Multi Sink RPL based Internet of Things for Emergency Response in Smart Cities

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Abstract—Internet of Things technology has given rise to many deployments such as smart city, smart health, smart transport, smart production and supply chain management, Smart Energy, smart home and many more. IoT for smart city is getting the attention of research and industrial communities. However, Emergency Response System in a smart city is in its infancy. Saving people's life, performing rescue and relief operations, safeguarding infrastructure from natural and man-made disasters are important tasks of a smart city. International Engineering Task Force (IETF) has standardized Routing Protocol for Low Power and Lossy Networks (RPL) for urban environment. RPL uses objective functions such as ETX and Hop Count for efficient use of network resources. Efficiency and performance can be improved by Multi Sink model of RPL. This paper suggests Multi Sink RPL for Emergency Response in Smart Cities. We evaluated Multi Sink RPL for Energy Conception, Packet Delivery Ratio, Traffic Control Overhead and Node Participation. We simulated network topology in Cooja with Contiki OS. The results showed improved performance of Multi Sink RPLK as compared to one sink model.

Keywords—Internet of Things, Smart City, RPL, Smart Emergency Response, Multi Sink

I. INTRODUCTION

Internet of Things (IoT) is an emerging paradigm which touches a wide range of applications such as smart city, smart and precision agriculture, smart energy and grid, smart transport, supply chain management and many more. IoT infrastructure consists of sensing devices, communication protocols, data management systems and a number of application protocols. Basically IoT is a resource-constrained network. They operate under low power, low bandwidth, limited memory, low processing capacity and lossy links. And therefore IoT architecture is designed to operate under network constraints. IETF has come out with standards such as 6LowPAN in the link layer, RPL in the network layer and CoAP in the application layer for IoT networks. IETF has also standardized routing requirements for home automation (RFC5826), industrial control (RFC 5673), urban environment (RFC 5548) and building automation (RFC 5867) [1]. By standardizing efforts, RPL gives much scope for universality, extensibility and stability.

Smart City concept and real-time deployment are gaining attention around the world. A Smart city can be defined as “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] It is estimated that the world population has increased at an average rate of 1.2% per year in the last 50 years. UN World Economic and Social Survey suggest that 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 provide opportunities for socio-economic growth, education, employment and health; migration to 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. RPL for urban environment can become a major player in IoT infrastructure. In recent times, research on smart home, smart city, smart grid, etc are finding enough space in research but seldom Smart Emergency Response. The National Crime Records Bureau Data in India indicates that a total of 113961 people lost their lives due to Fire Accidents from 2010 to 2014. This is an average of 62 deaths a day [4]. Figure 1, depicts this scenario. Absence of Emergency Response means massive loss of life and property.

**Figure 1: Number of Deaths and Fire Accidents in India**

Smart cities struggle to adequacy in times of rain floods, cyclones, building collapse by torrential rains, earthquakes, fire accidents etc.[4]. IoT infrastructure aims to bridge this gap by providing communication back bone to Emergency Response in Smart Cities. Multi Sink RPL offers great opportunity to meet this challenge.

In section Two, we discuss Internet of Things and RPL architecture. In section Three, various approach to Emergency Response System are discussed. Section Four describes the network set up and simulation parameters. In section Five, we record obtained results and analyze the performance of Multi sink RPL to the standard single sink model, followed by conclusion and future challenges.

**II. IOT AND RPL ARCHITECTURE**

The Internet of Things is the next evolution of the Internet. Cisco’s Internet Business Solution Group (IBSG) predicts that there will be 50 billion devices connected by IoT technology by 2020. According to the seventh EMC digital universe study report, India’s digital universe shall grow nine fold by 2020 [5]. In this section, we present IoT and RPL architecture.

**A. IoT and RPL Architecture**

RPL for Internet of Things is three layered architecture. Physical and communication layer involves, sensors, actuators, smart meters, RFID tags, communication protocols such as WiFi, 3GPP, NFC, Bluetooth Low Energy (BLE), IEEE 802.15.4, etc. Network and Transport Layer involves, IPv6 based RPL, UDP, ICMPv6, cloud Computing and Big Data to store and process obtained data from IoT environment. Finally The application layer uses HTTP, CoAP, MQTT, etc for user interaction with the IoT system. There is a adaptation layer called 6LoWPAN part of the Physical Layer.

**B. IEEE 802.15.4**

Internet of Things technology operates over IEEE 802.15.4 radio technology. It is designed for low-power, low memory and low-data rate applications with radio coverage of few meters. IEEE 802.15 Personal Area Network (PAN) Working Group has developed this standard. IEEE 802.15.4 typically has data rates varying from 20kb/s to 250 kb/s and a maximum output power of 1 mW. IEEE 802.15.4 uses scheduled duty cycling mechanism to save radio power. [1]

**C. RPL, ICMPv6 and Objective Functions**

The network layer is divided in to two: RPL and Internet Communication Message Protocol (ICMP). Routing related issues are handled by RPL and communication messages are handled by ICMP. In the standard, RPL supports mainly multipoint-to-point (MP2P) traffic. MP2P traffic is widely applicable for collection based applications. However it also support point-to-point (P2P) and point-to-point (P2P) traffics. In RPL, Destination Oriented Directed Acyclic Graph (DODAG) is formed to organize nodes in the network. The position of nodes in the network is calculated by a scalar value called rank. Rank increases monotonically from the DAG ROOT or sink. It is identified by a unique identifier DODAGID. RPL network may have many DODAGs or sinks under one RPL instance. However the DODAGs in one instance is optimized according to an Objective Function (OF) which is identified by an objective Code Point (OCP). OCP indicates DODAG optimization to be a constraint or a metric for DODAG construction. [6] Examples of metrics and constraints for DODAG construction are hop count, latency, expected transmission count, node energy, etc.

Nodes in RPL network send DODAG Information Object (DIO) message for the construction and maintenance of the DODAG. DAG ROOT initiates by sending multicast DIO messages to neighboring nodes. A DIO message contains information such as RPL instance, DODAGID, DAG Version no, OF used and details about the parent rank. All these information are received by the neighboring nodes and it updates its own rank and multicasts to other nodes in its vicinity till a route is created from leaf node to the root node via intermediary hop nodes. If a new node wants to join the
DODAG, it can either wait to receive DIO messages from nearby nodes or it can send a DOADG Information Solicitation (DIS) to neighboring nodes. DODAG Acknowledgement Object (DAO) messages are sent when P2MP communication is needed for route from root node to the leaf node. P2P traffic is used for node to node communication. [7]

RPL functionality defines two types of routes depending on the direction in which data are transmitted in a DODAG: upward and downward. An upward route provides a path towards the DODAG root from leaf nodes. A Downward route provides a path from DODAG root to leaf nodes. The upward routes are constructed using a node's preferred parent. When the node has some data that needs to be sent to the root, it immediately sends this to the preferred parent. The parent node sends to its own parent and so on until it reaches the DODAG root. In downward route, the root transmits the message to the destination either by appending the source route to the data packet or by simple hop-by-hop routing down the DODAG leaf node. [8]

RPL uses Trickle timer to reduce control message overhead by transmitting updates only when inconsistencies are detected in the network. Trickle timer sends out fewer control messages as the network becomes more stable. Trickle timer saves energy and reduced control traffic overhead of DODAG construction and maintenance. [9]

III. RELATED WORK

In recent times, many RPL simulations are under study by researchers. This has given rise to many variations of RPL such as simpleRPL, TinyRPL, ContikiRPL and RIOT-RPL. SimpleRPL implements Objective Function Zero (RFC 6552) and link quality information is not there. TinyRPL is an implementation of RPL for TinyOS. It uses Objective Function ETX by default. ContikiRPL is an implementation of RPL made to run on Contiki operating system that connect low power microcontrollers to the internet. ContikiRPL implements ETX as a default OF, but allows the configuration of different OF’s as well. RIOT-RPL is designed to match the requirement of Internet of Things devices and other embedded devices. It has been specially designed to work with very low memory footprint.

Researchers have also come out with RPL variations by composite routing metrics to meet the routing demands of various applications. In [10], authors suggest emergency response using node’s position in the crisis site. They use RSSI from landmarks placed by first responders from emergency site. In [11], authors propose an intelligent decision computing based paradigm for crowd monitoring in the smart city. The proposed framework measures the correlation measure based on extracted novel distinctive feature, and holistic feature of crowd data represent and to classify the crowd motion of individual. In [12], authors suggest a framework for integrated emergency routing system (IERS). This framework consists of an integrated outdoor and indoor Navigation Data Model (INDM) and DD algorithm of emergency routing based on INDM. INDM is a 3D geometric network model (GNM) that represents pedestrian access or search and rescue route analysis within buildings or urban built-environments. In [13], authors suggest a multi-agent based architecture for the management of Emergency Supply Chains (ESCs), in which each zone is controlled by an agent. A Decision Support System (DSS) states and solves, in a distributed way, the scheduling problem for the delivery of resources from the ESC supplying zones to the ESC crisis-affected areas. In [14], authors developed a method to assess the vulnerability of care homes and sheltered accommodation. The flood modeling gives network analysis that can be accessed by emergency responders during flood events. It also provides geographical analysis of service areas for the ambulance, fire and rescue service. In [15], authors use a novel concept of using smart wearable devices for disaster applications. In [16], authors proposed an ontology-based knowledge management method, where a unified and formalized plan repository is built to facilitate the efficient administrative and operational use of emergency plans. BIM technology is applied to provide realistic visualization of the plan knowledge for better understanding. In [17], authors suggest agent-based simulation tool to determine the optimal resource allocation of resources to manage emergency response such as minimize hospital arrival time for critically injured casualty patients. In [18], authors developed k-Nearest-Neighbor (kNN) overlay graph of an arbitrary crowd that interconnects over some short-range communication technology. A KNN overlay graph allows the crowd to connect to its geographically closest peers those can interact with the user and respond to an emergency crowd sourcing task, such as seeing/sensing similar things as the user (e.g., collect videos and photos). In [19], authors present a hybrid fuzzy method consisting fuzzy AHP and 2-tuple fuzzy linguistic approach to evaluate emergency response capacity. In [20], authors proposed Seismic Pedestrians’ Evacuation Dynamic Guidance Expert System (SpeedGuides) considers the influence of the main environmental and behavioral safety factors for evacuees (i.e. street vulnerability, street blockages probability, crowding conditions along paths, presence of mortal dangers, visibility conditions) and combines them in a safety index through the Multi-criteria techniques application. SpeedGuides dynamically collects safety factor data during the time and suggests the possible safest path to the nearest secure zone according to the Dijkstra's algorithm approach. In [21], authors suggested Geographical Routing for Mobile Tourist (GRMT) that selects a route that is best served with medical centers, and goes through the path that is as shortest as possible in regards with the distance. In [22], authors developed E-noe 6 project, with the purpose to reduce damages and losses caused by flood in urban centers, through the cheap flood warning system to authorities and population. The system monitors the water level of a runway or river and according to the risk with the level, triggers emergency alerts to the authorities through telephone calls and SMS messages.

Many researchers have proposed RPL variations and implementations with composite routing metrics, there are few attempts to evaluate and analyze multi sink RPL for Smart Emergency Response in smart cities. As the demand for smart
cities are increasing and so the need to manage smart city services such as Smart Emergency Response.

IV. NETWORK SIMULATION AND SETUP

The Simulation framework for evaluation of Multi sink RPL for Emergency Response is carried out in the popular Cojoa simulator with Contiki OS. The Network Topology parameters are given in Table 1.

<table>
<thead>
<tr>
<th>Network Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Model</td>
<td>UDGM</td>
</tr>
<tr>
<td>No. of Nodes</td>
<td>100 to 109</td>
</tr>
<tr>
<td>Area</td>
<td>200m x 200m</td>
</tr>
<tr>
<td>Start-up Delay</td>
<td>65s</td>
</tr>
<tr>
<td>Objective Functions</td>
<td>MHRHOF (ETX) and OF0 (Hop Count)</td>
</tr>
<tr>
<td>Channel</td>
<td>Channel Check rate 8Hz and Radio Channel 26</td>
</tr>
<tr>
<td>TX and INT Range</td>
<td>Tx=55m and INT=35m</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>100000 ms</td>
</tr>
</tbody>
</table>

Proposed Multi Sink RPL based IoT for Emergency Response is shown in fig. 3. It has 100 sender nodes and 9 sink nodes. The nodes are arranged in the area where emergency is reported. The network topology consists of a root node (So) and 4 sink nodes (S1, S2, S3, S4). The root is marked as DODAG and other sinks are marked as subDODAGs. The simulation is tested for Objective Functions (OFs) ETX and Hop Count. The nodes are randomly placed with a few hop counts to reach the sink node. We analyze the performance for ETX and Hop Count for varying number of sinks. The obtained results for 1, 2, 3 and 9 sinks are analyzed. Our proposed method is evaluated based on performance metric such as Packet Delivery Ratio (PDR), Power Consumption (PC) and Control Traffic Overhead and node participation in the network. Cojoa Mote Output Log file records the conversation between node and sink. Control Traffic Overhead, Power consumption and Packet Delivery Ratio are analyzed using 6LoWPAN Analyser with Pcap in Wireshark and Collect View functions in Cojoa simulator.

V. EVALUATION AND DISCUSSION

Multi Sink RPL for Emergency Response in Smart Cities offer solution to Emergency Response. A city IoT network is a collection based network. Emergency Response in smart cities involve critical environment. IoT communication technologies need to have parameters to meet such demanding challenges. We evaluate multi link RPL for Packet Delivery Ratio, Power Consumption and Control Traffic Overhead and number of participated nodes are given in graphs.

A. Node Participation

Emergency Response for smart cities becomes effective when the size of the network is big. More number of nodes will generate more data for real time analysis and response. The network also has better survivability when many sink nodes are active. In case of any sink node failure, nodes can attach to other sink nodes. Figure 4 gives details of node participation for various sinks. It is observed that in both OFs node participation is proportionally increasing with increase in the number of sink nodes. More number of sink nodes reduce the number of hops to reach sink and thereby improving the performance. The Rtmetric which is important to calculate the rank also has lower value. Node participation is important for better data collection and delivery.

B. Energy Consumption

Any Emergency Response scenario in smart city will hamper the power source. For the safety of urban dwellers, power supply will be affected. In such power constrained environments, communication networks need to be energy efficient. Energy efficient communication hardware, energy saving routing mechanisms, minimizing control traffic and energy harvesting from nature are real challenges. The obtained result is shown in fig. 5. Our proposed method show improved energy consumption for objective functions ETX and Hop Count. For example power consumption for one sink using ETX metric is 3.806mW but the same scenario when used having 9 sinks the energy consumption is 2.52. Hop Count also shows improved energy consumption. RPL conserves energy by considering factors like Low Powered Mode (LPM), CPU, Packet transmission and listening [8]. LPM is the default mode for all our simulations.
C. Control Traffic Overhead

Multi sink RPL routing for Emergency Response involves huge control traffic overhead. Internet Control Message Protocol version 6 (ICMPv6) manages the RPL topology through control messages are used to set up network, handle error events, network inconsistency and networks. In RPL, Control Traffic Overhead can be calculated by summing up the total number of DIO, DIS and DAO messages sent by every node in the network. Traffic overhead obtained from our simulation is explained in Figure 6. Obtained results show that Control messages for Objective Functions ETX and Hop Count are 32844 and 21176. The same scenario for 9 sinks are 15079 and 13064. Hence, our proposed system performs well in managing control traffic overhead.

D. Packet Delivery Ratio

Packet Delivery Ratio is an important performance metric for any network. And it is more so for resource constrained network as in IoT. When we evaluate multi sink RPL for Emergency Response in Smart Cities, packet delivery ratio need to be maximum. In critical communication network as this, the data must be ensured that it reaches the receiver. Packet Delivery Ratio in DODAG-RPL 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. Our simulation results suggests improved packet delivery ratio. The simulation results are shown in figure 7. Both the Objective Function performs well in Multi Sink concept. The 9 sink topology with ETX metric tops the PDR percentage (98.2%). The increase in Multi Sink in LLN is proportional to the number of sinks. Objective function MRHOF performs better than OF0.

E. Discussion and Future Scope

Our proposed method Multi sink RPL for Emergency Response in Smart City is made efficient by increased packet delivery ratio, minimum power consumption, low control traffic overhead and number of participating nodes. This model to certain extent responds to the need of data collection points in smart cities. It is observed that in both cases, Objective functions perform well. At many parameters hop count shows good results or improved results. It is also observed that Network performance metrics are interrelated. Deficiency in one metric will affect the performance of the other metrics as well. For example, Energy consumption, Packet Delivery Ratio and Control Traffic overhead and increased node participation affect one another. Therefore selection of routing and link metrics that support one another will pave way for managing multi sink RPL for Emergency Response in smart cities. It is also observed that multi sink RPL can address scalability issues in IoT network, sink position plays a vital role. If sinks are positioned such a way that there is less chance of collision, interference from neighboring nodes and nodes are distributed well then improvement in packet delivery ratio, low control traffic and efficient energy consumption can be obtained. The objective function used for parent selection and route discovery under one DODAGID is the same for multi sinks, it gives scope for better managing the network and its constrained resources. For our future research, designing composite metric (objective function for smart Emergency Response) to optimize energy efficiency, packet delivery ratio and energy consumption and Convergence Time is envisaged. In any Emergency scenario, citizen’s close to the site play a crucial role. In modern times, social networking sites play big role in dissemination of information regarding the emergency. So designing collaborative and content centric routing where feeds from local people and social networking sites offer quick and efficient response to Emergency scenario in cities.

However, there are limitations to this method. The number of nodes could be still higher to see how topology is managed. The simulation time is just enough to setup and transfer data. If the simulation time improves than more ideal network scenario can be created and tested. It is observed that the participating nodes are not equally distributed to each sink.
Some sinks have more nodes and other less number of nodes. Therefore load balancing of all the sinks will improve the system further.

VI. CONCLUSION

Internet of Things is an emerging trend in the field of communication technology. It has great potential to transform traditional cities into smart cities. Research communities around the world are engaged in deployment of many smart city services and Emergency Response is need of the hour. Traditional methods of responding to Emergency Response in cities lacks coordination, communication divide, ill preparedness, slow response and chaotic restoration. Internet of things technology and advanced communication system can play a great role in making Smart Emergency Response in to quick response, well prepared, digitally connected and safe to save citizens and city infrastructure. In such a scenario, multi link RPL can act as a back bone on which Emergency Response System can be designed. Simulation results suggest improved packet delivery ratio, power consumption, control traffic overhead and node participation. The Multi Sink RPL for Emergency Response System for Smart City IoT can be improved further by creating unique object function to meet the needs of Emergency Response.

REFERENCES


