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Device-to-Device Content Distribution in Cellular Networks: A User-Centric Collaborative Strategy

Paolo Castagno, Rossano Gaeta, Marco Grangetto, Matteo Sereno
Dipartimento di Informatica, Università di Torino
Corso Svizzera 185, 10149, Torino, Italia
Email: {castagno, rossano, grangetto, matteo }@di.unito.it

***Abstract*—In this paper device-to-device (D2D) communication is proposed as a tool for enhancing the services provided by mobile cellular networks. The proposed approach is tailored to mobile services with high bandwidth demands (e.g., real time streaming services).**

The technique we discuss relies on the cooperation among the mobile users that participate in the service delivery process, under the control of the base station. In particular, the paper proposes an incentive mechanism encouraging terminals to organize into an optimal number of clusters from the point of view of both bandwidth capacity and power saving. The aspects inducing users to collaborate are analyzed and modelled, e.g., the amount of mobile battery power drained during collaboration, to better design incentives to switch to D2D.

The proposed technique allows the base station to estimate the incentives to grant to the mobile terminals to optimize its cost. Through both analysis and simulations, we show that our scheme achieves a significant gain in terms of costs while increasing the bandwidth capacity of the whole cell.

I. INTRODUCTION

Device-to-Device (D2D) communications have recently attracted a large bunch of research as a promising approach capable to enhance the standard cellular infrastructure, e.g. 3G and 4G networks, under several aspects such as improved spectral efficiency, larger capacity and lower energy consumption [1], [2], [3], [4]. According to the D2D paradigm mobile terminals (MT) are required to behave as a part of a group in which members in a good state help one another to achieve the optimum state for the whole community.

In particular, it has been recently shown that D2D can significantly boost the performance of group oriented services [5], [6], e.g., bandwidth demanding multicast or broadcast of multimedia. According to the taxonomy of D2D communications described in several works (e.g., [7]) we consider *outband controlled D2D communication* where user terminals are allowed to collaborate using unlicensed spectrum channels, e.g., WiFi links, under the guidance of a central entity, i.e., the base station of the cellular infrastructure. By contributing their own short range bandwidth capacities MTs can increase the overall cell capacity while reducing the load on the base station with resulting reduction of cost and power consumption under certain circumstances.

Previous works [5], [6], [7] show that cooperation in this kind of scenario leads to optimal outcome for the whole community but do not analyze in detail many issues that may arise on the user side. In fact, cooperation can appear as an additional cost for the user because she/he can see her/his battery operated terminal drain more power to support a cluster of connected devices. So, what if any client is considered as a selfish and rational player? Is cooperation still the best choice?

Our contribution

In this paper we consider a set of MTs covered by the radio of a cellular base station and we assume that the users have subscribed a pay-per-view service to receive a common content, e.g., live streaming of a popular event. In this scenario, we define proper mechanisms to incentive collaboration by leveraging on the subscription costs. Several other papers have shown that D2D strategies can be used to relieve the base station task. This approach clearly amounts to shift some of the efforts to the MTs that are charged by an extra task (the relay service), hence increasing their energy consumption; such issues related to the MT point of view have attracted limited attention in the literature. The D2D-enhanced relay scheme proposed in this paper tries to fill this gap. In particular, the proposed analysis is centered on the MTs, on the incentive that the base station must offer them to participate to the content distribution, and on the relations between these issues and the user battery state.

The main contributions of the paper are:

- the proposal of an incentive mechanism encouraging terminals to organize into an *optimal* number of clusters from the point of view of both bandwidth capacity and power consumption;
- the consideration in the overall balance of hidden terminal costs, e.g., the battery power drained for altruistic collaboration.

We validate the model representing our incentive mechanism against detailed simulation in both static and dynamic scenarios. We then exploit the model analysis to quantify the cost reduction of the BS thanks to energy savings and the increased spare bandwidth that can be allocated to other services. Furthermore, we observe that gains increase as the BS incentivizes MTs to act as cluster heads for short periods of time.

The paper is organized as follows. In the next section the related work is summarized, in Sect. III the problem that we want to solve is defined precisely, Section IV defines and analyzes the incentive mechanism we propose, Section V validates the modeling approach and discusses some numerical results. Finally, Section VI draws conclusions and outlines future research lines.

II. RELATED WORK

There are many papers that focus on the use of D2D communications in cellular networks. First of all we must point out that while the classical cellular networks consist of connections from the BSs to the MTs, the D2D communications introduce a two-tier architecture consisting of a macrocell tier for the BS to MT communication, and a second device tier for D2D communications. Such architectures combine the classical cellular network architectures and features of ad-hoc networks.

Several taxonomies of possible D2D architectures have been proposed (e.g., [7]). In particular, according to the used radio spectrum we can have D2D communications that occur on cellular spectrum (i.e., in-band) or unlicensed spectrum (i.e., out-band). Concerning the out-band communications, the coordination between radio interfaces is either controlled by the BS (i.e, controlled) or by the MTs (i.e., autonomous). Most of the research proposals that focus on in-band D2D communications study the problem of interference mitigation between D2D and cellular communications (e.g., [1], [2], [8], [9]). Concerning out-band D2D communications, the research focuses on power consumption (e.g., [3], [4]) and inter-technology architectural design.

In this paper we restrict the attention on the D2D communications controlled by operator where the cellular network operator controls the communication process to provide better user experience and make profit [8], [10]. In particular, we consider how to efficiently use D2D communications for enhancing the quality of wireless multicast services in cellular networks. There are several other studies that address similar issues, see for instance [11], [12], [13], [5], [6]. In these papers several paradigms for multicast content delivery in LTE systems based on the joint use of cellular and short-range D2D communications have been proposed. All these proposals point out the potentialities of the different approaches in terms of energy consumption and of bandwidth resources. Our research focusses on the same type of applications but with a different viewpoint: the cooperation of the mobile users. That is, the exploitation of the D2D communications depends on the cooperation of the mobile users that must help the BS in the content distribution process. A cooperative mobile user consumes an extra amount of energy (e.g., the energy to forward the contents to other mobile users by using D2D communications) and this reduces its battery level. This paper defines an incentive strategy to boost the mobile users cooperation and a method to measure the effectiveness of the D2D communications in the content delivery process with respect the mobile user cooperative attitudes.

III. PROBLEM FORMULATION

A. System Description

We consider N *mobile terminals* (MTs) in the range of a *base station* BS that subscribed a pay-per-view service to receive a common content that is being transmitted by the BS (e.g., the live streaming of a popular event). The MTs are equipped with two wireless interfaces; a *long range* link interface that is used to communicate with the base station (e.g., 3G, 4G, LTE), and a *short range* link interface that can be used to communicate directly with other MTs without the brokerage of the base station (e.g., Wi-Fi Direct [14]).

In the absence of any strategy aiming at reducing energy consumption and/or bandwidth optimization, all N MTs would download the content over long range links that connect them to the base station. In this case, the base station would stream the complete content to each MTs that subscribed for it.

According to the taxonomy of D2D communication described in several papers (e.g., [7]) in this paper we consider *outband controlled D2D communication*. To this aim the MTs can cooperate and forward among each other on short range links the content that is received on long range links. As a result, the MTs can reduce the amount of data circulating over long range links targeting both a decrease in terms energy consumption and an increase in the capacity of the base station. In the following, we consider a generic model in which the cellular network uses as long range links technologies such as 3G, 4G, or LTE, while the short range links adopt the Wi-Fi Direct technology. The transmissions are done in unicast on long range links whereas on the short range links multicast is used. We assume that wireless multicast optimization techniques (e.g., [15]) are deployed to increase the number of receivers. An example of the system we study is depicted in Figure 1.

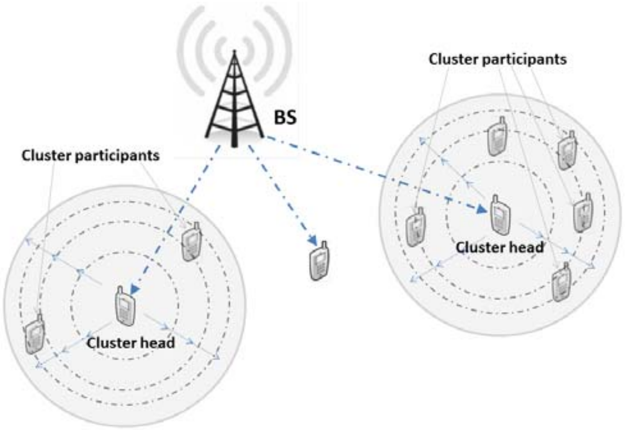

Fig. 1: Illustrative example of D2D communication assisting cellular content distribution

B. Energy consumption

In the following we assume that energy consumption is solely determined by transmissions (we neglect the energy consumption due to receptions). We only consider transmission costs for the base station and we assume that this energy consumption does not depend on the distance that divides it from MTs; we denote by $E_{tx,b2d}$ the power consumption rate (in W/Mbsp) needed by the BS to transmit (in unicast) to a MT. Furthermore, we describe the energy available to MTs as the normalized battery level $x \in [0, 1]$ where $x = 1$ represents a fully charged battery while $x = 0$ represents a completely discharged battery.

C. User cooperation

The exploitation of the D2D communication is profitable because it can increase the cell capacity and reduce the BS power consumption at the same time. To achieve these goals the BS must devise mechanisms to provide incentives to MTs to organize themselves into *clusters*. In a cluster the so called *cluster head* is the only MT that directly receives the stream from the BS. A cluster head then forwards the stream to the other MTs belonging to the same cluster (i.e., the *cluster participants*).

In the following section we describe an incentive mechanism that the BS (i.e., the mobile network operator) can use to foster the MTs cooperation in the content distribution process. In particular, we address two issues related with the BS goals: *i)* the incentive mechanisms to encourage the MTs to organize themselves into an "appropriate" number of clusters, and *ii)* a cooperation strategy between the BS and the MTs.

IV. THE D2D-ENHANCED RELAY SCHEME

Several other papers show that D2D communications can be helpful to relieve the task of a BS. Although it is well known that a MT that cooperates with the BS is charged by an extra task (e.g., the relay service), and hence increases its energy consumption, little attention has been paid to this issue up to now.

Note we assume that the energy consumption required to a MT for receiving the data via a short range links (i.e., throughout D2D communications) is lower than that needed to receive the same amount of data via the long range link (i.e., via the BS). As a consequence, in our analysis, a (rational) MT, if possible, would prefer joining a nearby cluster, and then receive the content from the cluster head, instead of downloading it via the long range link.

Assume that the battery level of a MT can be represented by a continuous random variable X with values in $[0, 1]$ with a given probability density function $f(x)$. Moreover, we denote by $x_{\min}$ the minimum power level that the battery must have to allow the MT of being cluster head for the time duration of the relay period. That is, when a MT has a battery level lower than $x_{\min}$ the MT's energy is not sufficient for accepting this task. Note that $x_{\min}$ depends on the power consumption rate in charge to the MT for receiving over the long range link, on the power consumption rate for forwarding the content via D2D communication, and on the time duration of the relay period.

A MT that serves as cluster head consumes an additional quantity of its battery and hence without an appropriate incentive, the MTs do not cooperate with the BS in the content distribution process. In the following we develop our analysis to determine an optimal strategy that the BS can use to encourage the MTs cooperation.

The (monetary) incentives used by the BS should be a form of payment that the BS recognizes to a cluster head MT for its help (and hence for its the extra consumption). The incentive could be a form of discount that the BS provides to the MT for the current or the future services delivered by the BS.

Please note that it is difficult to convince a mobile user by using considerations based on the cost of extra energy required for being cluster head (see [16] for details). The definition of appropriate incentives should be approached in terms of the value that the help provided by a MT brings to the BS and it should be a form of compensation for the decrease of the battery level.

In the following we formulate the problem as a bargaining problem between the BS and the MTs. Each MT has its own minimum incentive that is willing to accept, and this minimum depends on the battery level.

Let denote by $m(x)$ the minimum incentive that a MT is willing to accept (given a battery level $X = x$) for being cluster head. The BS chooses an incentive b that is being offered to the MTs. Each MT accepts, and hence it can assume the role of cluster head, if $b \geq m(x)$. Note that the BS does not know the MTs battery level but its knowledge can be summarized only by the probability distribution of these values. From this it follows that the BS can derive an estimation of the probability that a MT is willing to accept for being cluster head as function of b.

We assume that the minimum incentive that a MT is willing to accept is a function of x defined in the interval $[x_{\min}, 1]$; we assume this function takes small value when the battery of MT is fully charged increasing as x tends to $x_{\min}$. Furthermore, to define a such function we assume that $m(1) = co$, that is, *co* is the minimum incentive that the a MT is willing to accept when its battery is fully charged. A function that satisfies these features can be defined as:

$$m(x) = \begin{cases} \dfrac{1}{(x - x_{\min})^a}\lambda & \text{for } x \in (x_{\min}, 1] \\ \text{undefined} & \text{elsewhere,} \end{cases} \tag{1}$$

where $\lambda = (1 - x_{\min})^a \cdot co$, and a is a real number used to increase/decrease the concavity of the function. Figure 2 depicts the function defined by Equation (1), with $x_{\min} = 0.3$, $co = 0.1$, and for three different values of a.

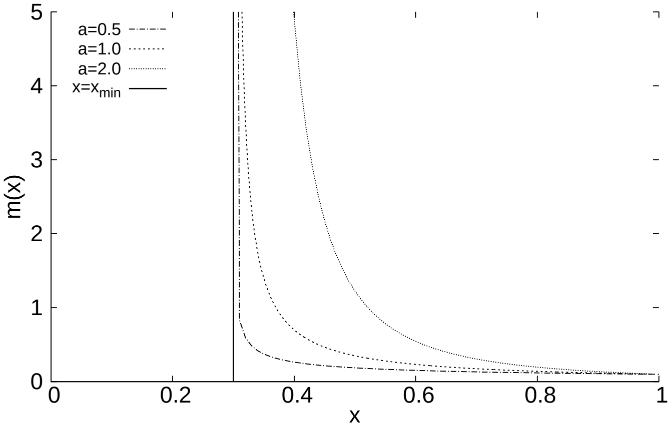

Fig. 2: Function defined by Equation (1) for $a = 0.5, 1$, and 2.

Please note that the function defined by Equation (1) is only one of the possible functions representing the minimum incentive that a MT is willing to accept; other different functions with the same behaviour in $(x_{\min}, 1]$ are plausible and can be used to this end.

In the following we assume that the normalized battery level is distributed according to a uniform random variable in $[0, 1]$ and then the minimum incentive that a MT is willing to accept for being cluster head is a function of such random variable. Nonetheless the following derivation does not depend on the uniform assumption and can be extended to any other probability distribution, if more accurate modeling of the normalized battery level is available.

To determine the c.d.f. of the minimum incentive we must account that the domains of the uniform random variable (i.e., $[0, 1]$) and of the function $m(x)$ (i.e., $(x_{\min}, 1]$) are not equal and hence we must derive the conditional c.d.f. From this it follows that if $X = Unif[0, 1]$ we can define a conditional random variable Y that represents the minimum that a MT accepts for being cluster head whose conditional c.d.f. is $\mathbb{P}(Y \leq y|X > x_{\min})$. In particular, since the function $m(x)$ is monotone, we can apply the classical method to derive the c.d.f. of a function of random variable, and hence

$$\mathbb{P}(Y \leq y|X > x_{\min}) = \begin{cases} 0 & \text{if } b < co \\ \dfrac{1 - \sqrt[a]{\dfrac{\lambda}{y}} - x_{\min}}{1 - x_{\min}} & \text{if } b \geq co, \end{cases} \tag{2}$$

where co is the minimum incentive a MT accepts when its battery is fully charged. In Section V, to analyze the effects of different distributions of the battery levels, we use a uniform distribution in $[l, u]$ (with $l < x_{\min} < u$). To this end, we must use a version of c.d.f. described in (2) that accounts for the different interval $[l, u]$ that can be written as

$$\mathbb{P}(Y \leq y|X > x_{\min}) = \begin{cases} 0 & \text{if } b < co \\ \dfrac{u - \sqrt[a]{\dfrac{\lambda}{y}} - x_{\min}}{u - l - x_{\min}} & \text{if } b \geq co. \end{cases} \tag{3}$$

From (2) we can derive the probability that a MT is willing to accept of being cluster head if the offer of the BS is equal to b:

$$p_r(b) = \mathbb{P}(Y \leq b|X > x_{\min})(1 - x_{\min}). \tag{4}$$

The probability that *exactly* l MTs accept to become cluster heads is binomially distributed and can thus be written as

$$p_n(l, b) = \binom{N}{l} p_r(b)^l \cdot (1 - p_r(b))^{N-l}, \tag{5}$$

yielding the average number of MT that accept to become cluster heads $\overline{n}_r(b) = p_r(b)N$.

Let us denote by A_{d2d} the area covered by a cluster head multicasting the data received from the BS on the long range link, and by A_{m2d} the whole area covered by the BS. If we assume there are l cluster heads we can approximate the probability that a generic MT does not fall in the area covered by the l cluster heads as

$$p_u(l) = \left(1 - \frac{A_{d2d}}{A_{m2d}}\right)^l. \tag{6}$$

Equation (6) has been derived under the hypothesis that the coordinates of the N MTs in the area covered by the BS are described by uniform independent random variables. Accuracy of approximation described by Equation (6) increases as the ratio $\frac{A_{d2d}}{A_{m2d}} \to 0$: in this case, the probability that a fraction of the A_{d2d} area falls outside the A_{m2d} area (this is the reason why Equation (6) is an approximation) also approaches 0.

By combining Equation (5) and Equation (6) we can derive the average number of MTs that are not covered by any cluster head that is multicasting the data as

$$\overline{n}_u(b) = \sum_{l=0}^{N} (N - l) \cdot p_n(l, b) \cdot p_u(l). \tag{7}$$

Note that in our content distribution scheme the MTs that are not covered by any cluster head that is multicasting the data are served by the BS over the long range link. We can derive the average number of MTs that received the data via cluster head MTs as

$$\overline{n}_c(b) = N - \overline{n}_r(b) - \overline{n}_u(b). \tag{8}$$

The average cost in charge to the BS to serve the N MTs (directly via long range link or indirectly via the D2D communications) can be computed by taking into account the energy costs for sending the data on long range links (i.e., for the $\overline{n}_r(b)$ cluster heads, and for the $\overline{n}_u(b)$ that are not served by any cluster head) plus the incentives that it pays to the cluster heads. In particular, if we denote by $E_{tx,b2d}$ the power consumption rate for the BS (i.e., expressed in Watt/Mbps), by vb the streaming bit rate, and by t the time duration of the streaming service, the energy that the BS consumes to serve the N MTs, directly via long range link or indirectly via the cluster heads (i.e., D2D) can be derived as

$$E_{BS}(b) = (\overline{n}_r(b) + \overline{n}_u(b)) \cdot vb \cdot t \cdot E_{tx,b2d} \text{ (in Watt} \cdot \text{h)}$$

To derive the costs in charge to the BS we must account for two terms, one of which is related with $E_{BS}(b)$ while the other one takes into account for the incentives paid to the MTs (for being cluster heads). If we denote by d the energy cost expressed in \$/KWh (or in €/KWh) we can write the BS costs (as a function of b) as

$$c_{BS}(b) \quad = \quad d \cdot E_{BS}(b) + b \cdot \overline{n}_r(b). \tag{9}$$

Note that average cost defined by Equation (9) is defined as a linear combination of several terms derived from the probability defined by Equation (4), and hence it is continuous in $\mathbb{R}^+$ (as a function of b). From this it follows that we can easily find the b^* that minimizes it.

To ease reading, Table I summarizes the notation we used in the paper.

V. NUMERICAL AND SIMULATION RESULTS

In order to assess the ability of our algorithm to reduce the BS costs, we perform a set of experiments, using the mathematical derivations presented in Section IV and two simulators that represents the studied system. A simplified C++ discrete event simulator has been used for validating the approximation we introduced (see Equation (5) and the issues related with its characteristics). In this case we simulate static

Parameter	Description
N	Number of MTs that subscribed the service
b	Incentive offered by the BS
d	Energy cost
x	Battery level for a generic M
$x_{\min}$	Minimum amount of battery needed to guarantee the cluster head
vb	Streaming bit rate
t	Streaming duration
$p_r(b)$	Probability that a MT accepts to become cluster head
$p_n(l,b)$	Probability that l MT accept to become cluster heads
A_{m2d}	Long range link covered area (BS's coverage area)
A_{d2d}	Short range link covered area
$p_u(l)$	Probability that a MT is not covered by any of the l cluster heads
$\overline{n}_r(b)$	Average number of MTs that accept to become cluster head
$\overline{n}_u(b)$	Average number of MTs that receive contents from the BS
$\overline{n}_c(b)$	Average number of MTs that receive contents via D2D
$E_{tx,b2d}$	BS consumption rate to transmit over long range link

TABLE I: Used notation (defined for an area covered by a BS)

Parameter	Value
A_{m2d}	0.1256 (Kmq)
A_{d2d}	0.0063585 (Kmq)
N	100
$E_{tx,b2d}$	14.65 (Watt/Mbps)
vb	1 (Mbps)
t	1 (hour)
d	0.2 (€/KWh)
co	0.1 (€)

TABLE II: Experimental settings

MTs randomly placed in a circle representing the BS service area and for each BS offer b we count the number of MTs that can accept to be cluster head and the number of MTs that can switch to D2D. In particular this simulator, being based on actual placement of MTs, does not use the approximation yielded by Equation (6) to check if a given node cannot participate to any cluster. Furthermore, we simulate the same scenario with ns-3 [17] to evaluate the proposed technique in more realistic settings that take into account user mobility. For the definition of the scenario we study we use the parameters listed in Table II

For the BS's power consumption we use the LTE energy model presented in [18]; with the parameters listed in Table II one can derive the power consumption rate $E_{tx,b2d} = 14.65$ (in W/Mbps). Using the results on WiFi consumption presented in [19] we estimate reasonable values for x_{min}, i.e., the percentage of battery consumed by the MT to act as a cluster head. Assuming a typical battery capacity of 1400 mAh and using the Peukert's law to approximate the drained charge we get $x_{\min} = 0.34$, when the cluster head relay period is one hour long.

Figure 3 shows the BS's costs $c_{BS}(b)$ as function of b. We can observe that the value of the offer that that minimizes BS's cost is equal to $b^* = 0.176$ when $c_{BS}(b^*) = 0.1375$; if one compares this value with the cost charged to the BS in absence of D2D (obtained setting $b = 0$) $c_{BS}(0) = 0.2915$, it can be noted that D2D allows for a cost reduction of about 54 %.

A deeper insight into the D2D benefits can be noted in Figure 4 that shows the number of MTs in the different roles, i.e., cluster heads, cluster participants, and MTs that receive the streaming from the BS without being cluster head. We can observe that for $b < co$ no MT accepts being cluster head and the BS station must provide the streaming service to all the MTs . Furthermore, for optimal $b^* = 0.176$ we have that $n_r(b^*) = 17.02$, $n_u(b^*) = 28.45$, and $n_c(b^*) = 54.5331$. That is, with the optimal offer 54.5 % of the streaming service is supported by MTs collaboration. Figure 3 and Figure 4 allow to point out the two perspectives of the D2D communication: *i)* the cost reduction derived by energy savings, and *ii)* the BS spare bandwidth (due to the reduced number of users being served directly) that can be allocated to other services with an overall increase of the BS capacity.

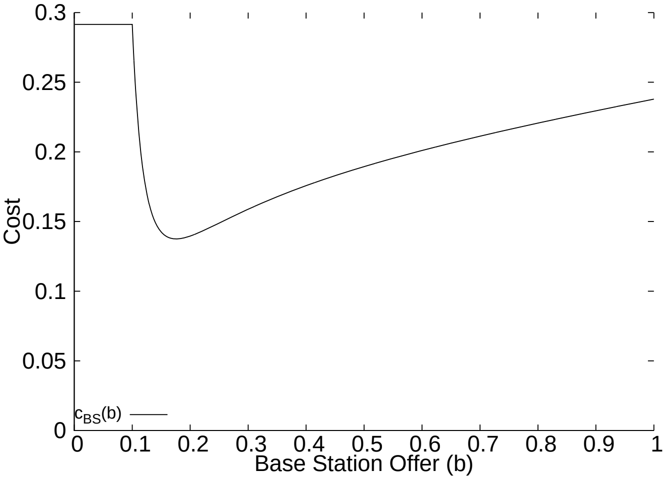

Fig. 3: BS costs as function of b

Furthermore, in Figure 4 we also superimpose to each curve the corresponding estimates (using square, circle and cross markers) obtained by simulation. It can be noted that the simulation and analytical results are consistent.

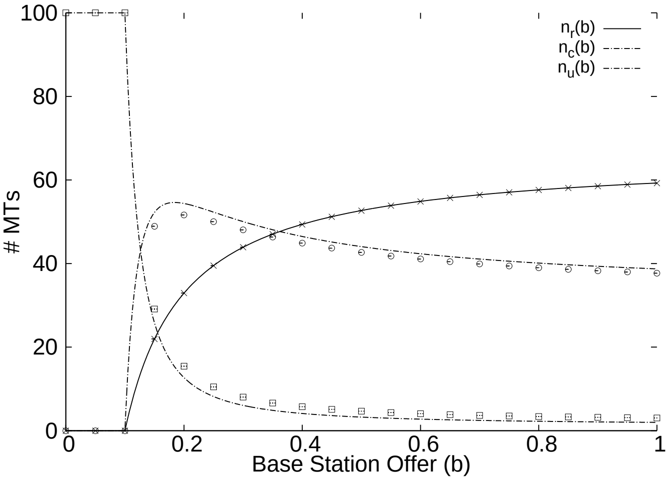

Fig. 4: MTs roles as function of the BS's offer

Until now we have considered a scenario where the streaming period and the relay period coincide (1 hour). In Figure 5 we consider a shorter relay period, i.e., we split the streaming period into 4 relay intervals of 15 minutes each, and the BS iterates the bargaining with the MTs in each round. Figure 5 compares the overall cost for 1 hour of streaming when $t = 15$ and $t = 60$ minutes, respectively. Since $x_{\min} = 0.09$, and $x_{\min} = 0.34$ for $t = 15$ and $t = 60$ minutes respectively, it follows that it is less costly for the BS to incentive a MT to act as cluster head for a shorter period. Moreover the number of MTs that can accept relaying is larger because the required battery level is smaller. Nonetheless to compare the two choices one has to look at the global cost for all the service duration, e.g., 1 hour in our case, as done in Figure 5. These results indicate a clear path: shorter relay periods yield better performance. Obviously, this is an issue that must be carefully addressed in future work taking into account the overhead due to cluster management and handover.

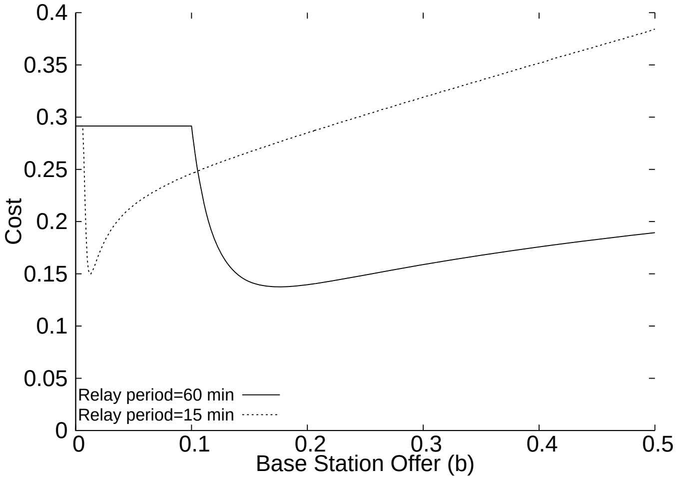

Fig. 5: Effects of different durations of the relay periods

In the next set of experiments we investigate the effect of the battery level distribution. We must point out that, to the best of our knowledge, there are no contributions in the literature addressing this aspect. To show the effect of the battery level we consider two uniform distributions with different average values, one biased towards lower levels and the other towards fully charged battery. In Figure 6 the BS's cost is shown as function of b for a battery distribution $f(x)$ uniformly distributed between $(0.4, 0.8)$ and $(0.6, 0.1)$, respectively. It can be noted that our model is able to capture the positive effect of more collaborative MTs in case of well charged devises, that allow the BS to lower the optimal offer.

The analytical results (and also the simulative results derived by using the C++ simple simulator) have been derived in an ideal scenario that does not take into account for the user mobility. To overcome this assumption and investigate the impact of the user mobility we implement the same discrete event simulator with ns-3. In the ns-3 model we study a system with 35 MTs and analyze the performance of the D2D assisted streaming system for a period of 15 minutes. Moreover, we assume that the MTs follow a random walk mobility pattern characterized by a speed in the range of $0 - 2m/s$ (given that the MTs are watching a streaming video a higher speed is not very realistic). Figure 7 compares the average number of MTs partecipating to D2D (cluster participants) computed by the ns-3 simulator and by using Equation (8). We can see that in presence of mobility the number cluster participants slightly decreases during the experiments with respect to the analytical prediction. This can be explained with the fact that, during a relay period, the cluster head moves potentially creating uncovered areas that are not captured by the analytical model. This issue can be limited by using shorter relay periods with proper management of the cluster handover.

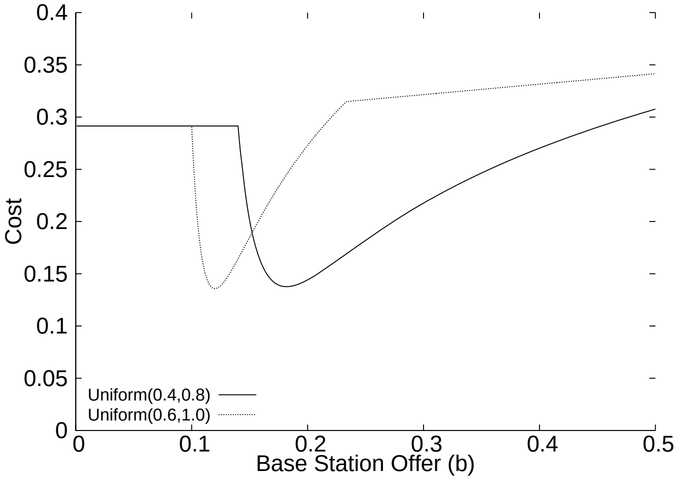

Fig. 6: Cost with different batteries distributions

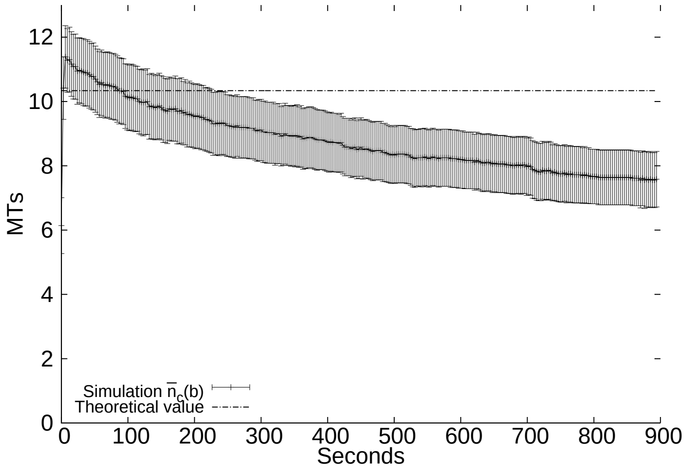

Fig. 7: Simulation result derived by using ns-3 (the plot shows the average number of cluster participants and the 95% confidence interval).

VI. CONCLUSIONS AND FURTHER WORK

In this paper we propose a D2D-based communication communication strategy for collaborative content delivery in mobile cellular networks suitable for services with high bandwidth demands such as for instance streaming services. The proposal is based on the cooperation of the mobile users that collaborate with the base station by distributing the received contents to other (neighbor) mobile terminals. This is the basis of our proposal and it quite easy to figure out that in a similar distribution scheme the base station reduces its load by shifting a fraction of it on the mobile users that decide to cooperate in the content distribution process. But it also well known that for their collaborative behaviors these mobile users incur in additional power consumption. From this it follows that a crucial issue for a successful exploitation of D2D communications concerns the incentive strategies that the mobile network operator (via the base station) must use to involve the mobile terminals in the content distribution process. Moreover, the collaborative attitude of the mobile terminals, that is, their propensity in incurring in a extra power consumption, depends on their battery levels. In other words, a mobile terminal with low battery level is more reluctant to collaborate, and on the other hand when it has a fully charged battery the collaborative attitude is higher.

The strategy presented in the paper allows the base station to derive an incentive strategy based on a statistical knowledge of the battery levels of the mobile terminals in its coverage area. The strategy originates an optimization method that the base station can use for deriving an estimate of the offer to provide to the mobile terminals.

We validated the model representing our incentive mechanism against detailed simulation in both static and dynamic scenarios. We then exploited the model analysis to quantify the cost reduction of the BS thanks to energy savings and the increased spare bandwidth that can be allocated to other services. Interestingly, we observed that gains increase as the BS incentivizes MTs to act as cluster heads for short periods of time.

We must point out that in the proposed study there are many issues that require further investigations. A non exhaustive list of them includes the transposition of the proposed theoretical framework into an implementable protocol. To this aim we must define, for instance, a method to handle the interference among D2D communications. We are tackling this issue by using a method based on the interference graph proposed in [20]. We are using this graph to determine (dynamically) the mobile terminals that overlap their D2D transmission areas. A possible protocol, under the base station control, starts with the base station offer and collects all the mobile terminals that accept it. In the next steps the base station sequentially selects mobile terminals from the list of those that accept the offer and give them the permission to activate the D2D relay. A set of signalling messages from the mobile terminals to the base station and vice-versa is used to handle the interference and manage the activation/de-activation of the D2D communication.

Other research directions are more oriented towards the analytical side of the proposed scheme. In particular, we are evaluating the effect of different distributions of the battery levels, and the effects of other functions to represent the mobile terminal behavior with respect to the base station offer and to its battery level.

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