An Efficient Traffic Detouring Method by Using Device-to-Device Communication Technologies in Heterogeneous Network

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An Efficient Traffic Detouring Method by Using Device-to-Device Communication Technologies in Heterogeneous Network

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***Abstract*—In recent years, HETerogeneous NETworks (HETNET) arises as a promising network technique to manage a large number of mobile devices. By using the networks having different coverage size in the HETNET, it enables to increase the network capacity drastically. However, sometimes variations in user distribution causes inhomogeneous traffic load among the networks having different coverage size in the HETNET. On the other hand, Device-to-Device (D2D) communication technologies have attracted much attention as another solution to increase the network capacity. The direct communication between user devices creates flexible networks. Thus, we focus on utilizing D2D communication technologies in HETNET to avoid the inhomogeneous load among the networks having different coverage size. In this paper, a traffic detouring method is proposed and the advantage of the proposed method is analyzed with some mathematical expressions. Additionally, numerical results demonstrate the effectiveness of our proposal.**

I. Introduction

The development of wireless communication network makes our daily lives more convenient and smarter. Recently, we can access the network anytime and anywhere by using communication terminal equipment such as cell phones, smart phones, tablets, and mobile PCs. Additionally, a huge variety of digital contents appears in the network. As a result, the usage of the network increases day to day and the capacity of the existing network becomes short to the requisition of network using from the people. Thus, the concept of HETerogeneous NETwork (HETNET) has attracted much attention as one of the solutions to manage the drastically increasing network traffic [1],[2].

In the HETNET, the networks having different coverage size are deployed in the same area and they provide network environment in a cooperative way [3]-[5]. Compared to the conventional networks constructed by macro cells in which each base station (BS) covers wide area, small cells such as pico cells and femto cells which cover smaller area than macro cells are deployed in the traffic congested area of the HETNET. Fig. 1 shows an example of HETNET model constructed by a macro cell, several pico cells, and femto cells. As shown in Fig. 1, smaller cells covers a small part of the area where bigger cells covers as overlay networks to avoid traffic congestion. The network users in the overlaid area can choose the access point from multiple cells according to the situation of each sell [6].

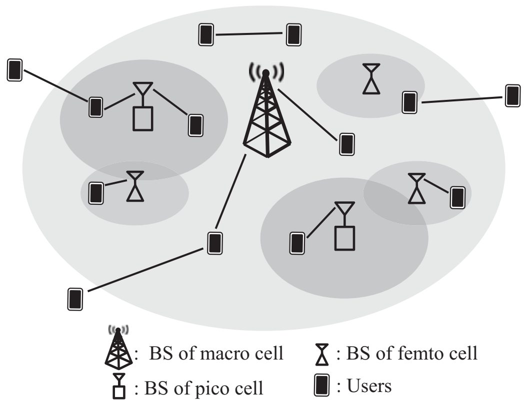

Fig. 1. An example of network configuration of HETNET and D2D communications.

On the other hand, we also focus on Device-to-Device (D2D) communication technologies as another solution to increase the network capacity [7]-[9]. In the D2D communication, the data is directly transmitted from user devices to other user devices. Since the users can communicate with each other without the BSs, it achieves to decrease the traffic load of the BSs. Additionally, by relaying the data from users outside of the network coverage area to the BSs via users inside the coverage area, D2D communication makes it possible to support data transmission from wider area than the usual coverage area of the network. An example of utilizing the D2D communication is also demonstrated in Fig. 1.

As shown in Fig. 1, multiple communication systems are utilized at the same area in the next generation network. However, in order to utilize the network resources efficiently, it is necessary to cooperatively use the different networks. Thus, we focus on, in this paper, the problem of occurring inhomogeneous load between the different types of cells such as macro cells, pico cells, and femto cells. In the HETNET, although the small cells are deployed at the traffic congested area in a focused manner and some handover management methods have developed a lot in recent years, the network resources of the small cells may remain available while the macro cells are congested due to the changing of users' distribution in time and space. Therefore, we propose an efficient traffic detouring method to resolve the inhomogeneous load distribution among the different types of cells by using D2D communication technologies. Additionally, the advantage of the proposal is analyzed with some mathematical expressions and numerical results.

The remainder of this paper is organized as follows. After describing assumed network model and introducing one of its shortcomings, a new method to detour traffic is introduced in Section II. Section III studies, using mathematical analyses, the efficiency of the proposed model. Section IV further extends the analysis for the general Poisson-Voronoi cell tessellation. Numerical results are presented in Section V. Finally, concluding remarks are provided in Section VI.

II. Traffic detouring by using D2D communication technologies in HETNET

In this section, at first, we introduce the supposed HETNET where different types of networks which have different size of the coverage area are deployed at the same area and D2D communication model. Additionally, the problems of the networks are represented. Moreover, to cope with the issue, we propose a traffic detouring method by using D2D communication technologies in HETNET.

A. Supposed D2D communication model in HETNET

In HETNET, different types of networks which have different size of the coverage area are utilized in the same area. As the next generation networks utilizing in the HETNET, there are many candidates such as Long Term Evolution (LTE), LTE-Advanced (LTE-A), Wireless Fidelity (WiFi), and so on. These networks having different size of coverage area are deployed in the same area to avoid traffic congestion. By utilizing the networks as overlay, the throughput of the network is considered to increase several times to several ten times. Generally, small cells are deployed at traffic congested area, and the traffic from users in the coverage area of the small cells is detoured to the small cells from the macro cells while all other users transmit their traffic to the BSs of the macro cells. However, since the network user distribution varies from hour to hour, traffic congestion may occur also at the macro cells while the network resources of small cells are remained available.

Meanwhile, the D2D communication technologies have attracted much attention as a way to increase the network capacity. By using direct communication between users' devices, it achieves to decrease the traffic to the BSs. To realize the D2D communications, WiFi is often adopted for the communication between the devices. For instance, in the research work in [10]-[12], the experiment using multi-hop D2D communication in real field is introduced. In the experiment, the data transmission via some smart phones is demonstrated. Since it achieves not only the communication between users but also data relaying from the users standing out of the coverage of the network to the BS via some users inside the coverage, the network capacity is drastically increased. However, the data relayed to the BS from outside the coverage area may cause the traffic congestion at the BSs. Thus, we focus on utilizing D2D communication technologies to detour the traffic to small cells to avoid traffic congestion at the macro cells in HETNET.

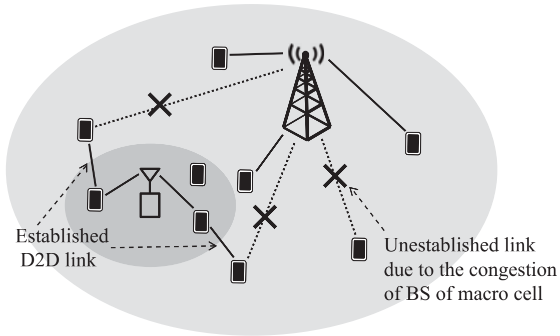

Fig. 2. An example of adopting the first step of the proposed method.

B. Traffic detouring method

In this paper, we propose a traffic detouring method by using D2D communication technologies in HETNET. Our proposal achieves to detour the traffic from the congested macro cell to uncongested small cells such as pico cells and femto cells. To introduce the proposed method with simplified network model, we suppose that some users are deployed in the network constructed by a macro cell and a pico cell. Additionally, the whole range of the pico cell is supposed to be inside of the macro cell. Moreover, we define that the network device which each user has (we call it "node" hereafter) is able to communicate with each other by using D2D communication technologies if the users are near adequately. The proposed method consists of two steps.

Step1: In this proposed method, the traffic to the congested macro cell is detoured to the small cell by using D2D communication technologies. Fig. 2 shows an example that the first step of the proposed method is adopted. At first, the BS of macro cell tries to find uncongested pico cell when a connection request from a node is received at a congested BS. After the BS finds the uncongested pico cell, it checks the existence of the free nodes which is not during communication and their location. If there are any free nodes in the coverage area of the uncongested pico cell, the node that is nearest to the requesting node is picked up. If the picked up free node is near enough to establish a D2D link with the requesting node, the traffic from the requesting node is detoured to the BS of the pico cell via the selected relay node.

Although the traffic is detoured from the congested macro cell to the pico cell by the step1 of the proposed method, which achieves to increase the network capacity, the opportunity that the D2D link is able to be established is limited. It is because that the D2D link which is utilized in the step1 is established only when the requesting node is sufficiently close to a free node in the coverage of the uncongested pico cell. Generally, the distance that the D2D link is possible to be established is considered to be several tens of meters. Thus, there may remain some nodes which cannot get the requesting connection. Therefore, the effectiveness of step1 is limited.

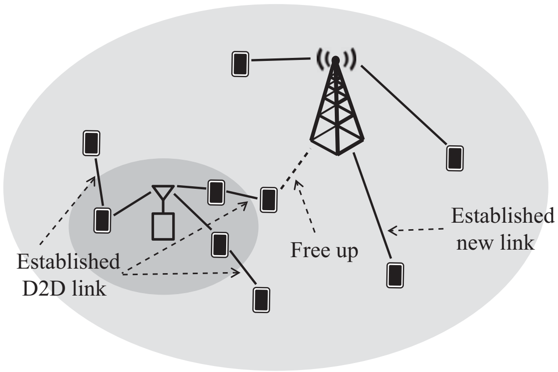

Fig. 3. An example that the second step of the proposed method is adopted.

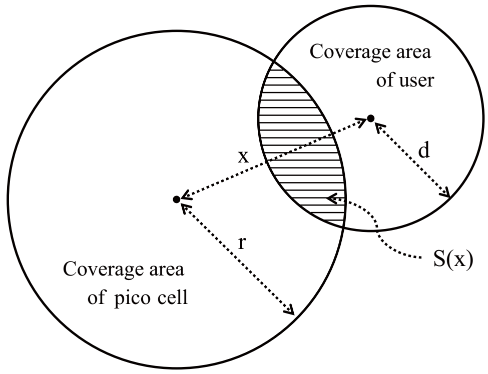

Fig. 4. A simplified model of the network consists of a pico cell and a user to represent the area of $S(x)$.

Step2: To improve the effectiveness of the proposed method, the limited condition to establish the D2D link in the step1 is expanded in the step2. In the step2, we employ to free up the established link to increase the utilization of the pico cell. Fig. 3 shows an example to utilize the step2. In the step2, the BS of the macro cell frees up the established link with a node which is able to establish a new D2D link with another node in the coverage area of the pico cell. By the "free up", a requesting node that is far from the pico cell is able to establish a link with the BS of the macro cell. Thus, the node which could not transmit its data in the step1 becomes possible to start the transmitting in the step2. Thus, the step2 increases the utilization ratio of the pico cell and increase the maximum number of nodes which can transmit their data at the same time.

Although we introduce the utilization of the proposed method in the limited network environment constructed by a macro cell and a pico cell, our proposal can also be adopted to other type of small cells such as femto cell. Additionally, traffic detouring between small cells by using the proposed method is also considered to be an efficient way to improve the network performance. Moreover, since the controlling of D2D links can be operated by the BS of macro cell with existing network information, such as position and link state of each node, the controlling overhead is expected to be small.

III. Analysis of enabled connections for a single macrocell

In this section, the effectiveness of the proposed method is analyzed with some mathematical expressions. To discuss the effectiveness, we formulate the success probability to establish the D2D link and the expectation of the number of nodes can get the connection in each step of the proposed method.

A. The success probability to establish the D2D link

The effectiveness of the proposed method depends on the number of free nodes in the coverage area of the uncongested pico cell while the node is near enough to establish the D2D link with the requesting node. To formulate the number, at first, we formulate the dimension of the area where the node can relay the data. Fig. 4 shows the simplified model of the network representing the area. The dimension of the area is defined as $S(x)$. The area is declared as the overlapped area of two circles, the coverage area of the pico cell and the communication range of the node requesting to establish the D2D link. Here, we define the radius of the coverage area of the pico cell and the maximum transmission range of the node to establish the D2D link as r and d, respectively. Additionally, the distance between the BS of the pico cell and the requesting node is defined as x. Thus, the dimension of the overlapped area, $S(x)$, is expressed as follows:

$$S(x) = r^2 \cdot \arccos\frac{r^2+x^2-d^2}{2\cdot r\cdot x} + d^2\cdot\arccos\frac{d^2+x^2-r^2}{2\cdot d\cdot x} - \frac{1}{2}\cdot\sqrt{4\cdot x^2\cdot r^2-(r^2+x^2-d^2)^2}. \quad (1)$$

Since the value of r and d are fixed parameters depends on the network, the value of $S(x)$ depends on the value of x. Actually, the overlapped area becomes larger when the distance between the BS of the pico cell and the requesting node. Thus, the smaller the value of x, the larger value of $S(x)$ is.

Secondly, we formulate the probability that the requesting node can establish the D2D link. Here, the probability that a user exists in an unit area is defined as p. The unit area is supposed to have very small dimension, we define the size as n, and there are no more than two nodes in a unit area at the same time. Thus, the probability that at least one node exists in the overlapped area, we defined it as $P_S(x)$, is expressed as follows:

$$P_S(x) = 1-(1-p)^{\frac{S(x)}{n}}. \quad (2)$$

Additionally, we define the ratio that the node is requesting the connection with the BSs as α. Therefore, the probability that the node transmitting the connection request can establish the D2D link, namely P_{D2D}, is expressed as follows:

$$P_{\mathrm{D2D}}(x) = (1-\alpha)\cdot\left\{1-(1-p)^{\frac{S(x)}{n}}\right\}. \quad (3)$$

B. The expectation value of the number of the nodes can get the requesting connection

Next, we formulate the expectation value of the number of nodes which can get the requesting connection by using the probability that the requesting node can establish the D2D link which we formulated in the previous subsection. Firstly, to compare the effectiveness of the proposed method with the situation without the proposal, the expectation value in the case where the proposed method does not applied is formulated. We define the value as E_{existing}. In this paper, we suppose the situation where the macro cell is congested, which means the number of requesting nodes is more than the maximum number of nodes a BS can communicate with at the same time. The maximum number is defined as C. Thus, the expected number of nodes connecting to the macro cell in the supposed situation equals to C. On the other hand, all the requesting nodes in the coverage area of the pico cells can communicate with the BS of the pico cell because the capacity of the pico cells remains more than the needs in the supposed situation. Thus, the expected number of the nodes connecting to the BS of the pico cell equals to the number of the nodes transmitting the connection request in the coverage area of the pico cells. Here, we define the number of the pico cells as k. Therefore, E_{existing} is expressed as follows:

$$E_{\text{existing}} = C + k \cdot \alpha \cdot \frac{\pi r^2}{n} \cdot p. \tag{4}$$

Secondly, the expected number of nodes which can get the requesting connection with the BS of the macro cell or pico cells when only step1 of the proposed method is applied is formulated. There are three conditions that the nodes can transmit their data newly in the setp1 in addition to the nodes which can communicate with the BSs without the proposed method. The first one is that the nodes need connection but cannot get the connection from the BS of the macro cell. The second one is that the nodes are in the range where the D2D link is able to be established with the nodes in the coverage area of the pico cells. The third one is that the nodes can find the node to establish the D2D link, that the probability to fill the condition equals to $P_{\text{D2D}}(x)$. Since the number of the nodes in the coverage area of the macro cell is expressed as $\frac{\pi(R^2-r^2)}{n} \cdot p$ where R denotes the radius of the coverage area of the macro cell and the number of the node communicating with the BS of the macro cell is C, the probability that the node is communicating with the BS of the macro cell, namely P_{macro}, is expressed as follows:

$$P_{\text{macro}} = \frac{n \cdot C}{\pi(R^2 - k \cdot r^2)p}. \tag{5}$$

Thus, the probability to fill the first condition is expressed as $\alpha \cdot (1 - P_{\text{macro}})$. Therefore, the expected number of the nodes which can communicate with the BS of the macro cell or pico cells when the step1 of the proposed method is applied is formulated as follows:

$$\begin{aligned} E_{\text{step1}} &= E_{\text{existing}} + k \cdot \int_r^{r+d} \frac{2\pi x}{n} \cdot p \cdot \alpha \\ &\cdot \ (1 - P_{\text{macro}}) \cdot P_{\text{D2D}}(x) dx. \end{aligned} \tag{6}$$

Finally, we formulate the expected number of the nodes which can get the requesting connection with the BS of the macro cell or pico cells when the step2 of the proposed method is applied. In the step2, in order to make new links between the BS of the macro cell and the nodes which are far from the pico cells, the nodes which are able to establish new D2D links and already connecting to the BS of the macro cell free up their links. In the supposed situation where the BS of the macro cell is congested, it is considered to be good to utilize the "free up" as much as possible to resolve the problem of the congestion. Thus, we assume as many as nodes try to free up their links to establish new D2D links. In this case, all requesting nodes in the range where the D2D link is able to be established with the nodes in the coverage area of the pico cells try to use the D2D links. Therefore, the expected number of the nodes which can get the requesting connection with the BSs in the step2 is expressed as follows:

$$E_{\text{step2}} = E_{\text{existing}} + k \cdot \int_r^{r+d} \frac{2\pi x}{n} \cdot p \cdot \alpha \cdot P_{\text{D2D}}(x) dx. \tag{7}$$

IV. Derivations for the general Poisson-Voronoi cell tessellation

Based on the above single macrocell analysis derived for the number of simultaneous connections that can be supported by our D2D traffic offloading scheme, we now further extend our analysis to the general two-tier HETNET where the macro BSs are randomly distributed in the network area.

Consider a two-tier HETNET consisting of multiple macro BSs, pico BSs, and mobile UEs. Similar to previous works [13], we assume the macro BSs are spatially distributed in the network area according to a homogeneous Poisson point process (PPP), and denote by λ_m the spatial intensity of macro BSs. Besides, the spatial distribution of mobile UEs follows another homogeneous PPP of intensity λ_u. Consequently, the PPP distributed macro BSs result in a Poisson-Voronoi (PV) cell tessellation of the network area. In each PV cell, there is only a single macro BS which is guaranteed to have the minimum distance to any point located within the PV cell among all macro BSs.

Without loss of generality, we focus on a tagged macro PV cell which has a pico BS located inside. Since the coverage radius r of a pico BS is usually much smaller than that of a macro BS, we assume the pico cell is fully covered by the macro cell. Furthermore, in light of the very limited transmission range d of each mobile UE, if we denote by A the area of the macro PV cell, then we can assume that $\pi(r+d)^2 \ll A$. Furthermore, we denote by N_m and N_p, respectively, the maximum number of mobile UEs that the macro BS and the pico BS can simultaneously support. One can see that in actual case, the values of N_m and N_p depend on the total number of channels available at the macro BS and at the pico BS, respectively. If we denote by n_m the number of mobile UEs located within the tagged macro PV cell, and denote by n_p the number of mobile UEs located within the pico cell, according to the Poisson spatial distribution of mobile UEs, we have $n_m \sim \text{Pois}(\lambda_u A)$, $n_p \sim \text{Pois}(\lambda_u \pi r^2)$.

Recall that in Section II, the D2D based traffic offloading method was proposed to alleviate the traffic congestion in macro BS by detouring some mobile UEs to the pico BS which is relatively lightly utilized. If we denote by α the probability that a mobile UE requests for Internet access via the macro BS or the pico BS, we have the following two cases:

Case 1: $n_m > \frac{N_m+N_p}{\alpha}$**,** $n_p \le \frac{N_p}{\alpha}$

In this case, the macro PV cell is severely congested and there are some remaining requesting mobile UEs which cannot have Internet access even after applying the D2D based traffic offloading. We denote by C^1_{D2D} the number of requesting macrocell UEs that fail to obtain a channel from the macro BS but are able to communicate with an idle picocell UE (i.e., D2D relay) after applying Step 1 of our offloading method. Then C^1_{D2D} can be given by

$$C^1_{D2D} = \int_r^{r+d} \frac{2\pi x(n_m-n_p)\alpha}{A-\pi\cdot r^2}\cdot\Big(1-\frac{N_m}{(n_m-n_p)\alpha}\Big)\cdot f(x)\cdot dx \quad (8)$$

where $f(x)$ denotes the probability that a macrocell UE (at distance x from the pico BS) communicates with an idle picocell UE,

$$f(x) = 1 - e^{-\frac{(1-\alpha)n_p\cdot S(x)}{\pi\cdot r^2}}. \quad (9)$$

If we denote by T^1_1 the expected number of mobile UEs that can be supported within the tagged PV cell after applying Step 1, then we have

$$T^1_1 = \int_0^\infty p_1(A)\cdot\min\{N_m+N_p, N_m+n_p\cdot\alpha+C^1_{D2D}\} \cdot f_{PV}(A)\cdot dA \quad (10)$$

where

$$p_1(A) = \sum_{t=\lfloor\frac{N_m+N_p}{\alpha}\rfloor+1}^{\infty}\ \sum_{k=0}^{\lfloor\frac{N_p}{\alpha}\rfloor} \Pr(n_m=t)\cdot\Pr(n_p=k). \quad (11)$$

In (10), $f_{PV}(A)$ is the probability density function of PV cell area A [14],

$$f_{PV}(A) = \frac{\lambda_m^a a^a A^{a-1} e^{-a\lambda_m A}}{\Gamma(a)}$$

where a is a constant $a = 3.575$, $\Gamma(z) = \int_0^\infty t^{z-1}e^{-t}dt$ is the gamma function.

Similarly, we denote by C^2_{D2D} the number of requesting macrocell UEs that fail to obtain a channel from the macro BS but are able to communicate with an idle picocell UE after applying Step 2 of our method, and denote by T^2_1 the expected number of mobile UEs that can be supported after applying Step 2. Then we have

$$C^2_{D2D} = \int_r^{r+d} \frac{2\pi x(n_m-n_p)\alpha}{A-\pi\cdot r^2}\cdot f(x)\cdot dx \quad (12)$$

$$T^2_1 = \int_0^\infty p_1(A)\cdot\min\{N_m+N_p, N_m+n_p\cdot\alpha+C^2_{D2D}\} \cdot f_{PV}(A)\cdot dA. \quad (13)$$

Case 2: $\frac{N_m}{\alpha}+n_p < n_m \le \frac{N_m+N_p}{\alpha}$**,** $n_p \le \frac{N_p}{\alpha}$

For Case 2, we denote by T^1_2 the expected number of mobile UEs that can be supported within the tagged PV cell after applying Step 1, and denote by T^2_2 the expected number of mobile UEs that can be supported after applying Step 2. After derivations similar to that for Case 1, it follows

$$T^1_2 = \int_0^\infty p_2(A)\cdot\big(N_m+n_p\cdot\alpha+C^1_{D2D}\big)\cdot f_{PV}(A)\cdot dA \quad (14)$$

$$T^2_2 = \int_0^\infty p_2(A)\cdot\Big\{\min\{N_p, n_p\cdot\alpha+C^2_{D2D}\} + \min\big\{(n_m-n_p)\alpha - C^2_{D2D}, N_m\big\}\Big\}\cdot f_{PV}(A)\cdot dA \quad (15)$$

where

$$p_2(A) = \sum_{k=0}^{\lfloor\frac{N_p}{\alpha}\rfloor}\Pr(n_p=k)\sum_{t=\lfloor\frac{N_m}{\alpha}+n_p\rfloor+1}^{\lfloor\frac{N_m+N_p}{\alpha}\rfloor}\Pr(n_m=t). \quad (16)$$

Therefore, for a general macro PV cell, the expected number of mobile UEs that can be supported after applying Step 1 and Step 2, can be determined as $T^1_1+T^1_2$ and $T^2_1+T^2_2$, respectively.

V. Numerical analysis

In this section, we analyze the changing of the probability that the node transmitting the connection request can establish the D2D link with some numerical calculation results. Additionally, the effectiveness of the proposed method is confirmed with the numerical results.

A. Parameter settings

In this numerical analysis, the HETNET constructed by a macro cell and some pico cells is considered as the network configuration. Supposed that the radius of the coverage area of the macro cell and the pico cells are set to be 500m and 100m, respectively. Additionally, the maximum number of the nodes which a BS of the macro cell can communicate with at the same time is supposed to be 100. Moreover, the number of the users in the coverage of the macro cell is set to be 1500 and 10% of the user requires the connection. Furthermore, the maximum transmission range of the node to establish the D2D link is set to be 30m. The nodes are deployed to the coverage area of the BS of the macro cell randomly.

B. Numerical results

Firstly, we study the change of the probability that the requesting node can establish the D2D link. Fig. 5 shows the change of the probability when the distance between the edge of the BS of the pico cell and the requesting node varies from 0m to 30m which is the maximum transmission range of the node to establish the D2D link. From the result, it is understood that the probability decrease with the increase of the distance between the edge of the macro cell and the node. This is because that the increase of the distance causes to decrease the size of the overlapped area consisting of the coverage are of the pico cell and the transmission range of the

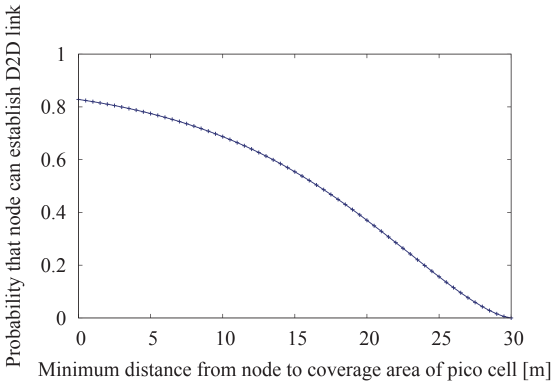

Fig. 5. The change of the probability that the requesting node can establish the D2D link.

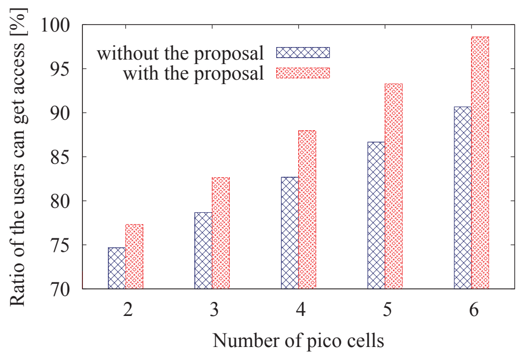

Fig. 6. The ratio of the users can get the requesting connection with the BSs of the macro cell or pico cell.

node. Thus, the probability that at least one node exist in the overlapped area decreases and it is difficult to establish the D2D link.

Secondly, Fig. 6 shows the ratio of the users that can get the requesting connection with the BSs of the macro cell or pico cells to all the users transmitting the connection request while the number of the deployed pico cells is different. From the results, the proposed method achieves higher ratio of the users who can get the requesting connection. Additionally, it is shown that the proposed method achieves higher performance when the number of the deployed pico cells is bigger. This is because that the deployment of pico cells makes it possible to establish more D2D links in the proposed method.

VI. Conclusion

The concept of the HETNET has attracted much attention to improve the network performance. In the HETNET, different types of networks which has different size of the coverage area are deployed at the same area, which increase the network capacity drastically. However, sometimes traffic congestion may occur at the macro cell due to the changing of the user distribution. Thus, in this paper, we proposed the method to utilize D2D communication technologies in HETNET to avoid traffic congestion at the BS of macro cell. By using the D2D communication technologies, our proposed method achieves to detour the traffic from the congested macro cell to the uncongested small cells. Additionally, the advantage of the proposed method is analyzed with some mathematical expressions. Moreover, the numerical results demonstrate that the proposed method achieves higher ratio of the users who can get the requesting connection. Therefore, our proposal can be considered to be an effective traffic detouring method using D2D communication technologies in HETNET.

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