Received July 19, 2016, accepted August 3, 2016, date of publication September 7, 2016, date of current version January 27, 2017.

*Digital Object Identifier 10.1109/ACCESS.2016.2602843*

# Efficient Resource Management by Exploiting D2D Communication for 5G Networks

**PAVAN KUMAR MISHRA[1], SUDHAKAR PANDEY[1], AND SANJAY KUMAR BISWASH[2]**

[1]Department of Information Technology, National Institute of Technology Raipur, Raipur 492010, India
[2]Department of Software Engineering, Institute of Cybernetics, National Research Tomsk Polytechnic University, Russia

Corresponding author: S. K. Biswash (skbismu@gmail.com)

**ABSTRACT** Device-to-device (D2D) communication is a promising technology for 5G networks, providing high data rates, increased spectral and energy efficiency, and reduced end-to-end delay and transmission power. However, in current cellular systems, the performance of cell edge devices suffers when multimedia content is directly uploaded toward the base station side due to poor link quality. This requires a greater number of resource blocks and additional upload time, thus degrading the quality of service. To reduce the number of resource blocks and upload time, this paper proposes an efficient resource management scheme that exploits D2D communication in the uplink case. This scheme consists of two phases. In the first phase, in the case of poor link quality, a novel relay selection scheme is used in the multihop (two-hop) communication strategy; in the second phase, an effective new resource allocation scheme is used in multihop communication. This scheme minimizes packet loss, upload time, and number of resource blocks, whereas it increases the throughput of the network. Simulation result demonstrates the superiority of the proposed scheme over other schemes in the literature.

**INDEX TERMS** D2D communication, multihop communication, resource management, relay selection, channel quality, 5G Networks.

## I. INTRODUCTION

During the last two decades, the wireless industry has become enormously popular. Several new technologies have been developed that provide better quality of service (QoS) [1]. Due to the increase in demand [2] of such applications as 3D holography, argument reality, machine-to-machine communication, virtual reality and e-health, users require more bandwidth from their telecom operators. The existing cellular system is not able to provide additional bandwidth due to certain limitations [3]: limited bandwidth, a finite number of base stations, and several new technologies that have been introduced, such as proximity services (ProSe). Therefore, it is necessary to rethink the existing cellular system and transition from architectural to conceptual approach and it is known as fifth generation networks (5G) [4]–[6].

Several possible research directions are investigated for 5G networks to maintain quality of service (QoS) and quality of experience (QoE). Device-to-Device (D2D) communication approach that address QoS and QoE from the user's perspective. D2D communication was introduced in 4G LTE-A (Long Term Evolution-Advance) release 12 [7]–[9] with limited services; telecom operators therefore did not focus on it. Due to proliferation of the indoor communication several proximity services were introduced [10] such as public safety [11], context-aware services, location-based services [12], and nearby communication. Therefore, the application of D2D communication in 5G networks has been focused [13], [14] on 5G networks for telecom operators, researchers and academicians. The other major advantage of D2D is the ability to offload network traffic over the base station/evolve node B (eNodeB).

In 5G D2D communication, devices/ user equipments (UE) communicate with proximity devices with minimal or no involvement of the BS/ eNodeB [4], [15]–[17]. Thus, a minimum amount of data is routed through the BS, reducing the load on the BS side and decreasing the end-to-end delay between communicating devices. In addition, D2D communication enhances cell throughput, in particular at the cell edge area where signals are much weaker and devices communicate poorly in cellular mode. In fact, D2D communication is more suitable for scenarios where a number of devices share the same information with scarce cellular radio resources. Due to the limited number of radio resources it is necessary to allocate resources efficiently for better throughput.

Efficient resource management significantly increases network throughput and reduces the traffic load from the BS in particular where a limited numbers of resources are available. The BS is responsible for allocating the resources [18]–[21], relay selection [22]–[24], interference management and mode selection [25], [26]. It measures the channel quality (CQI) based on signal-to-interference plus noise-ratio (SINR) and feedback before allocating the resource block. The device sends the request to the eNodeB for allocating the resource block; therefore, it can communicate with another device. Depending on the global and local channel quality indicator (CQI) and feedback, the BS allocates resource blocks to the requested device.

There are very limited contributions in resource block allocation for the uplink case. In [27], the authors proposed combined resource allocation and a power control scheme for D2D communication using the LTE-A uplink based on fractional frequency reuse (FFR) which also mitigates the interference between CUEs and D2D user equipment. In [28],the authors proposed a set of algorithms to solve the adjacency constraint in SC-FDMA and find the near-to-optimal scheme that best emulates the time domain proportional fair criteria. Another uploading scheme in long term evolution (LTE) for the cloud or central server was proposed in [29]. The author proposed two D2D solutions for content uploading. In [30], the concept of efficient spectrum management using D2D based uploading to reduce the number of resource blocks was proposed. The authors made a very limited contribution to D2D-based uploading conditions in terms of relay selection and resource allocation. In [31], the author proposed a relay based scheme for uploading the content towards the eNodeB by using constrained coalition formation game where each device is a player whose cost is identified as the content upload time.

In conventional cellular uploading systems, the interested users upload multimedia content toward the BS side or cloud make a request to the BS for allocation of resource blocks. Day-to-day increase in high definition large volume multimedia content and exchanges of information between users require a greater number of resource blocks and uploading time. This consumes more of the devices' energy in particular if the cell edge users want to upload data or exchange data. Therefore, directly uploading the content toward the BS degrades QoS and QoE. D2D is a possible solution for direct uploading, whereby the cell edge device searches some proximity device that can relay its content toward the BS side. Two type of communication are introduced; D2D communication between the cell edge device to nearby device and cellular communication between nearby selected device to the BS. Due to the increasing number of devices under the BS, there is a chance that more than one device (relay) will be common between the cell edge device and the BS that can relay content toward the BS.

The relay selection is one of the key factors for multi hop communication. There are several relay selection schemes exists for Multihop communication: max-min [32], max-max [23], max-link [33] and max-ratio [22]. The max-min relay selection policy has been discussed in [32]. In this scheme, the relay selection from available relay between communicating devices is based on local channel state information (CSI). The max-min relay selection scheme does not consider any buffer space. The another common relay selection scheme is max-max [23] with buffering capacity. The buffering capacity at the relay device increases performance gain over the max-min relay selection. This scheme chooses the best link between source-to-relay and relay-to-destination; therefore the relay device may not be same which increases the dependency and relay node has limited buffer capacity. Max-link [33] dynamically allocate each slot to the source or relay transmission depend upon the channel state information and the occupancy if the relay's buffer is free. The max-ratio [22] relay selection scheme is used for secure transmission between source-to-destination. In this scheme, the best relay selection is based on highest gain ratio among all available relay between communicating devices.

Although, there are several relay selection schemes exists, they are either for Multihop cellular or Multihop D2D communication. With respect to cell edge devices that are seeking to upload content toward the BS, two types of communication are used (D2D communication and cellular communication). The existing relay selection schemes do not perform well because D2D communication provides a higher data rate compared to cellular communication. Apart from that, the cellular data rate is differing from the D2D data rate over the same CQI [34]. Due to uneven link conditions between the source-to-relay and relay-to-destination, more packets are lost which degrades the quality of service and network throughput in the existing relay selection schemes. Therefore, a new relay selection scheme is required that not only addresses throughput but also minimizes the packet loss in Multihop communication. In addition, the required relay selection scheme is not only based on CSI or SNR but also addresses several other factors: reaming battery power and reliability of the relay device. If the device has a high reliability value, it will definitely participate in relay selection procedure. Fig. 1 depicts the system model for uploading content in a cellular network. Device $UE_6$ is communicating in CU mode eNodeB while devices $UE_3$, $UE_4$, and $UE_5$ are ideal. Devices $UE_7$ and $UE_8$ are communicating in D2D mode. The cell edge device ($UE_1$) uploads the data with the help of the ($UE_2$ or $UE_3$) device.

### A. MOTIVATION

In the existing cellular system, if any user wants to upload content toward the BS side, the BS initially measures the CSI feedback and allocates resources. Due to high path loss and deep path fading, cell edge devices require more resource blocks and uploading time to upload the multimedia content. This degrades the quality of service and network throughput. Therefore, for cell edge users, Multihop communication is a possible solution that reduces the number of resource blocks, and uploading time that maintains QoS. The first hop

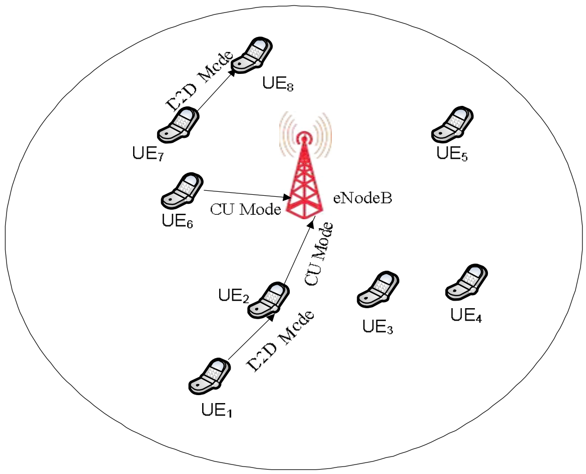


**FIGURE 1.** System model for uploading content in cellular system.

communication is in D2D mode and second hop communication in cellular mode. Although, several resource allocation methods have been discussed in [20], [27], [29], and [30] for the uplink case. They do not consider the different types of mode for resource allocation. The minimum data rate for the same CQI differs for D2D and CU mode. Another drawback of the existing resource allocation scheme is, the BS allocates the resource block in round robin scheme that increases number of resource block and uploading time.

Moreover, for two hop communication, cell edge devices require the relay. Although there are several relay selection schemes, such as max-min, max-max, max-link, max-ratio [22], [23], [32], [33], they do not perform better due to two different types of communication (D2D and cellular) and the existing content uploading scheme [29], [30]; the authors select the relay randomly which degrades network throughput. Due to the different types of communication, it is necessary to choose a relay that reduces packet loss and increases the throughput. Therefore, the existing relay selection and content uploading relay selection scheme are suitable for two different types of communication scenarios. Another drawback in the relay selection scheme for content uploading, they do not consider the reliability factor. Reliability is important parameter for maintaining the quality of experience (QoS) for 5G networks. The existing relay selection schemes select any relay, there is a possibility that the selected relay may not ready to act as a relay because the selected relay device has limited battery power or it is not happy with incentive/rewards provided by the telecom operators or it is interested to call some other users. Therefore, a new relay selection scheme is required that addresses both type of communication with reliability parameter that reduces packet loss in uploading. To upload multimedia content toward the BS side, it is also required to propose an efficient resource management scheme along with a relay selection scheme that minimizes packet loss, reduces the number of resource block, and upload time.

### B. KEY CONTRIBUTION

In this paper, we enhance research with the following objectives:

- To propose a semi-BS centric efficient resource management scheme for uploading multimedia content toward the BS side.
- To propose a new relay selection scheme for two different types of communication in hops with minimum packet loss.
- The relay selection scheme selects the parameters, including battery power and reliability, ahead of the SINR value.
- The proposed scheme minimizes the number of resource blocks, uploading time and packet loss in the uploading case.

The paper is organized as follows: In section II, we discuss the system model and problem formulation. In section III, we propose an efficient resource management scheme in uploading case. In section IV, the experimental result and discussion is addressed and the conclusion is presented in the last section.

## II. SYSTEM MODEL AND PROBLEM FORMULATION

In this paper, the communication scenario underlying a cellular network is considered. Fig. 2 depicts the network scenario for uploading the content toward the eNodeB. The cell edge device ($UE_{DX}$) can upload content with the help of any device ($UE_{R1}$, $UE_{R2}$ and $UE_{R3}$). There are several other cellular users who directly communicate with eNodeB ($UE_{CU1}$ and $UE_{CU2}$) to create interference to the relay device. Further, the system model is divided into the network model and channel model. Devices can become relay device depending on the requirement

*Network Model:* We consider the uplink case in a single cell that consists of one eNodeB and x number of devices under the coverage area of the BS. The eNodeB measures CQI feedback and its corresponding modulation coding scheme (MSC) which is chosen by CQI-MCS standardization [34] as shown in Table 1; thereafter, radio resource blocks are allocated to the requested use. If direct communication does not provide the minimum rate, the device searches for a nearby device so that with the help of the nearby device, it can send data to the eNodeB side. The eNodeB and devices have Omni-directional antenna.

### A. CHANNEL MODEL

We consider distance dependent macroscopic path loss between D2D and CU users to the eNodeB. We also assume the channels are quasi- static Rayleingh fading; therefore, the channel coefficient remains unchanged during one packet duration. In addition, the distance dependent path loss model is used to measure power loss. The channel is modelled as the Rayleigh fading channel, and the channel response follows the independent complex Gaussian distribution. The main notation (nomenclature) has been given below in Table 2 for analysis of channel model.

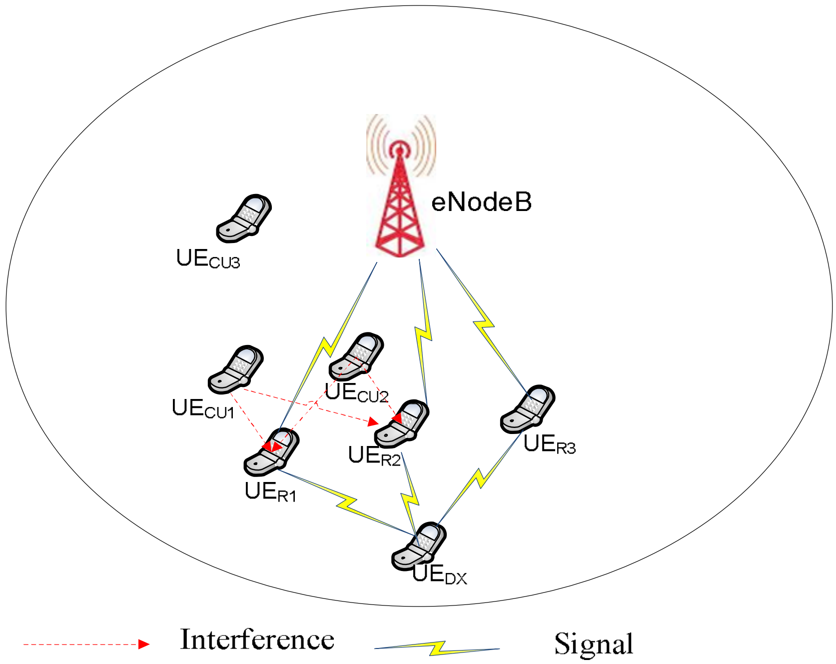


**FIGURE 2.** Hybrid scheme for uploading in Multihop D2D scenario.

**TABLE 1.** CQI-MCS mapping for cellular and D2D communication links.

| CQI Index | Modulation Scheme | Efficiency D2D [bit/s/Hz] | Min Rate D2D [kbps] | Efficiency Cellular [bit/s/Hz] | Min Rate Cellular [kbps] |
|---|---|---|---|---|---|
| 1 | QPSK | 0.1667 | 28.00 | 0.1523 | 25.59 |
| 2 | QPSK | 0.2222 | 37.33 | 0.2344 | 39.38 |
| 3 | QPSK | 0.3333 | 56.00 | 0.3770 | 63.34 |
| 4 | QPSK | 0.6667 | 112.00 | 0.6016 | 101.07 |
| 5 | QPSK | 1.0000 | 168.00 | 0.8770 | 147.34 |
| 6 | QPSK | 1.2000 | 201.60 | 1.1758 | 197.53 |
| 7 | 16-QAM | 1.3333 | 224.00 | 1.4766 | 248.07 |
| 8 | 16-QAM | 2.0000 | 336.00 | 1.9141 | 321.57 |
| 9 | 16-QAM | 2.4000 | 403.20 | 2.4063 | 404.26 |
| 10 | 64-QAM | 3.0000 | 504.00 | 2.7305 | 458.72 |
| 11 | 64-QAM | 3.0000 | 504.00 | 3.3223 | 558.72 |
| 12 | 64-QAM | 3.6000 | 604.80 | 3.9023 | 655.59 |
| 13 | 64-QAM | 4.5000 | 756.00 | 4.5234 | 759.93 |
| 14 | 64-QAM | 5.0000 | 840.00 | 5.1152 | 859.35 |
| 15 | 64-QAM | 5.5000 | 924.00 | 5.5547 | 933.19 |

*Problem Formulation:* The eNodeB manage resource block for CU and D2D users based on their instantaneous and global channel state information (CSI) feedback. The single carrier frequency division multiple access (SC-FDMA) is used for assigning an adequate number of resource blocks in uploading case. The number of resource blocks can vary between 6 for 1.4 MHz and 100 for 20 MHz depending on the system bandwidth. Due to the limited number of resource blocks, it is necessary to manage the available resource blocks in an efficient manner for optimize the network throughput. Here, we consider time division duplex (TDD) mode and refer to the frame structure type 2 configuration foreseen by third generation project partnership (3GPPP). This guarantees the highest number of uplink sub frame with six out of a total if ten (table 3) and transmission time interval is 1 ms.

The cell edge devices that are seeking to upload multimedia content toward the eNodeB send requests to the eNodeB. Initially, the eNodeB transmits equal power to all devices to measure the CQI and MCS and to allocate the resource block. Thereafter, the eNodeB allocates the resource block based on adopted scheduling policing. However, this scheduling does not provide maximum throughput because the cell edge user equipment suffers from a bad channel condition; therefore, a greater number of resource blocks additional power, and uploading time are necessary. Because this user equipment uses more power in the upload case, they create interference for other devices (CU and D2D users). This reduces the overall throughput.

We formulate the problem for uploading content toward the eNodeB, assigning and managing the resource block that achieves higher throughput and fewer resource blocks with the minimum upload time without degradation in QoS and QoE. We have separated downlink (DL) and uplink (UL) resource blocks because UL and DL cannot be possible at same sub channel carrier frequency. In UL phase of the cellular network, user equipment has $P_C$ power to transmit a signal toward the eNodeB side while $P_d$ power is used for D2D communication. If direct communication does not provide a better rate, the device attempt for Multihop communication. In this scenario, we consider two hop communication. First hop communication is in D2D mode while second hop communication is in cellular mode. There are other devices that can use the same band creating interference. In addition, other

**TABLE 2. Nomenclature.**

| Notation | Description |
|---|---|
| X | total number of users under the cellular coverage |
| S | Source (Any cell edge user) |
| $D_{eNB}$ | Destination (the eNodeB) |
| $UE_i$ | $i^{th}$ device or cell edge user equipment |
| $R_k$ | $k^{th}$ relay device |
| $P_{CU_i}$ | transmission power of $i^{th}$ device in CU mode |
| $\gamma_{CU_i eNB}$ | SINR at the eNodeB |
| $g_{CU_i eNB}$ | channel gain between $i^{th}$ cellular user to the eNodeB |
| $g_{D_d eNB}$ | Channel gain between $d^{th}$ D2D user to the eNodeB |
| $c^0_{CU_i}$ | cellular data rate for $I^{th}$ user |
| $g_{D_J D_R}$ | Channel gain between $J^{th}$ user to $R^{th}$ user in D2D |
| $g_{CU_c D_R}$ | Channel gain between $c^{th}$ user to $R^{th}$ user in CU mode |
| $P_{D_j}$ | Transmission power of $j^{th}$ device in D2D mode |
| $c^1_{D_d}$ | D2D data rate of $d^{th}$ user |
| $g_{D_R eNB}$ | Channel gain between relay $D_R$ to the eNodeB |
| $k$ | Mode (0- CU mode, 1- D2D mode ) |
| $P_{R_{remain}}$ | Remaining battery power of $R^{th}$ relay |
| $P_{R_i}$ | Initial battery power of $R^{th}$ relay |
| $\theta$ | Number of times, it act as a relay |
| $\sigma$ | Number of times, it was selected as a relay by BS |
| $\beta_i$ | Reliability of $i^{th}$ device |
| N | numbers of users who want to upload data |
| $rb_{cell}$ | Reference number of resource blocks for cellular uploading case |
| $t_{cell}$ | Reference uploading time for cellular uploading case |
| D | Volume of data to be uploaded (in MB) |
| $b_{UE_x eNB}$ | link rate between $x^{th}$ device to the eNodeB |
| $NRB_{DBURBM}$ | Number of resource block from DBU-RBM scheme |
| $RB_{proposed}$ | Required resource block from our scheme |
| $t_{proposed}$ | Uploading time from our scheme |
| $b_{UE_X UE_R}$ | Link rate between device $UE_X$ and $UE_R$ in D2D mode |
| $b_{UE_R eNB}$ | Link rate between device $UE_R$ and eNodeB in Cellular mode |

devices also communicate in D2D mode; they also create interference.

In direct transmission, the eNodeB allocates separate channels to the device. Assume that the $i^{th}$ device wants to upload data toward the eNodeB side in cellular mode. The SINR at eNodeB is

$$\gamma^k_{CU_i eNB} = \frac{P_{CU_i} g_{CU_i eNB}}{\sigma^2 + \sum_{c=1, c\neq i}^{C} P_{CU_c} g_{CU_c eNB} + \sum_{d=1}^{D} P_{D_d} g_{D_d eNB}} \tag{1}$$

**TABLE 3. Uplink-Downlink configuration for frame structure type 2 (TDD).**

| Uplink-Downlink configuration | Downlink-to-uplink switch-point periodicity | Sub frame number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0 | 5 ms | D | S | U | U | U | D | S | U | U | U |
| 1 | 5 ms | D | S | U | U | D | D | S | U | U | D |
| 2 | 5 ms | D | S | U | D | D | D | S | U | D | D |
| 3 | 10 ms | D | S | U | U | U | D | D | D | D | D |
| 4 | 10 ms | D | S | U | U | D | D | D | D | D | D |
| 5 | 10 ms | D | S | U | D | D | D | D | D | D | D |
| 6 | 5 ms | D | S | U | U | U | D | S | U | U | D |

The achievable data rate for $\gamma^k_{CU_i eNB}$ link with a bandwidth $w$ is given below

$$c^k_{CU_i} = w \log_2(1 + \gamma^k_{CU_i eNB}) \tag{2}$$

Due to high path loss and deep path fading, direct communication does not provide the minimum data rate therefore, direct communication requires breaking the communication into two hops. In the first hop, devices search proximity devices by broadcasting the beacon packet and if proximity devices are available, it chooses any device as a relay and communicates in D2D mode. In the second hop, the relay device will communicate in CU mode with the eNodeB.

Therefore, in the first hop, the SINR between cell edge user equipment and relay user equipment device (D2D mode) is

$$\gamma^k_{D_j D_R} = \frac{P_{D_j} g_{D_j D_R}}{\sigma^2 + \sum_{c=1}^{C} P_{CU_c} g_{CU_c D_R} + \sum_{d=1, d\neq j}^{D} P_{D_d} g_{D_d D_R}} \tag{3}$$

The achievable data rate for the $\gamma_{D_j D_R}$ link is given as follows:

$$c^k_{D_d} = w \log_2(1 + \gamma^k_{D_j D_R}) \tag{4}$$

In the second hop, the SINR between relay devices to the eNodeB in CU mode is

$$\gamma^k_{D_R eNB} = \frac{P_{D_R} g_{D_R eNB}}{\sigma^2 + \sum_{c=1}^{C} P_{CU_c} g_{CU_c eNB} + \sum_{d=1, d\neq R}^{D} P_{D_d} g_{D_d eNB}} \tag{5}$$

The achievable data rate for the $\gamma^k_{D_R eNB}$ link is given below.

$$c^k_{CU_c} = w \log_2(1 + \gamma^k_{D_R eNB}) \tag{6}$$

If the mode is 0 then it is cellular mode else D2D mode

$$k = \begin{cases} 0 & if \ \text{mod} \ e \ is \ cellular \\ 1 & if \ \text{mod} \ e \ is \ D2D \end{cases} \tag{7}$$

To increase the network lifetime, only those relays that have sufficient battery power will participate in relay selection. Every device/relay has different level of battery power, and its power decreases as it communicates with other devices [35]. Therefore, devices with less energy are not an ideal relay selection. The remaining battery power can be calculated for any time instance as follows:

$$P_{R_{remain}} = P_{R_i} - r(P_{i_c} + P_{i_{tx}}) \tag{8}$$

where $P_{R_{remain}}$ is the residual energy of the relay, $P_{R_i}$ is the total power/initial energy of i$^{th}$ relay, r is the data rate and $P_c$ is the circuit power, and $P_{tx}$ depends on the transmission distance.

The BS selects the relay from available relays between the communicating devices. The BS keeps a history of each device in terms of how many times any device has functioned as a relay, so that the BS increases its reliability factor. Highly reliable devices will definitely participate in the relay selection process. Relay reliability can be calculated as

$$\beta_i = \frac{\theta}{\sigma} \tag{9}$$

Where $\theta$ represent a device that act as a relay and $\sigma$ represent a device that is selected as a relay by the BS.

D2D communication provides a better rate than CU communication. If the cell edge device-to-relay has a better link compared to relay-to- eNodeB a greater number of packets are lost on relay side. If the cell edge device-to-relay has a poor link compared to relay-to-eNodeB, the relay will wait for transmission toward the eNodeB side; this also degrades the QoS of the network. Therefore, the selection of relay is a key factor in the case of resource block management. There are several devices that are within the proximity area of a cell edge device, as shown in figure 2.

The two hop achievable data rate is $(c^k_{D_d}, c^k_{CU_c})$

$$c = \min\{c^k_{D_d}, c^k_{CU_c}\} \tag{10}$$

To minimizing the upload time, the number of lost packets, and number of resource blocks and to increase network throughput, we propose an efficient resource management scheme for cell edge user equipment that is seeking to upload data in eNodeB or the cloud. Let us assume that there are N numbers of users where $(i = 1, 2, 3 \ldots N)$ that are interested to upload data. User $i^{th}$ requires $rb_i$ number of resource blocks and $t_i$ time for uploading content toward the eNodeB as per their requirement.

Thus, the objective can be expressed as follows:

$$\min \sum_{i=1}^{N} N_i rb_i \tag{11}$$

$$\min \sum_{i=1}^{N} N_i t_i \tag{12}$$

$$\max \left(\sum_{c=1}^{C}\sum_{k=1}^{K} x^k_{CU_c}\, c^k_{CU_c} + \sum_{d=1}^{D}\sum_{k=1}^{K} x^k_{D_d} c^k_{D_d}\right) \tag{13}$$

$$\gamma_{CU_ieNB} < \min(\gamma_{D_RD_j}, \gamma_{CU_ieNB}) \tag{C1}$$

$$\{P_{D_JD_R}, P_{R_ReNB}\} < P_{C_jeNB} \tag{C2}$$

$$P_{D_R} > P_{thresh} \tag{C3}$$

$$R_{Two\,hop} < R_{One\,hop} \tag{C4}$$

$$t_{two\,hop} < t_{One\,hop} \tag{C5}$$

The constraints given above are in accordance with the assumption that has been defined for our model. The first constraint dictates that the cell edge device pursue Multihop communication if it finds better channel gain for both hops compared to direct channel gain. The second constraint indicates that the power depleted in a two hop communication should be less than the direct power that is depleted. The third constraint means that the selected relay has sufficient energy. The fourth constraint means that the required number of resource blocks in two hops (D2D and CU) is less than single hop. The fifth constraint means that the required uploading time in two hops (D2D and CU) is less than the uploading time for a single hop.

## III. PROPOSED SCHEME

In this section, an efficient resource management scheme by exploiting D2D-based uploading for 5G cell edge users has been proposed. To reduce the packet loss and minimize the resource block and uploading time in addition to maximizing throughput, our scheme is divided into two phases. In the first phase, a new relay selection scheme has been proposed that selects the best possible relay among available relays between the eNodeB and cell edge device. In the second phase; a new resource allocation scheme for two hop communication in the uplink case has been proposed.

Initially, the BS broadcasts a packet over the network and measures channel quality and corresponding modulation and coding scheme (MCS) between the device and the eNodeB for direct transmission. The cell edge device suffers from deep path fading and high path loss. Therefore, poor channel quality has been found between them or direct communication does not provide the minimum data rate. This consumes a greater number of resource blocks and increases upload time and packet loss. Thus, the cell edge device moves for Multihop (MH) communication. In MH communication, the first hop communication is in D2D mode where the cell edge device searches a proximity device (relay) that can relay its information toward the eNodeB side; in the second hop, the selected relay forwards data toward the eNodeB side in cellular mode.

The BS checks the mode between the eNodeB and cell edge device. For checking the mode, it measures channel quality. Let us assume that the channel gain between $\mathrm{UE_{DX}}$ to the BS is $g_{DX\_BS}$, $\mathrm{UE_{R3}}$ to the BS is $g_{R3\_BS}$, and $\mathrm{UE_{DX}}$ to $\mathrm{UE_{R3}}$ is $g_{DX\_R3}$ as shown in figure 2). The device only chooses two hop communication if the minimum channel gain in two hop communication is better than direct communication. A pseudo code for Multihop communication is given in algorithm 1.

### A. RELAY SELECTION SCHEME

Due to a poor link and high path loss between the cell edge device and the eNodeB, the cell edge user chooses a relay for two hop communication if the relay is available and the relay device is ready to relay the information. In two hop communication, first hop communications are in D2D mode,

**Algorithm 1** Relay Selection for Proximity Communication

1. if $g_{DX\_BS} < \min(g_{DX\_R3}, g_{R3\_BS})$
2. choose for two hop communications
3. select relay node
4. Allocate the resource block
5. else
6. choose CU mode
7. Allocate the resource block
8. end if

while second hop communication is in cellular mode. If a single relay device is common between the cell edge device and the eNodeB, the BS automatically selects it for two hop communication. If there are multiple devices is common, the BS selects the best relay from available relays from our proposed scheme. To select a relay from available relays, we consider two factors, SINR and reliability of relay. Thus, the best relay $R_b$ selection between the cell edge device and the eNodeB is

$$R_b = \arg \{(SINR_{S-R_k}, SINR_{R_k-D}), (\theta_{R_K})\} \tag{14}$$

To identify the number of available relays between the cell edge device and the eNodeB, the cell edge device starts the neighbour discovery phase. However, each device has its own neighbour table that keeps a record of neighbouring devices. Due to dynamic network conditions, the devices have degrees of freedom for movement, so the neighbour table changes time-to-time. Therefore, to identify the neighbour devices, the cell edge device periodically broadcasts a transmit/receive discovery signal (request-to-send (RTS) or request-of-relay (ROR)) over the network. If any device receives this signal, it replies back to the source device. Thus, the device has updated its neighbour table. The neighbour table keeps information regarding multiple proximity devices. Therefore, selection of the relay device is one of the important factors for utilizing resources efficiently.

Major problems in existing relay selection schemes are as follows: They do not consider the packet loss or reliability aspect of the relay that may participate in relay selection. Due to different types of communication between the cell edge device and the eNodeB, there is greater packets loss. Because the cell edge device transmits data with a high rate in D2D mode toward the selected relay, the relaying device will not be able to transmit data at the same rate toward the BS side due to the CU mode. Due to the limited buffer size of the relay device, packets will also be lost on the relay side. In addition, the data rate is also differing with the same channel quality (Table 1) for both hops. This reduces the network throughput and leads to inefficient use of the resource blocks.

Our relay selection scheme is as follows: This scheme is semi-base centric, where the device and the BS are both involved in the relay selection procedure. When the minimum data rate does not meet the standard of direct communication, they move for two hop communication. The cell edge device starts the discovery process and identifies the number of proximity devices based on the updated neighbour table. To calculate the instantaneous SINR between the cell edge device and proximity devices, it broadcasts a beacon packet in the network. The cell edge device sends the SINR between it and the proximity device to the BS. After receiving the information by the BS, it broadcasts packet in network to calculate the instantaneous SINR between the BS and proximity devices. The BS has full information: number of proximity devices, the SINR between two hops and the reliability factor of each relay device.

If, a single proximity device is common between the cell edge device and the eNodeB, the BS will automatically select it for uploading content. If there are multiple relay devices in common (as shown in fig. 2), the BS calculates the dynamic SINR threshold value and dynamic reliability threshold value of all participating proximity devices. For calculating the dynamic threshold value of reliability, take the mean average of all participating relays. Calculate the dynamic threshold of SINR is as follows: For each participating relay, first take the difference of the SINR between the cell edge device to the relay device and the relay device to the eNodeB. Next, take the average of all differences. This average SINR is called the threshold value. If the difference between the cell edge device to the relay-device and the relay-device to the eNodeB is greater than the dynamic threshold value of SINR, it is eliminated. Here, the eNodeB only considers those relays that have less difference compared to the dynamic threshold value. Thereafter, choose relay that have the maximum SINR sum (SINR between the cell edge device to relay-device and relay-device to the eNodeB). If the reliability of a selected relay is greater than dynamic threshold reliability, then it will choose by the eNodeB. Otherwise, we take the relay that has second maximum sum of SINR value and compare it with the reliability of the first selected relay. If the reliability of the first selected relay is greater than the reliability of the second selected relay, the eNodeB will select the first select relay; otherwise, it will select the second relay.

The flow chart of the proposed relay scheme is as shown in figure 3.

The pseudo code of the proposed relay scheme is given in algorithm 2.

### B. RESOURCE ALLOCATION SCHEME

Once the appropriate relay is selected by our scheme, the eNodeB starts the resource block allocation process. In the existing cellular network in the resource assignment case, the transmitted power is uniformly divided with respect to the number of resource blocks. Later, the eNodeB allocates resource blocks in a round robin scheme to all requested users. The eNodeB also allocates separate channel to each device for uploading/downloading content. Direct data uploading suffers from high path loss and deep path fading. Therefore, the cell edge devices need more resource blocks, and more uploading time and consume high energy on the device side. This reduces overall network performance.

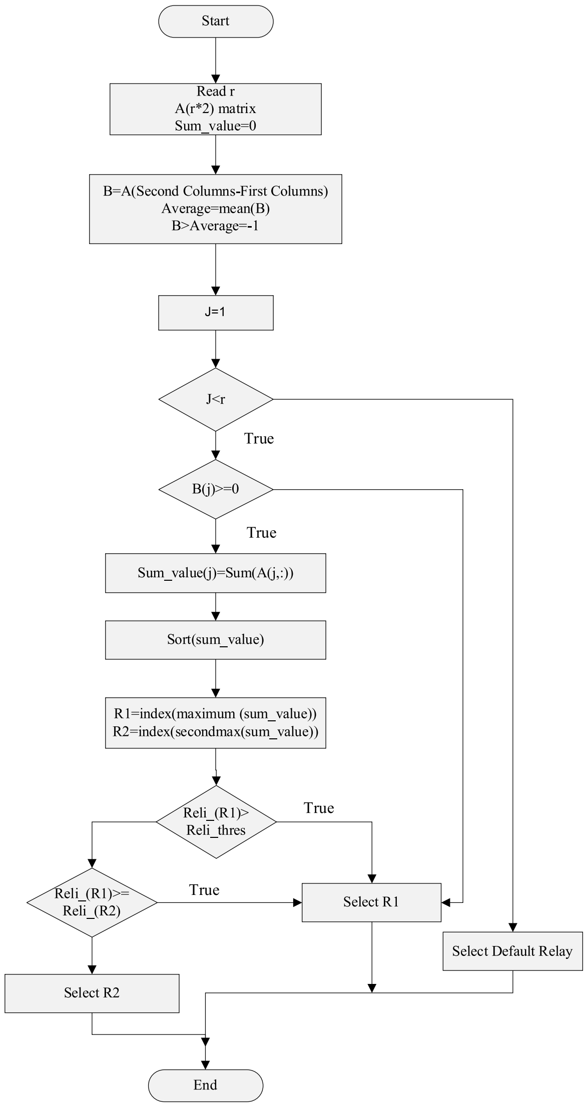


**FIGURE 3.** **Flow Chart of Relay selection scheme.**

To reduce the number of resource blocks and minimize the uploading time, D2D-based uploading-resource-block-minimization (DBU-RBM) has been proposed [30]. In this paper, the authors suggested that to reduce the number of resource blocks, it is necessary to break direct communication into two hop communication. In this scheme, the eNodeB allocates the resource blocks in round robin scheme for the first hop, while in the second hop, the eNodeB reduces the resource block. Therefore, this scheme does not reduce the resource block and uploading time significantly. In addition, the authors make a very limited contribution in relay selection and the resource allocation process. Therefore, we propose a new uploading scheme that significantly reduces the resource block and minimize the uploading time compared to the traditional cellular uploading scheme and DBU-RBM scheme.

The cell edge devices send a request for allocation of resource blocks to the eNodeB. The eNodeB broadcasts a packet for measuring channel quality and corresponding

**Algorithm 2** Relay Selection Scheme

1. Read r /* r is the number of relays */
2. Initialize A (rx2) matrix, sum_value=0
   /* take the SINR difference between two hop*/
3. B ← A (second column)-A(First Column)
4. Average=mean(B)
   /* set the threshold value for reliability
5. Threshold_reliability=average (reliability of all participating relay)
6. Set values B> average =-1
7. Repeat step 7 for j=1 to r
   a. If (B(j)>=0)
      i. sum_value (j)=sum (A(j,: ))
   b. End If
8. End For
9. R1=index (maximum(sum_value))
10. R2= index (second max(sum_value))
11. If (reliability_R1 >threshold_reliability)
    a. Select R1 relay
12. Else
    a. If (reliability_R1>=reliability_R2)
       Select R1 relay
    b. Else
       Select R2 relay
    c. End if
13. End if

modulation coding scheme for allocating the resource blocks. The CQI level and the corresponding MCS is used for uploading data that limit the cellular data rate $b_c$ (where $c = 1 \ldots 15$) per allocated resource block. In the direct uploading case, the channel quality and corresponding minimum cellular data rate are poor. With this cellular data rate ($r_c = b_c \times nrb_{cell}$), the eNodeB calculates performance metrics: reference required number of resource blocks and reference uploading time for uploading multimedia content of the cell edge device.

The eNodeB calculates the required performance metrics once. This allows breaking the direct communication in two hop communication. The eNodeB measures the link capacity between the cell edge device to the selected relay and the selected relay to the eNodeB. The eNodeB has already calculated the reference matrices. Here, we consider two cases. In the first case, we reduce the total number of resource blocks compared to the reference resource block that is required with the reference time constraint. In the second case, we reduce the uploading time compared to reference uploading time with the reference resource constraint. To reduce resource block usage in uploading multimedia, the eNodeB checks the link capacity for both hops before allocation of resource blocks. Thereafter, instead of allocating the resource blocks in a round robin fashion, the eNodeB assumes that r numbers of resource blocks are required for each hop. Thus, a total of 2*r resource blocks are required for both hop communication.

Let us assume that the D MB data are uploaded on the eNodeB side. Initially, the eNodeB allocates $rb_{cell}$ resource blocks for uploading content in direct transmission mode. The required uploading time is

$$t_{cell} = \frac{D}{b_{UE_x eNB} \times rb_{cell}} \tag{15}$$

where $b_{UE_x eNB}$ is the link rate and $t_{cell}$ is the uploading reference time.

In DBU-RBM, resource allocation is a round robin scheme; therefore, for two users (cell edge device and relay device) and first hop communication, the eNodeB allocates $rb_{cell}/2$, so the time required for sending the data on the relay side is

$$t_1 = \frac{D}{b_{UE_X UE_R} \times rb_{cell}/2} \tag{16}$$

where $b_{UE_X UE_R}$ is the link rate between the cell edge device to relay and $t_1$ is the required time for uploading the content on the relay side.

Now, there is a time constraint for reducing the number of resource blocks; therefore, the number of resource blocks are required is

$$t_2 = t_{cell} - t_1 \tag{17}$$

$$n_3RB = \frac{D}{b_{UE_R eNB} \times t_2} \tag{18}$$

The total number of resource blocks required for the D2D based uploading in DBU-RBM is

$$NRB_{DBURBM} = n_2RB + n_3RB \tag{19}$$

Assume that $RB_{proposed}$ is the number of resource block allocations at each link. Thus for two hops, the total number of resource blocks is $2RB_{proposed}$. For each link, the required number of resource blocks is

$$RB_{proposed} = ceil\left(\frac{D \times (b_{UE_X UE_R} + b_{UE_R eNB})}{t_{cell} \times (b_{UE_X UE_R} + b_{UE_R eNB})}\right) \tag{20}$$

The total number of resource blocks that is required for our proposed scheme with time constraint is

$$NRB_{\Pr oposed} = 2 \times RB_{\Pr oposed} \tag{21}$$

The uploading time that is required for our proposed scheme with resource block constraints is

$$t_{proposed} = ceil\left(\frac{2 \times D \times (b_{UE_X UE_R} + b_{UE_R eNB})}{r_{cell} \times (b_{UE_X UE_R} + b_{UE_R eNB})}\right) \tag{22}$$

The proposed scheme significantly reduces the resource block and uploading time. The pseudo code of the proposed relay scheme is given in algorithm 3.

**Algorithm 3** Resource Block and Time Minimization

1. Initialize rate_cellular,/* The eNodeB calculate data rate of cell edge UE */
2. Initialize rate_D2D_1 and rate_cellular_2 /* First hop and Second hop data rate*/
3. $rb_{cell}$, D /* D is size of file in MB, $rb_{cell}$ is required number of resource block for direct uploading */
4. Calculate t_cell /* time required for cellular upload D MB*/
$$t = \frac{D}{rate\_cellular{*}rb_{cell}}$$
5. Calculate $rb_{DBURBM}$ /* r is new required resource block for DBDRU scheme*/
$$t_1 + t_2 \leq t$$
Where
$$t_1 = \frac{D}{rate\_D2D\_1{*}rb_{cell}/2}$$
$$rb_{DBURBM} = \frac{D}{rate\_cellular\_2{*}t_2}$$
$$NRB_{DBURBM} = rb_{DBURBM} + rb_{cell}/2$$
6. $NRB_{\Pr oposed}$,$t_{proposed}$ /* total number of resource block and total time is required for uploading content*/
7. Choose the appropriate relay device from algorithm 2
8. For time constraint
$$NRB_{\Pr oposed} = \frac{2{*}D(rate\_D2D\_1 + rate\_cellular\_2)}{t_{cellular}{*}(rate\_D2D\_1{*}rate\_cellular\_2)}$$
9. For resource block constraint
$$t_{proposed} = \frac{2{*}D(rate\_D2D\_1 + rate\_cellular\_2)}{R_{cellular}{*}(rate\_D2D\_1{*}rate\_cellular\_2)}$$

## IV. NUMERICAL RESULT AND DISCUSSION

In this section, an analytical numerical evaluation in MatLab has been proposed for the performance of an efficient resource management scheme using two hop D2D communications for uploading the cell edge device content. For numerical evaluation, Monte Carlo simulations has been performed in which the program is run 1000 times, and then the average is calculated to plot the graph. In this work, we consider that the interested users want to upload the content with high quality multimedia content toward the BS side. The effective SINR is estimated according to the Exponential Effective SIR Mapping a [36] is mapped in to the CQI level with ensuring a block error rate smaller than 10%. We randomly deployed the devices in a cell. We calculate the dynamic threshold value for the reliability constraint.

To calculate the threshold of reliability constraint in dynamic network where the number of participating relay will differ between communicating devices, the average value of all participating relay reliability has been taken. For the large scale fading and path loss exponent in shadowing standard

**TABLE 4.** Simulation parameter and value.

| PARAMETER | VALUE |
|---|---|
| System Type | Single Cell |
| Cell radius | 100 m |
| Carrier Frequency | 2.5 GHz |
| Bandwidth | 10MHz |
| Max eNodeB TX power | 46 dBm |
| Max UE TX power for Cellular | 23 dBm |
| Max. antenna gain | 15dBi |
| Max UE TX power for D2D | 10dBm |
| Active Users in Cell | 10,20,30, 40, 50 |
| Proximity distance | 25 meter |
| UE noise figure ( $\sigma$ ) | 9 dBi |
| Simulation Type | Monte Carlo Simulation |

is set to 8 and 3.5 dB and for small scale multipath fading, urban channel model is consider. For the throughput and efficiency, we use modulation and coding scheme (MCS). Due to random behaviour of network, in some scenario scheme 1 can performs better as other scheme while in some scenario scheme 2 can performs better as compare to other schemes. Therefore, in this case statistical methods are used for finding the best significance scheme. In this paper, Friedman test [37] is used for identifying the best schemes for total throughput because max-min perform better compared to our scheme initially, later our scheme performs better compared to max-min. In table 4, we provide a list of simulation parameters and their default values.

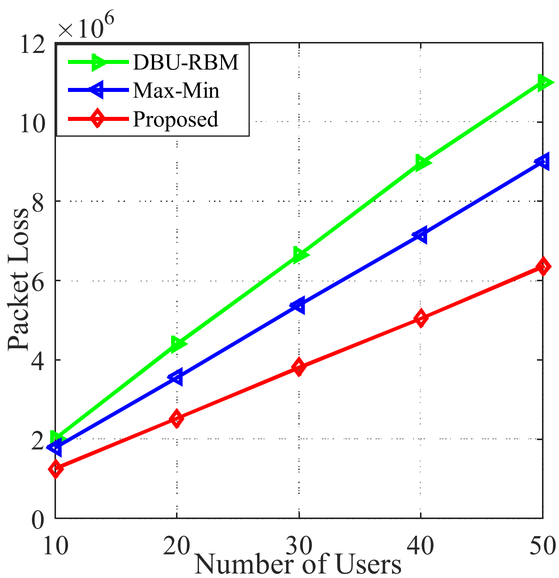


**FIGURE 4.** Number of packet loss in data upload towards the eNodeB.

Fig. 4 plots the graph between number of users and packet loss. Initially, there is a single cell edge device and four relays with different locations and they are in the proximity area of the cell edge device (in figure 2). Thereafter, we increase the number of cell edge device (from 1 to 50) and vary the number of relays from 1 to 5, between each cell edge device to the eNodeB. We assign a single resource block to each link. It is observed that when the second hop (cellular communication) does not provide a better data rate, a greater number of packets are lost at the relay. In the max-min scheme, the best relay based on CQI, while in DBU-RBM, the relay selection is random. Therefore, more number of packets is lost in these schemes, while our scheme select only that relay which give maximum throughput with minimum packet loss. Our scheme offers significant results over the max-min and DBU-RBM selection schemes.

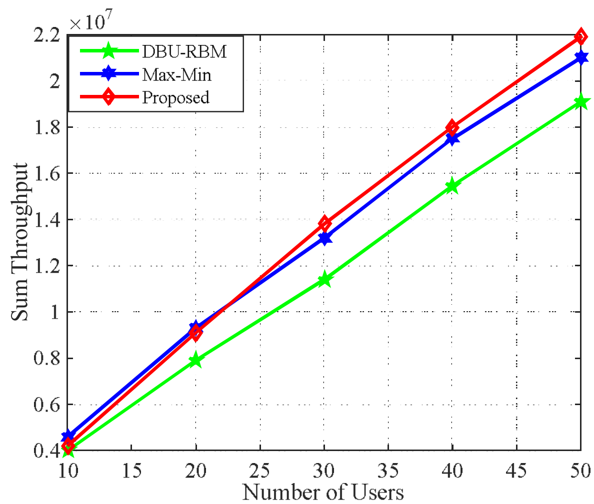


**FIGURE 5.** Sum throughput of different relay selection schemes.

Fig. 5 plots the graph between number of users and sum throughput. The number of relays varies from 1 to 5 between each cell edge device and the eNodeB. Due to random behaviour of the network, the max-min and our scheme initially give near identical result while DBU-RBM gives a lower sum throughput due to the random selection of relay. Later, our scheme shows slightly better performance over the max-min and much better performance than DBU-RBM. To find the most significance scheme, we do statistical analysis.

*Statistical Analysis* In the Friedman test [37], the different relay selection scheme are ranked according to their performance against the throughput. The most performing schemes gets first rank, the second most performing gets second rank and so on. Based on the average ranks obtained from different schemes, Friedman test statistics is calculated. A null hypothesis is then tested for *p-value*, and the *p-value* is compared with confidence level $\alpha$. If $p - value < \alpha$, then the null hypothesis that there is no significant difference between the individual scheme is rejected. In the case of rejection of null hypothesis, a post-hoc Nemenyi test is applied to report any significant difference between the individual approaches [38]. If the rank difference between a pair of scheme is larger than the critical difference (CD) at a certain confidence level, then the performance of the pair is considered to be significantly different.

The Friedman test is applied over the three different relay section schemes (max-min, DUR-RBM and our scheme) for sum throughput. Based on numerical results, the computed *p-value* (0.0174) was less than 0.05; therefore, the null hypothesis was rejected at 5% significance level. Consequences, a post-hoc Nemenyi test is applied where the critical difference (CD) is obtained at 1.23 at *p-value* = 0.05. The results of the post-hoc test for comparisons among multiple approaches are visually represented in figure 6. The average rank over for each scheme is illustrated in ascending order on black horizontal axis. Coloured horizontal lines (below the black horizontal axis) indicate that Nemenyi's post-hoc test shows no significant difference between the schemes connected by a single coloured line of same colour. From figure 6, it is observed that the average rank of proposed scheme is 1. It means, the scheme was always ranked first among the entire relay selection scheme.

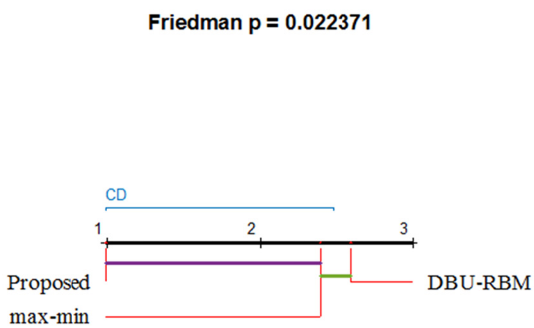


**FIGURE 6.** Visualization of Nemenyi post-hoc test for comparison of different relay selection schemes.

In fig. 7, we investigate the impact of the reliability constraint in relay selection scheme. In the cooperative communication system, we assume that devices are ready for relay, but in a real network scenario, the selected device may be refused due to limited battery power or it may attempt to call any other device or may not be happy with incentives/rewards of telecom operators. In the max-min and DBU-RBM scheme, reliability is not considered, while our scheme selects only the reliable device. Reliability is one of the performance matrixes of quality of experience (QoE) for 5G networks. To check the reliability performance over the relay selection schemes, we randomly drop 10% of total relay devices that have very less reliability value. We have observed that the max-min and DBU-RBM select the relay based on SINR; therefore, there is a chance that the selected relay may be dropped. Our scheme selects the relay that has sufficient reliability value. It is observed that our scheme performs better compared to other relay schemes.

Fig. 8 shows the minimization of resource blocks for uploading the data toward the eNodeB with a time constraint.

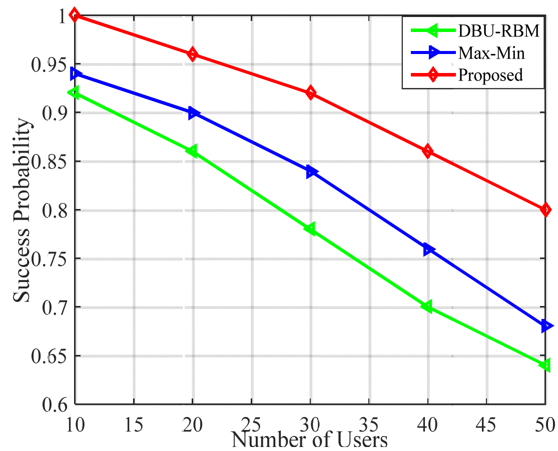


**FIGURE 7.** Reliability constrained relay selection.

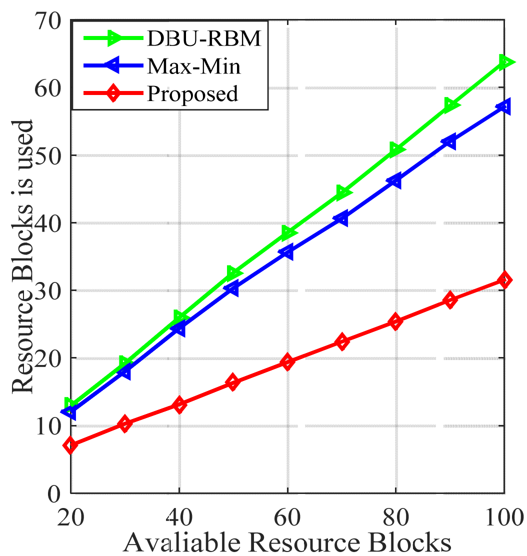


**FIGURE 8.** Mean RBs used (data amount equal to 100 MB).

In the existing cellular system, the eNodeB performs resource allocation in a round robin scheme involving all requested users while in the DBU-RBM scheme, the eNodeB initially allocates half the resources for first hop as a cellular user. With the cellular time constraint, calculating the required number of resource blocks again required for the second hop to upload the content toward the BS side. In the proposed scheme, the eNodeB measures the SINR and maps in CQI and calculates the data rate from table 1 as well as number of resource blocks. It is observed that with the time constraint, our scheme reduces the number of resource blocks as much 40% compared to DBU-RBM and cellular.

Finally in fig. 9, we plot the graph between amounts of data for uploading vs. required time. Initially, when the data size is

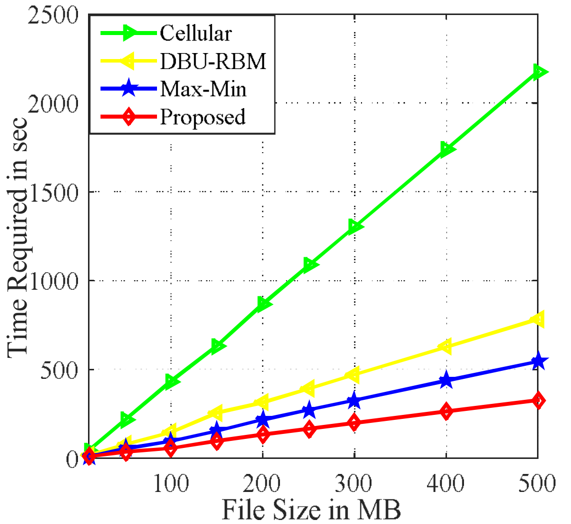


**FIGURE 9.** Time required for uploading file.

less (up to 100 MB) the max-min, DBU-RBM and proposed scheme require nearly equal amount of time while traditional cellular communication requires more time. However, when we increase the amount of data for uploading, cellular communication require enough time due to deep path fading in a single hop while DBU-RBM, Max-Min and our scheme upload data in two hops, however, in the max-min and DBU-RBM scheme, the first hop resource allocation is round robin therefore, more time is required while our scheme calculates the resource block for each hop and assigns. Therefore, our scheme performs better compared to DBU-RBM, max-min and traditional cellular communication.

## V. CONCLUSION

In this paper, we propose an efficient resource management scheme for cell edge users who are interested in uploading content toward the BS side. The proposed scheme is divided in two phases. In the first phase, if Multihop communication is required a relay is selected from the available relays between the cell edge device and eNodeB; in the second phase, an efficient resource allocation scheme is deployed that reduces the number of resource blocks and upload time in the uploading case. The relay selection scheme is semi-base centric, while the resource allocation scheme is network assisted where the eNodeB allocates resource blocks. Our proposed scheme provides superior result over the traditional cellular scheme and DBU-RBM scheme. An interesting extension of this work would be to select the relay and allocate resource at the device level so that the load on the eNodeB side is reduced and better throughput can be achieved.

## REFERENCES


[1] R. Berezdivin, R. Breinig, and R. Topp, "Next-generation wireless communications concepts and technologies," *IEEE Commun. Mag.*, vol. 40, no. 3, pp. 108–116, Mar. 2002.

[2] C. V. N. Index, "Global mobile data traffic forecast update, 2010–2015," White Paper, Feb. 2011.

[3] B. Bangerter, S. Talwar, R. Arefi, and K. Stewart, "Networks and devices for the 5G era," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 90–96, Feb. 2014.

[4] F. Boccardi, R. W. Heath, A. Lozano, T. L. Marzetta, and P. Popovski, "Five disruptive technology directions for 5G," *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 74–80, Feb. 2014.

[5] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wireless networks: A comprehensive survey," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 3, pp. 1617–1655, 3rd Quart. 2016.

[6] A. Gupta and R. K. Jha, "A survey of 5G network: Architecture and emerging technologies," *IEEE Access*, vol. 3, pp. 1206–1232, 2015.

[7] J. Roessler, *LTE-Advanced (3GPP Rel. 12) Technology Introduction White Paper*, document 1MA252, 2009.

[8] *Proximity-Based Services (ProSe); Stage 2; Release 12, v. 12.1.0*, document G. T. 23.303, Jun. 2014.

[9] *Study on Extended Architecture Support for Proximity-Based Services; Release 13, v. 0.1.0*, document G. T. 23.713, Jul. 2014.

[10] X. Lin, J. Andrews, A. Ghosh, and R. Ratasuk, "An overview of 3GPP device-to-device proximity services," *IEEE Commun. Mag.*, vol. 52, no. 4, pp. 40–48, Apr. 2014.

[11] G. Fodor, S. Parkvall, S. Sorrentino, P. Wallentin, Q. Lu, and N. Brahmi, "Device-to-device communications for national security and public safety," *IEEE Access*, vol. 2, pp. 1510–1520, 2014.

[12] J. P. Munson and V. K. Gupta, "Location-based notification as a general-purpose service," in *Proc. 2nd Int. Workshop Mobile Commerce*, 2002, pp. 40–44.

[13] G. Fodor *et al.*, "Design aspects of network assisted device-to-device communications," *IEEE Commun. Mag.*, vol. 50, no. 3, pp. 170–177, Mar. 2012.

[14] K. Doppler, M. Rinne, C. Wijting, C. B. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to LTE-advanced networks," *IEEE Commun. Mag.*, vol. 47, no. 12, pp. 42–49, Dec. 2009.

[15] L. Wei, R. Q. Hu, Y. Qian, and G. Wu, "Enable device-to-device communications underlaying cellular networks: Challenges and research aspects," *IEEE Commun. Mag.*, vol. 52, no. 6, pp. 90–96, Jun. 2014.

[16] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 4, pp. 1801–1819, 4th Quart., 2014.

[17] M. N. Tehrani, M. Uysal, and H. Yanikomeroglu, "Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 86–92, May 2014.

[18] J. Huang, Y. Yin, Y. Zhao, Q. Duan, W. Wang, and S.-C. Yu, "A game-theoretic resource allocation approach for intercell device-to-device communications in cellular networks," *IEEE Trans. Emerg. Topics Comput.*, 2014.

[19] D. H. Lee, K. W. Choi, W. S. Jeon, and D. G. Jeong, "Resource allocation scheme for device-to-device communication for maximizing spatial reuse," in *Proc. Wireless Commun. Netw. Conf. (WCNC)*, 2013, pp. 112–117.

[20] M. Zulhasnine, C. Huang, and A. Srinivasan, "Efficient resource allocation for device-to-device communication underlaying LTE network," in *Proc. IEEE 6th Int. Conf. Wireless Mobile Comput., Netw. Commun. (WiMob)*, Oct. 2010, pp. 368–375.

[21] S. Wen, X. Zhu, X. Zhang, and D. Yang, "QoS-aware mode selection and resource allocation scheme for device-to-device (D2D) communication in cellular networks," in *Proc. IEEE Int. Conf. Commun. Workshops (ICC)*, Jun. 2013, pp. 101–105.

[22] G. Chen, Z. Tian, Y. Gong, Z. Chen, and J. A. Chambers, "Max-ratio relay selection in secure buffer-aided cooperative wireless networks," *IEEE Trans. Inf. Forensics Security*, vol. 9, no. 4, pp. 719–729, Apr. 2014.

[23] A. Ikhlef, D. S. Michalopoulos, and R. Schober, "Max-max relay selection for relays with buffers," *IEEE Trans. Wireless Commun.*, vol. 11, no. 3, pp. 1124–1135, Mar. 2012.

[24] N. Nomikos *et al.*, "Relay selection for secure 5G green communications," *Telecommun. Syst.*, vol. 59, no. 1, pp. 169–187, 2015.

[25] C.-P. Chien, Y.-C. Chen, and H.-Y. Hsieh, "Exploiting spatial reuse gain through joint mode selection and resource allocation for underlay device-to-device communications," in *Proc. 15th Int. Symp. Wireless Pers. Multimedia Commun. (WPMC)*, 2012, pp. 80–84.

[26] K. Doppler, C.-H. Yu, C. B. Ribeiro, and P. Jänis, "Mode selection for device-to-device communication underlaying an LTE-advanced network," in *Proc. Wireless Commun. Netw. Conf. (WCNC)*, 2010, pp. 1–6.

[27] S. T. Shah, J. Gu, S. F. Hasan, and M. Y. Chung, "SC-FDMA-based resource allocation and power control scheme for D2D communication using LTE-A uplink resource," *EURASIP J. Wireless Commun. Netw.*, vol. 2015, pp. 1–15, Dec. 2015.

[28] S.-B. Lee, I. Pefkianakis, A. Meyerson, S. Xu, and S. Lu, "Proportional fair frequency-domain packet scheduling for 3GPP LTE uplink," in *Proc. IEEE INFOCOM*, Apr. 2009, pp. 2611–2615.

[29] A. Orsino, L. Militano, G. Araniti, A. Molinaro, and A. Iera, "Efficient data uploading supported by D2D communications in LTE-A systems," in *Proc. 21th Eur. Wireless Conf.*, 2015, pp. 1–6.

[30] L. Militano, A. Orsino, G. Araniti, A. Molinaro, A. Iera, and L. Wang, "Efficient spectrum management exploiting D2D communication in 5G systems," in *Proc. IEEE Int. Symp. Broadband Multimedia Syst. Broadcast. (BMSB)*, Jun. 2015, pp. 1–5.

[31] L. Militano, A. Orsino, G. Araniti, A. Molinaro, and A. Iera, "A constrained coalition formation game for multihop D2D content uploading," *IEEE Trans. Wireless Commun.*, vol. 15, no. 3, pp. 2012–2024, Nov. 2015.

[32] A. Bletsas, A. Khisti, D. P. Reed, and A. Lippman, "A simple cooperative diversity method based on network path selection," *IEEE J. Sel. Areas Commun.*, vol. 24, no. 3, pp. 659–672, Mar. 2006.

[33] Z. Tian, G. Chen, Y. Gong, Z. Chen, and J. A. Chambers, "Buffer-aided max-link relay selection in amplify-and-forward cooperative networks," *IEEE Trans. Veh. Technol.*, vol. 64, no. 2, pp. 553–565, Feb. 2015.

[34] *Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall Description; Stage 2 (Release 11)*, document TS 36.300 version 11.5.0, 3GPP, 2013.

[35] J.-M. Kang, C.-K. Park, S.-S. Seo, M.-J. Choi, and J. W.-K. Hong, "User-centric prediction for battery lifetime of mobile devices," in *Challenges for Next Generation Network Operations and Service Management*. Springer, 2008, Beijing, China, pp. 531–534.

[36] X. Li, Q. Fang, and L. Shi, "A effective SINR link to system mapping method for CQI feedback in TD-LTE system," in *Proc. IEEE 2nd Int. Conf. Comput., Control Ind. Eng. (CCIE)*, Aug. 2011, pp. 208–211.

[37] J. Demšar, "Statistical comparisons of classifiers over multiple data sets," *J. Mach. Learn. Res.*, vol. 7, pp. 1–30, Jan. 2006.

[38] P. Nemenyi, "Distribution-free multiple comparisons," *Biometrics*, vol. 18, no. 2, p. 263, 1962.

**PAVAN KUMAR MISHRA** is currently pursuing the Ph.D. degree with the Department of Information Technology, National Institute of Technology Raipur, Raipur, India. He is an Assistant Professor with the Department of Information Technology, National Institute of Technology. His research interests include cellular and mobile communication, 5G communication, device-to-device communication, and green communication.

**SUDHAKAR PANDEY** received the Ph.D. degree from Allahabad University. He is an Assistant Professor with the Department of Information Technology, National Institute of Technology Raipur, Raipur, India. His research interests include ad hoc networks, sensor networks, and cellular and mobile communication.

**SANJAY KUMAR BISWASH** received the Ph. D, degree from the IIT Dhandad (Indian School of Mines), Dhanbad, in 2012. He held post-doctoral position with the National Laboratory of Scientific Computing, RJ Brazil, and San Diego State University, CA, USA. He was a Visiting Scientist with the University of Coimbra, Portugal. He served as an Assistant Professor (on contract) with the Motilal Nehru National Institute of Technology, Allahabad, India. He is currently a Research Scientist with the Department of Software Engineering, Institute of Cybernetics, National Research Tomsk Polytechnic University, Russia. His research interests lies on network management, mobility management, 5G, device-centric networks, wireless and mobile networks, and bio-inspired networks. He serves as an Editorial Board Member of the *International Journal of Wireless Personal Communications* (Springer Verlag), the *International Journal of Mobile and Network Application* (Springer Verlag), and a Reviewer of many reputed international journals/conferences.