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Published in:
IEEE Wireless Communications and Networking Conference (WCNC), 2016

DOI:
10.1109/WCNC.2016.7565152

Published: 15/09/2016

Document Version
Peer reviewed version

Citation for published version (APA):
Ismail, M., Shakir, M. Z., Serpedin, E., & Qaraqe, K. A. (2016). Efcient selection of source devices and radio interfaces for green Ds2D communications. In *IEEE Wireless Communications and Networking Conference (WCNC), 2016* IEEE. https://doi.org/10.1109/WCNC.2016.7565152

Efficient Selection of Source Devices and Radio Interfaces for Green Ds2D Communications

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***Abstract*—In this paper, a novel devices-to-device (Ds2D) communication paradigm is proposed to enable green (energy efficient) wireless networks. Different from the conventional D2D communications, the sink device establishes simultaneous associations with multiple source devices for file download using its multiple radio interfaces and the multi-homing technique. In such a networking setting, we propose a network-controlled algorithm for optimal selection of source devices and their respective radio interfaces to support green Ds2D communications. Simulation results demonstrate that the proposed Ds2D communication paradigm under optimal selection of source devices and radio interfaces presents an improved energy efficiency performance compared with the conventional D2D communications, and leads to a lower energy consumption per source device.**

***Index Terms*—Devices-to-device (Ds2D) communications, green communications, energy efficient communications.**

I. INTRODUCTION

Recently, device-to-device (D2D) communications have been recognized as a promising solution to improve the cellular system throughput, delay, fairness, and energy efficiency [1]. Moreover, the past decade has witnessed a huge progress in the design and manufacturing of mobile devices. Nowadays, mobile devices are equipped with multiple radio interfaces that enable them to access different types of wireless networks including wireless local area networks (WLANs), Bluetooth, and Zigbee, besides cellular networks [2]. Furthermore, through multi-homing capabilities, mobile devices can maintain multiple simultaneous associations with different networks. However, the conventional D2D communication approach (as shown in Fig. 1 between D_3 and D_4) does not fully exploit such advancements. In literature, a mobile device can establish a direct link for D2D communications only over the cellular radio interface for inband communications [5] - [10]. In addition, a mobile device can use the cellular radio interface for coordination while using another single radio interface (LTE direct [11] or WiFi direct [12]) for data transmission in outband communications [13] - [20]. In both cases (inband and outband communications), data transmission takes place over a single link between a D2D pair. Enabling data transmission over multiple radio interfaces in D2D communications can take advantage of the diverse resources available at different radio interfaces (e.g., the supporting bandwidth). Aggregating such radio resources at the sink device allows for an improved system performance in terms of the achieved throughput, latency, and energy efficiency.

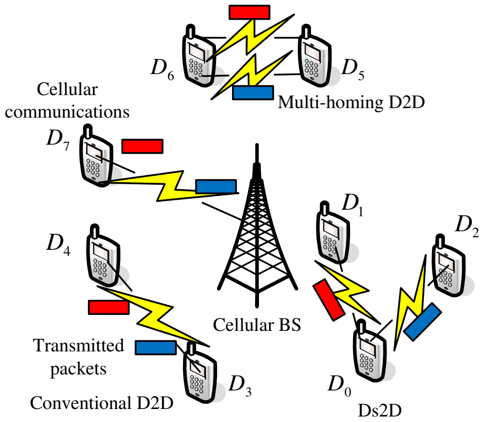

Fig. 1. Illustration of conventional D2D, multi-homing D2D, and Ds2D communication approaches.

In this paper, we aim to fully exploit the capabilities of the mobile device multiple radio interfaces to enable improved energy efficient data transfer. Specifically, the paper contributions can be summarized as follows:

- We propose a novel communication paradigm, namely Ds2D communications, where data transmission is established among one sink device and multiple source devices (as shown in Fig. 1 among sink device D_0 and source devices D_1 and D_2).
- We propose an algorithm for optimal selection of source devices and radio interfaces to enable improved energy efficient Ds2D communications. The proposed algorithm is based on ascending proxy auctions and leads to stable (NTU-core) selection.

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[1] This publication was made possible by NPRP grant # 6-415-3-111 from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors.

- We demonstrate via computer simulations that Ds2D communications exhibit an improved energy efficiency performance compared with two benchmarks. The first benchmark is the conventional D2D communication approach, while the second benchmark is a multi-homing D2D communication approach where data transmission takes place over multiple radio interfaces (e.g., LTE direct and WiFi direct) between two mobile devices (as shown in Fig. 1 between D_5 and D_6). We show that both multi-homing D2D and Ds2D communications exhibit a close energy efficiency performance that is superior to the performance achieved by the conventional D2D communications. However, Ds2D communications present a lower energy consumption per source device compared with the multi-homing D2D communications approach, which makes it more appealing.

The rest of this paper is organized as follows. The related work is reviewed in Section II. The system model is presented in Section III. The optimal algorithm for selection of source devices and radio interfaces is given in Section IV. Simulation results are presented in Section V. Conclusions and future work are given in Section VI.

II. RELATED WORK

In literature, two modes can be distinguished for D2D communications, namely, inband and outband communications. Inband D2D utilizes the cellular spectrum for both cellular links and D2D communications [3] - [10]. Inband D2D communications can be further categorized into underlay and overlay communications. Underlay inband D2D communications are recognized when both D2D and cellular communications take place over the same spectrum [3] - [8], while overlay inband D2D communications dedicate part of the cellular spectrum to D2D communications [9], [10].

Overlay inband D2D communications assign dedicated cellular resources to D2D communications [9], [10]. One advantage of such approach is that it avoids the interference caused by D2D communications on cellular users. However, this comes at the cost of a reduced amount of achievable resources for cellular users. Dedicating a fixed amount of the cellular spectrum to the D2D users can lead to inefficient spectrum utilization [1].

Outband D2D communications exploit different spectrum than the cellular band, e.g., the unlicensed spectrum band [13] - [20]. Consequently, D2D users do not cause interference to cellular users and the scarce cellular spectrum is dedicated only to the cellular users. However, interference issues should be handled by D2D users in the unlicensed spectrum band. Two modes of operation can be distinguished for outband D2D communications, namely, controlled and autonomous operation. Controlled outband D2D communications operate under the control of the cellular network. On the other hand, autonomous outband D2D communications is transparent to the cellular network.

Currently, mobile devices are equipped with multiple radio interfaces and new technologies have been proposed to support D2D communications. These technologies include LTE direct [11], WiFi direct [12], besides Bluetooth and Zigbee. However, the existing D2D communication mechanisms (underlay and overlay inband, and outband communications) do not fully exploit the mobile device advanced capabilities. Conventionally, data transfer takes place only over single radio interface between D2D pair. In this paper, we aim to achieve improved energy efficiency by establishing data transfer over multiple radio interfaces among sink and source devices. In this regard, optimal selection of source devices and their respective radio interfaces is imperative to guarantee an improved system performance. In this paper, we present an optimal algorithm for selection of source devices and radio interfaces to enable energy efficient communications.

III. SYSTEM MODEL

Let $\mathcal{D}$ denote a set of mobile devices that are in the coverage area of a single cellular network base station (BS). Four communication modes can be distinguished in such a network setting, as shown in Fig. 1:

- Cellular communications, in which the sink device receives its required file from the cellular BS, as shown in Fig. 1 for D_7.
- Conventional D2D communications, in which the sink device receives its required file from a single source device $D_s \in \mathcal{D}$ over a single radio interface $n \in \mathcal{N}$, as shown in Fig. 1 between D_3 and D_4.
- Multi-homing D2D communications, in which the sink device receives its required file from a single source device over multiple radio interfaces, as shown in Fig. 1 between the source device D_5 and the sink device D_6. For sake of illustration, assume that D_6 requests a file that consists of 2 packets from D_5. Two data communication links are established between D_5 and D_6, which can take place over the LTE-direct and WiFi-direct radio interfaces of the two devices (besides a third *cellular* link that is established for coordination). Based on the achieved data rate over each link (radio interface), different number of packets can be transmitted from D_5 to D_6 on each link. For instance, one data packet is transmitted over the first link and another data packet is transmitted over the second link, as shown in Fig. 1, assuming equal achieved data rates on each link. Eventually, the sink device D_6 aggregates the received 2 packets to reconstruct the required file.
- Ds2D communications, in which the sink device receives its required (popular) file from multiple source devices over multiple radio interfaces, as shown in Fig. 1 between the source devices D_1 and D_2, and the sink device D_0.

> Data communication links are established between each source device and the sink device over different radio interfaces. For instance, data communication can take place between D_1 and D_0 over the LTE-direct radio interface and between D_2 and D_0 over the WiFi-direct radio interface (besides a second *cellular* link that is established between each source device and the sink device for coordination). Again, based on the achieved data rate over each link (radio interface), different number of packets can be transmitted from each source device D_1 and D_2 to D_0. In Fig. 1, one data packet is transmitted from D_1 and another data packet is transmitted from D_2 and the sink device D_0 aggregates the received 2 packets to reconstruct the required file.

A network controlled Ds2D communications approach is considered. Hence, in Ds2D communications, the sink mobile device requests a given (popular) file from the BS and indicates that it can operate in a Ds2D communication mode. The BS broadcasts the file request message to the mobile devices within the sink device proximity. Based on the mobile devices feedback, the BS defines a set of candidate source devices that are 1) within the proximity of the sink device, 2) have a copy of the (popular) file required by the sink device, and 3) willing to contribute in such a Ds2D communication. Then, the BS selects (from the available candidate source devices) the optimal source devices and their respective radio interfaces that deliver the required file to the sink device in the most energy efficient manner. After optimal selection of source devices and their respective radio interfaces, the BS coordinates which source device transmits which chunk of the required file. The sink device aggregates the data chunks transmitted by different source devices. This approach can support data hungry applications such as file download or video streaming.

As a first step of research, we consider a system model with a single sink device and a set of candidate source devices. Let $\boldsymbol{\mathcal{D}} = \{D_0, D_1, \dots, D_S\}$ with D_0 representing the sink device and $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ representing the candidate source devices. Each mobile device $D_s \in \boldsymbol{\mathcal{D}}$ has a set of distinct radio interfaces $\boldsymbol{\mathcal{N}} = \{1, 2, \dots, N\}$. Radio interface $n \in \boldsymbol{\mathcal{N}}$ in all mobile devices $D_s \in \boldsymbol{\mathcal{D}}$ employs the same access technology. For instance, $n = 1$ represents cellular radio interface in all mobile devices, $n = 2$ represents an LTE direct radio interface, $n = 3$ represents a WiFi direct radio interface, etc. Let x_{ns} be a binary variable that indicates if the sink device D_0 communicates with source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ over radio interface $n \in \boldsymbol{\mathcal{N}}$ for data transfer.

The transmission bandwidth that can be supported at radio interface $n \in \boldsymbol{\mathcal{N}}$ for $D_s \in \boldsymbol{\mathcal{D}}$ is denoted by W_{ns}. Each source device D_s communicates with the sink device D_0 over radio interface n using transmission power P_{ns}. Let ρ represent the power amplifier efficiency for each source device. The circuit power consumption Q_{ns} for source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ and radio interface $n \in \boldsymbol{\mathcal{N}}$ scales with the transmission data rate R_{ns} via [21]

$$Q_{ns} = \mu_{ns} + \beta_{ns} R_{ns}, \tag{1}$$

where μ_{ns} and β_{ns} are two constants, measured in watt and watt per bit per second (bps). The total power consumption for source device $D_s \in \mathcal{D} \setminus \{D_0\}$ to communicate over its radio interface $n \in \mathcal{N}$ is given by

$$P_{ns}^{\mathrm{T}} = \frac{P_{ns}}{\rho} + Q_{ns}. \tag{2}$$

Let L_{ns} and α_{ns} represent the distance and path loss exponent between the sink device and source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$, respectively. Denote κ_{ns} as a Rayleigh random variable associated with the channel between the sink device and radio interface $n \in \boldsymbol{\mathcal{N}}$ of source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$. The channel power gain is given by

$$h_{ns} = \kappa_{ns} L_{ns}^{-\alpha_{ns}}. \tag{3}$$

The average channel power gain between the sink device and radio interface $n \in \boldsymbol{\mathcal{N}}$ of source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ is denoted by Ω_{ns}.

Each radio interface $n \in \boldsymbol{\mathcal{N}}$ of the sink device suffers from interference imposed by other mobile devices communicating over that specific band. Let $\boldsymbol{\mathcal{I}}_n = \{1, 2, \dots, I_n\}$ denote the set of mobile devices interfering with the sink device file reception over radio interface $n \in \boldsymbol{\mathcal{N}}$. The distance between the sink device and the source of interference $i \in \boldsymbol{\mathcal{I}}_n$ is denoted by L_{ni} and α_{ni} stands for the path loss exponent. Let P_{ni} denote the transmission power of interferer $i \in \boldsymbol{\mathcal{I}}_n$ over radio interface $n \in \boldsymbol{\mathcal{N}}$. The interference power over radio interface $n \in \boldsymbol{\mathcal{N}}$ of the sink device is approximated by a Gaussian random variable with zero mean and variance $\sum_{i \in \boldsymbol{\mathcal{I}}_n} P_{ni} L_{ni}^{-\alpha_{ni}}$. The one-sided noise power spectral density is represented by N_0.

IV. OPTIMAL SELECTION OF SOURCE DEVICES AND RADIO INTERFACES

In this section, the problem of optimal selection of source devices and radio interfaces is formulated and an algorithm is presented to solve it. This algorithm will be executed by the cellular BS.

A. Problem Formulation

The selection criterion of a given radio interface $n \in \boldsymbol{\mathcal{N}}$ of source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{0\}$ is the average achieved energy efficiency η_{ns}, which is a ratio between the average achieved data rate and the average power consumption. Using Shannon formula, the achieved data rate over radio interface $n \in \boldsymbol{\mathcal{N}}$ of source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ is given by

$$R_{ns} = W_{ns} \log_2\Big(1 + \frac{P_{ns} h_{ns}}{\sum_{i \in \boldsymbol{\mathcal{I}}_n} P_{ni} L_{ni}^{-\alpha_{ni}} + W_{ns} N_0}\Big). \tag{4}$$

The average achieved data rate on the link between the sink device D_0 and source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ over radio interface $n \in \boldsymbol{\mathcal{N}}$ is given by [22]

$$\begin{aligned}\mathbb{E}\{R_{ns}\} = \frac{W_{ns}}{\ln(2)} \exp(\frac{\sum_{i \in \boldsymbol{\mathcal{I}}_n} P_{ni} L_{ni}^{-\alpha_{ni}} + N_0 W_{ns}}{\Omega_{ns} P_{ns}}) \\ \cdot E_1(\frac{\sum_{i \in \boldsymbol{\mathcal{I}}_n} P_{ni} L_{ni}^{-\alpha_{ni}} + N_0 W_{ns}}{\Omega_{ns} P_{ns}}) \qquad (5)\end{aligned}$$

where $\mathbb{E}\{\cdot\}$ denotes the expectation and $E_1(x) = \int_0^{+\infty} \exp(-x)x^{-1}dx$ stands for the exponential integral. From Lemma 2.1 in [22], a lower bound of the average achieved data rate is given by

$$\widetilde{R}_{ns} = \frac{W_{ns}}{2} \log_2(1 + \frac{2\Omega_{ns} P_{nsm}}{\sum_{i \in \boldsymbol{\mathcal{I}}_n} P_{ni} L_{ni}^{-\alpha_{ni}} + N_0 W_{ns}}). \qquad (6)$$

Hence, the average achieved energy efficiency on the link between sink device D_0 and source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ over radio interface $n \in \boldsymbol{\mathcal{N}}$ is given by

$$\eta_{ns} = \frac{\widetilde{R}_{ns}}{\frac{P_{ns}}{\rho} + \mu_{ns} + \beta_{ns} \widetilde{R}_{ns}}. \qquad (7)$$

The objective is to select the source devices and their respective radio interfaces that maximize the total energy efficiency, i.e.,

$$\max_{x_{ns} \in \{0,1\}} \sum_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} \sum_{n \in \boldsymbol{\mathcal{N}}} x_{ns} \eta_{ns}. \qquad (8)$$

The total number of links used for data transmission is upper bounded by the maximum number of available radio interfaces N excluding the cellular radio interface that is used for coordination, i.e.,

$$\sum_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} \sum_{n \in \boldsymbol{\mathcal{N}}} x_{ns} \leq N - 1. \qquad (9)$$

Furthermore, only one source device is allowed to communicate with a given radio interface $n \in \boldsymbol{\mathcal{N}}$ of the sink device, i.e.,

$$\sum_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} x_{ns} \leq 1, \qquad \forall n \in \boldsymbol{\mathcal{N}}. \qquad (10)$$

For Ds2D communications, each source device employs only a single radio interface for data transmission, thus, we have

$$\sum_{n} x_{ns} \leq 1, \qquad \forall D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}. \qquad (11)$$

The summation over n in (11) excludes the cellular radio interface, which is used for coordination.

Hence, the optimal selection of source devices and radio interfaces for green Ds2D communications is obtained by solving the optimization problem

$$\begin{aligned}&\max_{x_{ns} \in \{0,1\}} && \sum_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} \sum_{n \in \boldsymbol{\mathcal{N}}} \eta_{ns} \qquad (12)\\ &s.t. && (9) - (11).\end{aligned}$$

B. Proposed Solution Approach

One way to solve (12) for Ds2D communications is based on the ascending proxy auctions [23]. In this context, each source device $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ defines a set F_s that includes pairs of candidate radio interface and the achieved average energy efficiency over that interface, i.e., $F_s = \{(2, \eta_{2s}), \ldots, (n, \eta_{ns}), \ldots, (N, \eta_{Ns})\}$, which excludes the cellular radio interface that is used for coordination. Define one element of F_s by f_s, e.g., $f_s = (n, \eta_{ns})$ and a selection f is given by $f = \{f_s \forall D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}\}$, i.e., $f = \{(n, \eta_{n1}), (\hat{n}, \eta_{\hat{n}2}), \ldots, (\check{n}, \eta_{\check{n}S})\}$. Each source device ranks F_s based on η_{ns}. Let $\succ_s$ denote a strict preference ordering over F_s based on η_{ns}. All candidate source devices report such a preference order over the cellular radio interface to the cellular BS, which will be in charge of selecting the optimal combination of source devices and radio interfaces.

Let set $\mathcal{F} \subset F_1 \times F_2 \times \ldots \times F_S$ denote a feasible selection set of source devices and their respective radio interfaces that satisfies the constraints in (9) - (11). The BS can form the feasible selection set $\mathcal{F}$ by considering possible combinations of F_s elements for all $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ (f) and eliminating those combinations that do not follow the constraints in (9) - (11). For a given source device, if $f_s = \phi$ then device D_s is not selected to contribute in the Ds2D communication session (i.e., $x_{ns} = 0 \forall n \in \mathcal{N}$ for that device D_s). Furthermore, $(\phi_1, \phi_2, \ldots, \phi_S)$ means that no source device contributes to the Ds2D communication session and the sink device receives the requested file from the cellular BS via cellular communication. The cellular BS specifies a preference ordering $\succ_0$ over the set of feasible selection profile $\mathcal{F}$ based on the total average energy efficiency (i.e., $\sum_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} \sum_{n \in \boldsymbol{\mathcal{N}}} \eta_{ns}$).

The ascending proxy auction works over iterations (t) until the optimal selection of source devices and their respected radio interfaces is obtained. Define a bid as the proposed F_s element from devices D_s at iteration t, i.e., f_{0s}^t and $f_0^t = \{f_{0s}^t \forall D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}\}$. Define B_s^t as the set of bids (radio interfaces and average energy efficiencies) offered by source device D_s till iteration t, i.e., $B_s^t = \{f_{0s}^{t-1}, f_{0s}^{t-2}, \ldots, f_{0s}^0\}$. Let $B^t = \{B_s^t \, \forall D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}\}$. The set of available new bids by device D_s is denoted by C_s^t, i.e., feasible radio interface and corresponding energy efficiency that have not been offered till iteration t. The optimal selection of source devices and their respective radio interfaces for Ds2D green communication is described by Algorithm 1, which is executed by the cellular BS. From Theorem 1 in [23], the selection made by Algorithm 1 is a stable (NTU-core) selection with respect to the reported preferences.

Algorithm 1 Optimal Selection of Source Devices and Their Radio Interfaces at the Cellular BS

```
Initialization: $B_s^0 = \{\phi\}$, $f_{0s}^0 = \phi$, and $J = 1$;
while $J = 1$ do
  for $D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}$ do
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        $C_s^t = F_s - \{f_s | f_s \succ_s \phi_s\} - B_s^{t-1}$;
    end for
    Any $D_s$ with $f_{0s}^t = \phi$ and $C_s^t \neq \phi$
    $B_s^t = B_s^{t-1} \cup \{\max C_s^t\}$;
    for All $D_s$ with $f_{0s}^t \neq \phi$ or $C_s^t = \phi$ do
        $B_s^t = B_s^{t-1}$;
    end for
    if $B^t = B^{t-1}$ then
        $J = 0$;
    else
        $\mathcal{F}^t = \mathcal{F} \cap \{\bigcap_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} \{f | f_s \in B_s^t\}\}$;
        $f_0^{t+1} = \max \mathcal{F}^t$;
        $t \longleftarrow t + 1$;
    end if
end while
Output: $f_0^t$.
```

In Algorithm 1, each source device first updates its new available bids that can be offered in iteration t. If there exists a source device with $f_{0s}^t = \phi$ and still has new bids to offer (i.e., $C_s^t \neq \phi$), the source device will offer his most preferred radio interface to participate in the Ds2D communication (the preference order here is based on the source device most energy efficient radio interface). The source device also updates his set of bids offered till iteration t (B_s^t). All other devices make no new bids at this iteration. The BS updates the set of feasible bids at the current iteration t ($\mathcal{F}^t$) and then selects the most energy efficient set of source devices and radio interfaces (the selection here is made based on the total average energy efficiency $\sum_{D_s \in \boldsymbol{\mathcal{D}} \setminus \{D_0\}} \sum_{n \in \boldsymbol{\mathcal{N}}} \eta_{ns}$).

V. SIMULATION RESULTS

This section presents comparative simulation results for green Ds2D, multi-homing D2D, and conventional D2D communications. The optimal selection of source devices and their respected radio interfaces for the Ds2D is implemented using Algorithm 1. For conventional D2D communications, only the source device and radio interface offering the maximum energy efficiency η_{ns} are selected for data transfer. For multi-homing D2D, the source device achieving maximum total (sum) energy efficiency across all its radio interfaces is selected for data transfer. All mobile devices have 2 radio interfaces besides the cellular radio interface (i.e., $N = 3$). In all three modes, coordination is established over the cellular radio interface ($n = 1$) and data transfer can take place over the other radio interfaces ($n = 2$ and $n = 3$). The candidate source devices are uniformly distributed within proximity of [50,100] meters away from the sink device [11]. The supporting bandwidth for the radio interfaces used for data transmission are $B_{2s} = 1$ MHz and $B_{3s} = 5$ MHz. Each radio interface of the sink device is subject to a random number of interferers uniformly distributed in the range [5,10]. The interferers are assumed to be close to the sink device (for a worst case scenario), i.e., uniformly distributed within proximity of [50,60] meters away from the sink device. The transmission power is 100 milli-watts for P_{ns} and P_{is}. The power amplifier drain efficiency is 35%. The circuit power constants are $\mu_{2s} = 50$ milli-watts, $\mu_{3s} = 75$ milli-watt, $\beta_{2s} = 10^{-6}$ watt/bps, and $\beta_{2s} = 5 \times 10^{-6}$ watt/bps. The path loss exponent equals 4 for α_{ns} and α_{ni}, and $N_0 = -174$ dBm/Hz.

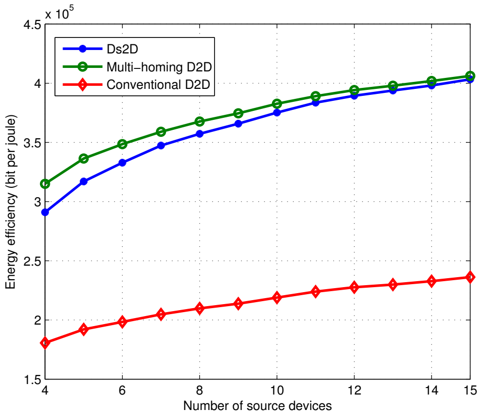

Fig. 2. Achieved average energy efficiency versus number of candidate source devices.

Fig. 2 shows the achieved average energy efficiency versus the number of candidate source devices. With more candidate source devices, a better energy efficiency can be achieved due to the diverse channel conditions among the candidate source devices and the sink device. Both Ds2D and multi-homing D2D communications exhibit an improved energy efficiency performance compared with the conventional D2D communication (up to 70% improvement in energy efficiency). This is mainly due to the aggregated resources at the sink device from multiple radio interfaces, which allows for higher achieved throughput and hence improved energy efficiency. Such an improvement is also due to spatial diversity as some differences are expected in the channel conditions among the sink device and different source devices for Ds2D communications. As shown in Fig. 2, Ds2D communications exhibit a closer performance to multi-homing D2D communications as the number of candidate source devices increases. This is due to the higher probability of having more than one source device with good channel conditions with the sink device. While Fig. 2 shows a slightly improved performance for multi-homing D2D over Ds2D communications in terms of the total energy efficiency, the next result shows that Ds2D communications is an attractive alternative as it exhibits much lower energy consumption per source device. Such an option motivates source devices to contribute in D2D communications.

Fig. 3 shows the average energy consumption performance per source device to transfer a 1 Mbit-file to the sink device versus the number of candidate source devices. The worst energy consumption performance per source device is for

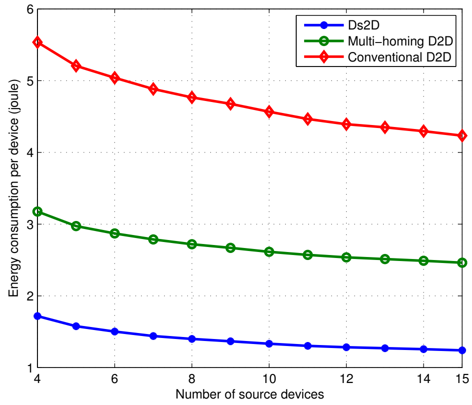

Fig. 3. Energy consumption per source device to transfer a 1 Mbit-file versus number of candidate source devices.

the conventional D2D communications approach since only one radio interface is used for data transfer, which results in longer latency to transfer the file to the sink device, and that results in higher energy consumption. On the other hand, Ds2D communications exhibit the least energy consumption per source device (up to 70% compared with the conventional D2D communications and up to 50% compared with the multi-homing D2D communications). This is mainly because Ds2D communications split the total energy consumption burden over different source devices contributing in the file transfer, while multi-homing D2D communications relies on a single source device for file transfer, which incurs higher energy consumption to activate all radio interfaces and transmit across them. With more available radio interfaces at the sink device, additional energy saving is expected per source device when compared with multi-homing D2D, as more source devices will be involved in the file transfer.

VI. CONCLUSIONS

This paper presents a novel communication paradigm referred to as Ds2D communications that incorporates several source devices and multiple radio interfaces for data transfer to the sink device. An optimal algorithm for source device and radio interface selection is presented based on the ascending proxy auctions mechanism. The proposed mechanism achieves higher energy efficiency compared with the conventional D2D communications approach. From simulation results, both multi-homing D2D and Ds2D communications achieve almost the same system energy efficiency (which is superior to the conventional D2D communications). However, Ds2D communications achieve the minimum energy consumption per source device as compared with multi-homing and conventional D2D communications. Hence, from both system and per device energy efficiency perspectives, Ds2D communications offer an effective mean to support green communications and motivate source devices to participate in D2D communications. Future work will extend the current research to include the presence of multiple sink devices.

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