

Research Article

A Proposed IoT-Enabled Smart Waste Bin Management System and Efficient Route Selection

Asim Zeb ¹, Qurban Ali,² Muhammad Qaiser Saleem,³ Khalid Mahmood Awan ⁴,
Ali Saeed Alowayr,³ Jamal Uddin,² Saleem Iqbal ⁵ and Faisal Bashir⁶

¹Department of Information Technology, Abbottabad University of Science and Technology, Havelian, Pakistan

²Department of Physical and Numerical Sciences, Qurtuba University of Science and Information Technology, Peshawar, Pakistan

³College of Computer Science and Information Technology, Al Baha University, Al Baha, Saudi Arabia

⁴Department of Computer Science, COMSATS University, Attock Campus, Islamabad, Pakistan

⁵AGRID University, Rawalpindi, Pakistan

⁶Bahria University, Islamabad, Pakistan

Correspondence should be addressed to Khalid Mahmood Awan; khalid.awan@ciit-attock.edu.pk

Received 17 August 2018; Revised 12 December 2018; Accepted 30 September 2019; Published 16 December 2019

Academic Editor: Peter Mueller

Copyright © 2019 Asim Zeb et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Internet of Things (IoT) is an emerging technology that offers promising solutions to modernize the traditional systems. It accords promising result in crystallizing smart cities, smart homes, smart industries, and smart environment. This article presents the smart waste management architecture for smart cities and efficient routing technique considering least delay for the architecture. In wireless sensor networks, end-to-end delay is one of the important Quality of Services (QoS) parameter to overcome delay in data communication. In this article, we consider end-to-end delay minimization in smart waste management application. The term “end-to-end delay” is defined as the total time taken by a single packet to reach the destination node. The proposed scheme considers the interference level, the length of the routing path, and the number of hops along the path. The simulation results show that the proposed scheme outperforms current schemes.

1. Introduction

The revolution in communication and drastic computer application are the consequences of advancement in the Internet. From the traditional message transfer, today's era is of Web, machine-to-machine (M2M) communications, the communication of real-time audio, video, and sensory data, etc., which are possible due to advancements in super-media. Internet of Things (IoT) links the physical things such as vehicles, refrigerators, thermostats, and vehicles to the Internet over the wireless network and activate them to share and coordinate information [1–6]. The diverse applications of IoT include transportation, healthcare, manufacturing, home automation, and the power grid. IoT plays a remarkable role in improving the quality of life and growing the world's economy [7–9]. The Information and Communication Technology (ICT) developments generate more and more

objects which are becoming embedded with the sensors and having the ability to communicate with other things and objects, that is, transforming the physical world itself into an information and knowledge system [10, 11]. The IoT enables the things/objects in the environment to actively participant using internet. That is, they share data and information with other members or stack holders through wireless/wired networks, often using the same internet protocol (IP) that connects the Internet [12, 13]. In this way, the things/objects are capable of recognizing actions and deviations in their surroundings and are capable of acting/reacting autonomously largely without human intervention in an appropriate way. These future IoT growths need to see acceleration and a maturation of common standards, creative approaches, and more cross-sector collaboration with business models [14].

Wireless sensors are one of the important applications of IoT [7, 15]. Many sensors may join to establish the network,

namely, wireless sensor network, which is a self-organizing network. The sensors gather the sensed data back to the information center to be stored and analyzed in real time [16, 17]. The sensors gather the data from their surroundings and send the data to the base station through intermediate nodes. These sensor nodes can be deployed in diverse IoT applications as mentioned above for specific tasks. Moreover, the smart city application has attained high attraction in the last few years.

It has been investigated that efficient waste management is still missing in state-of-the-art research on smart city applications. Therefore, an application, namely, Smart Waste Management (SWM) System is intended to be developed to overcome the garbage collection issues in smart city. The SWM provides on-time garbage collection and minimizes the total cost of the garbage collection process. This work demonstrates that the smart waste management system in IoT empowers the cleaning operators to detect cleaning issues in real time. Therefore, this system ensures increase in the overall productivity and cleanness. Moreover, the end-to-end delay is also taken into consideration for the proposed architecture. The term “end-to-end delay” is demonstrated as the sum of the time taken by a packet to reach from the source to destination which is the resultant of many factors such as interference level along the path, the length of the routing path, and the number of nodes/hops in the routing path. This article focuses on the nodal delay, which is the delay from the source to destination and the delay at the single node.

Traditionally, waste bins are deflated at certain intervals by cleaners. This procedure has numerous drawbacks as follows [18]:

- (1) Some garbage bins are filled up faster than the rate of picking up and emptying while they are filled up before the next time scheduled for collection which postures hygiene risks
- (2) There are some special days, for example, public holidays, weekends, and festivals, during which many waste bins fill up very quickly that may require faster collection interval

The work proposed here illustrates the smart waste management architecture that ensures the cleaning operators for detecting cleanliness issues in real time. Moreover, minimizing the end-to-end delay is also taken into consideration when a message is required to be sent for garbage collectors.

The article is organized as follows. In Section 2, the background of the Internet of things is discussed. The proposed methodology is described in Section 3. Section 4 describes the simulation results. Conclusion and future works are described in Section 5.

2. Background of Internet of Things

Communication is the most vital part of IoT, that is, the interconnectivity of different devices which are able to communicate with other devices [19]. All the additional properties, such as maneuvering, sensing, capturing, process, and data storage, are unnecessary unless and until devices precisely require one of these properties. However, the communication ability is necessary when classifying a

device as an IoT device. It is less important than the communication being performed; meanwhile, the physical and link layer communication within IoT can be comprehended in many ways.

Figure 1 shows that the communication of devices does not always require a specific communication network. That is, when two devices are in communication range, they can directly communicate with each other; for example, radio technologies, such as Bluetooth or ZigBee, enable direct communication [20]. In Figure 1, devices communicate via a gateway using one protocol, that is, IPv6 over “Low-Power Wireless Personal Area Networks” and then the gateway could communicate using another protocol that is IPv4 which is the Internet. In Figure 1, case B demonstrates two devices are directly connected to the communication network, while not requiring a gateway, and are able to communicate even when nodes are positioned in various places. A physical device can be plotted in the information world by using more than one virtual thing; however, a virtual thing does not need to be associated with multiple physical things. It will have existence of any physical thing autonomously; for example, a physical thing can be executed by multiple applications having multiple characteristics in the virtual world. In the same way, the virtual things also have many identities; for example, a virtual thing may be an audio file in a USB drive. This audio file may have different file names and multiple copies, and these files may possibly have different qualities.

In [21], the transport protocol is introduced for efficient delivery of super-media data from smart surveillance systems. Flow control and synchronization techniques are taken into consideration to maximize the efficiency of smart surveillance systems. There are three channels considered in the proposed architecture between the collected data from the environment and the data center. The first channel is the video channel, the second channel is the audio channel, and the third channel is the multisensory channel.

Learning-based synchronous (LS) approach is presented in [22] to minimize the transmission delay for Industrial Internet of Things (IIoTs), while showing no effect on reduction of network lifetime. LS algorithm considers forwarding nodes to minimize the transmission delay for IIoTs. In the LS scheme, each sender node looks the intermediate node which is closer to the sink node is selected through which the data are communicated to the sink node. The sender node synchronizes its duty cycle with its neighbor node by self-learning. In sensor-based IIoTs, the nodes near to the sink consume high energy than the nodes far away from the sink. However, the nodes nearer to the sink have lesser delay, which eventually enhances the network performance in terms of delay.

Utility-based adaptive duty cycle (UADC) is presented in [23] that shows robust energy efficiency, minimizes transmission delay, and increases the lifetime of the network. The algorithm considers comprehensive performance evaluation to determine the selection of relay nodes. In data dissemination, the algorithm selects the nodes which improve the efficiency in terms of energy conserving. The transmission efficiency is enhanced via maximizing the attempt of retransmission of energy consumption per unit

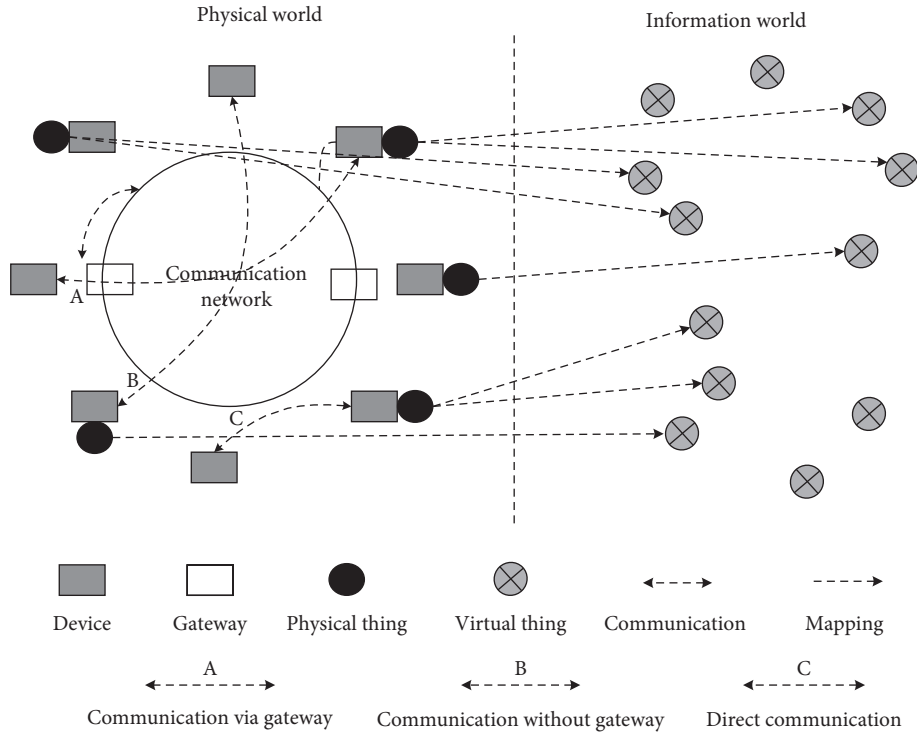


FIGURE 1: IoT communication [14].

transmission. To gain the superior value, the forwarding nodes consisting of small unit transmission bit energy dissipation, minor delay, and high energy are considered. Thus, the overall energy efficiency is achieved, energy utilization is stabled, and delay in data dissemination is minimized. Accordingly, the overall UADC achieves an optimum outcome from the network via selecting a link that increases the network’s function.

Waste management system (WMS) is proposed in [24] that focuses on the social aspects of the waste management systems. WMS uses IoT devices with RFID tags, weight, and ultrasonic sensors to measure the citizen interaction with the WMS. Each bin is equipped with an IoT device, ultrasonic sensor, weight sensor, RFID reader, solar cell, and two light emitting diodes as indicators, such that one of these indicators is colored in red and the other is colored in green. Every citizen who wants to interact with the system have an RFID card associated with a credential for the citizen. However, architecture is not efficient in terms of bin management, resource conservation, and message dissemination.

The time taken by a message to travel from the source to destination is called end-to-end delay. The delay depends on the number of hops and congestion on the network. The sensor nodes in wireless sensor networks are powered by small batteries that can be charged or replaced. Hence, sensors can only send a finite number of bits from the source to sink until they run out of energy [25]. The major metrics for QoS is end-to-end delay. Both data rate and end-to-end latency are a combined effect for user-perceived data transfer speed. For the transmission of the small-sized file, end-to-end delay is the dominating factor, and for transmission of large-sized file, the data rate is the dominating factor. In wireless sensor

environment, where the sensor nodes are required to be reported periodically to the sink, end-to-end delay plays a key role. For this purpose, we focus to find and minimize the end-to-end delay in wireless sensor nodes. The term “end-to-end delay” is described as the sum of time taken by a packet to reach the destination. Many factors can be resultant of it, including the interference level along the path, the routing path length, and the number of hops in that routing path.

So far, our focus is on the nodal delay in smart waste management architecture, which is the delay from the source to destination and the delay at the single node. Now, let us observe the total number of delay from the source to destination. Suppose we have “ $N - 1$ ” numbers of nodes from the source node to the destination node. Let us consider for a while that the network is uncongested so the “queuing delay” is insignificant, and at each router, the processing delay exists and host source is D_{proc} . Each router transmission rate out of the source host is R bits per second while D_{prop} is the propagation on every link; the delays at each node accumulate the end-to-end delay:

$$D_{end_end} = N(D_{proc} + D_{trans} + D_{prop}), \tag{1}$$

$$d_{trans} = \frac{L}{R},$$

where L is the packet size and R is the router.

3. Proposed Methodology

This section provides the proposed methodology which demonstrates the smart waste management system to empower the cleaning operations and to detect cleaning issues

in real-time IoT. The Smart Waste Management Architecture is presented in Section 3.1 that ensures increase in overall productivity and cleanness. Section 3.2 presents end-to-end delay minimization when a source node (bin) is full of garbage and needs to be emptied. Both the sections are described in the following.

3.1. Smart Waste Management Architecture. One of the difficult operational problems of municipal and local authorities are facing is the collection of municipal solid waste. In recent years, due to environmental concerns and number of costs, most of the municipalities have been forced for assessing their solid waste management and examining their cost-effectiveness and environmental impact, for example, designing the collection of routes. During the past 15 years, numerous technological advancements, new acquisitions, and developments were provided in the industries. Consequently, both municipal and private haulers are giving serious considerations to use advanced technologies such as computerized vehicles that take the decision of route planning and schedule of collection of waste [26]. This proposed system describes a study of planned and computerized vehicle routes for the collection of municipal solid waste in the different regions of Pakistan. The proposed system contains all the stages from the collection of our waste material, load to the truck, and recycling it in the recycling unit.

For this purpose, it includes the following list of activities:

- (i) Controlling and monitoring the collection of wastes; efficient and speedy transportation to the recycling units/point
- (ii) Preventing the waste from spilling from the waste bins during transportation to the recycling units
- (iii) Speedy transportation to recycling units so that the traffic condition will not be bothered in peak hours
- (iv) Proper storage and maintenance in the storage units

This is the only one aspect of recycling of the waste. Now, let us talk about the smart waste container recycling and management system. We have used smart bins in which waste-detecting sensors are fixed. These sensors are capable of sending signals to the nearest sensor referenced to the base station.

When the sensors detect the volume of the garbage, they communicate to the respective centers, indicating the volume of the garbage. The garbage centers will have the garbage pickup truck sent to collect garbage from the garbage bin and recycle it in the recycle unit.

In the following diagram, it is indicated that the garbage pickup goes on the routes which are the most optimized routes, both cost-wise and hygiene-wise.

In Figure 2, it can be easily noticed that the pickup truck is directed to those waste bins which are more than 90% full or about to be 100% full and not selecting the path which is partially filled. In this case, the pickup truck selects the most optimized route that not only reduces its costs in the

collection round trips but also shields from the unfavorable conditions.

3.2. The Proposed End-to-End Delay Technique. The estimation and calculation of the delay estimator at any node n_i are performed by using equation (2) which is given in the following, where $TD_{i,j}$ is the delay which is caused by transmitting the packet (P) to the node n_j from the node n_i using the link $L_{i,j}$ and QD_{ni} is the queue delay. P_r is the propagation delay from one node to another node while processing delay can be put in other delays which are experienced by the packet (p); however, it can be ignored as these are negligibly small:

$$ND_{ni} = QD_{ni} + TD_{ij} + P_r D_{ni}. \quad (2)$$

Queue delay QD_{ni} of packet P is the delay at any node before processing of the packet P which remains in the queue. The smoothing factor value is constant α which is 0 and 1. Initially, QD_{ni} is the queue delay experienced by the first packet:

$$QD_{ni} = \alpha QD_{ni} + (1 - \alpha) QD_{ni}. \quad (3)$$

The transmission delay ($TD_{i,j}$) is the amount of time taken by the packet (P) which remains in the MAC layer of node n_i before successful transmission to the node n_j on link $L_{i,j}$ or dropped. It can be calculated by the formula given in equation (4), where the data rates in bits are represented by DR bits, the size of the packets are represented by SP bits, and the number of transmitted packets in time interval δt is NP:

$$TD_{ij} = \frac{1}{DR_{bits}} \times \frac{\sum_{z=1}^{NP} SP_{bits}(z)}{NP}. \quad (4)$$

Propagation delay, $P_r D$, is the amount of time taken by the packet to make physical journey from the node n_i to node n_j . d_{ni} is the distance divided by velocity v as given in the following equation:

$$P_r D = \frac{d_{ni}}{v}. \quad (5)$$

If there are N paths from the sender node to the destination node, then the sender estimates the Path Delay PD and chooses the path that has least delay comparative to other paths to send messages. Let n_p denote the number of paths and n_i denote the number of nodes, where $I = 1, 2, 3, \dots, N$.

Path delay (PD) on each path is estimated as follows:

$$PD = \sum_{i=1}^{ni} ND_i. \quad (6)$$

If $p > 1$, where p denotes the number of paths, then

$$PD = \sum_{i=1}^{ni} ND_i, \sum_{i=1}^l ND_i, \sum_{i=1}^m ND_i, \dots, \sum_{i=1}^N ND_i. \quad (7)$$

The transmission is considered from a source to a destination with the minimum end-to-end delay over the wireless network where transmission can be reserved and guaranteed on the links. Different paths will be required for

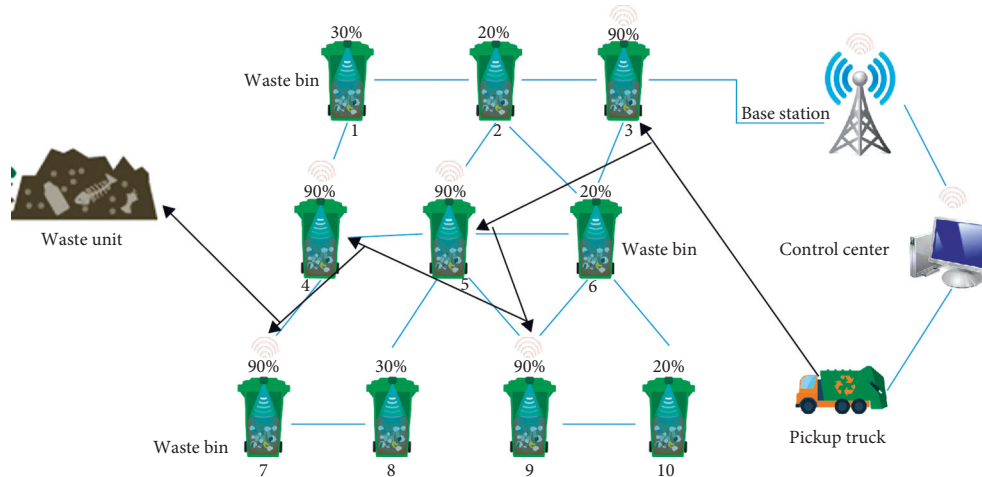


FIGURE 2: The proposed smart waste management system.

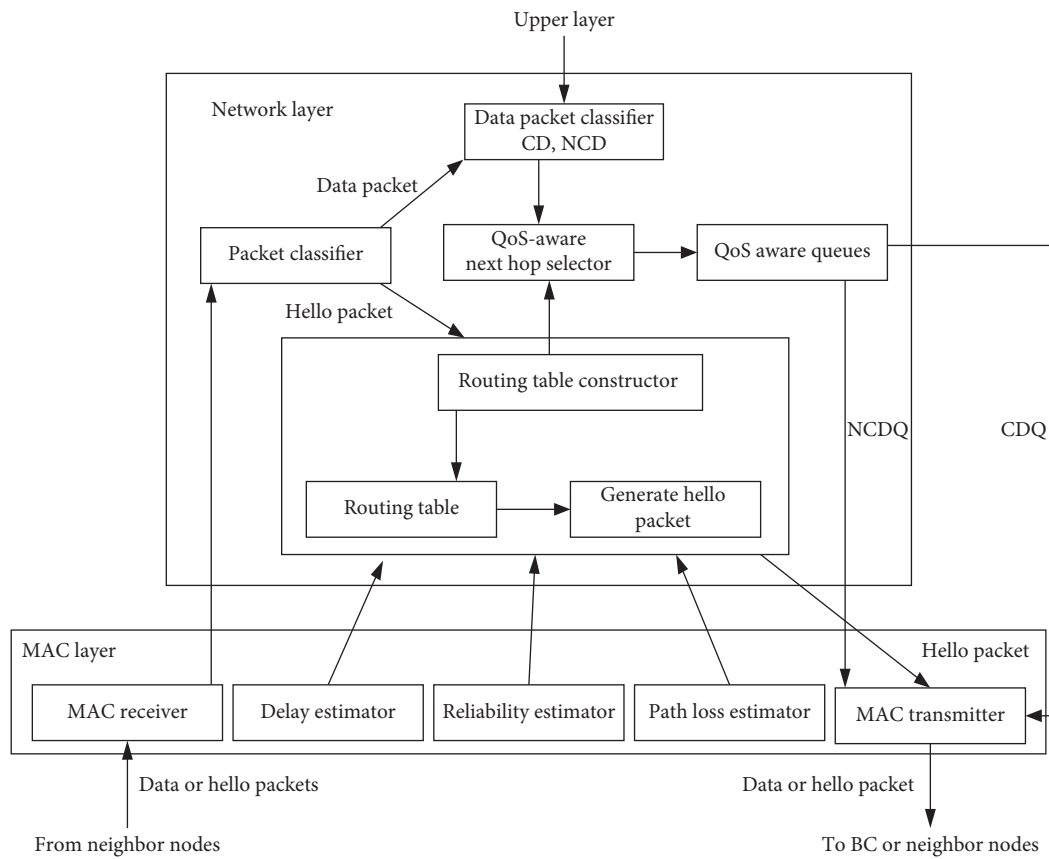


FIGURE 3: Routing model for efficient routing election in terms of least delay and high reliability.

different intervals of values that compute a table that maps all intervals for corresponding paths that minimize the end-to-end delay as described in Figure 3.

The responsibility of EREP algorithm is to select the desired next hop based on the demanded QoS parameters as described in Algorithm 1. Upon receiving the data packets (DPs) from the data packet classifier module, our proposed EREP algorithm, given in the following, searches the routing table (R_i) for

only those nodes in the neighborhood whose link quality ($L-QUAL_{i,j}$) is greater than or equal to the predefined threshold level ($L-QUAL_{thre}$) and places them in $NNL-QUAL$ (lines: 2-4). The DP is discarded immediately in case of empty $NNL-QUAL$ (lines: 5-6). Otherwise, in case of DP belonging to CD, delay aware procedure is called with inputs $NNPD$ and DP (lines: 7-8). While in case of DP belonging to NCD, the desired hop (DH) is the node belonging to $NNL-QUAL$.

```

IDDest = Destination ID
LOCdest = Co-ordinates of the NOD
IDnj = ID of the Neighbor Node  $n_j$ 
L-QUAL $i,j$  = Link Quality between nodes  $n_i$  and  $n_j$ 
PR $i,j$  = Path Reliability from node  $n_i$  to destination through node  $n_j$ 
PD $i,j$  = Path Delay from node  $n_i$  to destination through node  $n_j$ 
LOC $n,j$  = Co-ordinates of the neighbor node  $n_j$ 
Inputs: Rt and Data Packet P
(1) for each data packet DP do
(2)   for each node  $n_i \in RT$  do
(3)     if L-QUAL $i,j$  >= L-QUAL then
(4)       store node  $n_i$  into NNL-QUAL
(5)     if NNL-QUAL == NULL then
(6)       discard DP immediately
(7)     else if DP  $\in$  CD
(8)       call Delay Aware Procedure
(9)     else DH =  $n_j \in$  NNL-QUAL
Delay Aware Procedure
(10)  for each node  $n_i \in$  NNL-QUAL do
(11)   if PD $i,j$  >= PDreq then
(12)     store node  $n_i$  into NNPD
(13)   if NNPD == NULL then
(14)     discard DP immediately
(15)   else if NNPD == 1 then
(16)     DH =  $n_j \in$  NNPD
(17)   else call Reliability Aware Procedure
Reliability Aware Procedure
(18)  for each node  $n_i \in$  NNPD do
(19)   if PR $i,j$  >= PRreq then
(20)     store node  $n_i$  into NNPR
(21)   if NNPR == NULL then
(22)     DH =  $n_j \in$  NNPD with highest PR $i,j$ 
(23)   else if NNPR == 1 then
(24)     DH =  $n_j \in$  NNPR
(25)   else DH =  $n_j \in$  NNPR

```

ALGORITHM 1: Efficient Route Election procedure (EREP).

TABLE 1: Simulation parameters.

Simulation network		
Deployment	Area	100 * 100 m
	Number of nodes	50
	Buffer size	70 packets
	Transmission range	10 m
	Transmission power	5. 8467e - 12
Task	Bit error rate	20-2-20-4
	Application type	MATLAB
	Network interface type	Wireless
MAC	Traffic type	Constant bit rate (CBR)
	IEEE 8. 2. 15. 4	Default values
Simulation	Time	1000s

Once delay aware procedure is called, it selects only those nodes belonging to NNL-QUAL, whose end-to-end path delay (PD _{i,j}) is less than or equal to required delay (PD_{req}), and places them in NNPD (lines: 10–12). In the case of empty NNPD, the data packet is discarded immediately (lines: 13–14). If there is a single node in NNPD, then that node is selected as DH (lines: 15–16). Otherwise, the reliability-aware procedure is called with inputs NNPD and DP (line: 17).

Upon calling the reliability-aware procedure, it selects only those nodes whose end-to-end path reliability (PR _{i,j}) is greater than or equal to the required reliability (PR_{req}) and stores them in NNPR (lines: 18–20). If none of the nodes fulfills the required reliability demand, then the DH is the node belonging to NNPD having highest PR _{i,j} (lines: 21-22). If there is a single entry in NNPR, then that node is selected as DH (lines: 23-24). Otherwise, the node belonging to NNPR with least PT _{i,j} is selected as DH (line: 25).

4. Simulation Results

To study the performance of the proposed algorithms and to compare them to the existing ones, a wide experiment is conducted using a simulation tool. MATLAB is a high-precision level numerical-simulation environment and a popular tool to evaluate network models, which is used as the simulation tool. The simulation network is considered in Table 1 to evaluate the performance of the algorithm. The simulation results are analyzed to evaluate the efficiency of the proposed algorithms. Various performance parameters, like packet loss, congestion, packet delivery,

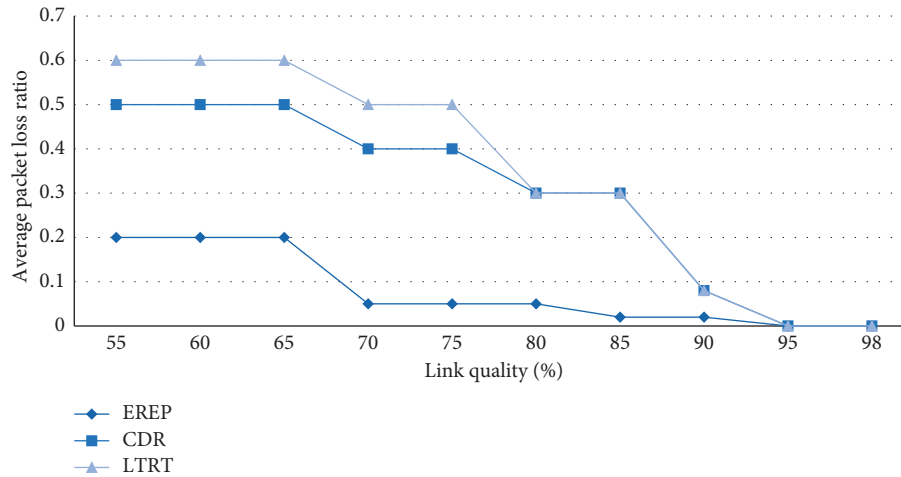


FIGURE 4: Link quality vs. packet loss ratio at different data generation rates.

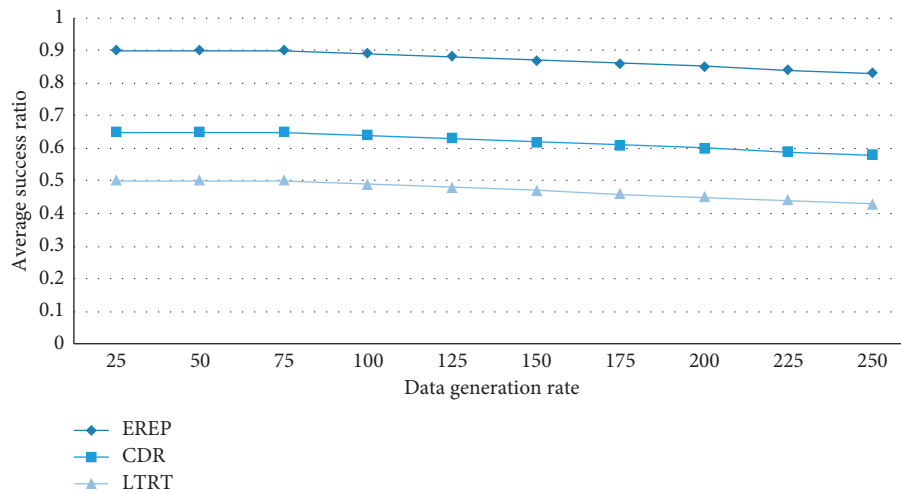


FIGURE 5: Data generation rate vs. packet success ratio at different link qualities.

and buffer size, are taken into consideration to compare the proposed scheme with the current scheme. A brief description of the mentioned parameters is given in the following section.

4.1. Simulation Network Parameters

4.1.1. Packet Loss. When some data are traveling across computer networks and one or more packets fails to reach its destination, then it is called packet loss. The packet loss is mostly caused by the computer network congestion. It can be measured by the percentages of packets lost with respect to the packet sent.

4.1.2. Congestion. The network congestion can be defined as reduction of quality of service (QoS) which occurs in those cases when a network carry more data than it can handle. This affects the queuing delay, resulting in the blockage of connections and loss of packets.

4.1.3. Packet Delivery. Packet delivery is the ratio of generated data packets to the ratio of data packets received at the destination.

4.1.4. Buffer Size. Buffer size is the physical region of memory storage that is used by temporarily stored data which are being moved from one place to another.

4.1.5. Bit Rate. Bit rate is the rate at which data are transferred from the source to destination. In other words, we can say that in a given amount of time how much data are transmitted. It is mostly measured by bits per second (bps) or (Kbps) and (Mbps).

4.2. Average Packet Loss Ratio. The performance of the algorithm can be evaluated using the average packet loss ratio where a better algorithm can be defined when the packet loss ratio is least upon the data generation increase. Figure 4 describes the performance of efficient route election

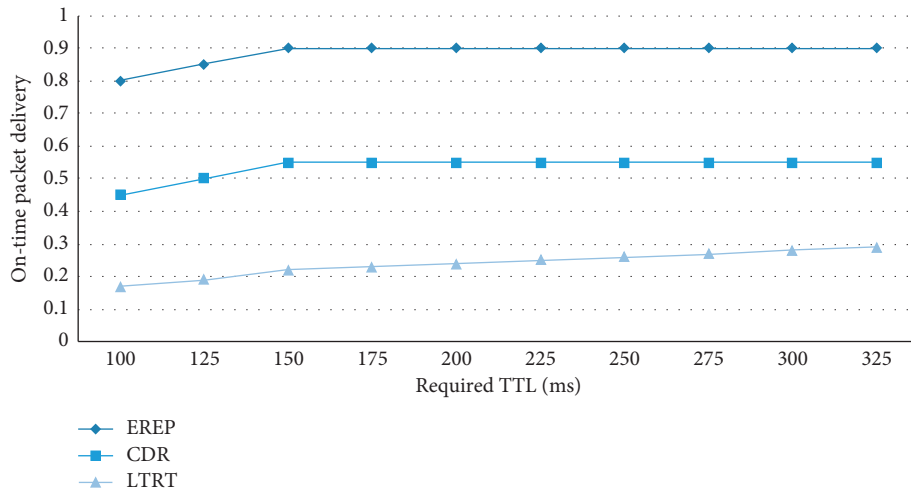


FIGURE 6: On-time packet delivery ratio vs. required TTL considering different data generation.

procedure (EREP) in terms of packet loss ratio, while the result for EREP is compared with CDR and LTRT procedures.

4.3. Average Success Ratio. The performance of the algorithm can be evaluated using the average success ratio where a better algorithm can be defined when the packet success ratio is greater. Figure 5 describes the performance of EREP in terms of average success ratio, while the result for EREP is compared with CDR and LTRT procedures.

The impact of data generation rates is shown in Figure 5 over packet success ratio by considering different link qualities. With the increase in data generation, the packet success ratio is decreasing slightly for all schemes which might be due to congestion.

4.4. On-Time Packet Delivery. The performance of the algorithm can be evaluated using on-time packet delivery where a better algorithm can be defined when the on-time packet delivery is greater while the data generation is increasing. Figure 6 describes the performance of EREP in terms of on-time packet delivery, while the result for EREP is compared with CDR and LTRT procedures.

The time constraint impact on the average time packet delivery ratio is similar by considering different link qualities.

It is clear from Figures 4–6 that the proposed EREP scheme outperforms than other current schemes such as CDR [27] and LTRT [28]. This is because of considering propagation delay during evaluation of end-to-end delay on each hop.

5. Conclusion and Future Work Direction

The article proposes IoT-enabled waste management system (SWM) for smart city applications. Therefore, an application is developed initially in the smart cities, namely, the smart waste management (SWM) system. The SWM system provides on-time garbage collection which eventually

minimizes the total cost of the garbage collection process. The proposed work demonstrates that the waste management system in IOT empowers the cleaning operators to detect cleaning issues in real time. Therefore, this system helps in increasing overall productivity and cleanness. Moreover, the end-to-end delay is also taken into consideration for the proposed architecture. The term “end-to-end delay” is demonstrated as the total time taken by a packet to reach from the source to destination which is resultant of many factors, including the interference level along the path, the length of the routing path, and the number of nodes/hops in the routing path. Propagation delay is also considered during evaluation of end-to-end delay. It has been observed from the simulation results that the proposed scheme outperforms existing works.

Maintenance algorithm, reliability, redundancy minimization, and data broadcasting are open research issues in SWM application.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Asim Zeb proposed the methodology. Qurban Ali was responsible for validation. Muhammad Qaiser Saleem reviewed the manuscript. Khalid Mahmood Awan was responsible for resource management and conceptualization. Jamal Uddin and Muhammad Qaiser Saleem were involved in funding acquisition. Ali Saeed Alowayr and Saleem Iqbal wrote the manuscript and were responsible for final proof approval of the manuscript. Faisal Bashir carried out reviewing and editing.

Acknowledgments

This work was developed in the Qurtuba University of Science and Information Technology, Pakistan, in collaboration with COMSATS University Islamabad Attock Campus, Pakistan.

References

- [1] J. Louis and P. S. Dunston, "Integrating IoT into operational workflows for real-time and automated decision-making in repetitive construction operations," *Automation in Construction*, vol. 94, pp. 317–327, 2018.
- [2] A. Khan, M. Pohl, S. Bosse, S. W. Hart, and K. Turowski, "A holistic view of the IoT process from sensors to the business value," in *Proceedings of the 2nd International Conference on Internet of Things, Big Data and Security*, Porto, Portugal, April 2017.
- [3] A. M. George, S. Kulkarni, and V. George, "A survey on ultra low power design techniques for IOT application," *Current Trends in Information Technology*, vol. 7, no. 3, pp. 9–16, 2018.
- [4] L. Anthopoulos, M. Janssen, and V. Weerakkody, "A unified smart city model (USCM) for smart city conceptualization and benchmarking," in *Smart Cities and Smart Spaces: Concepts, Methodologies, Tools, and Applications*, pp. 247–264, IGI Global, Hershey, PA, USA, 2019.
- [5] M. Gasco-Hernandez, M. P. Rodríguez Bolívar, and T. Nam, "Introduction to the minitrack on smart and connected cities and communities," in *Proceedings of the 52nd Hawaii International Conference on System Sciences*, Wailea, HI, USA, January 2019.
- [6] G. C. Deka, *Applications of Computing and Communication Technologies*, Springer, Berlin, Germany, 2018.
- [7] I. Lee and K. Lee, "The internet of things (IoT): applications, investments, and challenges for enterprises," *Business Horizons*, vol. 58, no. 4, pp. 431–440, 2015.
- [8] M. Chiang and T. Zhang, "Fog and IoT: an overview of research opportunities," *IEEE Internet of Things Journal*, vol. 3, no. 6, pp. 854–864, 2016.
- [9] F. Tao, Y. Zuo, L. D. Xu, and L. Zhang, "IoT-based intelligent perception and access of manufacturing resource toward cloud manufacturing," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1547–1557, 2014.
- [10] D. Uckelmann, M. Harrison, and F. Michahelles, "An architectural approach towards the future Internet of Things," in *Architecting the Internet of Things*, pp. 1–24, Springer, Berlin, Germany, 2011.
- [11] K. Kumar and S. Kumar, "Energy efficient link stable routing in Internet of Things," *International Journal of Information Technology*, vol. 10, no. 4, pp. 465–479, 2018.
- [12] O. Vermesan, P. Friess, P. Guillemin et al., "Internet of things strategic research roadmap," *Internet of Things-Global Technological and Societal Trends*, vol. 1, pp. 9–52, 2011.
- [13] R. Kasana, S. Kumar, O. Kaiwartya et al., "Fuzzy based channel selection for location oriented services in multi-channel VCPS environments," *IEEE Internet of Things Journal*, vol. 5, no. 6, pp. 4642–4651, 2018.
- [14] I. F. Akyildiz and I. H. Kasimoglu, "Wireless sensor and actor networks: research challenges," *Ad Hoc Networks*, vol. 2, no. 4, pp. 351–367, 2004.
- [15] K. Kumar, P. K. Kashyap, and S. Kumar, "Aeronautical assisted IoT implementation: route lifetime and load capacity perspective," in *Proceedings of the International Conference on Application of Computing and Communication Technologies*, Springer, Delhi, India, March 2018.
- [16] W. He, G. Yan, and L. D. Xu, "Developing vehicular data cloud services in the IoT environment," *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1587–1595, 2014.
- [17] L. Catarinucci, D. de Donno, L. Mainetti et al., "An IoT-aware architecture for smart healthcare systems," *IEEE Internet of Things Journal*, vol. 2, no. 6, pp. 515–526, 2015.
- [18] A. M. Seifert and K. Messing, "Cleaning up after globalization: an ergonomic analysis of work activity of hotel cleaners," *Antipode*, vol. 38, no. 3, pp. 557–578, 2006.
- [19] L. Atzori, A. Iera, and G. Morabito, "The internet of things: a survey," *Computer Networks*, vol. 54, no. 15, pp. 2787–2805, 2010.
- [20] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of things: a survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.
- [21] G. Kokkonis, K. E. Psannis, M. Roumeliotis, and D. Schonfeld, "Real-time wireless multisensory smart surveillance with 3D-HEVC streams for internet-of-things (IoT)," *The Journal of Supercomputing*, vol. 73, no. 3, pp. 1044–1062, 2017.
- [22] M. Wu, Y. Wu, X. Liu, M. Ma, A. Liu, and M. Zhao, "Learning-based synchronous approach from forwarding nodes to reduce the delay for industrial Internet of Things," *EURASIP Journal on Wireless Communications and Networking*, vol. 2018, no. 1, p. 10, 2018.
- [23] J. Wang, C. Hu, and A. Liu, "Comprehensive optimization of energy consumption and delay performance for green communication in Internet of Things," *Mobile Information Systems*, vol. 2017, Article ID 3206160, 17 pages, 2017.
- [24] M. Al-Jabi and M. Diab, "IoT-enabled citizen attractive waste management system," in *Proceedings of the 2017 2nd International Conference on the Applications of Information Technology in Developing Renewable Energy Processes & Systems (IT-DREPS)*, IEEE, Amman, Jordan, December 2017.
- [25] Y. Wang, M. C. Vuran, and S. Goddard, "Cross-layer analysis of the end-to-end delay distribution in wireless sensor networks," *IEEE/ACM Transactions on Networking*, vol. 20, no. 1, pp. 305–318, 2012.
- [26] M. M. Khan, "Cross-layer designs: a survey," *International Journal of Computer Applications*, vol. 53, no. 8, pp. 44–49, 2012.
- [27] J. I. Bangash, A. H. Abdullah, M. A. Razzaque, and A. W. Khan, "Critical data routing (CDR) for intra wireless body sensor networks," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 13, no. 1, pp. 181–192, 2015.
- [28] M. M. Monowar, M. M. Hassan, F. Bajaber, A. Hamid, and A. Alamri, "Thermal-aware multiconstrained intrabody QoS routing for wireless body area networks," *International Journal of Distributed Sensor Networks*, vol. 10, no. 3, Article ID 676312, 2014.



Hindawi

Submit your manuscripts at
www.hindawi.com

