Smart Trash Pool System for Smart Cities

A. Sebastian, S. Sivagurunathan

Abstract— **Internet of Things (IoT) is an emerging technological paradigm. Its applications vary from smart transport to smart environment monitoring. Smart city is another IoT application that is attracting researchers across the world. Smart city focuses on developing a city in smart ways to manage, govern, deliver public services, provide business opportunities and sustainable future. Under the umbrella of smart city come Smart Health, Smart Transport Logistics, Smart Space management, Smart Grid and Smart Building. Another important criteria that marks a city smart is its cleanliness and Waste Management System. Clean and hygienic city ambience can act as a booster to smart city initiatives. This article proposes Smart Trash Pool System for smart cities using Internet of Things Technology. This study analyses the proposed system for network efficiency and suitability of Routing Protocol for Low Power and Lossy Networks (RPL) taking distance between trash bins as a test case. For analysis, RPL in Contiki OS and Cooja simulator are used. The results suggest that 30m to 40m is ideal for Smart Trash Pool System in Smart City.**

Index Terms— **Internet of Things, Smart City, RPL, Smart Trash Pool System, Wastage Management**

I. Introduction

Waste management is a tough challenge that modern cities face. Waste management consists of different activities such as collection, transportation, segregation, recycling or disposal and monitoring. Optimizing waste management not only saves significant amount of money, time and labor but also gives clean ambience for citizens and business enterprises [1]. Smart Trash Pool System (STPS) automates waste collection from trash bins in smart cities. To understand the importance of wastage management, lets look at a the world scenario on urbanization.

A Smart Sustainable City can be defined in the following way, "A Smart Sustainable City (SSC) is an innovative city that uses information and communication technologies (ICTs) and other means to improve the quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects"[2].

In the last 50 years, the world population has increased exponentially at an average rate of 1.2% per year. As the UN World Economic and Social Survey suggested Africa, Asia, and other developing regions will be housing an estimate of 80% of the world's urban population in the coming years. Since cities give avenues for socio-economic growth, education and employment, and social networking; migration to urban cities has become synonymous to opportunities and prosperity for millions of people around the world [3].

Along with the associated natural population growth, environmental changes, urban migration adds pressure to the resource base, and increases demand for energy, water, sanitation, public services, education, health care and these will continue to grow. Studies have demonstrated that cities around the world are accountable for 70% of global greenhouse gas emissions as well as 60-80% of global energy consumption [3]. Due to sedentary lifestyle and use of more packaging materials, per capita waste generation is increasing by 1.3 % per year. Figure 1, reveals the ratio of total population with growth in urban population. With the urban population growing at 2.7 % to 3.5 % per year, the yearly increase in the overall quantity of solid waste in the cities will be more than 5 %. The Energy and Resources Institute (TERI) has estimated that waste generation will exceed 260 million tonnes per year by 2047; that is more than five times the present level. It is observed that Cities with 100,000 plus population contribute 72.5% of the waste generated in India [4].

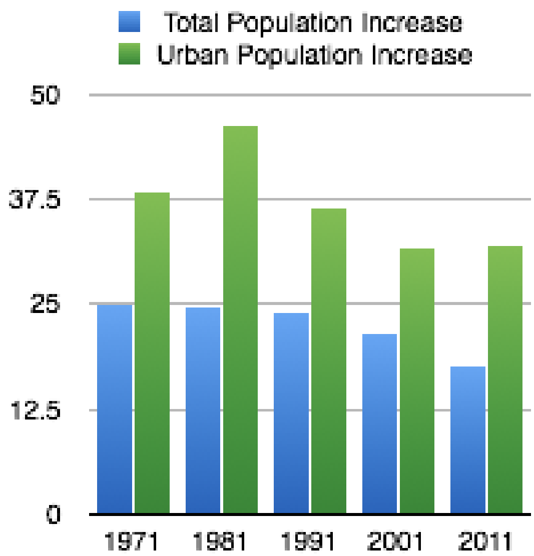

Figure 1: Total Population and Urban Population growth in India

The obvious question one has to ask is: how can cities' waste be managed under such conditions? The answer lies in making cities 'smarter' by efficient use Information

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Communication Technology (ICT). Internet of Things (IoT) provides such as opportunity.

Chapter Two analyses literature related to smart city and smart trash pool system. Chapter three details the standardized RPL for urban environment and suggest Smart Trash Pool System (STPS) for Smart Cities. It also provides in detail the steps involved. In chapter, we implement the proposed design in Contiki-RPL OS and Cooja simulator for network performance and record the values. In chapter 5, we evaluate the obtained results and discuss the efficiency and suitability of the system followed by concluding remarks and future scope.

II. RELATED WORK

Waste management is an important issue in smart city but lacks in technological framework for waste management. In [1], the authors suggest sensing as a service model for waste management in smart cities. Instead of deploying sensor and collecting information independently, the sensing as a service model allows all the interest groups (e;g. city council, recycling companies, manufacturing plants and authorities related to health and safety) to share the infrastructure of gathering, processing and using the data in real time depending on each one's requirement. In [5], the authors talk about moving 'up' the waste hierarchy towards reduction, re-use and repair raises questions about the ways in which municipal authorities can effectively engage individuals to conceptualize and deal with household materials in ways that move beyond disposal of things, to a re-consideration of 'waste' through new practices of (re)creating value via both habitual and externally driven behaviors. In [6], the authors propose water monitoring system in smart cities. It is an effort to provide safe drinking water and to avoid accidental contamination of drinking water from sewage water. In [7], the authors suggest monitoring of the pollution level of air, retrieving smog information such as the level of CO2 and PM10 delivered to health care agencies in smart city environment. In [8], the authors suggest smart city solutions for parking, evaluating air quality and providing notification when trash containers are full. Smart Trash Pool System ia another attempt to automize the collection of waste through RPL based IoT technology.

III. SMART TRASH POOL SYSTEM

In many cities, waste management is manual, scheduled and person centric. Trash bins are placed at corners of the streets and prominent places where people gather to shop. Municipal workers clean the streets and gather them in trash for trash collection vehicle to pick them up. In such system, there is scope for time delay in detection and trash clearance, non report to duty, absence due to holidays, bad weather, etc. This manual method of Wastage collection and disposal is cumbersome and often it is noticed that these bins get filled fast and left unattended making it hazardous and unhygienic for the citizens. Due to negligence if these trash bins are not emptied for a long period, it can become breeding ground for diseases. This way the city administration, the sanitary workers and general public are exposed to health and hygienic related hazards.

The proposed Smart Trash pool System (STPS) can be of great help to solve these problems. This system in a way is automated, using sensor and computer controlled service mechanism. Figure 2, gives details sketch of STPS. At the pre process level, all the trash bins (T2, T3,T4, ……, T9) are attached with sensor nodes. T1 is not only a trash bin but also sink node or Local Border Router (LBR) which communicates with Internet. The Internet is a high end system with can handle database and analytical processes. Each trash bin is enabled with sensors and communication radio and they send messages to sink node. Since the sensing nodes are resource constrained they do not communicate with other objects (such as vehicle V1 or V2 or Internet system) but sink.

The Sink (T1) or LBR routes the request from sensor nodes to Internet system which communicates to Trash Clearing Vehicles V1 and V2. In nutshell, upon receiving threshold warning message from nodes T1 to T9, Sink sends clearing request to Internet system. The request will have details of TrashBinId, Location, Distance, Time of report, etc. Upon receiving the request, Internet System will send clear request to clearing vehicle V1. If V1 responds with 'Yes'. Internet System updates the data base for related to trash clearance else it sends clearing request to V2 and so on till it finds one. Once trash bin is cleared, the clearing vehicle sends trash clearing complete message with details such as TrashBin Id, Location, distance, request time, complete time, etc. to Internet system which updates the data base. These processes continue automatically.

A. Step 1: Alert Message is Triggered

In the first step of the STPS, the sensors and actuators attached to the trash bins keep monitoring the threshold/set level of trash in the bin. Once it crosses the threshold, the actuator sends a warning message to sink. Sink in turn sends trash clearing request to Internet system with details of the node such as trash Bin Id, Location, distance, report time, etc. The Internet system updates the details of the trash clearing request in its data base and send the request message to the closest Trash Clearing Vehicle (V1/V2).

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B. Step 2: Update the Database Server

The closest Trash Clearing Vehicle receives the request and immediately updates the Database Server and responds it with a 'Yes' or ignores it. In a scenario, where the nearest Trash Clearing Vehicle is engaged or unable to respond, after certain time period, the Internet System sends the clearing request to another Vehicle. This process continues until some Trash Clearing vehicle communicates with 'Yes'.

C. Step 3: If Response is 'Yes', then V_1 clears the bin

In a 'Yes' case, the Trash Clearing Vehicle swiftly clears the bin. And the Trash Clearing Vehicle and the Trash bin are ready for a new cycle of the above process.

D. Step 4: If Response is 'No'.V_2 clears the bin

It is our experience that the Trash Clearing Vehicle will not be in a position to respond 'yes' always, It is already

Figure 2: Smart Trash pool System for Smart Cities

busy clearing some other Trash bin or it receives request but the vehicle is not ready, vehicle breakdown, etc. In such a scenario, 'No' case is recorded in the database of Internet system. And the Internet system sends trash clearing request to the next Trash Clearing Vehicle (V2) which is in its network vicinity. And this process continues until such time that the Trash Request is fulfilled.

E. *Step 5: Vehicle V_2 updates the server*

Once Trash Clearing Vehicle (V1/V2) attends to the job, it again sends trash clearing complete message to the Internet system and database is updated to complete the job cycle. These processes repetitively occur to manage waste in a smart city.

IV. Simulation and Network Setup

The Simulation framework for Smart Trash Pool System (STPS) is shown in Figure 3. We tested the proposed framework in Contiki OS, Cooja simulator. Cooja is a open source discrete network simulator to study the performance of RPL based sensor networks. IETF Working Group Routing over Low power and Lossy networks (ROLL) has standardized Routing Protocol named IPv6 Routing Protocol for Low power and Lossy Networks (RPL) for urban environment. RPL was proposed because none of the existing known protocols such as AODV, OLSR or OSPF met the specific requirements of Low power and Lossy Networks (LLN) [9].

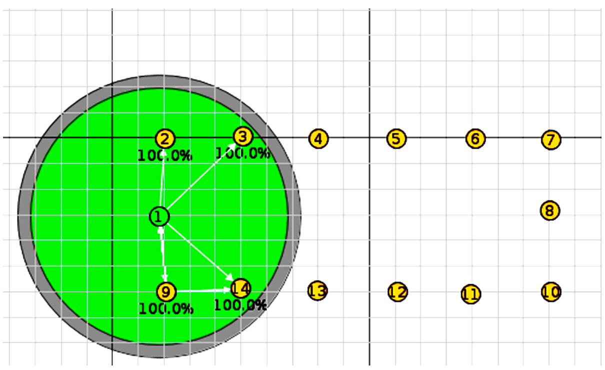


Figure 3: Network Topology of Smart Trash Pool System. Node 1 which is green is sink and other nodes in yellow are trash nodes. The green area is the Transmission Range (Tx) and area in grey is the Interference Range (INT) of the sink node. The distance between nodes d= 30m

The proposed framework has one sink node or LBR (node id 1) and 13 sender or client nodes (trash bins). The nodes follow Multi Point to Point (MP2P) traffic towards the sink. The Table 1, gives the details of the simulation parameters.

Table 1: Network Parameter values

Network Parameter	Values
Simulation Model	UDGM
Startup Delay	65s
Objective Function	MRHOF (ETX)
DIO Min Interval	12
Send Interval	4s
RX Ratio	100%
TX Ratio	100%
Channel	Channel Check Rate 8Hz Radio Channel 26
Transmission Range	50m
Interference Range	55m
Simulation Time	600000ms
No. of Nodes	1 /2 sink and 13 sender nodes

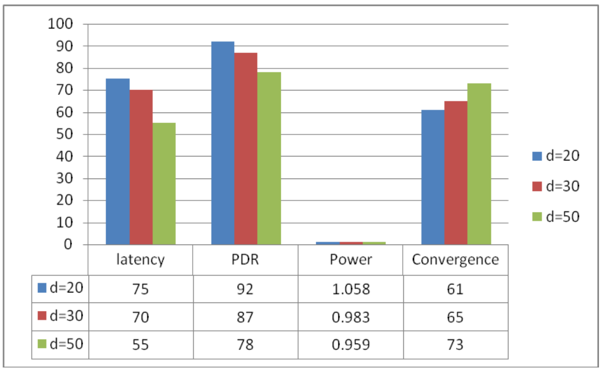
To make our test resemble real world scenario, we have chosen Unit Disk Graph Model (UDGM) in Cooja which is also called link failure model. In real world, the sensors in trash bins will have interference. The nodes are geographically arranged to resemble a street in a city. It covers an area of 150mx60m. The nodes are fixed in their locations and so no mobility is tested. Nodes use two different range of parameters: one for transmission (Tx) and one for Interference (INT).

One of the main issues in STPS is the location of the Trash bins. By changing the distance between nodes, we test the performance of the nodes and RPL network for efficiency and Suitable distance. In our experiment, we simulate 2 test cases. In case 1, we have one sink node and 13 sender nodes. ithout altering Tx and INT parameters, the distance between trash bins are altered: 20m, 30m and 50m. In case 2, we have 2 sink nodes and 13 sender nodes (trash bins). The test cases were simulated for a duration of 600000ms (10min) and the values are tabulated. The results are evaluated using RPL performance metric such as Latency, Packet Delivery Ratio

(PDR), Power Consumption (PC), Convergence Time (CT) and Control Traffic Over head. Convergence Time and Latency are collected from Cooja Mote Output Log file. Control Traffic Over head and data packets are analyzed by 6LoWPAN Analyser with Pcap in Wireshark. Routing parameters such as energy consumption, number of hops, ETx and other parameters are recorded by Collect View function in Cooja simulator.

A. *Case 1: One sink node and 13 sender nodes*

This scenario is represented in Figure 3. In this test case, we have 3 use case scenario. In this case the TX and INT values remain the same but the distance between nodes are changed such as 20m, 30m and 50m. The obtained results will give us the correct distance where the network is stable and performs better. Figure 4, compares the obtained results for Latency, PDR, Power and Convergence Time.



	latency	PDR	Power	Convergence
d=20	75	92	1.058	61
d=30	70	87	0.983	65
d=50	55	78	0.959	73

Figure 4: Latency, PDR, Power and CT results for case 1

In figure 5, we list the obtained results for Control Traffic Over head. It involves control Messages such as DODAG Information Object (DIO), DODAG Information Solicitation (DIS) and DODAG Advertisement Object (DAO).

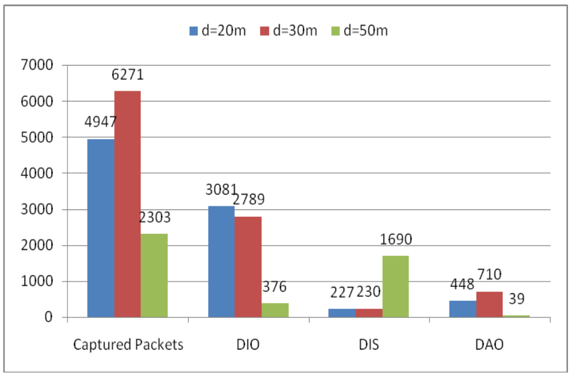
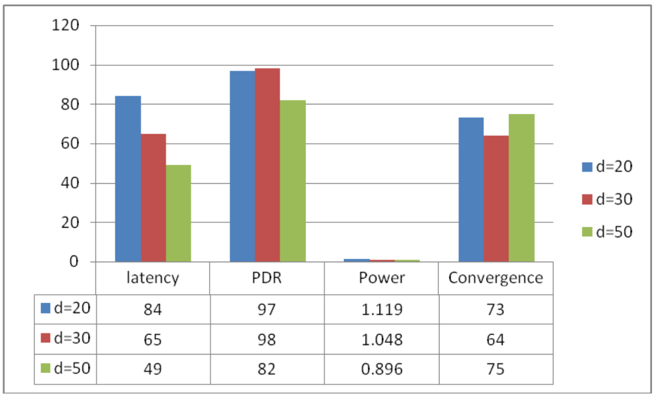


Figure 5: Control Traffic Overhead for case 1

B. *Case 2: 2 sinks and 13 sender nodes*

In Case 2, we study the performance of the RPL when 2 sink nodes (node1 & node 15) are deployed. This topology is considered because in cities the streets will be long and trash bins will be placed at the ends of the street. But the transmission range of the sink may not reach the leaf nodes far from sink. This may result is non participation of nodes in the network or it may become a network resource waste. The obtained results for case 2 are shown in figure 6 and 7.



	latency	PDR	Power	Convergence
d=20	84	97	1.119	73
d=30	65	98	1.048	64
d=50	49	82	0.896	75

Figure 6: Latency, PDR, Power and CT results for case 2

We evaluate the performance of RPL for Latency, Packet Delivery Ratio, Convergence Time, Power Consumption and Control Traffic Over Head. All these parameters are important for the stability and efficiency of the Network where the nodes are resource constrained.

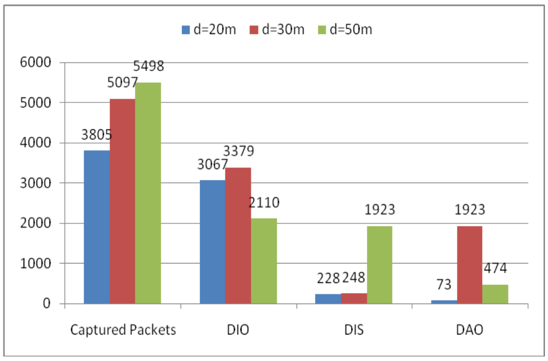


Figure 7: Control Traffic Overhead for Case 2

A. *Convergence Time*

We determine the Convergence Time in RPL for the first DIO sent from the client nodes and the last DIO joined the DAG [10]. The default interval in contiki is 12 (Imin=4.096s) which gives a network setup time of 19 seconds. From Table 2 for case 1 & Table 4 for Case 2, we observe that CT is between 60s to 75s. RPL is able to setup the network in short duration irrespective of varying distance between the nodes. It is very essential because these nodes have less memory and so low setting time is crucial for packet routing. However, it will be interesting to study the Convergence Time when the network is large with hundreds of nodes with long routes and many links. Short Convergence Time also helps in preserving power which is crucial to resource constrained nodes. In both cases, 30m distance between nodes bring stable and sufficient results

B. *Energy Consumption*

We measure energy consumption by considering factors like Low Powered Mode (LPM), CPU, Packet transmission and listening [11]. In all nodes the LPM remains the same. In both cases, the power consumption is on the decrease as distance between the nodes is increased. This is due to the fact that shorter distance between nodes may have more interference and collision. As a result, retransmission of packets will occur. This is well explained by Figure 8. The power consumption is high initially when the network is setting up and as the network becomes stable then the power consumption also becomes stable. In such scenario the nodes closer to the sink (node 2 & node 9) consume more power initially.

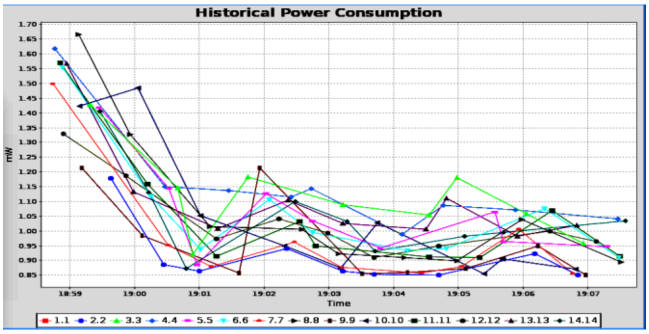


Figure 8: Power consumption for case 1 where d=30m

C. Control Traffic Overhead

To compute the Control Traffic overhead , we collect DIO/DIS/DAO messages sent per node and sum them up for the total RPL network overhead [12]. The experimental results of DIO/DIS/DAO messages for case 1 are shown in Table 3 and for case 2 in Table 5. In both cases, Control messages (DIO, DIS & DAO) when d=20 and d=30, have resemblance. On the other hand when d=50, has more DIS than DIO in both cases. This brings out the fact that when the distance between the nodes are high, the nodes at the edges send Solicitation messages to the sink. And the nodes that are close to the sink or within communication range easily join the DODAG and participate in the network. Therefore, for better power consumption and stability of the network distance between nodes (trash bins) is 20m to 30m.

D. Latency

To compute Latency, we calculate the time taken by a packet from a node to reach the sink and is the average of the latencies of all the packets in the network from all the nodes. In both cases, for the distance 20m and 30m latency is 60 to 80 ms. But for the distance 50 m the latency is <60ms. Since the increase in distance result is fewer links, fewer nodes participate in the network, data packets are delivered in small latency time. In other cases, the network links are many and so more control messages making the network busy.

E. Packet Delivery Ratio (PDR)

Packet Delivery Ratio is measured by computing the number of sent packets from all the nodes to the sink and divide it by the number of successfully received packets at the sink. Packet Delivery Ratio is inversely proportional to the no. of nodes participating in the network. More no. of nodes means more packet loss and vice versa. More no. of nodes also means long routes, many failed links and more lossyness in the network. Packet Ratio also affects Power Consumption. When there is more packet loss, the nodes have to resend the packets. This way, Packet Delivery Ratio will be a challenge when no. of nodes in the network increases.

F. Discussion

The evaluation of the performance of RPL, for Smart Trash Pool System brings out many issues. We have listed some of them for further study. This will help to overcome the hurdles in realizing smart cities that can handle waste in an automated manner.

1. It is observed that the distance between trash bin 30m is ideal in both cases. For shorter distance, energy consumption is more and for longer distance Control Over Head is more.

2. The Convergence or Setup time is efficient for all cases and so any number of nodes and sinks will have low convergence time. This will help the network to start transmitting packets immediately after network starts its function.

3. Surprisingly, the no. of control messages are less when d=50 in both cases and control messages are more when d=20m 0r d=30m. This may be due to the fact that when d=50m, many nodes may be out of Transmission range and unable to join the network. In such case, their resource will be a waste for the network. So it shows less control messages.

4. The testing results show that 77% of the packets are control messages. So to establish the network with all the nodes involve lot of control and communication messages. Once the network is established, then the data packets are more. Therefore, the simulation time needs to be high to achieve better performance. This is in line with the nature of RPL where the sensors gathering physical data, sense things round the clock or in quick time.

5. To get maximum efficiency and reliability, the RPL must show low latency, less power consumption, high packet delivery ratio and low control over head. But in the results, we notice that when the distance between the nodes is either less: there are more no of nodes, more packets are generated resulting in more collisions, more consumption of power and more packet loss. When the distance between nodes is higher, few no. of nodes participate resulting in waste of resources, links are few and unstable resulting in power consumption, latency and packet loss. Therefore having distance in between set to bring efficiency and reliability to the system

VI. Conclusion and Future Scope

Internet of Things is an emerging modern trend in the field of communication technology. It has great possibility to transform the traditional way we use internet and related communication networks. Automation in many areas of human life is becoming a reality due to IoT technology. For such LLN, we can count on RPL for efficiency in convergence time, energy consumption, easy way of new nodes joining and leaving the network without disturbing larger network, etc. This article has proposed the prospect of implementing Smart Trash Pool System for smart Cities. From the results and analysis, it is clear that 30-40m, distance between trash bins brings network efficiency and suitability for STPS. However there are challenges: Security of the nodes from physical tampering and handling intrusion are big challenges. To handle control over head, new optimization techniques need to be developed. Although the nodes (trash bins) are fixed, the Trash collecting vehicle will be on the move, so developing and testing RPL performance for mobility is a challenge. Having mobile sink is another challenge. In times of poor weather conditions such as heavy rain, mist and fog, cloudy, etc will affect the communicating channels resulting in wrong sensed data, etc need attention. The use of trash bins and their geographical placing differs: a street, a shopping mall and a crowded market needs different ways of handling trash collection. So, topological challenges are there. In spite of all the challenges, clean and hygienic city will bring better living condition to its citizens and RPL fits the scheme well.

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