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Mobile network connectivity analysis for device to device communication in 5G network

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ABSTRACT

Since long term evolved release 14 (LTE R14), the device to device (D2D) communications have become a promising technology for in-band or out-band mobile communication networks. In addition, D2D communications constitute an essential component of the fifth-generation mobile network (5G). For example, to improve capability communication, reduce the power dissipation, reduce latency within the networks and implement new applications and services. However, reducing the congestion in D2D communications and improving the mobile network connectivity are the essential problems to propose these new applications or services. This paper presents new solutions to reduce the congestion of devices around a base station and improve the performance of the D2D network; in terms of the number of connected devices or user equipment (UE). The simulation results show that our proposed solution can improve the network capacity by doubling the number of connected devices (or UE) and reducing the congestion. For this reason, our proposition makes it possible to reduce the financial cost by reducing the cost of deploying equipment. For example, instead of using two base stations, we can use only one station to connect the same number of devices.

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1. INTRODUCTION

The device to device (D2D) communications are used in the fourth-generation (4G) and fifth-generation (5G), and now it will allow for direct transmissions between devices [1]. Currently, the communications between two devices are possible without any contribution from the base station called evolved NodeB (eNB) [2]. Nearby devices can communicate directly with any other by establishing direct links [3].

Several services can be improved, including reliability, spectral efficiency, system capacity, and latency within the network [4]. Therefore, the network operators will be able to offer new applications and services based on D2D technologies, in particular, in the 5G [5]. So, D2D communication is an essential technology to improve 5G performance [6]. In terms of spectrum usage, there are two types of D2D communications: in-band and out-band. In-band communications use a licensed spectrum, and out-band communications use an unlicensed spectrum to make the direct links between devices by using Wi-Fi, and Bluetooth [7].

In the D2D communications, we refer to three coverage scenarios depending on the network and devices' location: in-coverage, relay-coverage, and out-of-coverage. In the first scenario (in-coverage), the devices are located within the network coverage area, and the mobile network operator assures some operations: identification, authentication, access control, and connection establishment [8]. The cellular licensed spectrum is shared with cellular connections (user equipment: UE) established by the base station (eNB). The mobile network operator guarantees the coordination of this operation [9]. In the second scenario (relay-coverage), the devices or UEs that are out eNB coverage area can communicate to the eNB by using other devices. The network coverage can be extended, and the operator can improve the existing services or propose new applications or services [10]. Technically, the mobile network operator assures the connections: between the devices out of area coverage to the devices from inside area coverage and between the devices (UE) to the base station (eNB). Also, the mobile network operator guarantees other operations: connection, security management, and resource allocation. The cellular licensed spectrum is shared with conventional communications. In this case, the network coverage can be expanded. In the third scenario (out-of-coverage), the devices are out of area coverage. For this reason, the D2D communications take place between devices without any operator intervention. For example, the UE1 and UE2 shown in Figure 1 can independently set up the connections with each other nearby devices without any operator intervention or assistance. This functionality represents a promising technique to makedirect connections between devices (UEs) without the intervention of base stations (eNB) or access points [11], [12]. In this case, the D2D communications constitute an ideal solution for connecting devices outside of coverage areas. This direct communication between devices reduces network congestion [13].

The fifth-generation (5G) proposes many features of D2D communications that will play an undoubted key role in this future mobile generation as shown in Figure 2 [14]. Many researchers and experts share the opinion that D2D communications can reduce the power dissipation and latency within networks, improve the communications capacity, and enable new applications and services [15]. Also, this technology is an essential communication paradigm that helps solve many heterogeneous object interconnection problems and provides significant benefits [16].

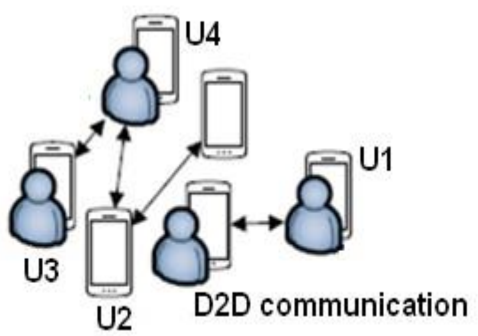

Figure 1. D2D direct communication

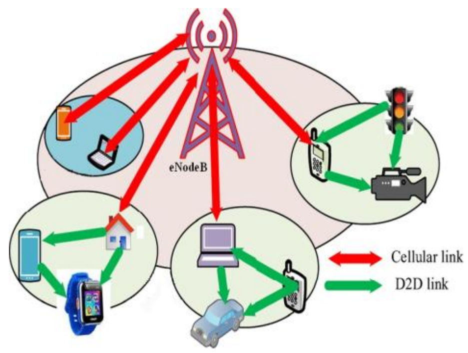

Figure 2. D2D communications in 5G network [14]

In the literature, several works related on our research consist of grouping the devices into classes by using some metric. For example, this procedure is applied in the extended access barring (EAB) to regroup the devices or UEs into the clusters [17]. This technique can reduce network congestion problems.

He *et al.* [18] propose a centralized clustering model and present a resource allocation algorithm based on a clustering procedure in the D2D communications. The algorithm proposed in this article can increase the number of users by more than half. Wang *et al.* [19] present their solution based on the information sharing on D2D cellular networks. They use a cluster formed by the connected terminals located in a close geographical area. Cheng *et al.* [20] present a congestion reduction mechanism using a D2D cooperative relay in the LTE Advanced system and propose their algorithm to improve performance and reduce network congestion problems. Ioannou *et al.* [21] present a D2D clustering solution in the 5G network based on distributed artificial intelligence (DAI) and innovative in D2D, and machine learning (ML). Zafar *et al.* [22] propose an algorithm to solve some problems related to energy efficiency and co-channel interference in the 5G network. The proposed solution focuses on the principle of clustering procedure and D2D communication. Raziah *et al.* [23] propose a collaborative technique based on an adaptive relay selection scheme (ARS) intended to improve the D2D communications in the case of devices located out-band in the 5G mobile network. Hmila *et al.* [24] present an optimization-based model for multicast device-to-device (MD2D) communications based on a clustering process in the 5G mobile network.

Currently, there is an exponential increase in the use of various applications and services focused on network communications: smart cars, smart e-healthcare, and smart education. This type of communication requires a significant investment to implement the new equipment to satisfy this high demand. However, the use of D2D will make it possible to optimize the performance of this type of application and thus reduce the cost of investment in new equipment. So, the main idea of this research is: to propose solutions to increase the connectivity and reduce the congestion of devices around a base station (eNB) in the 5G mobile network without investing in new equipment. The main idea of these works and other similar works is based on the clustering or cooperative devices process to improve the network capability. Also, these solutions resolve only one technical problem: connectivity or congestion. Our proposed solution can solve two problems at the same time. Via our algorithms, we can increase the connectivity of the devices and reduce network congestion problems. For this reason, the remainder of this paper is organized as follows: the second section focuses the proposed method, the third proposes some simulation results, and the fourth presents the conclusion.

2. RESEARCH METHOD

2.1. Problem formulation

In this sub-section, we describe and formulate the problem situation. We focus on clustering devices (UEs). Our objective is to increase the number of connected devices (UEs) by using the clustering process. Note that each base station (eNB) cannot connect many devices exceeding its capacity.

Figure 3 shows the problem situation. Many devices attempt to connect to the base station (eNB). However, this base station (eNB) cannot serve more devices (UEs). So, this situation creates network congestion problems. For this reason, we will propose a solution that can support a high number of devices and thus reduce the congestion of the network.

To formulate our problem situation, we consider: N_B the maximal number of the devices (UEs) supported by the base station (eNB). N_C the number of devices (UEs) connected to the base station (eNB). N_{Ba} the number of devices (UEs) that attempt to connect to the base station (eNB).

Then we can write $N_B >= N_C$. In this case, the base station (eNB) supports only this number (N_B) of devices (UEs). In addition, if $N_{Ba} > N_C$ (the number of devices (UEs) exceeds the capacity of the base station). In this case, we observe the congestion around the base station (eNB), and that influences the D2D network capacity because the number of devices (UEs) attempting to connect to the base station (eNB) exceeds the maximal number of connected devices (UEs) supported by this base station (eNB). We can write also:

$$D_{nc} = N_{Ba} - N_c$$

where, D_{nc} the number of devices not connected to the base station (eNB).

Our objective is to augment the number of connected devices or UEs (N_C) and thus reduce the number of devices (UEs) that are not connected (D_{nc}). That allows reducing the congestion of the network and improves the network capacity. For this reason, we propose a method to switch between two situations: the grouping (or clustering) mode and the individual mode as shown in Figure 4. Our work is to provide a solution to reduce the congestion around network nodes and increase the number of connected devices. In the rest of this paper, we will present our algorithms, give some numerical results and compare our solution with others.

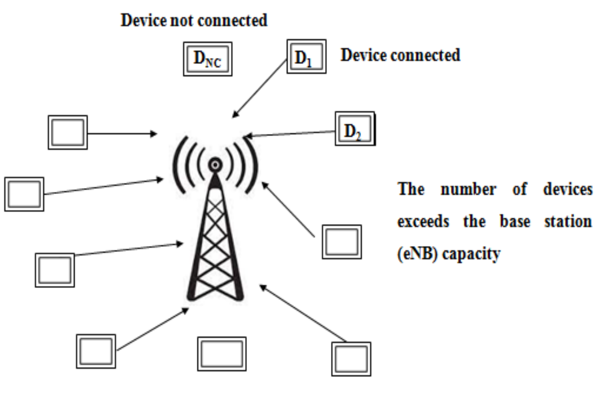

Figure 3. Problem situation

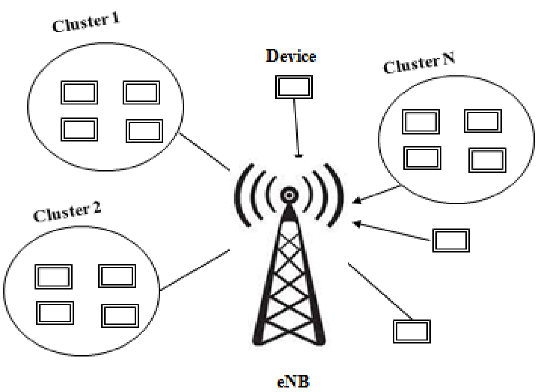

Figure 4. Scheme of our proposed situation

2.2. New algorithms

In this sub-section, we present our proposed solution to increase the number of connected devices (or UE) and reduce the congestion of the network. For this reason, we will present our general algorithm and the grouping process algorithm. The general algorithm as shown in Figure 5 manages all devices (UEs) and, the grouping process algorithm as shown in Figure 6 makes it possible to group the devices (UEs) in the form of a cluster and thus improve the connectivity of the network.

2.2.1. General algorithm

We suppose: N_B the maximal number of the devices (UEs) supported by the base station (eNB). N_C the number of devices (UEs) connected to the base station (eNB). In the beginning, the algorithm in Figure 5 waits for arrival devices and then: if $N_B>N_C$ (the base station (eNB) can support new devices or UEs), the algorithm connects the device (UEs) to the base station (eNB). The number of N_C is incremented by 1. Else, if $N_B==N_C$, the base station (eNB) cannot support any new device or UE (saturation). For this reason, the algorithm puts all devices or UEs into the clustering process. This operation increases the network capacity by augmenting the number of connected devices (UEs). The clustering process consists of grouping the number of devices (UEs) in the form of clusters. Also, in the case of the disconnection of a device or UE, we decrement the number of the connected devices $N_C=N_C-1$.

2.2.2. Grouping process

In the grouping process of our proposed solution, we put the devices in several clusters as shown Figure 6. Here, we consider E the integer part of the division N_{TD}/N_{CMax}.

a. N_{TD}: The total number of devices or UEs (connected and not connected);
b. N_{CMax}: the maximum number of devices (UEs) assigned to each cluster. This number indicates the devices (UEs) supported by a cluster. The formation of this cluster is subject to several criteria: coverage of D2D technology, head of the cluster, traffic and intensity, and channel throughput of the cluster [25]. According to these criteria and the technology used in this paper, this number is fixed at 4 (more explication in the simulation part).
c. M is calculated as follows: $M=N_{TD}$ mod N_{CMax}, Modulo of N_{TD}/ N_{CMax} (this number is used to calculate the number of clusters).

At the beginning of the grouping process, if $M==0$, the algorithm creates E clusters (E is the integer part of division N_{TD}/N_{CMax}) and assigns these clusters to a base station (eNB). Else, the algorithm creates E clusters and assigns the cluster to a base station (eNB). The rest of the devices M ($M= N_{TD}$ mod N_{CMax}) is individually assigned to a base station (eNB). In this scenario, we use two modes: clustering and individual.

Unlike several proposed solutions and methods, our solution can increase the number of connected devices (UEs) to double and reduce the congestion problems. Similar solutions use only one technique or method: grouping mode or individual mode, and cannot solve various difficulties simultaneously. Our proposition can solve two technical problems simultaneously: reducing the congestion problem and increasing the number of devices (UEs) supported by the network. In addition, this solution makes it possible to reduce the financial cost by reducing the cost of deploying equipment. For example, instead of using two stations (eNB), we can use only one station (eNB) to connect the same number of devices. This result presents a significant investment gain.

It is possible to use the network simulation 3 (NS3) to validate this work. This simulator is an open-source software to simulate several works based on mobile network technologies: LTE, D2D communications, 5G NR, eNodeB, HeNodeB, internet of things (IoT) cross-vertical and horizontal applications, integration of radio access with software-defined networks, ext. Our simulation is displayed on a machine (Intel Core i7, 16 GB, 2.8 GHz) under the Linux operating system (Ubuntu 18.04). We present below the main steps to simulate this research:

a. We have installed the following version: "ns-3.30" from the official website. This version is the most suitable for our work. The official website proposes more details on how to install and configure the NS3 simulator;
b. We have used the C language programming (it is possible to use Python) to create a module called: "5GD2Dcommunication". We have configured this module to support our algorithms and return output files that contain our simulation results, Figure 7 shows an example of an output file. Many documents are available on the internet, especially on the official NS3 website, showing the configuration steps and how to create modules and classes;
c. The last step is to set up the simulation and retrieve the results files generated by NS3 (output files). These results will then be analyzed and processed using graphics processing software. It is also possible to configure NS3 to display the results in the form of a graphical interface called: "Result window".

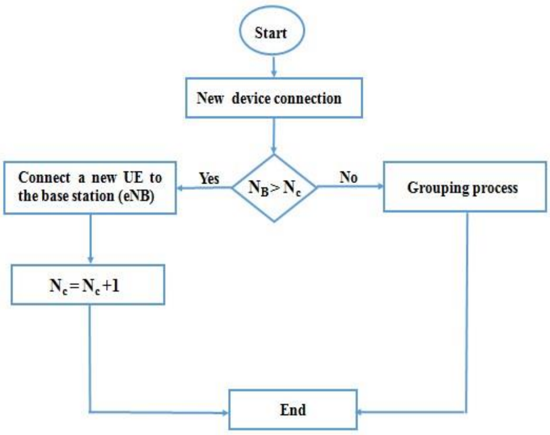

Figure 5. Flow chart of our general algorithm to manage devices

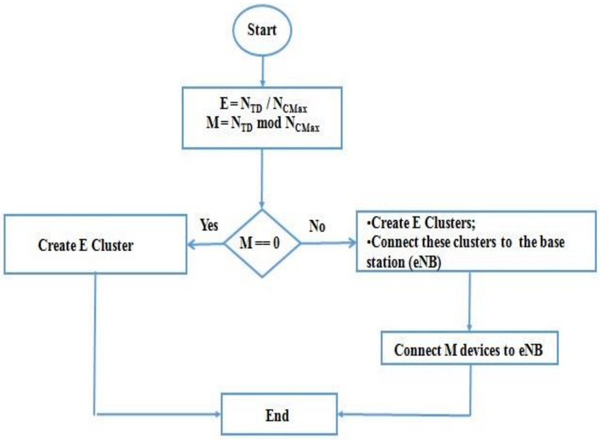

Figure 6. Flow chart of the grouping process

```
Grouping processes simulation
11:40:00
AD:Assigned devices
BSR:Base station reference
AD          Time                BSR
4           11:40:01            BS1
8           11:40:04            BS1
11          11:40:09            BS1
12          11:40:29            BS1
13          11:40:35            BS1
14          11:40:39            BS1
16          11:40:42            BS1
32          11:40:62            BS1
```

Figure 7. Example of output files of grouping process simulation

The output files are composed as follows:

a. Assigned devices (AD): this parameter indicates the devices or UE assigned to a base station (eNB);
b. Time: this parameter indicates the connection time of each device to the base station;
c. Base station reference (BSR): this parameter indicates the number of the base station.

3. RESULTS AND DISCUSSION

This part of the article presents some numerical results to validate our proposed solution. To simulate our work, we have used a small cell base station (femtocell) [26]. The base station (femtocell) used in this simulation can support only 8 devices (it is the maximum capacity). Table 1 shows some specifications of the base station used in this simulation. We will compare two situations: the first uses the base station without our solution (our algorithm is not implemented), and the second uses our algorithm. The simulation was carried out in the laboratory of our university dedicated to this type of study.

This graph in Figure 8 shows the evolution of the connected devices. The time in the y-axis for Figures 8 and 9 shows the approximate time of devices (UEs) connections and allows us to follow the evolution of the number of connected devices over time. Here, the base station cannot exceed its maximum capacity (8 devices or UEs), and then we observe the saturation point. Over time, the base station reaches the saturation point with 8 devices (UEs), and we cannot connect an additional number of devices (UEs). This situation leads automatically to network congestion. This figure shows two technical problems: network congestion and connectivity. Our solution can solve these problems as shown in Figure 9.

Table 1. The specifications of the base station used in our simulation

Base station used: femtocell	Specifications
Coverage range	50 m
Transmit power	20 dBm
Carrier frequency	2 GHz
Services	voice and data

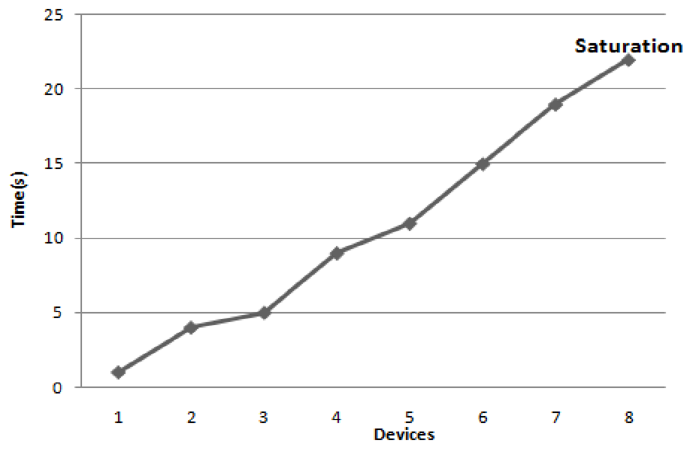

Figure 8. Evolution of the connected devices without grouping process

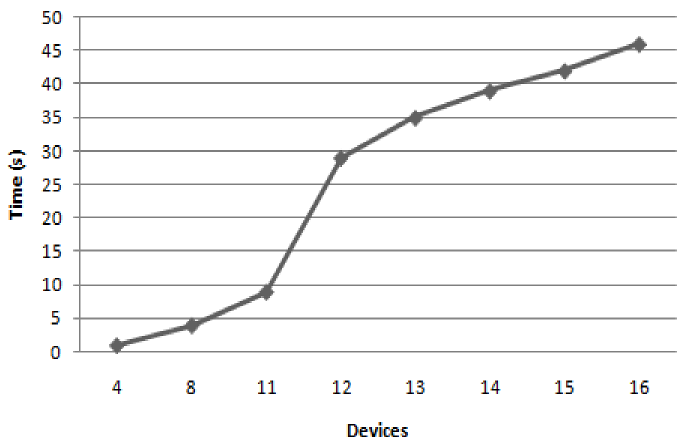

Figure 9. Evolution of the connected devices depending on our solution

This graph in Figure 9 shows the evolution of the connected devices (UEs) according to our solution. Over time, this solution can double the connected devices (UEs); we go from 8 to 16 devices. This figure shows that our proposed solution can double the number of connected devices (UEs) and reduce the congestion problem. In effect, our solution increases the network connectivity (more devices or UEs are connected), and this way of managing the devices or UEs makes it possible to avoid congestion around the base station (eNB). Unlike the solutions and methods presented in the introduction section, our solution solves two technical problems: network congestion and connectivity.

To better understand the usefulness of our proposition, we compare our solution with the method proposed by He *et al.* [18]. They offer a solution that can increase the number of connected devices in the network by more than half. However, our proposed solution can double the connected devices. In addition, unlike several proposed solutions and methods such as: [18]–[24], our proposed solution can be easily implemented without any additional equipment. Our proposition can solve two technical problems simultaneously: reducing the congestion and increasing the number of devices (UEs) supported by the D2D networks. This method can reduce the investment cost for operators. In effect, the telecom operators can reduce the financial cost by reducing the cost of deploying equipment. For example, instead of using two stations (eNB), we can use only one station (eNB) to connect the same number of devices.

4. CONCLUSION

In this paper, we have presented our solutions to increase the number of connected devices (or UEs) and reduce the congestion around the base station (eNB) in the 5G network. These solutions are based on the new clustering process in the D2D communications. The numerical results of this method show the usefulness of our approach. In addition, the implementation of our algorithms makes it possible to double the connected devices (or UEs) without any investment. Therefore, the simulation results show that these proposed algorithms can improve network connectivity by doubling the number of devices connected to the base station (eNB). This proposition presents two types of advantages: technical and economic. Technically, our algorithms can increase the network connectivity and reduce the congestion problems. Economically, our solution can reduce the cost of network deployment, notably for the 5G network.

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