Network-Assisted Device-to-Device Scheduling in LTE

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***Abstract* — Device-to-device (D2D) communication is a new feature being introduced to LTE in 3GPP Release 12. This feature will provide proximity services including support for public safety applications. For D2D communication within the network coverage area, network assistance is very beneficial for interference management purpose to ensure reliable communication. In this case, a simple algorithm can be used wherein the network manages the number and selection of simultaneous D2D transmissions within its cell. This will help manage interference from D2D transmission in case of time-frequency reuse to ensure that minimum performance requirement can be satisfied. In this paper, we outline a method for determining the maximum number of simultaneous D2D transmitters in a given cell. In addition, a method for selecting D2D pairs for simultaneous transmission is also provided. It is shown that, with network assistance, the percentage of reliable D2D communication links can be improved significantly.**

Keywords—D2D, LTE cellular system, network-assisted D2D scheduling, capacity analysis.

I. Introduction

Device-to-device (D2D) communication is a new feature being introduced to LTE in 3GPP Release 12. This feature will provide proximity services including commercial as well as public safety use cases [1]. Commercial use cases include social networking, direct communication, e-commerce, advertising, and machine type communication. Public safety uses include direct communication between first responders (e.g. in case of out-of-network coverage), direct group and broadcast communication, discovery, relay, and range extension. In 3GPP Release 12, the focus of the feature will be on public safety applications.

Proximity services have been studied in 3GPP in [1]-[3]. In [1], the communication scenarios, use cases, and requirements were established. Enhancements to the network architecture were considered in [2], while enhancements to the physical layers were considered in [3]. Based on these studies, proximity services using D2D communication is being standardized in 3GPP Release 12 as described in [4].

In this paper, we consider D2D communication sharing the same time-frequency resources as cellular communication. Thus, they interfere with each other. In [6][7], the effect of this interference has been analysed. It was shown that LTE system may not work well with uncoordinated D2D transmissions due to high interference. As a result, D2D links have to be coordinated for successful LTE communications. This can be done by the eNB (i.e. base station) using several user selection and resource allocation strategies. However, these strategies are generally complicated and require additional information such as D2D user location or channel information [8][9][10][11]. In this paper, we consider a simple coordination scheme to allow multiple simultaneous D2D transmissions but without needing channel or location knowledge. In this scheme, the maximum number of supportable D2D transmissions is determined based on simple system parameters. The eNB then allows only up to the maximum number of D2D transmissions to occur. The selection of the D2D transmissions may be done using the existing scheduling scheme.

The paper is organized as follows. In Section II, an overview of D2D communications in LTE is presented. In Section III, the need for coordination is discussed. This is followed by network assisted scheduling and performance results in Section IV. Finally, conclusions are drawn in Section V.

II. D2D in LTE

The objectives of proximity services using D2D communication are to enable device to device discovery and communication in network coverage (both within the same cell and among different cells), in partial network coverage and also outside network coverage. These scenarios are illustrated in Fig. 1.

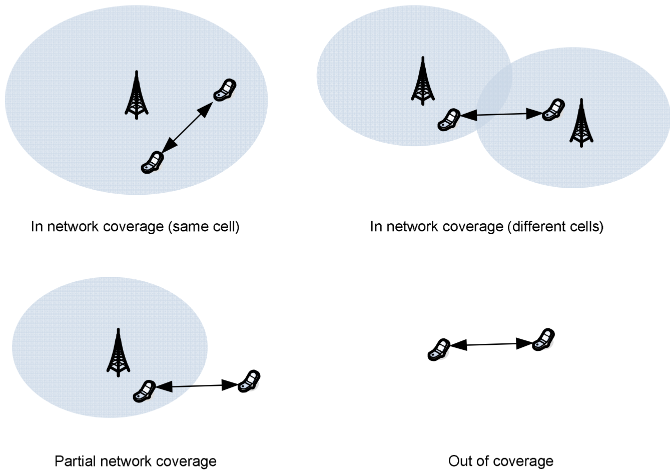

Fig. 1. Scenarios for device to device discovery and communication.

On the radio access network side, the features include discovery and broadcast communication. This requires the following new channels to be added to the physical layer specifications –

- Physical Sidelink Broadcast Channel (PSBCH) used for transmitting broadcast information for the sidelink.

- Physical Sidelink Control Channel (PSCCH) used for transmitting control information for the sidelink. The control information contains the Sidelink Control Information (SCI) that is used for scheduling of the PSSCH. SCI contains frequency hopping flag, resource block assignment, time resource pattern, modulation and coding scheme, timing advance indication, and group destination identifier.
- Physical Sidelink Discovery Channel (PSDCH) is used to provide discovery information.
- Physical Sidelink Shared Channel (PSSCH) is used to transmit data for device to device communication.

On the system architecture side, the features include support for public safety use such as discovery, group communication, relays, service continuity, location status, proximity estimation, etc.

In 3GPP Release 13, further enhancements for device to device proximity services have been proposed in [5]. These enhancements are intended to complete features that were not standardized in Release 12. They include discovery and communication in partial and outside of network coverage. The discovery mechanism can be applied to both commercial and public safety applications, while the communication mechanism will focus on public safety use.

III. The Need for Coordination

In [6], the effect of co-channel interference in D2D-enabled LTE systems has been analysed using system-level simulations. It was shown that D2D communication using LTE system may not work well with uncoordinated transmissions due to high interference. Here, we take a closer view and consider a macro-cell deployment. The simulation scenario is of a traditional 57-cell (19 sites, with 3 cells or sectors on each site) system setup with wrap-around as shown in Fig. 2. The inter-site distance (ISD) is 500m for urban area and 1732m for rural area.

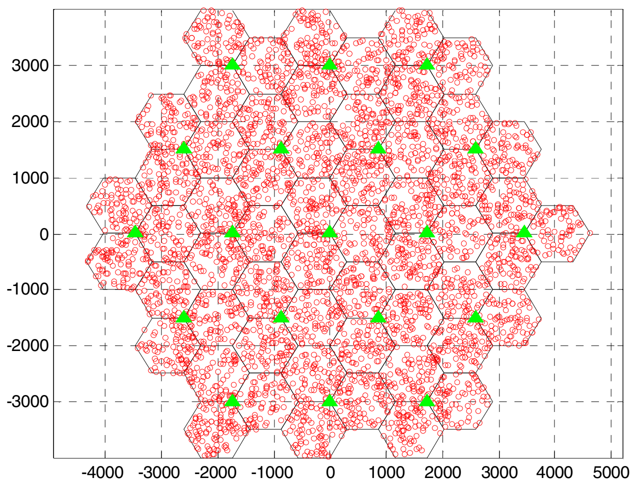

Fig. 2. Macro-cell simulation scenario.

The cellular users are randomly and uniformly dropped throughout the area and are considered to be out of coverage if signal to Interference plus Noise (SINR) is less than -6dB. As for a D2D pair, the transmitting UE is dropped uniformly in the cell while the receiving UE is dropped within a circle centered at the transmitting UE with some radius (called D2D range in the sequel). There are 12 D2D links per sector. We focus on the uplink with open loop power control

$$P_t = \min(P_{max}, SNR + P_{noise} + alpha \cdot PL),$$

where P_t denotes the transmit power, P_{max} denotes the peak transmit power and equals 23 dBm, SNR is the adjustable SNR target, P_{noise} denotes the noise power, $alpha$ is the pathloss compensation factor, and PL denotes the link path loss (with shadowing included). Further, if there is no power control, each UE transmits at its maximum power. Other relevant parameters are provided in [3].

Figure 3 shows the SNR CDF of D2D links with 250m D2D range and 500m ISD based on system-level simulations. We can see that D2D links have good SNR performance, especially when line of sight (LOS) exists, even with a D2D range up to 250m. Figure 4 shows the corresponding SINR performance. We observe that only 10% of the D2D links have greater than -6 dB SINR, regardless of the existence of LOS. This is because the SINR performance is dominated by co-channel interference. Note that the presence of LOS is undesirable for bottom 30% D2D links since the absence of LOS can provide better spatial separation among the co-channel links.

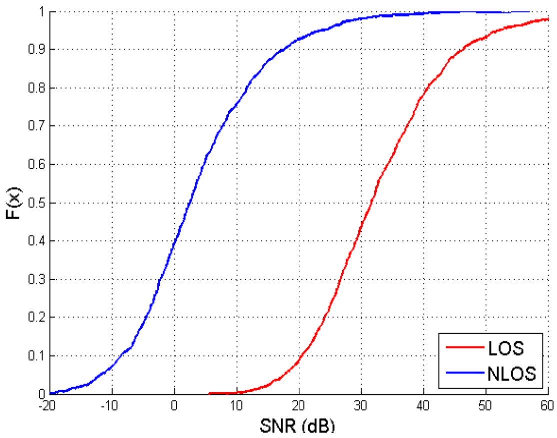

Fig. 3. D2D SNR CDF with 250m D2D range and 500m ISD.

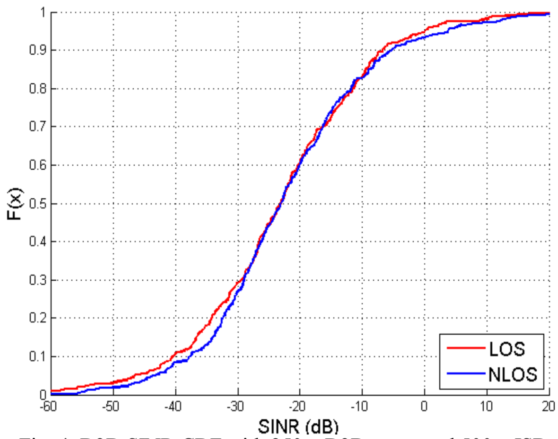

Fig. 4. D2D SINR CDF with 250m D2D range and 500m ISD.

To improve the SINR performance, a first natural choice is to coordinate the D2D links to reduce the number of co-channel transmissions. Fig. 5 shows the SINR performance with only 1 D2D link per sector. In this case, 70% of the D2D links can have greater than -6 dB SINR, which is a significant improvement versus Figure 4. Still, it may not be acceptable that 30% of the D2D links are not in coverage.

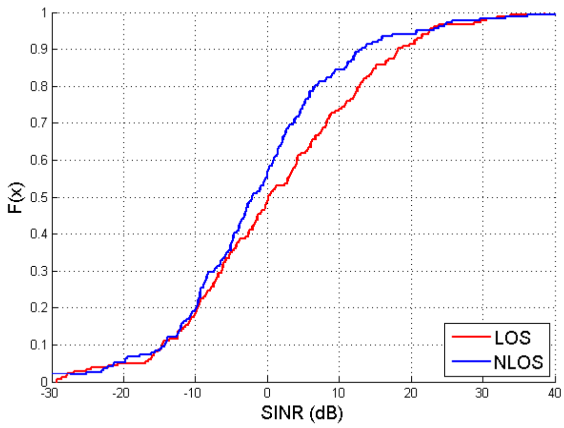

Fig. 5. D2D SINR CDF with 250m D2D range, 500m ISD, and reduced D2D link density.

In Fig. 3 - Fig. 5, power control is not used. One may wonder if the SINR performance can be improved using the open loop power control. Figure 6 shows that power control cannot further improve the SINR performance. This is because due to random dropping there is a certain fraction of D2D links having bad geometry (i.e., two links that are arbitrarily close to each other) and causing strong mutual interference. Power control is not effective in dealing with this kind of interference. Power control however does save energy.

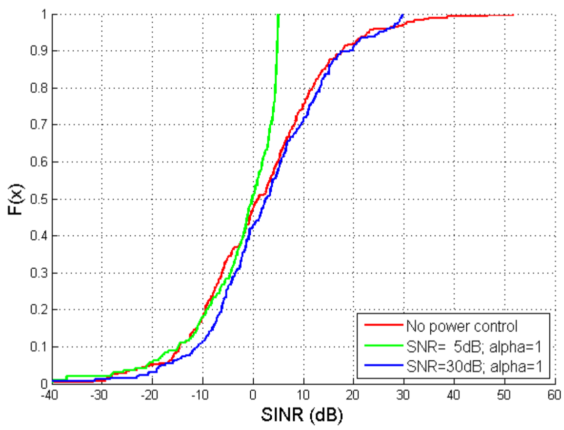

Fig. 6. D2D SINR CDF with 250m D2D range, 500m ISD, reduced D2D link density, and open loop power control.

To further improve the SINR performance in a deployment with 500m ISD, we have to reduce the D2D range in order to reduce the fraction of the D2D links being in bad geometry. Figure 7 shows that with D2D range reduced from 250m to 50m, about 95% of the D2D links can have greater than -6dB SINR while supporting 4 D2D links per sector. Alternatively, we can support 250m D2D range in rural area with 1732m ISD. This is shown in Figure 8: 98% of the D2D links can have greater than -6dB SINR while supporting 1 D2D link per sector.

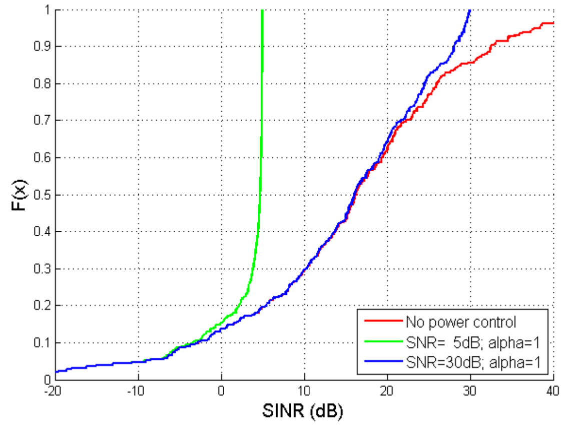

Fig. 7. D2D SINR CDF with 50m D2D range, 500m ISD, moderately reduced D2D link density, and open loop power control.

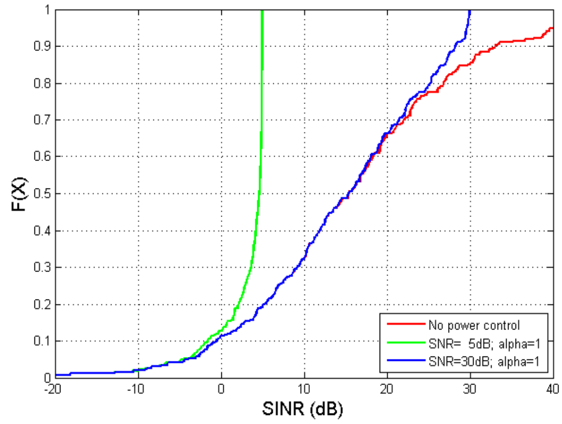

Fig. 8. D2D SINR CDF with 250m D2D range, 1732m ISD, reduced D2D link density, and open loop power control.

The above results imply that D2D links have to be coordinated for successful LTE communications. This can be done by the eNB using several user selection and resource allocation strategies, for instance –

- Frequency multiplexing among different D2D transmissions. This keeps the transmission orthogonal, thus eliminating interference. However, this resource management scheme is more complicated and may require large amount of signalling, without necessary providing optimal throughput for D2D.
- Time multiplexing among different D2D transmissions. In this case, only one D2D transmission is allowed per subframe. This is a simple scheme, however will limit the D2D throughput.
- Spatial multiplexing where difference D2D pairs are allowed to transmit using the same time-frequency resources. This scheme provides throughput improvement but will require close management,

including, for example, channel knowledge among D2D transmissions, power control, or locations.

One possible approach to providing throughput improvement is to allow multiple simultaneous D2D transmissions but without needing channel or location knowledge. Instead, the number of supportable D2D transmissions is predetermined based on simple system parameters. The selection of the D2D transmissions is done using the existing scheduling scheme, e.g. proportional fair scheduling.

IV. Network-Assisted Scheduling

In this section, we propose a method for determining the number of supportable D2D transmissions sharing the same time-frequency resources, which heavily depends on system parameters, as shown in the previous section. First, the network determines the maximum number $\bar{N}$ of D2D transmitters per sector or cell. This number depends on system parameters including D2D range, coverage percentile or performance target, cell radius, D2D SINR target, pathloss exponent, and shadowing standard deviation variance. Each eNB schedules up to $\bar{N}$ D2D transmissions in its sector at the beginning of each scheduling period.

Specifically, consider a large simulation area $\mathcal{S}$ of size $|\mathcal{S}|$. D2D transmitters are uniformly and independently dropped in the area $\mathcal{S}$. Consider a typical D2D Tx-Rx pair of distance D. Without loss of generality, let the typical D2D Rx be at the origin. The intefering D2D transmitters that dominate the interference are those located in the ball of radius D centered at the origin, denoted as $B(o,D)$. Let Z_i denote the indicator random variable: It equals 1 if D2D transmitter i is in the ball $B(o,D)$ and 0 otherwise. In particular,

$$Z_i = \begin{cases} 1 & with\ prob.\ \dfrac{\pi\ D^2}{|\mathcal{S}|}\ ; \\ 0 & with\ prob.\ 1\ -\ \dfrac{\pi\ D^2}{|\mathcal{S}|}\ . \end{cases}$$

Let X denote the number of intefering D2D transmitters in the ball $B(o,D)$. Then we have

$$X = \sum_i Z_i$$

Denote by λ the density of D2D transmitters, i.e., the number of D2D transmitters per unit area. Then the mean and variance of X can be calculated as follows.

$$\mu_X = \lambda|\mathcal{S}|\cdot\mathbb{E}[Z] = \lambda|\mathcal{S}|\cdot\frac{\pi D^2}{|\mathcal{S}|} = \lambda\pi D^2$$

$$\sigma_X^2 = \lambda|\mathcal{S}|\cdot\sigma_Z^2 = \lambda|\mathcal{S}|\cdot\frac{\pi D^2}{|\mathcal{S}|}(1-\frac{\pi D^2}{|\mathcal{S}|}) \approx \lambda\pi D^2,$$

where the last approximation holds for large simulation area $\mathcal{S}$. When λ is large, X is a sum of i.i.d. of random variables, and by central limit theorem X can be well approximated by a Gaussian random variable, i.e., $X \sim \mathcal{N}(\mu_X, \sigma_X^2)$.

When λ is large, the SINR of the typical D2D link can be approximated by

$$SINR = \frac{P_0 D^{-\alpha}}{\sum_i P_i Y_i^{-\alpha} + N_0} \approx \frac{P_0 D^{-\alpha}}{\sum_i P_i Y_i^{-\alpha}} \approx \frac{P_0 D^{-\alpha}}{\sum_{i:Y_i<D} P_i Y_i^{-\alpha}}$$

where α is the pathloss exponent.

Suppose all the D2D transmitters transmit at the maximum power P_m. Then,

$$SINR \approx \frac{D^{-\alpha}}{XY^{-\alpha}},$$

where Y is distributed as $\mathbb{P}(Y \le y) = \frac{y^2}{D^2}, 0 \le y \le D$. Hence, conditioning on X,

$$\mathbb{E}_Y[SINR] = \frac{1}{XD^\alpha}\mathbb{E}[Y^\alpha] = \frac{1}{XD^\alpha}\int_0^D y^\alpha \frac{2y}{D^2}\mathrm{d}y = \frac{2}{\alpha+2}\frac{1}{X}$$

Let T (dB) be the SINR target and ε the performance target. Denote by σ (dB) the standard variance of the shadowing, simply treated as the SINR target margin. Then we require that

$$\mathbb{P}(SINR \ge 10^{(T+\sigma)/10}) \ge 1-\varepsilon$$

For example, with $\varepsilon = 5\%$ and $T = -6$ dB, the above condition may yield a rough estimate on the maximum D2D transmitter density such that at least 95% D2D links can have greater than -6 dB SINR. The last equation can be approximated as

$$\mathbb{P}(SINR \ge 10^{(T+\sigma)/10}) \approx \mathbb{P}\left(\frac{2}{\alpha+2}\frac{1}{X} \ge 10^{(T+\sigma)/10}\right) = \mathbb{P}\left(X \le \frac{2}{\alpha+2}\cdot\frac{1}{10^{(T+\sigma)/10}}\right) \ge 1-\varepsilon$$

which is equivalent to

$$Q\left(\frac{\frac{2}{\alpha+2}\cdot\frac{1}{10^{(T+\sigma)/10}} - \mu_X}{\sigma_X}\right) < \varepsilon$$

$$\Leftrightarrow \quad Q\left(\frac{\frac{2}{\alpha+2}\cdot\frac{1}{10^{(T+\sigma)/10}} - \lambda\pi D^2}{\sqrt{\lambda\pi D^2}}\right) < \varepsilon$$

For reasonable system parameters, $\sqrt{\lambda\pi D^2} \approx \lambda\pi D^2$ because $\lambda\pi D^2$ represents the number of interfering D2D transmitters located in the ball $B(o,D)$, which should be a small number. It follows that

$$\lambda \le \frac{1}{Q^{-1}(\varepsilon)+1}\cdot\frac{2}{\alpha+2}\cdot\frac{1}{10^{(T+\sigma)/10}}\frac{1}{\pi D^2}$$

Now consider a hexagonal cell composed of three sectors with radius R. The sector area is $\frac{\sqrt{3}}{2}R^2$. So the maximum number $\bar{N}$

of D2D transmitters that may be scheduled in each sector is given by

$$\overline{N} = \frac{1}{Q^{-1}(\varepsilon)+1} \cdot \frac{2}{\alpha+2} \cdot \frac{1}{10^{(T+\sigma)/10}} \frac{1}{\pi D^2} \cdot \frac{\sqrt{3}}{2} R^2$$

Note that in practice this approximation can be generalized for other cell or network layouts.

We report some numerical results here. With ε=5%, α=2.3, T=-6 dB, σ=7 dB, our simulation shows that 1 D2D link per sector may exist for 250 m D2D range and 1000 m cell radius. The proposed formula for $\overline{N}$ gives a value 0.62. Similarly, our simulation shows that 4 D2D link per sector may exist for 50 m D2D range and 500 m cell radius. The proposed formula for $\overline{N}$ gives a value 3.87. The good match between simulation and analysis confirms that, using the simple formula for $\overline{N}$, the network is able to rougly determine the maximum number of D2D links that can be scheduled per cell.

The methods on selecting the $\overline{N}$ D2D transmitters can be flexible. Some examples are given as follows.

- The eNB may randomly pick up any $\overline{N}$ D2D transmitters. If the number of D2D transmitters in any cell is less than $\overline{N}$, the corresponding eNB simply lets all the D2D transmitters be active.
- The selection may take into account simple D2D statistics like SINR target and number of times user has been scheduled.
- The selection may take into account other factors like the previously achieved throughput, current channel state information, buffer status, etc.
- The selection may take into account spatial information including e.g. location, propagation channel, antenna information, and spatial correlation.
- The selection may take into account power-based information (e.g. power control parameters as assigned by the eNB).

In this paper,the $\overline{N}$ D2D transmitters were selected randomly. More intelligent selection criteria can also improve the SINR of the D2D links.

V. Conclusion

This paper considered D2D communication sharing the same time-frequency resources as cellular communication. Due to high interference, D2D links have to be coordinated for successful communication. A simple coordination scheme is provided based on allowing maximum number of supportable D2D transmissions. It is shown that, with network assistance, the percentage of reliable D2D communication links can be improved significantly.

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