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Energy-Efficient Localization-based Link Setup Scheme for Device-to-Device Communications

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Abstract— **A new energy efficient link setup scheme for device-to-device (D2D) communications in cellular networks is proposed that employs approximate localization easily performed using new radio technologies. To set up a D2D link, the obtained location estimates are used to judge whether two user-devices can be a D2D pair, and to control the transmit power between two devices, taking into account the accuracy of the estimated distance between them. Simulation results show that the scheme not only removes the neighbor discovery step, leading to faster setup, but also significantly improves energy efficiency and resource block utilization, while maintaining a high success probability for the D2D discovery and communication setup.**

Keywords— Device-to-Device discovery, Device-to-Device communication, cellular networks, energy efficient, resource block utilization, localization methods

I. INTRODUCTION

Device-to-device (D2D) communication is now regarded as an important component in the design of future cellular networks [1]. The technology allows two devices in proximity to detect each other and communicate directly, under the control of a base station (BS) [2], bringing several benefits. First, the short distance between D2D devices should lead to better channel conditions, resulting in higher data rate and energy efficiency [3]. Secondly, as D2D links generally employ frequency reuse among different D2D pairs, the system spectral efficiency can be significantly improved [4].

In D2D communication, an important process is to discover neighbors and set up the D2D link. The main procedure for this is for one device to send discovery signaling to find neighbor devices and receive their responses [5], which is followed by a channel measurement report. The Third-Generation Partnership Project (3GPP) has introduced D2D communication since Release-12 [5], which included Proximity Services (ProSe) as the device discovery process. At first, direct discovery was introduced in ProSe: this periodically allows UEs to find each other with the BS arranging the setup of the D2D link when it receives a connection request. For direct discovery, most research has focused on reducing the collision probability and interference in the direct discovery process, as multiple D2D users are allowed to send their discovery signal simultaneously. In [6], strategies were proposed to reduce the interference between the direct discovery signalling, whereas in [7], a collision detection scheme that reduces the collisions in discovery signalling was proposed. On the other hand, in [8], it was proposed that user equipments (UEs) identify their neighbors by listening to the cellular uplink (UL) channels in which they each periodically broadcast a Sounding Reference Signal (SRS). SRS provides specific information related to each UE and thus can serve as a discovery beacon in the establishment of D2D links, changing the discovery step triggered by the communication request; this improves energy efficiency. However, although direct discovery has a high success ratio, it has very high signalling overhead, and thus has high battery and resource block (RB [9]-[11]) consumption.

In order to reduce the signalling overhead, ProSe also proposed core network/Evolved Packet Core (EPC)-assisted discovery, which employs higher layer protocols to discover D2D pairs by extracting the device's periodic location updates, e.g., through a user equipment identification (UE ID) and/or Internet Protocol address (UE IP). As ProSe EPC-assisted discovery assumes that UE locations are known and frequently updated, there is no need to send discovery signals, reducing the D2D link setup signalling overhead significantly. In the context of ProSe EPC-assisted discovery, in [12], multiple P-Areas were introduced to reflect the location of UEs. UEs entering the same P-Area are allowed to set up D2D communications without sending a discovery signal, so as to reduce power consumption. Based on this concept, the impact of the UE movement on the system performance was then investigated in [13]. However, EPC-assisted discovery has a lower success ratio than direct discovery due to the poor accuracy of the location information. So far, no research has addressed the impact of the accuracy of UE location information in the design of the D2D link setup. In addition, EPC-assisted discovery will involve longer setup delays and additional overheads for the communication with the core.

Therefore, in this paper, taking advantage of technologies employed in fifth generation (5G) networks, a novel location-based D2D (LDD) link setup scheme is proposed to improve the energy efficiency and the success ratio of D2D link setup. The scheme relies on more accurate location information obtained from new technologies, such as multiple-input multiple-output (MIMO) communications and beamforming, but its power allocation scheme takes into account inaccuracy in the location estimates.

The contributions of the paper lie in three aspects: 1) an LDD scheme is proposed, which relies only on information already available at a base station (BS) in 5G cellular networks and is fully controlled by the BS; 2) a power allocation algorithm proposed for the LDD scheme addresses localization inaccuracy to improve its success ratio while delivering significant energy efficiency; 3) simulation results of the proposed scheme are compared with the ProSe direct discovery scheme, to verify that the proposed scheme outperforms it in terms of energy efficiency and RB utilization, while achieving almost the same success ratio.

The remainder of the paper is organized as follows: in Section II, the focus is on an introduction to the new LDD link setup scheme and its comparison to the ProSe direct discovery. Section III provides a detailed description of the operation of the proposed LDD scheme and Section IV proposed a power allocation algorithm designed for LDD scheme and also can be used in all Localization-based Link Setup D2D Scheme. Section V presents simulation results, and the paper is concluded in Section VI.

II. D2D LINK SETUP

This section will introduce both the ProSe direct discovery scheme and the proposed LDD scheme.

A. *ProSe direct discovery scheme*

The ProSe direct discovery has two main objectives: 1) finding the communication pairs in proximity, and 2) measuring the channel state for the discovered D2D pair. It is generally completed by the steps shown in Fig. 1 [5]. Referring to Fig. 1, the steps involved are as follows:

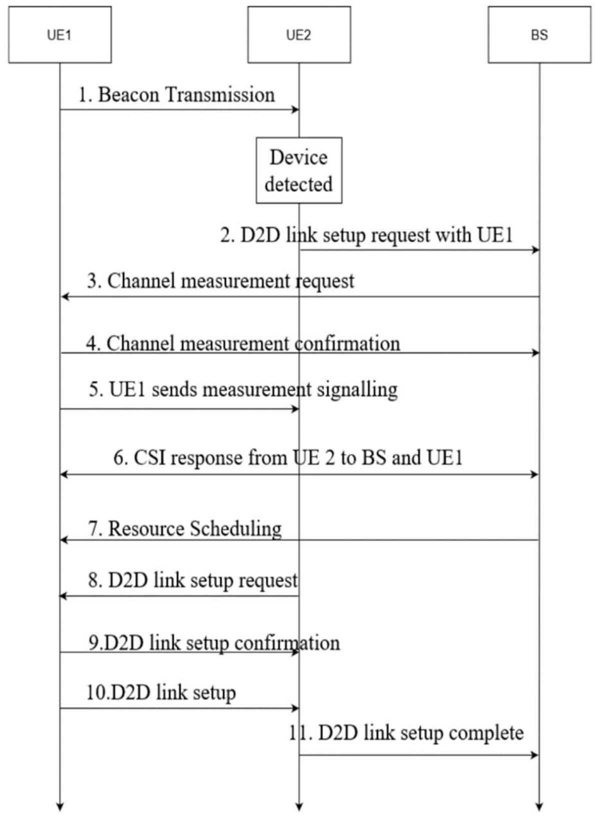

Fig. 1. Flowchart of signalling in ProSe direct discovery scheme.

1. Beacon transmission: An announcing UE (UE1) announces certain information that could be used by other UEs in proximity that have permission to discover. A monitoring UE (UE2) in its proximity monitors certain information of interest. (Announcing UEs broadcast discovery messages at certain pre-defined discovery intervals and monitoring UEs read and process them.)
2. UE2 sends a link setup request message to the base station (BS) to indicate its interest in reception from UE1.
3. After the BS receives the request, the BS schedules resources for channel measurement, indicating this to UE1.
4. UE1 responds to the BS to confirm it will measure the channel between UE1 and UE2.
5. UE1 sends a measurement signal to UE2
6. UE2 reports the channel state information (CSI) back to the BS and UE1.
7. If the CSI report indicates that the two UEs can communicate at adequate data rate, the BS allocates the resources for the D2D pair.
8. UE2 sends the setup request to UE1.
9. UE1 responds to UE2 .
10. UE1 sets up a D2D link with UE2.
11. UE2 reports that the link setup is complete to the BS.

The signalling overhead of the scheme is non-trivial, in terms of energy and RBs used. Especially, if the discovery procedure fails, considerable resources are wasted, because of the UEs do not know if the procedure will eventually be successful.

B. *The proposed LDD scheme*

In the proposed LDD scheme, there is no beacon discovery step, and Step 2 is different from Fig. 1: when the UE sends a request for communication, it is not identifying a UE to connect with, rather the BS must find a suitable UE. The BS will do this only if there is an available neighbour UE with the information of interest, by calculating the distance between the two UEs, according to localization estimates, and judging if these two UEs could communicate directly as a D2D pair. If there are multiple UEs available, the BS will calculate the distance between the different possible D2D pairs and judge which pair will provide higher system throughput. Then, from Step 3, the LDD scheme follows a similar procedure to the direct discovery scheme. The fact that the BS decides which two devices could be a D2D pair rather than relying on them sending discovery signaling to find their neighbors, removes the neighbor discovery signalling step. This advantage relies on the BS having sufficient localization information on the UEs in the cell.

III. Localization information

This section will first introduce localization information which could be used in the proposed LDD scheme, and then introduces the method of power allocation for channel measurements to enhance performance, in terms of energy efficiency, in particular.

The use of current localization methods, such as angle-of-arrival (AoA), time-of-arrival (ToA), time-difference-of-arrival (TDoA), and global positioning system (GPS), to track the location of each UE, could cost many RBs and/or significant energy in their operation. It is difficult to propose such additional resource cost in the place of direct discovery. However, as described in the following, there are two particular localization methods which together provide full localization information, at no extra cost in their use.

The authors of [14] proposed a localization technology where CSI measured from multiple subcarriers is used to estimate the distance between a UE and the BS. CSI is a fine-grained value which describes the amplitude and phase on each subcarrier. The multiple subcarriers will suffer different multipath fading, naturally bringing in the frequency diversity attribute of CSIs of multiple subcarriers, leading to a more accurate localization result. However, using CSI alone would be no different in principle to AoA, ToA, and TdoA schemes, as it would need at least three BS to work together to perform triangulation, again requiring the use of many RBs. At a single BS, its use could be only to obtain the distance between a UE and the BS. Then, by assuming MIMO technology is adopted in the BS, AoA positioning can be obtained based on the pre-coder indices of MIMO schemes [15], again, at no extra cost. Thus, the proposed LDD scheme can obtain the distance and angle between BS and UE by using the two above localization methods together to determine the UE location.

Assuming a polar coordinate system with the BS as its central point, the location of UEs can be determined, and their distances from each other calculated, as follows:

$$L_{k,j} = \sqrt{\left[L_k \cdot \sin\theta_k - L_j \cdot \sin\theta_j\right]^2 + \left[L_k \cdot \cos\theta_k - L_j \cdot \cos\theta_j\right]^2} \quad (1)$$

where $L_{k,j}$ is the distance between two UEs k and j, and L_k / L_j and θ_k / θ_j are the distance and angle between UE k /UE j and BS, respectively.

A random distribution for the estimated errors can be assumed and obtained according to the simulation results of the works on the localization techniques in [14], [15].

Denoting $\hat{L}_{k,j}$ as the estimated distance between UE k and j, when there is an estimation error in the localization information, one obtains

$$\hat{L}_{k,j} = \sqrt{\begin{array}{l}\left[L_k(1+E_{Lk})\cdot\sin\left(\theta_k+E_{\theta k}\right)-L_j(1+E_{Lj})\cdot\sin\left(\theta_j+E_{\theta j}\right)\right]^2 \\ +\left[L_k(1+E_{Lk})\cdot\cos\left(\theta_k+E_{\theta k}\right)-L_j(1+E_{Lj})\cdot\cos\left(\theta_j+E_{\theta j}\right)\right]^2\end{array}} \tag{2}$$

where E_{Lk} and E_{Lj} are the estimation errors for L_k and for L_j. $E_{\theta j}$ and $E_{\theta k}$ are the estimation errors for θ_j and for θ_k.

It should be noted that other localization techniques are possible. Distance estimates based on CSI may be inaccurate in environments with significant shadowing, for example. CSI-based fingerprint methods may improve accuracy [16]. In this paper, the objective is to investigate how location inaccuracy can be overcome by a suitable power allocation algorithm as described in the following section.

IV. POWER ALLOCATION

The localization- based D2D link setup scheme requires a novel power allocation algorithm in order to overcome inaccuracy in location estimates, while enabling energy efficiency. For setting up a D2D pair, a signal to noise ratio (SNR) threshold at the receiver UE is considered which would enable the pair to communicate at a required data rate. For a D2D pair, given the transmit power, p, the receiver SNR is given by

$$\gamma = \frac{p\cdot\alpha_{k,j}{}^2\cdot L_{k,j}^{-\lambda}}{\sigma^2} \tag{3}$$

where $\alpha_{k,j}$ is the channel fading for the channel between UE k and j, which is assumed to follow a Rayleigh distribution, $L_{k,j}$ is the distance between the two UEs, $L_{k,j}^{-\lambda}$ is the path loss, and λ is the path loss exponent, the value of which depends on the environment, and σ^2 is the noise power at the receiver, which is assumed to be the same for all UEs.

Practically, the transmit power, p, for two UEs to communicate cannot be higher than the maximum UE transmit power, which is assumed to be 0.2W. In the proposed LDD scheme, at the receiver, the receiver SNR needs to be no less than a threshold, γ_{th}. Since the channel fading, $\alpha_{k,j}$, is an unknown random value, the transmit power allocated needs to guarantee that the outage probability is smaller than a threshold β. Here, the outage probability P_{out} is the probability that the received SNR is smaller than γ_{th}. Given two UEs, k and j, knowing that the channel fading, $\alpha_{k,j}$, is known only by its distribution, and that the distance between the two UEs is only an estimate, a transmit power $\hat{p}$ can be calculated according to the outage probability constraint, given by

$$P_{out} = P\left(\frac{\hat{p}\cdot\alpha_{k,j}{}^2\cdot\hat{L}_{k,j}^{-\lambda}}{\sigma^2}\le\gamma_{th}\right)\le\beta \tag{4}$$

where P_{out} is the outage probability. P(x⩽x0) indicates the probability of x⩽x0. The transmit power $\hat{p}$ derived from (4) may not guarantee the satisfaction of the outage probability constraint as it is derived based on the estimated distance $\hat{L}_{k,j}$ between UE k and j. Therefore, in this paper, $\hat{p}$ is called the estimated transmit power. Considering that the real distance $L_{k,j}$ without estimated error could be either larger or smaller than the estimated distance $\hat{L}_{k,j}$, if the LDD scheme transmit power was set simply based on estimated distance, it may lead to (4) being unsatisfied, and a very low success ratio.

The power required to meet the outage probability in (4) is dependent on the path loss, fading and inaccuracy in location estimates. As $\hat{p}$ is calculated based on an estimated distance, an excess transmit power (called the power margin), p_e, is added to approach the desired outage probability, as given by

$$p_t = \hat{p} + p_e \tag{5}$$

where p_t is the transmit power allocated.

A. The approximation for power margin

As explained above, it is important to obtain the power margin in allocating transmit power to meet the outage probability constraint. However, it is very difficult to theoretically obtain its value. This margin clearly depends on the (estimated) distance between UEs (to account for fading variations) and the estimated distances from the BS to UEs, to account for increasing inaccuracy in the location estimates.

Simulations are carried out by randomly generating the locations of two UEs with an average distance of X between the UEs and the BS and an inter-UE distance of Y. Using the average distance between the UEs and the BS gives results that are more easily visualized and a little more tractable than in a case with independent distances to the BS. As the proposed system is assumed to obtain location information with estimation errors for the UEs, the simulation is run one million times for one million estimated locations and statistically generated channel fading factors for the same pair of UEs.

From the distribution of $\hat{p}$, the value of β is set to be 5% to find the power estimation margin p_e in order to take into account the inaccuracies in location estimation and the statistically varying fading.

Table. I shows the simulation results for $\hat{p}$ and p_e; the rows represent the BS to UE distance (X) and the columns represent the UE to UE distance (Y). A polynomial regression based curve fitting method is used to analyze the relationship between power estimation margin and location information, X and Y. The polynomial is of the general form:

$$\begin{aligned} p_e = {} & p_{00} + p_{10}X + p_{01}Y + p_{20}X^2 + p_{11}XY + p_{02}Y^2 \\ & + p_{30}X^3 + p_{21}X^2Y + p_{12}XY^2 + p_{03}Y^3 \end{aligned} \tag{6}$$

TABLE I. ESTIMATED TRANSMIT POWER (W) AND POWER MARGIN (W) IN DIFFERENT UE LOCATIONS

X / Y		11.55m	20m	34.64m	74.64m
10m	$\hat{p}$	4e-5	2.02e-4	1.04e-3	1.038e-2
	p_e	2.3e-6	6e-6	2.16e-5	1.98e-4
60m	$\hat{p}$	7.65e-5	2.83 e-4	1.2022e-3	1.068e-2
	p_e	3.88e-5	8.7e-5	1.838e-4	4.974e-4
110 m	$\hat{p}$	1.482e-4	4.25e-4	1.515e-3	1.16e-2
	p_e	1.105e-4	2.29e-4	4.966e-4	1.418e-3
160 m	$\hat{p}$	2.563e-4	6.173e-4	1.9009e-3	1.28e-2
	p_e	2.186e-4	4.213e-4	8.825e-4	2.614e-3
210 m	$\hat{p}$	4.056e-4	8.91e-4	2.42e-3	1.44e-2
	p_e	3.679e-4	6.95e-4	1.4016e-3	4.218e-3
260 m	$\hat{p}$	6.089e-4	1.2192e-3	29982e-3	1.575e-2
	p_e	5.712e-4	1.0232e-3	1.9798e-3	5.572e-3
310 m	$\hat{p}$	9.1015e-4	1.5611e-3	3.6813e-3	17785e-2
	p_e	8.7245e-4	1.3651e-3	2.6629e-3	7.603e-3
360 m	$\hat{p}$	1.185e-3	2.0973e-3	4.5133e-3	1.992e-2
	p_e	1.1473e-3	1.9013e-3	3.4949e-3	9.735e-3

In Fig 2, the white points are the simulation results of Table II, and the surface is the polynomial fit, using the following values of curve fitting coefficient, which provide the best fit with the simulation results:

p_{00} = -4.999×10^{-5}; p_{10} = 8.748e×10^{-7}; p_{01} = 2.159×10^{-6}; p_{20} = -9.797×10^{-10}; p_{11} = -6.245×10^{-8}; p_{02} = 6.155e×10^{-8}; p_{30} = 4.295e-12; p_{21} = 5.958×10^{-10}; p_{12} = 2.823×10^{-9}; p_{03} = -2.073×10^{-9}

The goodness of fit of the curve-fitting using summed square of residuals (SSE) is 9.676 × 10^{-8} and using R-square is 0.9994.

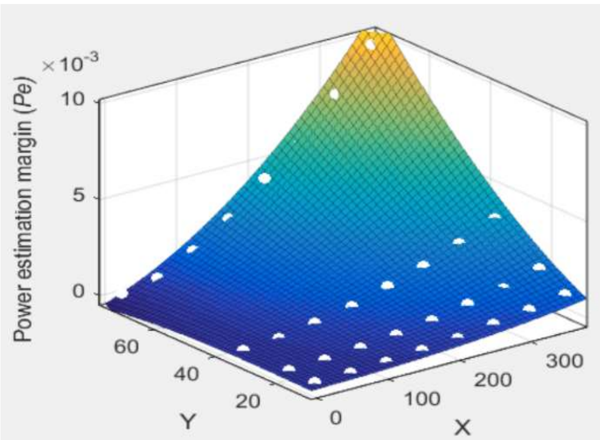

Fig. 2. Estimated error of the transmit power *Pe* vs the distance between UEs and the distance between users and BS.

The LDD scheme determines that the two UEs can connect as a D2D pair if $p_t \leq 0.2$ W, i.e. samller than the maximum UE transmit power. However, it is possible to allow the BS to set a higher threshold for making the decision. Increasing the threshold allows checking more pairs even if they might not eventually be set up. Even though energy and RB consumption are increased, the success ratio might also increase. Although location accuracy impacts the system performance significantly, we show that even the simple curve-fitting performed can help to improve the success ratio of LDD scheme to be close to the ProSe direct discovery scheme with much lower battery and RB consumption. Finally, it can be stated that the accuracy of the power margin estimation might be improved through (i) fitting to more results, (ii) taking into account the different distances to the BS of each UE, and (iii) the use of machine learning, for example, to take into account correlations between user requests and location, large-scale fading dependence on location and CSI-fingerprinting, for example.

V. PERFORMANCE OF LDD SCHEME

From Section VI, it can be assumed that the BS is able to apply general polynomial curve fitting from a limited set of simulation results to find the coefficients necessary for the calculation of the power margin for a given pair of UEs, dependent on their estimated average distance from the BS and the estimated distance between the UEs. Then, according to (4) and (6), the allocated transmit power can be calculated for these two UEs to communicate.

TABLE II. SIMULATION PARAMETERS

Number of UEs	2
UE distribution	Random
Fading	Rayleigh Distribution
Pass loss exponent	3
Bandwidth	100MHZ
RBs used of direct discovery signaling	2
RBs used of measurement signaling	12
Modulation level for discovery signaling	QPSK
Modulation level for measurement signaling	64 QAM
Noise density of device	-110dBm/Hz

Simulations are now used to compare the performance of the proposed LDD scheme with the ProSe direct discovery scheme. Comparisons are first based on the success ratio of D2D discovery. This is defined as the ratio of the number of D2D pairs set up successfully by each scheme to a benchmark of the number of D2D pairs that could be set up in the system based on their real distances and the maximum transmit power. The value of the success ratio of D2D discovery is calculated for each scheme over 100,000 simulation runs for each of 10 different cell radii, 1 million runs in total. First, for the benchmark, when two UEs are created in the simulation, the transmit power of measurement signaling is set as 0.2 W to check if they can be a D2D pair or not. If they can be a D2D pair, the two UEs can be counted as a potential D2D pair in the system. The LTE standard RB is used in the simulation. Then, the simulation will check each scheme whether the same two UEs can be determined as a D2D pair or not. The direct discovery uses QPSK for the beacon and uses 64 QAM for measurement signalling in order to have a high quality D2D communication link. Because the power used is very low in a radius an less than 50m, the use of the power margin will significantly impact the success ratio. Therefore, the LDD scheme has increased power margin below 50m cell radius in order to guarantee the success ratio of the scheme.

In Fig. 3, the success ratio is obtained for each scheme for randomly generated UEs in cells of different radius. From the results, it can be seen that the success ratio of the LDD scheme is slightly lower than the direct discovery. The reason is the LDD scheme uses inaccurate location information to determine the power allocated to the measurement signalling while direct discovery always uses full power beacons to discover UEs which can achieve a high success ratio. It can be seen that the success ratio of the LDD scheme approaches that of direct discovery due to the power allocation taking into account location inaccuracy and fading varia.tions.

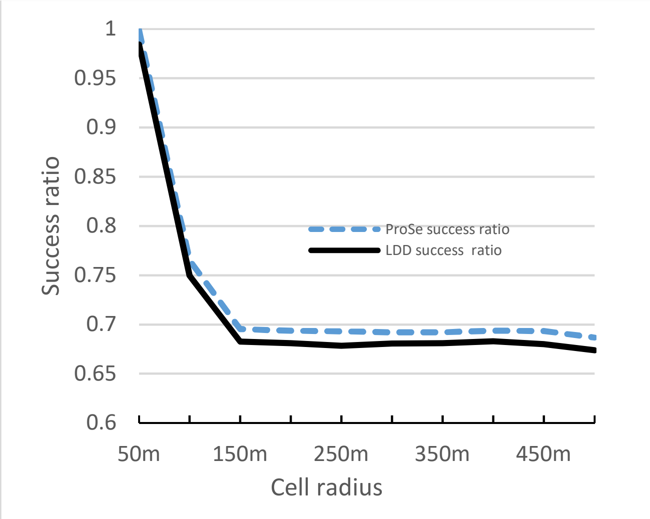

Fig. 3. D2D discovery ssuccess ratio versus cell radius

In Fig. 4, The energy consumption in the signalling required of the D2D link setup is plotted for different cell radius. Up to 50m, the ProSe direct discovery uses full power and the LDD scheme use less power. Between 50m to 100m, the longer distance causes greater energy cost in the LDD scheme while also reducing the number of successful D2D pair setups. The ProSe direct discovery scheme sends discovery signalling but if it cannot find neighbours, a UE will not send the connection request to the BS, so there will be no measurement signalling. This decreases the energy cost in the ProSe direct discovery scheme. After 100 m, the LDD scheme costs less energy with cell radius increases; here, there will be a large estimated error in UE location, and the LDD scheme is more likely to judge the two UEs to have a low possibility of being a D2D pair and not proceeding to link setup. The UEs do indeed have a higher probability of being far from each other.

The energy per successful setup continues to increase as expected for larger distances between UEs (larger cell sizes), but by much less in the case of the LDD scheme as it usually knows to avoid trying to set up D2D pairs which might be quite distant from each other. In the direct discovery, discovery signalling is always sent and there are more unsuccessful attempts.

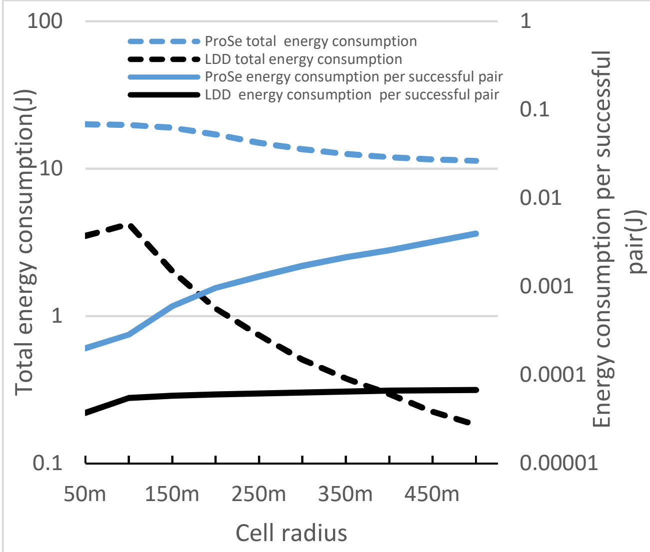

Fig. 4. Energy consumption of D2D scheme versus cell radius

From the result, it can be easily seen that the LDD scheme is highly energy efficient. There are two reasons that the LDD scheme achieves energy efficiency. The first reason is the LDD scheme does not have the neighbour discovery steps. The second reason is the power allocation algorithm. As the LDD scheme has location information for all UEs, the proposed power allocation algorithm is used to adaptively compensate for the effect of the inaccurate location information and achieve a high success ratio, while maintaining energy efficiency.

Fig. 5 shows that the total RBs consumption of the LDD scheme is reduced when increasing the cell radius, as the longer distance leads to a reduced number of successful D2D pairs setup. The LDD scheme is more likely to ignore the UEs which have low possibility to be D2D pairs. The LDD scheme also uses smaller numbers of signalling steps/frames, thus setting up D2D pairs faster, and uses fewer RBs than direct discovery. With faster setup speed, the proposed scheme could setup more D2D pairs at the same time with greater resource efficiency.

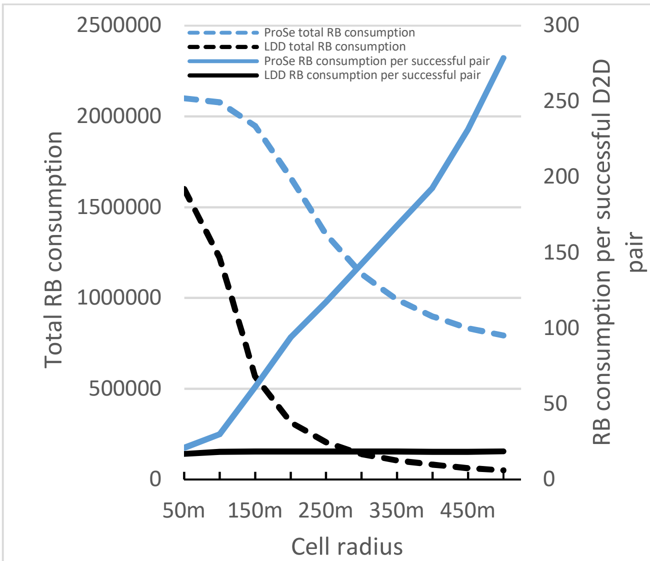

Fig. 5. Total RB cost versus cell radius and RB cost per successful D2D pair versus cell radius

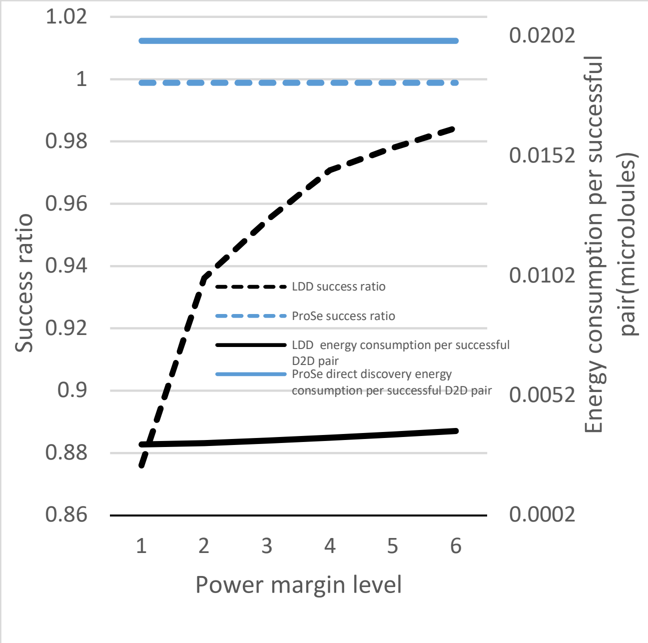

Fig. 6. Success ratio and energy consumption versus p_e at 50m cell radius

Fig. 6 shows that for the ProSe direct discovery, the successful ratio is not affected by the energy consumption. That is, there is no trade-off between success ratio and enerfy consumption for the ProSe direct discovery. However, it can be seen from the figure that while increasing the power margin level for power allocation in the LDD scheme, the power margin increases, which leads the success ratio of the LDD scheme to approach the success ratio of the ProSe direct discovery scheme, at the cost of increased energy consumption. That is, for the LDD scheme, there exists a trade-off between the increment of the success ratio for setting up D2D links and the corresponding increment of energy consumption. It is also worth noting that the energy consumption of the LDD scheme with increased power margin is still far less than ProSe direct discovery.

VI. Conclusion

A new D2D link setup scheme with inaccurate localization information has been proposed. The scheme is shown to have almost the same success ratio compared with ProSe direct discovery but has much better energy efficiency and RB utilization, with lower signaling overhead. The proposed power allocation algorithm can significantly reduce the impact of inaccurate localization, achieving energy efficiency. The algorithm could be extended to overcome inaccuracies from different localization techniques, although here it has been tested for CSI and beamforming-based localization. For a single pair of D2D users, there is a trade off in the LDD scheme in choosing between a higher success ratio or a much better resource/energy efficiency. This may be adaptable by setting parameters of the LDD scheme. Moreover, as there is no need for a UE to send a discovery signal, there are no discovery signal collisions. With less signaling overhead and no collisions in the proposed system (which has not been modelled for the direct discovery, as only one pair of UEs is generated for each simulation run), the LDD system performance should potentially be even better compared to direct discovery in multi-user scenarios.

Further, the performance of the proposed LDD scheme could be improved using CSI-based fingerprint or machine learning to reduce the estimated localization errors and adapt to each specific cell environment. The benefit brought from multi-UEs frequency reuse will be analyzed in future work.

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