, and L. Gustin, Community-based solid waste bank program for municipal solid waste management improvement in Indonesia: a case study of Padang city, Journal of material cycles and waste management (2015), 1-12 %@ 1438-4957.
A. Rovetta, F. Xiumin, F. Vicentini, Z. Minghua, A. Giusti, and H. Qichang, Early detection and evaluation of waste through sensorized containers for a collection monitoring application, Waste Manag 29 (2009), 2939-2949.
[34]. Sartaj and R. Arabgol, Assessment of healthcare waste management practices and associated problems in Isfahan Province (Iran), Journal of material cycles and waste management 17 (2015), 99-106.
[35]. Sharholy, K. Ahmad, G. Mahmood, and R.C. Trivedi, Municipal solid waste management in Indian cities - A review, Waste Manag 28 (2008), 459-467.
[36]. Xu, S. Rangwala, K.K. Chintalapudi, D. Ganesan, A. Broad, R. Govindan, and D. Estrin, A wireless sensor network for structural monitoring, in, ACM, 2004, pp. 13-24 %@ 1581138792.
[37]. Z. Baloch "Internet of Things Platform for Smart Water Resources Management using Artificial Neural Networks," Ph.D. dissertation, Dept. Civil and Envir. Eng., Hanyang Univ., Seoul, South Korea, 2017.