Energy optimization approach in a relay-assisted D2D communication

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Abstract In this paper, we are interested in the problem of radio resources management in order to optimize energy consumption in a D2D communication. This aims being able to meet the needs of all users and therefore the establishment a Quality of Services (QoS). We will propose an approach whose objective is to manage not only overcoming interference situations in order to guarantee QoS but also optimizing the energy consumption of various devices in the D2D communication.

Keywords D2D · Radio Resource Management · 5G · IoT

1 INTRODUCTION

Mobile Radio Communications Networks have evolved up to 5th generation (5G) networks. This is done in full swing with research activities dealing with different layers of protocol stack. In future, systems must provide relevant infrastructure giving interconnection of objects (IoT) and devices (D2D). In a D2D communication Networks, Mobile stations are able to detect each other with an eventual’s directly link communication. Unfortunately (or Even though), some drawbacks appear such Interference. Consequently, an efficient resource management must be done as mentioned in the literature. This is done not only to allow D2D communication but also to support applications of
future systems. Based on the rapid evolution of terminals, their variety (smartphone, tablet, etc.) and the traffic increase this causes a high energy consumption. Compared to a standard LTE network, the architecture of a D2D network adds two new entities on the network side. These are named as Proximity-based Service (ProSe) Function, and ProSe Application Server. The user side adds an entity named ProSe Application [1]. Device-to-device communication is a data transmission technology developed to increase network efficiency. Activated devices may interact using a secure transmission protocol, similar to that used for base station communications [1]. A possible D2D usage could be shown in the figure 1.

![Illustration of possible use cases of the D2D](image)

Fig. 1 Illustration of possible use cases of the D2D [8].

### 2 D2D PHYSICAL CHANNEL

A communication link between two mobile devices without going through the base station defines a Sidelink. This requires a new physical layer design. This layer is mainly designed to minimize D2D communications based on SC-FDMA in both directions. Four types of physical communication channels are recognized [2]:

- Physical SideLink Broadcast Channel (PSBCH) : that carries system information and timing signals.
- Physical SideLink Control Channel (PSCCH) : which controls system information and synchronization signals between the UEs.
- Physical Sidelink Discovery Channel (PSDCH) : which supports the direct discovery of EU transmissions.
- Physical SideLink Shared Channel (PSSCH) : used for data transmissions from the user’s plan.


3 D2D COMMUNICATIONS CLASSIFICATIONS

Three points of view, could be used, to classify the Communications process. We can first of all consider the management aspect that gives the D2D Management.

3.1 D2D Management

This classification shows in a way the participation rate of mobile equipment and the network in the support of D2D communications.

- D2D control: The control of a D2D communication is of three types; total (full control), light (loose control) or hybrid (a balance between total control and light).
  In the case of total control, the communication is entirely managed by the operator’s network for the authentication phase, the allocation of the resources necessary for the smooth running of the communication. For lightweight control, D2D terminals can communicate with each other, with very limited operator network intervention. The network is only responsible for the authentication of the terminals when they are connected to the network; communication as well as the management of radio resources can be managed autonomously by the D2D equipment.
  The last option is hybrid control. In this perspective, critical aspects are managed by the network, including authentication, allocation of radio resources, energy management.
- D2D Discovery: this task is an essential part of D2D communications where device looks for knowing neighbors. This is done to locate a suitable potentially equipment for communication. This process can be composed by two steps named as[3]; discovery initiation and discovery control. The first step deals with the fact that two users want to share specific content. The second one, goes when both users are already engaged in cellular communication, being on the move and end up in close proximity to each other [3].

3.2 Radio Resource Management (RRM)

The management of radio resources is shown in the figure 2.

D2D communications may have access to resources in either TDD (Time division Duxing) or FDD (Frequency division Duxing). Resources initially allocated in UL (uplink) or DL (downlink). Both could also be reused in D2D [4]. This mode has the advantage of being used fewer compared to Downlink since users are more likely to receive data from the network than from other terminals around. As well, interference problems would be easier to manage. They affect basestations and not users [4].
3.3 D2D Communication Forms

As indicated in the literature, D2D communications are classified in four distinct categories called ”topologies” (see Figure 3) as below indicated [8]:

- DR-OC (Device Relaying with Operator Controlled link establishment)
- DC-OC (Direct D2D Communication with Operator Controlled link establishment)
- DR-DC (Device Relaying with Device Controlled link establishment)
- DC-DC (Direct D2D Communication with Device Controlled link establishment)

4 RESEARCH WORK

Due to short-distance, D2D communication can also reduce communication delay and increase network throughput. In [10], author examines future challenges in order to improve network throughput by proposing a joint selection
mode (MS) and a centralized power control (PC) that maximizes the rate sum of D2D links. In [16], the authors proposed an approach to solve the energy efficiency problem for an OFDMA resource allocation type. The proposed method takes into consideration the energy cost. We have selected a few approaches that propose solutions based on the sleeping technique. In [11] and [18], authors propose a solution for cells’s choice to be put in standby based on a threshold equaling the mean load. The value of the threshold determines the trade-off between energy saving goal and network’s performance. In [19], the authors propose a context management platform to reduce energy consumption. This platform consists of three modules.

The first aims to collect information related to energy consumption and to monitor in real time the different interfaces. The second module manages user experience and context information collected through the different access points and radio interfaces in terms of energy consumption and QoS.

The third module however is concerned by network’s discovery. Indeed, authors use in their suggested learning methods, solutions that are greedy in terms of treatment and calculation [19].

5 proposed solution

5.1 Problem formulation

In order to minimize the D2D communication technology’s energy consumption defining basically 5G mobile network, we will exploit the advantage of the PF order in terms of user radio condition. This is mainly based on the principle of the Proportional Fair (PF) scheduler taking into account the energy consumption. To design our approach, it is assumed that the user gives feedback to the emitting terminal of its energy live state like CQI or PLI (Power level Indicator) indicators. This can improve the user experience in terms of energy consumption (taux du gain?). Thus, a relay terminal or the selected node forming a relay between equipments, want to communicate between them. It will switch after a given time in standby or in passive mode when their battery’s level fall down (or will go lower). Closer terminals will have more chance to be served by the relay terminal. At this stage, we call the Duty-cycling technique as it will be explained.

5.2 Duty-cycling technique

Whenever communication is not required, the most effective way to conserve energy is to put the transmitter radio in standby mode. Thus, based on the
network’s activity, the nodes switch between sleep and active periods. This is called Duty-cycling \(^1\).

5.3 hypothesis

We assume that the architecture of our D2D network is a decentralized one. Nodes are organized as a cluster (device group), with a cluster head (Cluster Leader), which communicates the data received to the sending device.

Initially, equipment has the same features dealing energy, calculation and storage capacities. Our goal is to minimize energy consumption for D2D communication in the 5G mobile network, by reducing interference between devices. In this work we will focus on the scenario of a decentralized D2D communication that is to say a direct communication without passing through a relay station.

5.4 Used Topology

We will use the relay topology as following schematized: a DR-DC type relay topology, was considered to evaluate our approach:

![Proposed topology](image)

- **Number of devices**: 6
- **Transmitter Node**: 1

\(^1\) A Duty-cycle is defined as the fraction of time where the nodes are active [14].
We use the duty-cycle protocol, which aims to reduce node activity time in a given communication network. By adding criteria if the battery level of one of the relay device is a low level, it will switch to standby or passive mode (a simple terminal that can receive only the establishment link control signal for example) and wake up after a certain time t, then we will select the devices to communicate according to the level of their battery and the distance between them.

- 1st communication: Transmitter - receiver 2: direct communication
- 2nd communication: Transmitter - device relai 1 (20%) - receiver 1
- 3rd communication: Transmitter - device relai 2 (15%) - receiver 1
- 4th communication: Transmitter - device relai 3 (10%; passive) - receiver 1

In the 4th communication: relai 3 will switch to standby mode and after a moment t changes to active mode because the latter (relai 3) is closer to the issuer.

As a second contribution, we will use the aggregation technique whose purpose is to reduce interference between nodes for peripheral to peripheral communication. We’re adding the aggregation technique to our approach to minimize interference.

We have a device head (head of devices), a single device cluster and three receivers, then the device head collects the different information of the other devices (current state: active, passive, battery level) using the performance indicator CQI, then the latter they will send to the device cluster. Then according to the aggregate information (collect), On using one of utility function (Max, Min, Sum ...), It will select which network will communicate the first “The comparison was made according to the residual energy (remaining energy)”.

The fact that a limited number of nodes are active at a given time preserves the energy of the other nodes that are passive and further increases the life of the network.

6 DIFFERENT D2D SELECTION TECHNIQUES

6.1 Minimum Overdraft Distance between D2D

In this algorithm, the selection will be based on the shortest distances between the devices by neglecting the SINR values although we have an SINR threshold’s value for the system to work. The authors set min threshold at 0, 10 and 20 dB for the analysis of differences in an SINR threshold increase in on the system [6]. This algorithm can be used by the rescue team’s D2D devices to search for survivors in areas around them.
6.2 SINR Maximum without distance limit

In this algorithm the selection will be based on the SINR values because the author chooses the D2D pair, it reaches the minimum SINR threshold and select a maximum SINR value in both directions\[6\]. Theoretically the NASM can be the best as we have not made it consider the threshold of the distance of discovery, so if we solve this problem by rebroadcasting tags, there is a time range of discovery and also power limitations are still open points for further research.

7 SIMULATION AND EVALUATION OF THE PROPOSED APPROACH

In this section, to validate our proposal, we will give the simulation parameters and the different performance metrics that we look for. Then we will analyze and interpret the simulation results.

7.1 simulation parameters

Table.I lists the different parameters used in the simulation.

Path Loss: This is the relationship between the link distance d and average attenuation in a given environment by:

\[
A_{pl} = C(d/d_0)^\alpha
\]  

(1)

Where \(\alpha\) is the path loss exponent, and C is the attenuation at the reference distance \(d = d_0\).
### Table 1 Simulation parameters

| parameters                  | Values  |
|-----------------------------|---------|
| Total power                 | -10 dB  |
| Circuit power               | 0.05 W  |
| Frequency                   | 2.15 GHz|
| Number of users             | 5       |
| Pathloss parameter (Path loss exponent $\alpha$) | 3.5     |
| Number of resource blocks   | 10      |
| Bandwidth (BW)              | 10$^6$  |

### 7.2 Performance Key Indicator

In order to assess the performance of the D2D communication, we will select one of the following performance key indicators:

- Throughput: data rate Average over connection time.
- Energy efficiency: This indicator measures the gain in energy consumption in a D2D communication.
- Latency: measures the time of connection in D2D communications.
- SINR: Signal to interference plus noise ratio, it is a measure that allows to calculate the ratio between the level of the useful signal and those of interference and noise:

$$SINR = \frac{USP}{PoI + NP} \quad (2)$$

USP : Useful Signaling Power  
POI : Power of Interference  
NP : Noise Power

### 7.3 Energy Consumption Calculation Models

#### 7.3.1 transmit powers

First, we assume that for all transmitted data, the bandwidth used for transmission is constant over time. In order to verify the possible gain in terms of energy efficiency within a D2D network, we will analyze the overall energy consumption of the entire network. In the first step, we use the Shannon capacity formula as used by the authors of [20]. This formula gives us the relationship between the data rate transmitted by user equipment $i$ ($D_i$) and the power emitted by user equipment $i$ for data rate transmission ($P_i$) as follows:

$$D_i/W = log2(1 + SNR) \quad (3)$$

Where, W is the channel bandwidth. Our goal is to determine the overall energy efficiency gain for the entire network. We therefore introduce the total
power consumption of the entire network with UA is the source device, UB is the destination node and UR is the relay node, as follows:

\[ P_T = P_{UA} + P_{UB} + P_{UR} \]  

(4)

Where

- \( P_{UA} \) is the total power consumed per UA
- \( P_{UB} \) is the total power consumed per UB
- \( P_{UR} \) is the total power consumed per UR.

7.3.2 Scenario

In our study, we consider topologies DC-DC, DR-DC and adding the proposed approach. Our main objective is to determine whether there could be a minimization of energy consumption for devices in a D2D communication consisting of three devices. These three devices are called UA, UB and UR. UA is the source device transmitting its own data. UB is the destination node, receiving data from UA noted \( X_d \). UR is the relay device, relaying data from UA to UB.

**Direct communication**

In DC-DC topology, UA transmits its \( X_d \) data directly to UB. This topology involves two transmissions:
- UB sends a discovery signal ("beacon") to UA
- UA sends its own \( X_A \) data to UB.

The figure 6, illustrates the time process that is considered for the DC-DC topology.

![Fig. 6 DC-DC topology transmission timing processes](image)

We will use the direct communication topology: DC-DC. The mobile station of proximity are able to detect each other via a discovery processing and to communicate using a direct Sidelink link.
Flow study by number of users

To assess the average throughput of a D2D communication, we will change the number of nodes as shown in the Table II. The simulation result shows that when the number of nodes increases the average rate of direct communication (DC-DC) increases, but in a minimal way.

Table 2 flow study

| Number of nodes | Average throughput (Mbit/s) |
|-----------------|-----------------------------|
| 2 nodes         | 553.9114                    |
| 5 nodes         | 554.8851                    |
| 10 nodes        | 555.3264                    |
| 25 nodes        | 556.1012                    |

Transmission powers according to distance

The optimal transmission power for direct communication according to the different values of \( \epsilon \) (Tolerance factor) shows that when \( \epsilon = 0 \), the transmission power reaches its maximum value depending on the distance between the two. In other cases \( \epsilon = 0.5 \) and \( \epsilon = 1 \), the power of the transmission decreased. We also note, in Figure 7 that as the distance between two proximity nodes increases, there is considerable power conservation, which exceeds 10dB for 50m for \( \epsilon = 0.5 \) compared to \( \epsilon = 0 \) and \( \epsilon = 1 \) compared to \( \epsilon = 0.5 \).

Fig. 7 Power consumed by distance

D2D relay communication

In the DR-DC topology, UA transmits its \( X_A \) data to UB through the UR
relay device, with four steps of the following transmissions:
- UB sends a beacon to UR
- UR sends a beacon to UA
- UA sends its $X_A$ data to UR
- UR sends the data from UA ($X_A$) to UB
Figure 8, graphically explains the Time Process that is taken into account for the DR-DC topology.

![Fig. 8 Time processes of DR-DC topology transmissions](image)

Energy consumed by distance

Figure 9, illustrates the power of the accepted transmission by varying the distance between nodes.
We vary the AB distance between 0 and 200m. Indeed, we assume that 250m is a reasonable distance for D2D communications. When $\epsilon = 0$ or $\epsilon = 0.5$ with the distance between two devices equals 20m: the maximum accepted transmission power reaches its maximum value ($20dBm$). When $\epsilon = 0$ or $\epsilon = 0.5$ with a distance $d = 80m$: the transmission power is increased by comparing with the case $d = 150m$ with the same value of epsilon. Then we notice when the distance ($d$) between the transmitter(UA) and the receiver(UB) in a D2D relay communication increases, the maximum transmission power decreases.

Simulation of the proposed approach
For the transmitter to communicate with the receiver, It sends a message (beacon) for establishing a communication at an instant t. The selection criteria we used are: if the battery level of the relai device is low then it will switch to standby mode (inactive) after an instant t(30 ms) and choose another relai device to ensure communication, respecting the criterion of distance (proxim-
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ity) compared to the source device because the proximity device is more likely to detect and communicate together using the radio interface (PC5 radio interface).

**Energy efficiency as a function of transmission distance** (10m)

For the simulation, we consider the passive state with a power of 0 Watt and the active state with different maximum (40W) and average (25W) transmit power. The two figures 10, 11, illustrate the energy consumption for a D2D communication as a function of node position and energy efficiency (dB),
varying the distance for each configuration. In this illustration the transmission distance is set at 10m.

**Energy Efficiency by Transmission Distance (50m)**

We are proposing to focus on energy efficiency, looking at whether our solution could increase the energy efficiency of the entire system (and then reduce the average energy consumption of the appliances).

7.4 Evaluation of Communication Topology D2D

In this section, we will compare the two D2D communication topologies with our proposed approach in terms of total energy consumption by distance: DR-DC topology, DC-DC direct topology, Proposed approach. Figure 12, shows when $d_{AB} \geq 100$ m the more expensive direct communication topology in terms of energy consumption than relay mode. In all cases, the proposed approach consumes less energy than DR-DC topology. We can also note that for both topologies, DR-DC and our approach the overall energy consumption first believes to reach a local maximum then decreases to a minimum value of $d_{AB}$ which is less than or equal to 20m. The total energy consumed from relai topology (DR-DC) reaches the maximum value when the communication distance between the device UA(transmitter A) and UB(receiver B) is 160 m. We also note that energy consumption by reducing the distance for all three scenarios is decreasing and our approach presents the minimum total consumption.

![Fig. 11 Energy efficiency vs transmission distance (50m)](image)
Device-to-Device communications in the future generation 5G system are very interesting, because they allow more subscribers to communicate at the same time without reducing the quality of communications due to too much network load. During this work, we first introduced the principle of D2D communication. Then a classification of the latter according to three criteria namely D2D management, D2D Scenario and D2D Radio Resource Management. In the second section, we described our proposed approach to managing not only interference situations to ensure the quality of service, but also the energy consumption of different devices in D2D communications. We finished by presenting some simulations using the Matlab tool to evaluate our proposed approach. The simulations showed, in most cases, low energy consumption, extended service life and low end-to-end lead time. We can start from the perspective of public safety (public safety) in a D2D communication, because the main challenge of 5G is to improve the QoS/QoE of users with the efficient exploitation of available resources and by ensuring continuity of services with more cooperation and interoperability.

9 Declarations

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