

QoS-aware Resource Allocation for Healthcare Data Transmission using D2D Communication in NB-IoT

Nahar Sultana, Farhana Huq, Md. Abdur Razzaque, Md. Mustafizur Rahman

Green Networking Research Group, Department of Computer Science and Engineering, University of Dhaka, Bangladesh

Email: nahar61-2020-21@student.cse.du.ac.bd, farhana62-2020-21@student.cse.du.ac.bd, {razzaque, mustafiz}@du.ac.bd

Abstract—The deployment of Narrowband Internet of Things (NB-IoT) for the transmission of healthcare data has recently gained special attention. Existing works in the literature are limited by handling heterogeneous data in an inefficient way due to lack of prioritization of health events. In this work, we investigate the use of Device to Device (D2D) integrated NB-IoT to ensure the Quality of service (QoS) while allocating radio resources to maximize the data rate of an application's urgency in smart healthcare. We specifically create a novel system with a two-tier structure for prioritized health data transfer across cellular user equipment (CUE), D2D, and eNB to increase throughput and develop an optimization framework using multi-objective non-integer linear programming (MNILP) for fair resource distribution among the participants. Performance analysis results demonstrate that the suggested resource allocation results in a higher percentage of data delivery ratio and offers a significantly decreased data delivery delay.

Index Terms—Device to Device communication, Resource Allocation, Health Monitoring, NB-IoT

I. INTRODUCTION

The Narrow Band Internet of Things (NB-IoT), a licensed Low Power Wide Area Network (LPWAN) and derived from 3GPP (Third Generation Partnership Project), is projected to play a significant role in smart applications due to its promise to offer a dependable connection with extended coverage [1] [2]. It's long-range communication and long battery lifetime enables a variety of applications, including smart meters, smart agriculture, smart vehicles, and smart healthcare etc [3]. Furthermore, the NB-IoT offers excellent indoor coverage, massive number of connections, cost efficiency etc. As a result of rising public awareness of health issues and widespread participation in a smart healthcare system, smart hospitals can integrate assets and resources, make decisions based on data and utilize resources optimally [4]. To handle reliable transmission of heterogeneous and time-sensitive data in a short span of time, the limited availability of the NB-IoT cellular spectrum must be significantly improved in order to fulfill the requirement for more smart devices and user information sharing in healthcare applications.

Any disease or characteristic that is detected instantaneously inside a smart hospital is labeled as a Critical Event (CE) [5], which needs to be handled as a crisis or emergency. To support critical events in an NB-IoT-based smart hospital, it is very challenging to transmit time-sensitive, prioritized relevant data [5] throughout inter- and intra-department communication. The authors of [5] characterizes the event classification for smart healthcare (i.e. Critical event, Relevant event, and

Normal event) appropriately. In order to fulfill event urgency, higher throughput, and boost the communication effectiveness, D2D based NB-IoT communication [6] may serve as a routing extender. Another issue is the limitations on interference between D2D users and CUE, which adversely impacts QoS and leads to higher End to End (E2E) delay, lower transmission efficiency (poor in delivery ratio), etc. Additionally, D2D users in the underlay cellular communication mode reuse the same cellular user equipments (CUE) resources in a non-orthogonal way, requiring a proper resource allocation between D2D and CUE, coordinated by the base station (eNB), to maintain the system's energy efficiency. A D2D communication is used in the scope of NB-IoT in [1] to alleviate the issue of significant battery drains during low power, long range communication. The ideal resource allocation algorithms for underlay and overlay D2D communication [7] as well as the future direction of E2E latency for D2D-powered NB-IoT applications were defined in this paper. In [2], jointly optimal resource allocation for uplink and downlink of D2D communication has been addressed. However, they only took into account the conventional homogeneous network, which is ineffective for heterogeneous networks, device mobility, and resource allocation with the least amount of interference and most energy gain.

The authors of [6] suggested cellular aided D2D communication and created a related radio resource allocation mechanism to avoid WBAN collisions in a crowded pedestrian path, that were both time-sensitive and insensitive in terms of throughput and latency. D2D communication for NB-IoT delay sensitive application such as IoT healthcare application, vehicle communication has been investigated in [8] to obtain the higher end-to-end delivery ratio. In this research, the paper develops a D2D assisted prioritized heterogeneous data transmission for classified events using NB-IoT D2D based healthcare applications using in band underlay mode which maximizes throughput and assure QoS. At the same time, we propose an optimization framework to allocate resources between CUE and D2D by eNB to assign the communication channel and to control transmission power that introduces Quality Aware Resource Allocation for D2D communication (QRD2D). The increased communication performance using D2D for healthcare applications is expected to be achieved by this architecture. The following is a summary of this work's main contributions:

- We use D2D based underlay transmission to manage heterogeneous prior relevant health data and provide high-quality medical data transmission to the application's urgency level.
- The developed system can significantly reduce the interference level during D2D transmission with cellular users.
- To optimize transmit power and assign communication channels to both cellular and D2D transmission, an optimum radio resource allocation technique is addressed as a multi-objective non-integer linear programming (MNILP) problem under specified conditions.
- We evaluate the efficacy of the proposed protocol to perform end to end delay and packet delivery ratio in heterogeneous medical data transmission.

The structure of this paper is as follows: The state of the art of various works are presented in Section 2, the system model and assumptions are described in Section 3, the design of the QRD2D is proposed in Section 4, and the performance findings are examined in Section 5. The conclusion of this paper is narrated in Section 6.

II. STATE OF ART WORKS

In [1] [2], a comprehensive research effort has been launched to look into new potential for low-power, long-range IoT applications. The ever increasing number of IoT devices necessitates for high-quality radio conditions, high battery drain, handle sensitive data transfer and enhancing the efficiency of the spectrum combine a number of research issues with various radio access networks like NB-IoT [3] [8]. A fully connected world in which billions of devices are connected to the Internet could be feasible with the help of a D2D assisted NB-IoT network [9] [10].

Device-to-device (D2D) communication is deployed as a forwarding extension for NB-IoT networks, allowing two-hop paths between NB-IoT devices and the serving base station via a group of D2D relays. The reuse mode, which allows D2D users to share and reuse cellular terminal resources in order to increase cell spectrum efficiency, is one of the various D2D communication modes being considered by the authors of [11]. They have looked into how the inclusion of a random number generator in the allocation process can affect the performance benefits of the multi-user diversity that is generally ensured by allocation schemes. However, further research is required before these findings can be generalized to heterogeneous circumstances in which all types of cells overlap. As mentioned in [12], D2D communication provides a trustworthy way to transmit the data gathered by the NB-IoT UE to the BS using neighboring cellular devices that act as relay nodes.

Due to intolerance of packet drop and delay, the authors explored that, delay sensitive applications need to use the relay node which are selected deterministic-ally. They approached to use a deterministic D2D (2D2D) strategy to increase End to end Delivery Ratio(EDR) and decrease End to End Delay(EED), where, re-transmission is not taken into consideration in this method. In [13], [14] the device-to-device

(D2D) type of NB-IoT is addressed as a scheduling algorithm for uplink and downlink latencies based on the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol. LEACH based D2D aided NB-IoT network topology decreased queuing delays (latency) at the base station, resulting in lower energy usage, longer battery life, lower communication costs etc. The authors came up with an intuition to work with integrated D2D assisted NB-IoT network in smart city, smart grid, smart vehicle etc. in future. Their strategy optimized each device's communication mode and assigned resources in accordance with user request and the network's various aspects.

The paper [15] discussed how device-to-device (D2D) communication might reduce network congestion in 5G NB-IoT networks that are overcrowded and vulnerable to interference. The authors of [16] took into account both the uplink and downlink subcarrier resources for D2D users, but they did not combine D2D with NB-IoT, which would have a significant impact on healthcare applications.

We emphasis on resource allocation methods for smart healthcare systems in this paper using D2D-assisted NB-IoT devices for healthcare, that was not taken into account in earlier research. In this proposed model, D2D pair user from different location of a hospital communicates without visiting base station directly and formulate an optimization framework to maximize the throughput and reliability by reducing delay and containing higher delivery ratio.

III. SYSTEM MODEL

This paper explored how to establish an efficient heterogeneous data transmission based on event necessity from different locations of a smart hospital using D2D NB-IoT and how to optimally allocate radio resources, sketched in Figure 1. In this section, assumptions are provided after discussing the network environment and application model .

A. Network Environment

This paper considers a two-layer network architecture that combines NB-IoT devices (D2D), cellular users (CUE), and NB-IoT base station (eNB). The network model considers the case of a smart hospital where D2Ds are required to convey urgently important data while timely relevant data exchanges take place with other devices close to the coverage region. We assume that, NB-IoT devices are set up in a smart medical setting or as a Wireless Body Area Network (WBAN) that produces particular sensed data from sensors and interacts with other devices (Analyzer, Spiro-meter, insulin pumps etc). What is taken into account for data transmission in a smart healthcare system is an end device's ability to consistently exchange data from multiple locations, such as an emergency room, outpatient department, cabin, nursing station, etc., with or without the help of an eNB. The system architecture of a D2D communication system in a smart hospital is shown in Figure 2. Using D2D communication, which serves as a routing extension and is not necessarily interacting with eNB, any device can communicate with other devices and work as a pair in this paper. In this method, the cellular user (CUE)

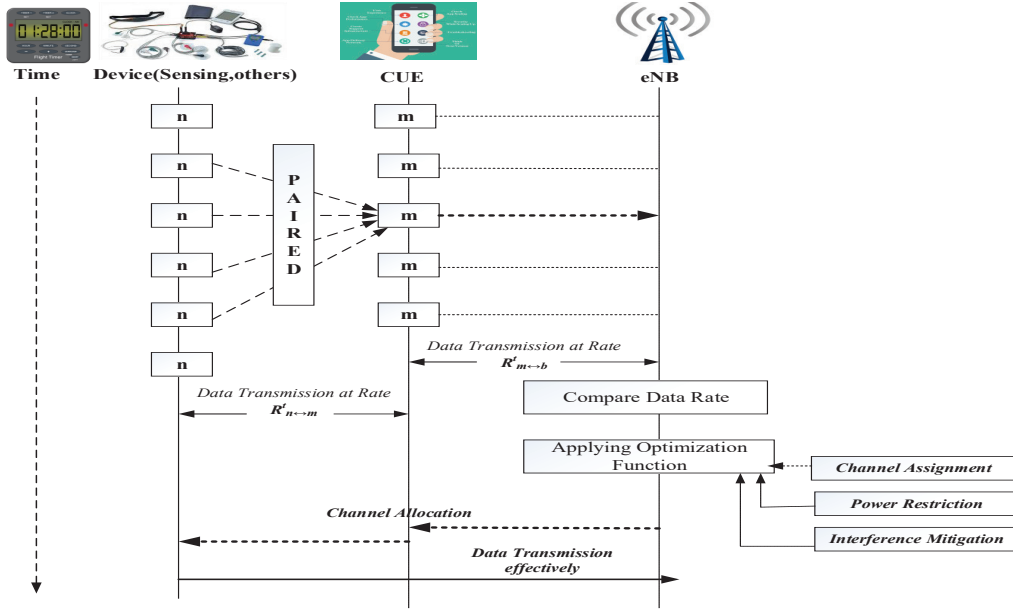


Fig. 1: Sequence diagram of the proposed system

relays the data to the eNB to increase data throughput and improve communication efficiency of emergent/critical event.

B. Assumptions

Due to the necessity of data communication between D2D devices, we assume a smart hospital scenario and also assume that D2D communication applies in band underlay mode in this scenario applying non-orthogonal resource sharing. In this system, uplink channel $u \in U$ and downlink channel $d \in D$ is modulated by multiple sub-carriers, and different time slots $t \in T$ of a single time frame (T) are mapped with those sub-carriers. In this paper, the base station eNB, b assigns resources to cellular user (CUE) $m \in M$, with multiple D2D or UE pair user $n \in N$ in a time slot $t \in T$ for D2D-in band-underlay communication.

IV. PROPOSED DESIGN OF QRD2D

This section summarizes the research issues that have already been described into understandable terms. In order to achieve high data rates, maximize D2D communication coverage, and minimize interference, what we really want is for the base station to offer bandwidth resources to the cellular UEs. This will allow users to access high-quality resources. This approach is done in a smart hospital that communicates with an eNB through a cellular user(CUE) by selecting near proximity. This section is approaching with joint data calculation followed by achievable data rate and finally propose an optimal solution of resource allocation between cellular user and device to device users offer by eNB.

A. Data Rate Calculation

This section delineates D2D communication to exchange medical data between medical devices without communicating

base station directly and in next subsection, we developed an optimization framework to allocate the resources optimally to the CUE based on desired user communication.

Data rate for cellular user(CUE) $m \in M$ for uplink and downlink communication respectively are given by,

$$R_m^u = \log_2(1 + \gamma_m^u); \quad (1)$$

$$R_m^d = \log_2(1 + \gamma_m^d); \quad (2)$$

where,

$$\gamma_m^u = \frac{\rho_m^u \times G_m^u}{I_m^u + N_0}, \quad \gamma_m^d = \frac{\rho_m^d \times G_m^d}{I_m^d + N_0}. \quad (3)$$

Here, γ_m^u and γ_m^d express the the Signal to Interference Noise Ratio (SINR) value of a CUE, for uplink and downlink communication, respectively. In the Equation (3), the ρ indicates corresponding transmission power, G is assigned as channel gain, I is for interference among the communications of CUEs and N_0 represents the additive white Gaussian noise value (AWGN).

Data rate for D2D user $n \in N$ for uplink and downlink communications, respectively are given by,

$$R_n^u = \log_2(1 + \gamma_n^u); \quad (4)$$

$$R_n^d = \log_2(1 + \gamma_n^d); \quad (5)$$

where,

$$\gamma_n^u = \frac{\rho_n^u \times G_n^u}{I_n^u + N_0}, \quad \gamma_n^d = \frac{\rho_n^d \times G_n^d}{I_n^d + N_0}; \quad (6)$$

Similarly, here, in Equation (6), γ_n^u and γ_n^d are for SINR values of D2D user and ρ, G, I, N_0 are indicating corresponding transmission power, channel gain, interference, AWGN, respectively.

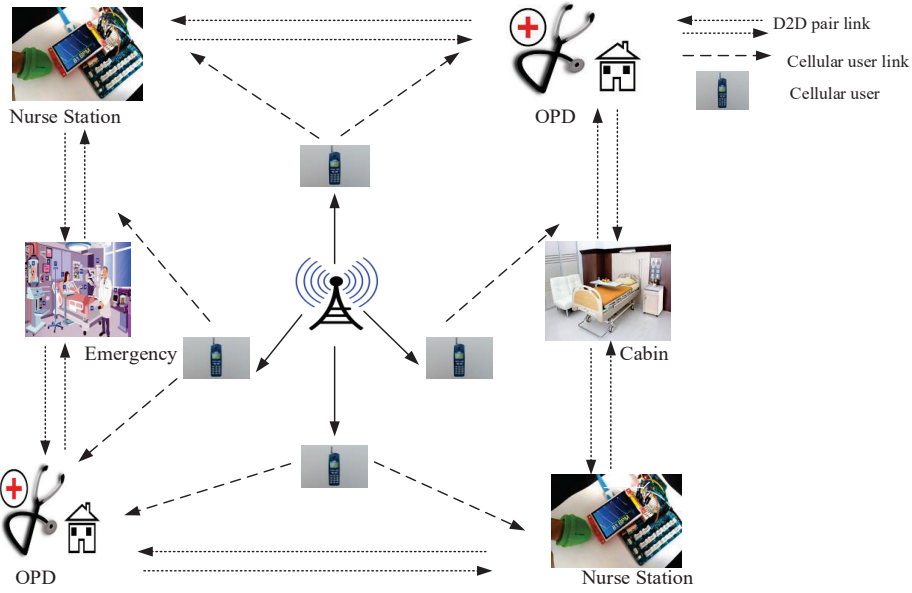


Fig. 2: D2D Communication System Environment for Healthcare Application

In this scenario, it is assumed that D2D communication working as pair with CUE indicating by $i_{m,n}$ which is a binary variable having 1 when a D2D $n \in N$ is connected with a CUE $m \in M$; 0 otherwise. Here, $R_{n \leftrightarrow m}^t$ in Equation (7) denotes data rate which considers both data transmission from a D2D n to CUE m and vice versa, under allocated uplink channel $u \in U$ and downlink channel $d \in D$ from a certain base station b , in a time slot t using by Equation (4) and Equation (5) following,

$$R_{n \leftrightarrow m}^t = \sum_{\forall u \in U} \sum_{\forall d \in D} i_{m,n} \times (R_{n \rightarrow m}^{u,t} + R_{m \rightarrow n}^{d,t}). \quad (7)$$

Again the next hop data rate is calculated as, $R_{m \leftrightarrow b}^t$ in Equation (8) which considers both the data transmission from cellular relay user m to a certain base station b and vice versa, under allocated uplink channel $u \in U$ and downlink channel $d \in D$ from a certain base station b , in a time slot t using by Equation (1) and Equation (2) following,

$$R_{m \leftrightarrow b}^t = \sum_{\forall u \in U} \sum_{\forall d \in D} i_{m,b} \times (R_{m \rightarrow b}^{u,t} + R_{b \rightarrow m}^{d,t}), \quad (8)$$

where, $i_{m,b}$ is a binary variable having 1 when a CUE $m \in M$ is connected with a base station b ; 0 otherwise. A performance assessment for multi-hop transmission is throughput. It is relied on increased data rates from D2D (NB-IoT devices) to cellular relay user (CUE) and from CUE to the base station (eNB). To achieve maximum throughput, achievable data rate for a certain CUE $m \in M$ in channel $u \in U$ and $d \in D$ in a given time slot $t \in T$ is calculated as follows,

$$Z^t = \max \left(\sum_{\forall m \in M} \sum_{\forall n \in N} (R_{n \leftrightarrow m}^t), \sum_{\forall m \in M} (R_{m \leftrightarrow b}^t) \right). \quad (9)$$

In Equation (9), Z^t preferences the maximum data rate between $R_{n \leftrightarrow m}^t$ and $R_{m \leftrightarrow b}^t$ which will achieve to assign resources accordingly in our system by maximizing throughput.

B. Resource Allocation and Problem Formulation

The proposed joint (uplink and downlink) resource allocation from a base station to its CUEs and D2D aims to identify the higher data rate with relay paired coefficient ($i_{m,n}$) that would optimize overall cell throughput and satisfy QoS requirements for all nodes. As a result, we define and provide a realistic alternative to the achievable data rate maximization and resource optimization formula for NB-IoT systems. Mathematically, the issue is presented as follows:

Maximize:

$$\zeta = \arg \max_{u \in U, d \in D} \sum_{\forall t \in T} Z^t \quad (10)$$

Subject to:

$$0 \leq \rho_m \leq \rho_m^{max}; \quad \forall m \in M \quad (11)$$

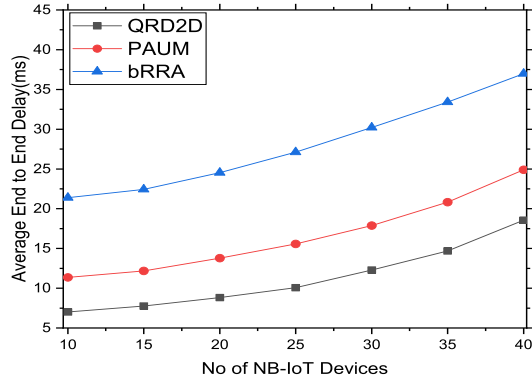
$$0 \leq \rho_n \leq \rho_n^{max}; \quad \forall n \in N \quad (12)$$

$$0 \leq \rho_{b,m} \leq \rho_{b,m}^{max}; \quad \forall b \in B, \quad \forall m \in M \quad (13)$$

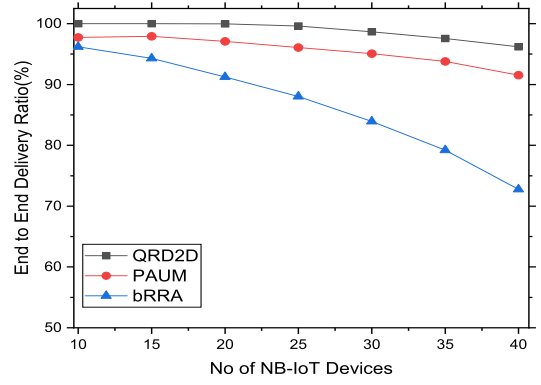
$$\sum_{\forall m \in M} \sum_{\forall n \in N} i_{m,n} \times u_{n \rightarrow m}^t \leq 1; \quad \forall t \in T, \forall u \in U \quad (14)$$

$$\sum_{\forall m \in M} \sum_{\forall n \in N} i_{m,n} \times d_{m \rightarrow n}^t \leq 1; \quad \forall t \in T, \forall d \in D. \quad (15)$$

Here, the objective function in Equation (10) is formulated as an MNILP (Multiobject Non-Integer Linear Programming) to be solved by eNB. Maximizing power, throughput with allocated uplink/ downlink channel and its data rate for all users outputs an optimum solution with some effective constraints. Power constraints in Equation (11), Equation (12),

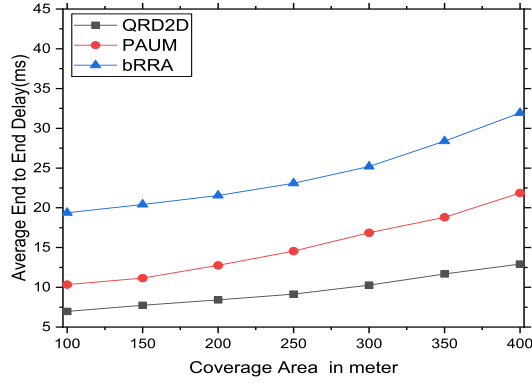


(a) Average delay

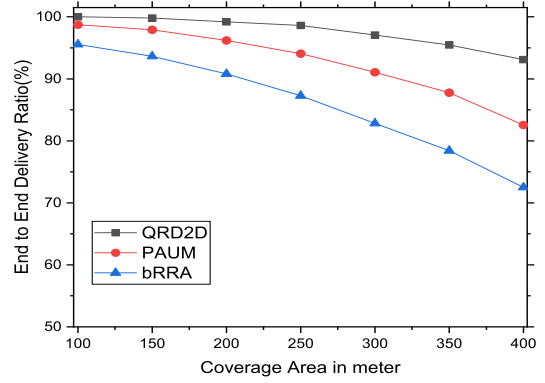


(b) Delivery ratio

Fig. 3: Impact of varying number of NB-IoT Devices



(a) Average delay



(b) Delivery ratio

Fig. 4: Impact of varying radius of eNB

Equation (13) are the transmission power range for cellular user, CUE, $m \in M$, D2D user $n \in N$ and power between eNB, b and CUE $m \in M$, respectively. The constraint in Equation (14) is responsible to assign at most one pair of CUE and D2D, i.e., $i_{m,n}$, which is shared by each uplink subcarrier of CUE assigned by eNB. Again, Equation (15) refers to each downlink subcarrier of CUE, assigned by eNB, is shared by at most one pair of $i_{m,n}$.

TABLE I: Simulation Parameters

Parameters	Values
Cellular layout	Hexagonal Grid, 3 sectors per site
Carrier	900 MHz
Inter-site distance	500m /1732 m
NB-IoT Device Deployment	Uniform random distribution
CUE Deployment	random distribution
BS Transmit Power	43 dBm
Device transmit power	Maximum 23dBm
Coverage Area	400m and 500m
No of NB-IoT Devices	40 and 50

V. PERFORMANCE EVALUATION

The proposed Quality Aware Resource Allocation for D2D communication (QRD2D) performances are compared with

Priority Aware Utility Maximization (PAUM) [5], Basic Resource Allocation (bRRA) [16], with various parameters in network simulator version-3 [NS-3] for a smart healthcare, where, LTE network cell has taken for simulation

A. Simulation Environment

In the simulation environment, P independent users are randomly distributed in one single cell. We first divide the P users into NB-IoT users $n \in N$ and cellular relays $m \in M$ before choosing one D2D pair $i_{m,n}$ who attempts to upload its data packet to the certain eNB b utilizing the chosen relay $m \in M$. According to 3GPP, the cellular layout is considered as hexagonal grid where frequency band is 900 MHz along with 180kHz channel bandwidth, assuming channel conditions are dynamic, maximum transmission power of base station and NB-IoT UE is 43dBm and 23dBm respectively.

B. Performance metric

- *Average End-to-End Delay*: It is the overall data packet's average time delay originated from pair of D2D user and CUE to reach at the corresponding eNB.
- *End-to-End Delivery Ratio*: It is described as the ratio of delivered packets to eNB to the total number of packets sent from all D2D pairs with CUE.

C. Performance Analysis

1) *Impacts of varying No of NB-IoT Devices:* This study investigates the impact of NB-IoT device density on the average end-to-end delays of various resource allocation systems. As the number of devices grows, the average packet delivery delays for all systems examined increase continuously, as shown in Figure 3(a). Throughput is maximized while resource allocation is jointly optimized, resulting in least delay as predicted by theory for QRD2D. The graphs in Figure 3(a) also demonstrate that, on an average, PAUM and bRRA system's delays are 1.75 times and 4.5 times higher, in comparison to the QRD2D, respectively.

The graphs in Figure 3(b) express that, end to end delivery ratio (EDR), for all evaluated systems, constantly decreases as the number of devices increases. In case of QRD2D, even a slight rise in the number of NB-IoT devices can maintain a consistent delivery ratio for all devices. Since they communicate in D2D pairs with cellular users, the data rate is increased by using the allocated uplink/downlink channel and time slot. As a result, the QRD2D system greatly outperforms the PAUM and bRRA systems as PAUM takes all classified event from all devices results in higher EDR.

2) *Impacts of varying the radius of eNB:* In comparison to PAUM and bRRA, the graph of QRD2D in Figure 4(a) achieved the least delay despite having a broader coverage. It is due to D2D communication, which enables the highest possible data throughput and expanding coverage while relaying messages to the base station. The graphs in Figure 4(b) demonstrate that the end-to-end delivery ratio (EDR) for all studied systems consistently decreases as the coverage area grows, which illustrates the effectiveness of the QRD2D in optimizing resource allocation. In comparison to PAUM and bRRA, QRD2D minimizes interference and maximizes throughput with higher EDR. It occurs as a result of the D2D communication's ability to increase coverage and relay data to base stations via cellular users, both of which increase data rate and reduce average hop distance of transmitted data packets.

VI. CONCLUSION

In this work, we developed a two-tier architecture for D2D communication using NB-IoT for smart healthcare application, where the proposed radio resource assignment maximizes the throughput reducing interference for effective data transmission. The QRD2D system followed the in band underlay transmission to handle heterogenous prior health data under allocated uplink/ downlink channels jointly. The simulation results clearly indicated that the QRD2D achieved the least delay while the number of devices is increased and also when coverage area is extended. It also performed very well in terms of delivery ratio, even though multi-hop transmission had a steadily decreasing delivery ratio because of its pairing approach. The simulation results showed significant performance improvement in terms of delay, and packet delivery ratio by 25% and 15% respectively, compared to the PAUM system.

ACKNOWLEDGEMENT

This work is supported by a student Research Fellowship (2019–2020) of the Information and Communication Technology Division, Ministry of Posts, Telecommunications and Information Technology, Government of Bangladesh.

REFERENCES

- [1] Krzysztof Mateusz Malarski, Farnaz Moradi, Kalpit Dilip Ballal, Lars Dittmann, and Sarah Ruepp. Internet of reliable things: Toward d2d-enabled nb-iot. In *2020 Fifth International Conference on Fog and Mobile Edge Computing (FMEC)*, pages 196–201. IEEE, 2020.
- [2] Sawzan Selmi and Ridha Bouallègue. Joint uplink and downlink resource allocation for device to device communications. *IET Communications*, 15(11):1493–1506, 2021.
- [3] Andreas Philipp Matz, Jose-Angel Fernandez-Prieto, Joaquin Cañada-Bago, and Ulrich Birkel. A systematic analysis of narrowband iot quality of service. *Sensors*, 20(6):1636, 2020.
- [4] Fatima Tul Zuhra, Kamalrulnizam Bin Abu Bakar, Adnan Ahmed Arain, Umair Ali Khan, and Ali Raza Bhangwar. Miqos-rp: Multi-constraint intra-ban, qos-aware routing protocol for wireless body sensor networks. *IEEE Access*, 8:99880–99888, 2020.
- [5] Nahar Sultana, Farhana Huq, Md Abdur Razzaque, and Md Mustafizur Rahman. User utility maximization in narrowband internet of things for prioritized healthcare applications. *Sensors*, 22(3):1192, 2022.
- [6] Peng-Yong Kong. Cellular-assisted device-to-device communications for healthcare monitoring wireless body area networks. *IEEE Sensors Journal*, 20(21):13139–13149, 2020.
- [7] Ghazanfar Ali Safdar, Masood Ur-Rehman, Mujahid Muhammad, Muhammad Ali Imran, and Rahim Tafazoli. Interference mitigation in d2d communication underlying lte-a network. *IEEE Access*, 4:7967–7987, 2016.
- [8] Ali Nauman, Muhammad Ali Jamshed, Yazdan Ahmad Qadri, Rashid Ali, and Sung Won Kim. Reliability optimization in narrowband device-to-device communication for 5g and beyond-5g networks. *IEEE Access*, 9:157584–157596, 2021.
- [9] Athanase M Atchome, Hafiz Husnain Raza Sherazi, Rodrigue Alahassa, Frantz Tossa, Thierry O Edoh, Luigi Alfredo Grieco, and Antoine C Vianou. A hybrid network model embracing nb-iot and d2d communications: Stochastic geometry analysis. In *Int'l Conf on e-Infrastructure and e-Services for Developing Countries*, pages 154–165. Springer, 2019.
- [10] Yanjun Li, Kaikai Chi, Honglong Chen, Zhibo Wang, and Yihua Zhu. Narrowband internet of things systems with opportunistic d2d communication. *IEEE Internet of Things Journal*, 5(3):1474–1484, 2017.
- [11] Osama ElGarhy and Luca Reggiani. Increasing efficiency of resource allocation for d2d communication in nb-iot context. *Procedia computer science*, 130:1084–1089, 2018.
- [12] Ali Nauman, M. Ali Jamshed, Y Ahmad, R. Ali, YB Zikria, and SW Kim. An intelligent deterministic d2d communication in narrow-band internet of things. In *15th Int'l Wireless Commun & Mobile Comput Conf (IWCMC)*, pages 2111–2115. IEEE, 2019.
- [13] Ohood Saud Althobaiti and Mischa Dohler. Narrowband-internet of things device-to-device simulation: an open-sourced framework. *Sensors*, 21(5):1824, 2021.
- [14] Si Wen, Xiaoyue Zhu, Xin Zhang, and Dacheng Yang. Qos-aware mode selection and resource allocation scheme for device-to-device (d2d) communication in cellular networks. In *2013 IEEE International Conference on Communications Workshops (ICC)*, pages 101–105. IEEE, 2013.
- [15] Safiu A Gbadamosi, Gerhard P Hancke, and Adnan M Abu-Mahfouz. Interference avoidance resource-allocation for d2d-enabled 5g narrow-band internet of things. *IEEE Internet of Things Journal*, 2022.
- [16] Caihong Kai, Lei Xu, Jiaojiao Zhang, and Min Peng. Joint uplink and downlink resource allocation for d2d communication underlying cellular networks. In *10th Int'l Conf on Wireless Commun and Signal Processing (WCSP)*, pages 1–6. IEEE, 2018.