Reducing Congestion in Two-tier Cellular Network Using Multi-Relay D2D Communications

Bhed Bahadur Bista, Shingo Sasaki, Kanayo Ogura and Toyoo Takata

***Abstract*—Due to the large increase of mobile devices called User Equipments (UEs), that connect to cellular networks, it may be impossible for a user to satisfy data communication if a large number of them are connected to a Base Station (BS). We propose a congestion mitigation method as one solution to this problem. Our proposed method transfers traffic to neighboring non-congested Base Stations using Device-to-Device (D2D) communications. As a result, the number of UE connections within the coverage area of the BS can be increased. In this paper, we propose a method for two-tier cellular networks composed of a macrocell and picocells which are within the coverage area of the macrocell. When the macrocell BS is congested, some of the UE connections to the macrocell BS are forwarded to a non-congested picocell BS using multi-relay D2D communications. We evaluated the performance of our proposed method by simulation. The simulation results have shown that the number of UEs that can be connected to BSs can be increased using multi-relay D2D communications.**

***Index Terms*—User Equipment, D2D communication, multi-relay, congestion, cellular network.**

I. INTRODUCTION

THE most widely used high performance mobile wireless devices in the world are smartphones and tablets, whose number is increasing year by year. The proliferation of these devices and constant use of them to access the Internet have strained the wireless access points specially cellular network access points called Base Stations (BSs). Almost all these devices are frequently used to upload and download videos, photos, audio files or access SNS services generating a huge amount of data traffic which is increasing year by year [1]. The GSMA real time tracker puts that the number of mobile devices are more than the world population and will be double the world population soon [2].

In order to satisfy ever increasing number of UEs connections to BSs, wireless cellular networks are also evolving and increasing their network capacity by integrating new technologies and shifting their paradigms. Currently, the cellular network is in fourth generation (4G) which is replacing 3G around the world. The 4G is being actively developed and is well-known by 3GPP LTE-Advanced [3],[4]. Besides providing higher channel capacity by introducing multi-antenna technology and carrier aggregation, LTE-Advanced is shifting its paradigm of communication model known as Device-to-Device (D2D) communication by taking advantages of high performance wireless devices [5], [6]. D2D improves resource utilization of wireless cellular networks by letting a pair of D2D devices which are in proximity of each other to communicate directly instead of communicating via Base Station (know as evolved Node (eNB) Base Station in LTE).

In D2D communication, two devices called User Equipments (UEs), which are in proximity of each other, can establish a direct communication link using the licensed band. Because of their proximity, there is limited interference from other users even if they use the same licensed band. Since D2D communication can be established by sharing channel, the eNB can provide service to other UEs using the same channel thereby increasing the throughput and the number of UE connections of the network.

Another approach to mitigate the traffic overload and accommodate ever increasing mobile devices in 4G networks are heterogeneous networks which are being deployed in various places [3], [7]. In heterogeneous networks, there are small cells – picocells, femto-cells and relay cells – within the larger coverage area of a macrocell. UEs within the coverage area of a small cell are linked to the BS of the small cell instead of the BS of the macrocell, effectively reducing the congestion at the macrocell BS and increasing the node density to further improve the network capacity [8]. Combining D2D communications and heterogeneous networks, the network capacity of the macrocell can be further improved if the traffic from the congested BS is forwarded to a non-congested small cell BS within the coverage area of the macrocell using D2D communications.

In this paper, we propose a multi-relay D2D communication in which connection requesting UEs and/or already connected UEs at the macrocell BS are forward to a non-congested small cell BS using multi-relay D2D, reducing the congestion at the macrocell BS and increasing the overall UEs connections to BSs.

The paper is organized as follows. In section II, we present the related works. In section III, we present our proposed multi-relay D2D scheme to mitigate congestion at the macrocell BS. In section IV, we present the performance evaluation of our proposed scheme with simulation followed by conclusion in section V.

II. RELATED WORKS

Authors in [9] have proposed a traffic detouring method from the macrocell to small cells by establishing D2D links between UEs which are outside the coverage area of the small cells to UEs which are free and inside the coverage area of the small cells. Liu et al. [10], [11] have improved the method of [9] and have proposed a scheme in which a mobile UE selects an operation mode individually whether to establish a cellular link with the BS or a D2D link using the pilot signal strength received from its nearest BS.

The above approach is only suitable for cellular link UEs or UEs requesting for cellular links in the macrocell, which

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are within the D2D establishment distance to UEs in the small cell. Moreover, if there are no free UEs in the small cell, the D2D link cannot be established between the UEs and the traffic cannot be detoured to the small cell.

In this paper, we propose a multi-relay D2D to forward traffic from the macrocell to the small cell in a heterogeneous cellular network. With multi-relay D2D communications, an UE which is linked to or requesting link to the macrocell BS, can be forwarded to the small cell even if it is not within the D2D distance to UEs in the small cell. Furthermore, using multi-relay D2D, even if there is no free UE in the small cell, a macrocell UE can be detoured to another small cell which has free UEs as shown in Fig. 1 where r_1 is within the D2D distance to a UE of the small cell P_2 which has no free UEs. With multi-relay D2D r_1 can be linked to the small cell P_1.

III. The Proposed Multi-Relay D2D Scheme

When an UE which is outside the coverage area of a picocell (here we consider a small cell as a picocell) and is requesting connection to the macrocell BS, it will not get connection if the BS is congested or has no capacity for new connections as shown in Fig. 1(a). If some of requesting UEs or already connected UEs can be connected to a non-congested picocell BS using D2D, the number of UEs that can be connected will increase. In order to utilize the resources of BSs in a heterogeneous cellular network, we propose a method for multi-relay D2D communication to forward connections to non-congested BSs.

In Algorithm 1, we first find free UEs in a picocell. For an example $f_2 \sim f_5$ in picocell P_1 as shown in Fig. 1(a) are free UEs. Then we find requesting UEs or connected UEs to the BS of macrocell which are within the D2D distance from free UEs in the picocell. As an example, let us suppose, r_2 a connection requesting UE to the macrocell BS, and c_1 a connected UE to the macrocell BS, are within the D2D distance from free UEs f_3 and f_4 respectively as shown in Fig. 1(a). Now D2D connection is established between r_2 and f_3 and, c_1 and f_4. The requesting UE, r_2 and connected UE, c_1, are connected to the BS of picocell P_1 via f_3 and f_4 respectively as shown in Fig. 1(b). The work in [9] forms only this 1st-Relay D2D connection. The single relay D2D connections may not sufficiently utilize the resources of picocells and mitigate the congestion at the macrocell BS.

In Algorithm 2, we find free UEs outside the picocell coverage area and are within the D2D distance to free UEs of the picocell. We mark them as 2nd-Relays. As an example, let us suppose, f_1 and f_6 as shown in Fig. 1(a) are such free UEs. Next, we find requesting UEs first and then connected UEs which are within the D2D distance to 2nd-Relays. If there are such UEs, we establish D2D connections and connect requesting UEs and/or connected UEs to the BS of picocell. As an example r_1 is now connected to the BS of picocell P_1 in Fig. 1(b).

In Algorithm 3, we find free UEs outside the coverage area of the picocell and are within the D2D distance to the 2nd-Relays. If there are, we mark them as 3rd-Relays. Then we find if there are requesting UEs or connected UEs which are within the D2D distance to 3rd-Relays. If there are we establish D2D connections. As an example, let us suppose, f_7 is 3rd-Relay and r_3 is within the D2D distance to f_7 as shown in Fig. 1(a). Then we establish D2D connections between r_3 to f_7, f_7 to f_6, f_6 to f_5 which will be connected to the BS of picocell P_1 as shown in Fig. 1(b).

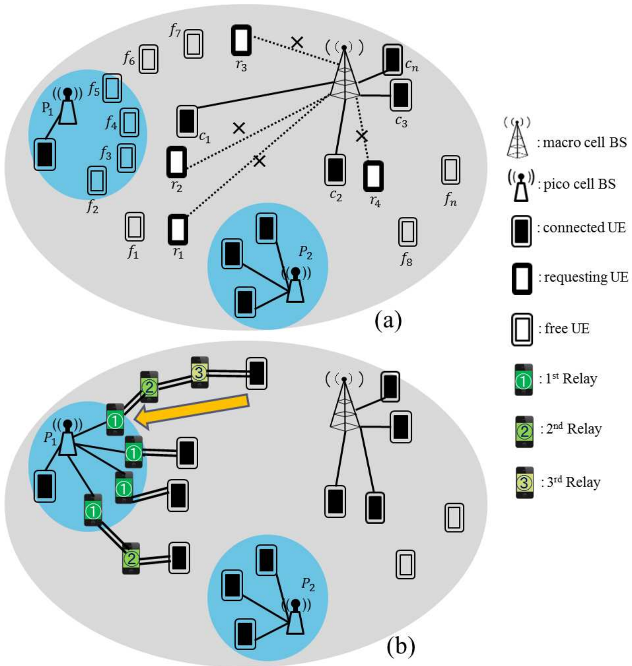

Fig. 1. An Overview of Our Proposal

A. Algorithms for Finding Multi-Relay D2D UEs

We define the following sets of UEs which we use in our algorithms. The BSs of picocells and the macrocell select UEs for possible D2D communications considering minimum interference if D2D is established. How a BS selects UEs, manages resources and allocate channels to UEs is beyond the scope of the paper [12], [13].

Let
f_UE_m: be a nonempty set of free UEs in macrocell,
r_UE_m: be a nonempty set of requesting UEs in macrocell,
c_UE_m: be a nonempty set of connected UEs in macrocell and
f_UE_p: be a nonempty set of free UEs in picocell.

In Algorithms 1, 2 and 3, first requesting UEs are connected to the picocell BS. If there are no such requesting UEs or all possible requesting UEs are connected, only then connected UEs are connected to the picocell BS. This is reasonable because we do not want the already connected UEs to change the connection if not required.

In Algorithm 1, steps 2∼11 will find D2D pairs between requesting UEs of macrocell and free UEs of the picocell and steps 12∼23 will find D2D pairs between connected UEs and free UEs of the picocell.

In Algorithm 2, steps 2∼12 will find 2nd-Relays (set $R2$) from the macrocell's free UEs which are in D2D distance to free UEs of the picocell. Steps 13∼24 will find D2D pairs between 2nd-Relays and requesting UEs and steps 25∼36 will find D2D pairs between 2nd-Relays and connected UEs.

Similarly, in Algorithm 3, after finding 2nd-Relays and 3rd-Relays, D2D pairs are found between 3rd-Relays and requesting UEs and connected UEs.

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Algorithm 1 Forwarding with 1st-Relay D2D

$D2D\_Pair = \{\}$
for each $s \in f\_UE_p$ **do**
  for each $t \in r\_UE_m$ **do**
    find min_dist(s, t)
  end for
  if min_dist(s, t) $<$ D2D_Dist **then**
    $D2D\_Pair = D2D\_Pair \cup \{(s, t)\}$
    $f\_UE_p = f\_UE_p - \{s\}$
    $r\_UE_m = r\_UE_m - \{t\}$
  end if
end for
if f_UE_p not empty **then**
  for each $u \in f\_UE_p$ **do**
    for each $v \in c\_UE_m$ **do**
      find min_dist(u, v)
    end for
    if min_dist(u, v) $<$ D2D_Dist **then**
      $D2D\_Pair = D2D\_Pair \cup \{(u, v)\}$
      $c\_UE_m = c\_UE_m - \{v\}$
      $f\_UE_p = f\_UE_p - \{u\}$
    end if
  end for
end if
if $D2D\_Pair$ not empty **then**
  Establish D2D connection
else
  No First Relay D2D
end if

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Total number of UEs	1500
Number of requesting UEs	150,300,450
Number of Picocells	1,2,3,4
Maximum D2D distance	30m
Radius of Macrocell	500m
Radius of Picocell	100m
Connection capacity of Macrocell BS	100
Connection capacity of Picocell BS	100

Algorithm 2 Forwarding with 2nd-Relay D2D

$D2D\_Pair_1 = \{\}$, $D2D\_Pair_2 = \{\}$, $R2 = \{\}$
for each $s \in f\_UE_p$ **do**
  for each $t \in f\_UE_m$ **do**
    find min_dist(s, t)
  end for
  if min_dist(s, t) $<$ D2D_Dist **then**
    $D2D\_Pair_1 = D2D\_Pair_1 \cup \{(s, t)\}$
    $R2 = R2 \cup \{t\}$
    $f\_UE_m = f\_UE_m - \{t\}$
    $f\_UE_p = f\_UE_p - \{s\}$
  end if
end for
if $R2$ not empty **then**
  for each $u \in R2$ **do**
    for each $v \in r\_UE_m$ **do**
      find min_dist(u, v)
    end for
    if min_dist(u, v) $<$ D2D_Dist **then**
      $D2D\_Pair_2 = D2D\_Pair_2 \cup \{(u, v)\}$
      $r\_UE_m = r\_UE_m - \{v\}$
      $R2 = R2 - \{u\}$
    end if
  end for
end if
if $R2$ not empty **then**
  for each $w \in R2$ **do**
    for each $x \in c\_UE_m$ **do**
      find min_dist(w, x)
    end for
    if min_dist(w, x) $<$ D2D_Dist **then**
      $D2D\_Pair_2 = D2D\_Pair_2 \cup \{(w, x)\}$
      $c\_UE_m = c\_UE_m - \{x\}$
      $R2 = R2 - \{w\}$
    end if
  end for
end if
if $D2D\_Pair_1$ & $D2D\_Pair_2$ not empty **then**
  Establish D2D connection
else
  No Second Relay D2D
end if

IV. PERFORMANCE EVALUATION

We evaluated our proposal using simulation to see how the number of connected UEs are increased using multiple D2D relays. We compare the simulation results of our proposal with non-relay D2D [9] and without any D2D, i.e., only with picocells.

A. Simulation Parameters and Procedure

The simulation parameters are as shown in the Table I. We put 1500 UEs randomly in a circular area of 500 meters radius of a macrocell with the BS at the center. We vary the number of picocells with radius of 100 meters from 1 to 4. The picocells are placed as shown in Fig. 2. The number of requesting UEs are 150, 300 and 450 which are 10%, 20% and 30% of total UEs respectively. First, we simulated without any D2D connections. Secondly, we simulated with D2D only, i.e., simulation of the related work [9]. The related work can be considered as the 1st-Relay also when an UE in the picocell is relaying traffic of an UE in the macrocell. Then we simulated our proposal with 2nd-Relay and 3rd-Relay where these relays are UEs in the macrocell. In each simulation, picocells and the number of requesting UEs are varied. The simulation was performed 10000 times for each scenarios and the results presented are the average values.

B. Performance Results

Figures 3, 4 and 5 show the percentage of UEs that get connections to the BSs of macrocell and/or the BSs of picocells when connection requesting UEs are 150, 300 and 450 respectively. The "none", "related(1st-Relay)", "proposal(2nd-Relay)" and "proposal(3rd-Relay)" represent without D2D, related work, our proposal with 2nd-Relay and 3rd-Relay which are outside picocells respectively.

From the results, we see that as the number of picocells increases, the percentage of connected UEs also increases in

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Algorithm 3 Forwarding with 3rd-Relay D2D

1: $D2D\_Pair_1 = \{\}$, $D2D\_Pair_2 = \{\}$, $D2D\_Pair_3 = \{\}$, $R2 = \{\}$, $R3 = \{\}$
2: Add steps 2∼12 code of Algorithm 2 to find $R2$ and $D2D\_Pair_1$ here.
3: **if** $R2$ not empty **then**
4:     **for** each $y \in R2$ **do**
5:         **for** each $z \in f\_UE_m$ **do**
6:             find min_dist(y, z)
7:         **end for**
8:         **if** min_dist(y, z) < D2D_Dist **then**
9:             $D2D\_Pair_2 = D2D\_Pair_2 \cup \{(y, z)\}$
10:             $R3 = R3 \cup \{z\}$
11:             $f\_UE_m = f\_UE_m - \{z\}$
12:             $R_2 = R_2 - \{y\}$
13:         **end if**
14:     **end for**
15: **end if**
16: Add steps 13∼36 code of Algorithm 2 replacing $R2$ with $R3$ and $D2D\_Pair_2$ with $D2D\_Pair_3$ to find $D2D\_Pair_3$ here.
17: **if** $D2D\_Pair_1$ & $D2D\_Pair_2$ & $D2D\_Pair_3$ not empty **then**
18:     Establish D2D connection
19: **else**
20:     No Third Relay D2D
21: **end if**

all scenarios. This is obvious because when we increase BSs with certain number of connection capacity (here picocells with 100 connections capacity), the number of UEs that can be connected to BSs will also increase. However, if the number of requesting UEs increases, the percentage of UEs that get connection to BSs decreases because some BSs may be congested with connections requests and the number of requesting US being refused connections will also increase. We can see that in Fig. 5, the percentage of connected UEs is less than that of Fig. 4 which is less than that of Fig. 3 where the number of requesting UEs are 450, 300 and 150 respectively.

After introducing multi-relay D2D to relay requesting UEs connections from the congested BS, the macrocell BS in our case, to non-congested BSs of picocells, the percentage of connected UEs increases compared to without using D2D communications. The percentage of increase in 3rd-Relay D2D is higher than 2nd-Relay D2D which is higher than 1st-Relay D2D. This is because the multi-relay D2D can relay the connections of requesting UEs which are further away from coverage areas of picocells to BSs of picocells.

Figures 6, 7 and 8 show the ratio of connected UEs when relays are increased from 0 to 1st-Relay, 1st-Relay to 2nd-Relay and 2nd-Relay to 3rd-Relay. We see that the ratio decreases in all scenarios. This is because finding 2nd-Relays depends upon the number of 1st-Relays and the number of free UEs in the macrocell which are within the D2D distance to the 1st-Relays. Similarly finding the 3rd-Relays depends upon the number of 2nd-Relays and free UEs which are in D2D distance to 2nd-Relays. The number of relays decreases as they are multi-relays away from the picocell. Finally the number of requesting UEs or connected UEs that can be relayed to BSs of picocells depends upon how many of them are within the D2D distance to relaying UEs. As the number of relays decreases further away from a picocell, the number of UEs that can be relayed for connections also decreases as we can see from Figs. 6, 7 and 8. An optimum number of relays to be introduced needs further study.

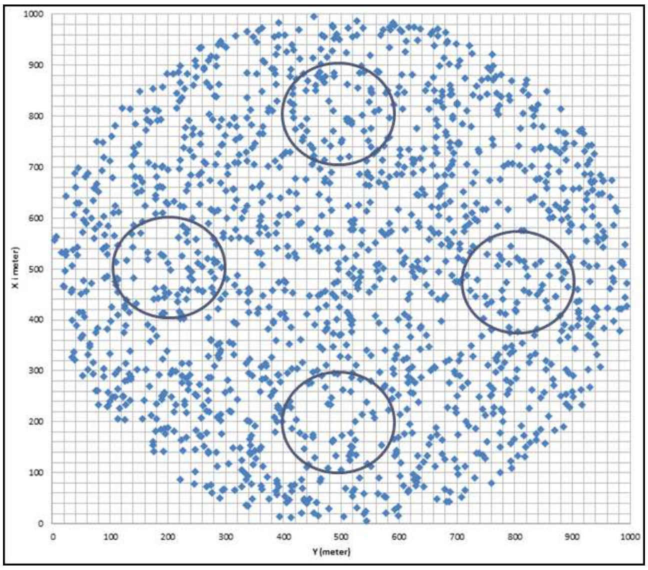

Fig. 2. Placements of macrocell, picocells and UEs

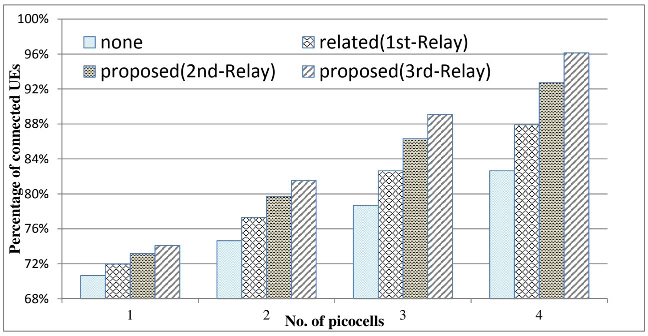

Fig. 3. Percentage of connected UEs when requesting UEs are 150

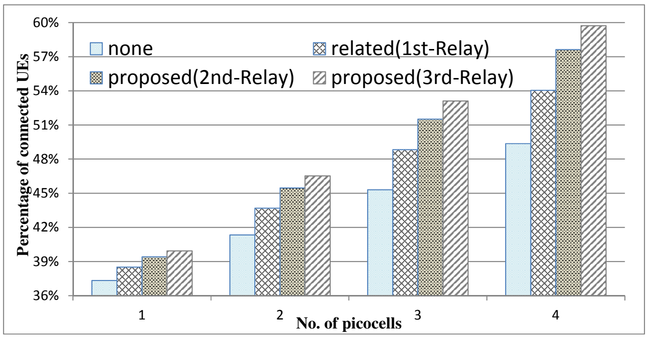

Fig. 4. Percentage of connected UEs when requesting UEs are 300

Figures 9, 10 and 11 show the percentage of requesting UEs which are outside picocells and connected to BSs of picocells as the distance from the edge of a picocell increases. From the results, we see that if requesting UEs are near the edge of the picocell edge, chances of them getting connected to the picocell BS by multi-relay D2D is higher

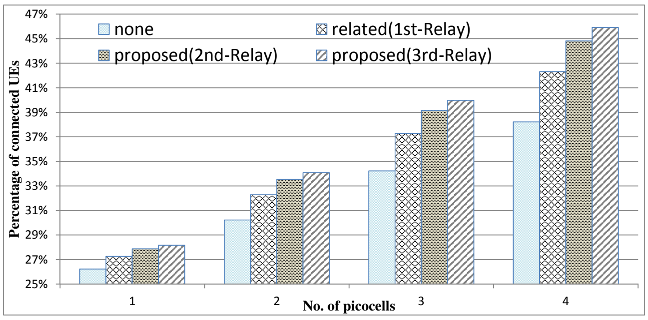

Fig. 5. Percentage of connected UEs when requesting UEs are 450

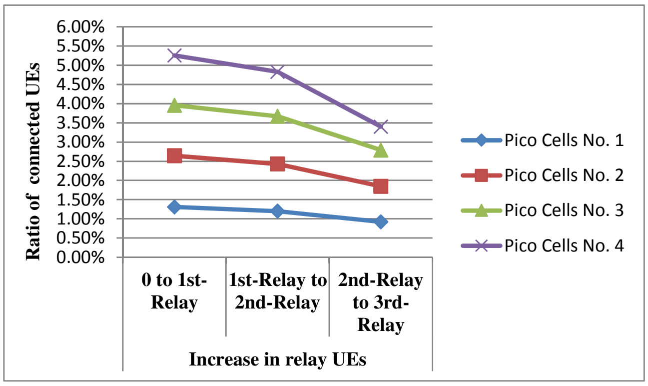

Fig. 6. Change in connected UEs as relays increase for 150 Requesting UEs

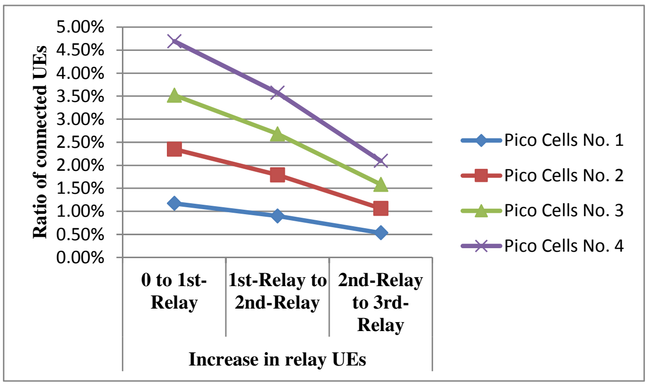

Fig. 7. Change in connected UEs as relays increase for 300 Requesting UEs

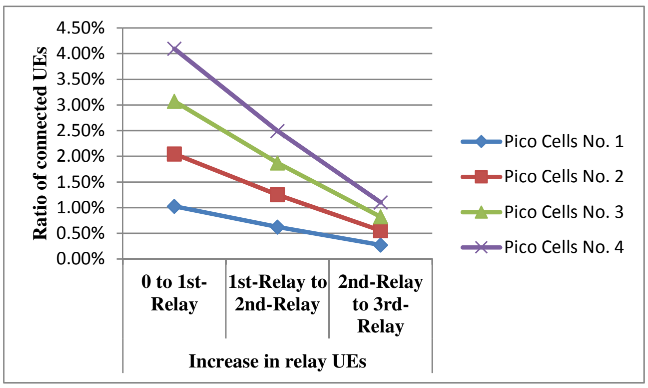

Fig. 8. Change in connected UEs as relays increase for 450 Requesting UEs

than if they are further away. Though the multi-relay D2D extends the distance of requesting UEs from the picocell

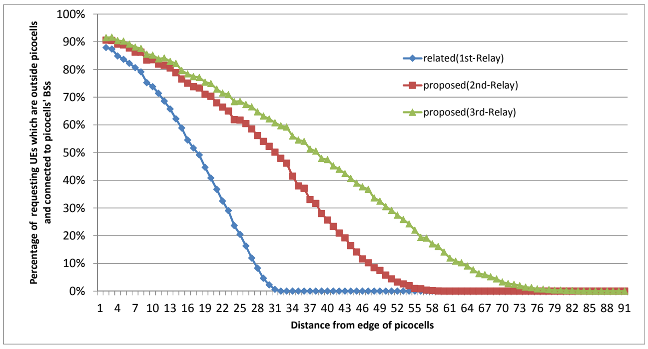

Fig. 9. Percentage of requesting UEs which are outside picocells and connected to BSs of picocells for 150 requesting UEs and 4 picocells

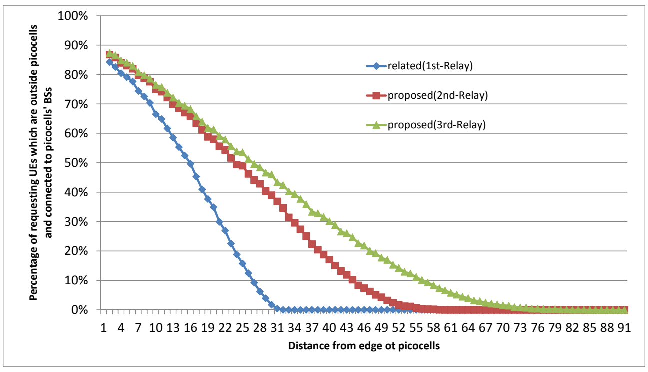

Fig. 10. Percentage of requesting UEs which are outside picocells and connected to BSs of picocells for 300 requesting UEs and 4 picocells

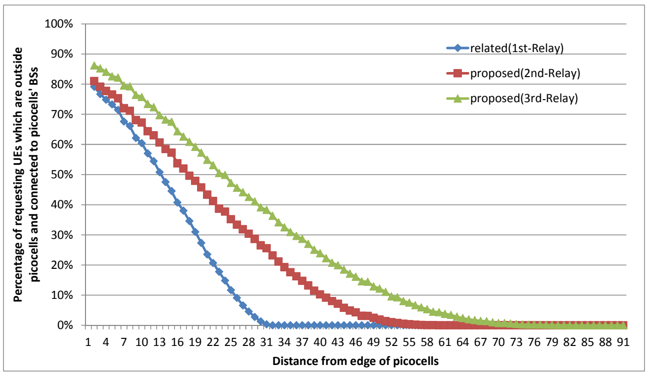

Fig. 11. Percentage of requesting UEs which are outside picocells and connected to BSs of picocells for 450 requesting UEs and 4 picocells

to be connected to the picocell, it has a limit. After some distance, no requesting UEs can be connected to picocells. From the figures, we observe that for a given distance from the picocells, the number of requesting UEs being connected to picocell BSs is higher in 3rd-Relay than 2nd-Relay which is higher than 1st-Relay. Moreover, the 3rd-Relay coverage distance from the edge of the picocells is further than the 2nd-Relay which is further than the 1st-Relay.

V. Conclusion

In this paper, we proposed multi-relay D2D communications to mitigate congestion at the macrocell BS in a heterogeneous two-tier cellular network. The proposed scheme relays the connection requesting UEs and/or already connected UEs of the congested macrocell BS to the non-congested BS of a small cell. The simulation results have

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shown that not only do we reduce the congestion at the macrocell BS, but also increase the number of UEs that can be connected to the network.

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