Network-assisted Neighbor Discovery based on Power Vectors for D2D Communications

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***Abstract*—Device-to-Device (D2D) communication is seen as a promising technology to increase the capacity of current wireless systems without extra electromagnetic spectrum bands. However, before starting a D2D communication, Mobile Stations (MSs) must be aware of their neighbors, through a discovery process. While operating in cellular networks, such process may benefit from the network-assistance. In this paper, we propose a method based on the available network power measures to improve the discovery process. Results show that our proposal is less complex but still outperforms traditional methods when considering the time to detect all neighbors.**

I. INTRODUCTION

The notable popularity of smartphones and tablets along with the increasing demand for rich multimedia services and the scarcity of electromagnetic spectrum has motivated the research of technologies that are able to improve the capacity of wireless systems without requiring extra spectrum bands. In this context, Device-to-Device (D2D) communication represents a promising technology that has attracted the attention of scientific community in the last couple of years [1].

D2D communication is a new type of direct wireless communication between two or mode network nodes, hereafter generally referred as Mobile Stations (MSs), that exploits the proximity between them to achieve very high data rates and low delays, with a reduced power consumption. But, it comes with the cost of introducing additional interference, which is seen as the main drawback. Benefits and challenges of D2D communications, especially in cellular networks, are discussed in, e.g., [1]–[3].

However, before commencing a D2D communication, each D2D-capable MS must have the knowledge of its neighbors, i.e., other D2D-capable MSs in the vicinity of the former with whom it may directly communicate with. Ideally, MSs shall discover their neighbors as quickly as possible, which enables them to save power. Also, a speedy discovery allows routing and other protocols to quickly start their execution, without significantly decrease the MSs' operation time [4], [5]. Moreover, the discovery shall be adaptive from sparse environments, with just few MSs, to densely populated places, with a large number of MSs [6].

Therefore, the main problem herein is to determine the pool of neighbors for each D2D-capable MS: if the process does not occur or no neighbors are found, the D2D communication will not happen; simply because the MS is not aware of other surrounding D2D-capable MSs.

A. Relevant Prior Art

As such, each MS may employ a neighbor discovery mechanism without being network-assisted. This is a decentralized beaconing mechanism [7], [8], where each MS acts only on its own. The natural improvement is to combine the beaconing mechanism with an exchanging protocol, where the Identitys (IDs) of already detected neighbors are shared between all MSs in the neighborhood [9]. However, both approaches have the following problems:

- Time to discover and stopping criteria: if the discovery process takes too long, it may be useless, since no time is left for data transmission, and good stopping criteria are difficult to be effectively defined [10]. This is especially relevant because the surrounding environment is unknown and the discovery may happen from sparse to crowded environments [6];
- Power consumption: the discovery process may completely discharge the MS's battery, namely if the number of possible neighbors is not prior-known and stopping criteria are not correctly implemented [6], [11];
- New protocol: for the beaconing sequence, and particularly in the case of exchanging information about the already known (discovered) neighbors, a new protocol needs to be defined and implemented [12], implying more network load on signaling;
- Hidden MS problem: relying only on power detection at physical layer, and, for directional antennas, the misalignment between transmitter and receiver's antennas, may lead to undetected neighbors [13].
- Fake MS attack: security attacks may happen from a MS which fakes its ID and pretends to be another.

In order to overcome the problems mentioned above, MSs may be network-assisted [1], [6], [11], [14] to determine the pool of their neighbors, speeding up the discovery process along with its accuracy. The proposed method, which is described in the next paragraphs, despite being a simple concept, also offers the same advantages in all listed aspects.

The rest of the paper is organized as follows: in Section II a detailed explanation about power vectors and the neighborhood matrix is given, in Section III the system model used

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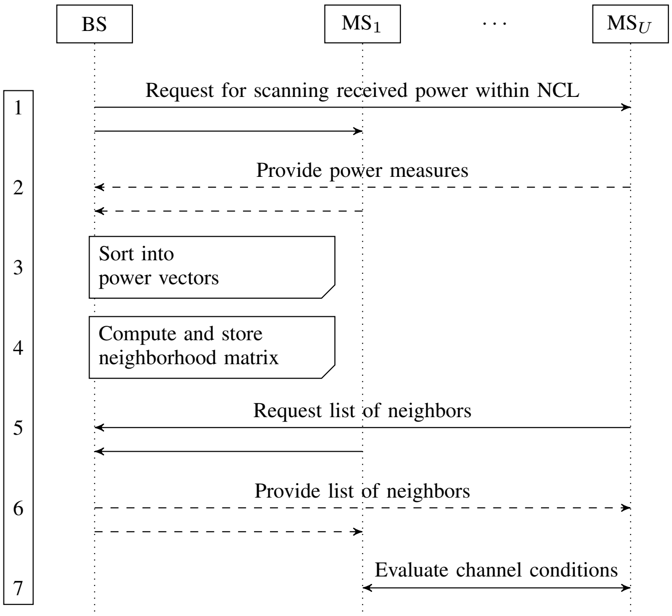

Fig. 1. Messages exchange between the serving BS and D2D-capable MSs

in simulations is presented, in Section IV the main results are shown and discussed, and in Section V conclusions are drawn.

II. POWER VECTORS AND NEIGHBORHOOD MATRIX

In this section we focus on the detailed explanation about power vectors and how to construct the neighborhood matrix. For this, the explanation below is based on Fig. 1 that presents a set of messages exchanged between the serving Base Station (BS) and D2D-capable MSs.

A. Collecting Power Measurements from Neighbor Cell List

All MSs while operating in structured networks, as the case of cellular systems, need to perform a set of measurements. One of the very basic of those measurements is the received power from their serving BS. Furthermore, MSs must also perform power measurements on the pilots of vicinity cells (phase 1 of Fig. 1) and report back those values to the serving BS (phase 2 of Fig. 1). This procedure is mandatory in any cellular system because of mobility and cell-reselection, due to, e.g., handover and resource allocation reasons. Additionally, a timestamp can be associated to each set of power measurements and if a power measure is detected to be too old (outside a given useful lifetime period), it can be discarded and a new measurement requested.

Moreover, each BS knows its neighbor cells which are stored in a list, commonly described as Neighbor Cell List (NCL) or monitored set. Note that the model is easily extensible to other systems, such as Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX), since most systems already dispose of methods to measure the received power, which is used, at least, during connection establishment [1], [15].

B. Sorting Power Measurements into Power Vectors

The reported power measures are then sorted in what is called power vectors (phase 3 of Fig. 1), i.e., each MS has reported different power values for the scanned BSs and since both MS and cell's IDs are assumed to be unique, it is easy for the serving BS to arrange them in a specific order, like in Eq. (1), with $\mathbf{P} \in \mathbb{R}^{U \times B}$, where U is the number of MSs within the BS serving area and B the number of BSs to be scanned, i.e., number of elements within the NCL, see Fig. 2,

$$\mathbf{P} = \begin{array}{c} \\ \mathrm{MS}_1 \\ \mathrm{MS}_2 \\ \vdots \\ \mathrm{MS}_U \end{array} \begin{array}{c} \begin{array}{cccc} \mathrm{BS}_1 & \mathrm{BS}_2 & \dots & \mathrm{BS}_B \end{array} \\ \begin{bmatrix} P_{1,1} & P_{1,2} & \dots & P_{1,B} \\ P_{2,1} & P_{2,2} & \dots & P_{2,B} \\ \vdots & \vdots & \ddots & \vdots \\ P_{U,1} & P_{U,2} & \dots & P_{U,B} \end{bmatrix} \end{array}. \qquad (1)$$

In this representation, each row is a power vector, where $P_{u,b}$ is the power received by MS$_u$ from BS$_b$, with $u \in \{1, 2, \dots, U\}$ and $b \in \{1, 2, \dots, B\}$.

Considering the case of Long Term Evolution (LTE) family standards the power measures would be the Reference Signal Receive Power (RSRP) and Reference Signal Receive Quality (RSRQ), and the ID of each MS can be obtained with the Demodulation Reference Signal (DMRS) which is transmitted in the Uplink (UL) direction, and the cell ID with the Physical-layer Cell ID (PCI) transmitted in Downlink (DL) [16].

Whenever the received power for a specific BS cannot be measured due to any particular reason, a standard value (e.g., zero or maximum long-term fading value towards the first ring of interfering cells) may be used to fill the corresponding gap in the power vector so that the method is still applicable. Additionally, this value can be controlled, limiting the number of false neighbors and maximizing the number of real neighbors.

Also, the received power from the serving BS is orders of magnitude greater than the received power from other BSs. Thus, in order to not polarize the results, the received power from the serving BS shall be removed from the power vector of each MS (i.e., set to zero).

C. Building the Neighborhood Matrix

When values are organized in the form of power vectors (phase 3 of Fig. 1), a cross correlation metric, ρ, is used to determine the correlation between them. Therefore, taking two different power vectors and defining a correlation threshold, P_{TH}, two cases may happen:

- The correlation is high, i.e., $\rho > P_{\mathrm{TH}}$. In this case, MSs are considered neighbors because their set of measures is very similar and, therefore, it is likely to happen that they are in physical proximity[1];
- The correlation is low, i.e., $\rho \leq P_{\mathrm{TH}}$. In this case, MSs are not considered as neighbors because their set of measures is not similar and, therefore, it is likely to happen that they are far away from each other.

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[1] The real position within the cell is most of the times unavailable. However, cellular links with similar channels do have similar propagation effects related with distance, path blockage, and motion.

Thus, the next step is to calculate the cross correlation metric among all power vectors. A possible metric is defined in Eq. (2).

$$\rho_{x,y} = \left\langle \frac{\mathbf{x}}{\|\mathbf{x}\|}, \frac{\mathbf{y}}{\|\mathbf{y}\|} \right\rangle, \text{ and } x \neq y \in \{1, 2, \ldots, U\}, \tag{2}$$

in which $\rho_{x,y}$ is the normalized cross correlation for power vectors $\mathbf{x}, \mathbf{y} \in \{\mathbf{P}_{\mathrm{MS}_1}, \mathbf{P}_{\mathrm{MS}_2}, \ldots, \mathbf{P}_{\mathrm{MS}_U}\}$; or in other words, $\mathbf{x}$ and $\mathbf{y}$ are the contents of two different rows of matrix $\mathbf{P}$. $\langle \cdot, \cdot \rangle$ is the inner product defined as $\langle \mathbf{i}, \mathbf{j} \rangle = \sum_{k=1}^{K} i_k j_k$ and $\|\cdot\|$ is the l_2 norm as $\|\mathbf{i}\| = \sqrt{\sum_{k=1}^{K} |i_k|^2}$, with $\mathbf{i} = \begin{bmatrix} i_1 & i_2 & \cdots & i_K \end{bmatrix}$ and $\mathbf{j} = \begin{bmatrix} j_1 & j_2 & \cdots & j_K \end{bmatrix}$.

Moreover, since $\mathbf{x}$ and $\mathbf{y}$ are composed by non-negative quantities, $\rho_{x,y}$ will range between 0 (non-correlated) and 1 (very high correlated). Finally, the neighborhood matrix, shown in Eq. (3), is constructed and stored in the BS (phase 4 of Fig. 1) as follows:

- If the correlation between MS_x and MS_y is high, they are tagged as neighbors, and $\rho_{x,y}$ fills the corresponding (x, y) and (y, x) indexes (note that $\rho_{x,y} = \rho_{y,x}$);
- Else, MS_x and MS_y are tagged as non-neighbors, and a zero fills the corresponding (x, y) and (y, x) indexes.

$$\mathbf{\Omega} = \begin{array}{c} \\ \mathrm{MS}_1 \\ \mathrm{MS}_2 \\ \vdots \\ \mathrm{MS}_U \end{array} \begin{array}{c} \begin{array}{cccc} \mathrm{MS}_1 & \mathrm{MS}_2 & \ldots & \mathrm{MS}_U \end{array} \\ \begin{bmatrix} 0 & w_{1,2} & \ldots & w_{1,U} \\ w_{2,1} & 0 & \ldots & w_{2,U} \\ \vdots & \vdots & \ddots & \vdots \\ w_{U,1} & w_{U,2} & \ldots & 0 \end{bmatrix} \end{array}, \tag{3}$$

with

$$w_{x,y} = \begin{cases} \rho_{x,y}, & \text{if } x \neq y \text{ and } \rho_{x,y} > P_{\mathrm{TH}}, \\ 0, & \text{otherwise.} \end{cases}$$

Note that matrix $\mathbf{\Omega} \in [0, 1]^{U \times U}$ is symmetric, thus only its lower or upper triangles may be used, e.g., for saving storage space. Also, the proposed normalized cross correlation metric expressed as the normalized inner product between two power vectors is one possible correlation metric, but other metrics can be used instead, that are easily found in literature (e.g., Pearson product-moment correlation coefficient). Similarly, instead of using the real correlation value in matrix $\mathbf{\Omega}$, ones can be stored whenever $x \neq y$ and $\rho_{x,y} > P_{\mathrm{TH}}$, obtaining a binary matrix. However, by storing real values, they may be used to sort the list of neighbors of a MS, improving routing protocols in multicast or broadcast scenarios.

D. Storage and Exchange of Neighborhood Matrix

Next, the corresponding row or the full neighborhood matrix is delivered to MSs upon request (phases 5 and 6 of Fig. 1). Moreover, the D2D link must be evaluated before commencing a D2D communication (phase 7 of Fig. 1) by any means.

Additionally, regarding the running time for the message flowchart in Fig. 1 it can be settled in the following basis:

- Phases 1 to 4: may be done at every 200 ms to 1 s or 200 to 1000 Transmission Time Intervals (TTIs) [15];
- Phases 5 to 7: may be done at each new service request or whenever the MS is scheduled.

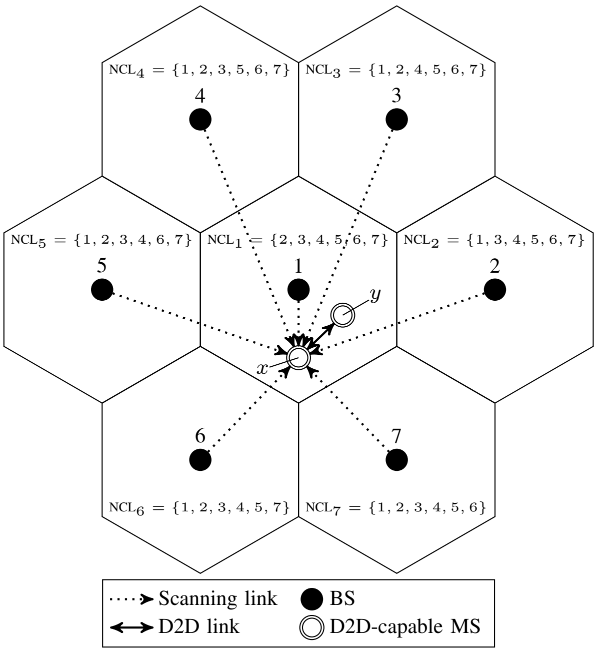

Fig. 2. Simulation scenario; MS_x and MS_y perform the scanning within NCL_1 (for MS_y it is not shown in the picture), and since $\rho_{x,y} = \rho_{y,x} > P_{\mathrm{TH}}$ they are neighbors and may form a D2D pair

III. SYSTEM MODEL AND SIMULATION FRAMEWORK

In this section we describe the models and simulation framework that were adopted to evaluate the system performance. Simulations are divided in two main parts: in the first part, the simulation scenario is built and the neighborhood matrix is computed as described in Section II; and in the second part, each D2D-capable MS uses the direct link to perform the detection of its neighbors being network-assisted or not.

A. Cellular Scenario

Consider a network where each BS is placed at the center of a site, which is represented by a regular hexagon. This scenario corresponds to a regular multi-cell network as presented in Fig. 2. The urban-microcell propagation environment is used, where each site is a single-cell [17]. Therefore, the multi-cell scenario has B cells and each one serves U MSs uniformly dropped over its coverage area. Moreover, all MSs and BSs are equipped with a single omnidirectional antenna [18].

Despite the multi-cell scenario, each BS acts on its own, i.e., no connection between BSs is assumed. Hence, statistics are independently collected and treated within each cell coverage area. Furthermore, all MSs are D2D-capable, thus the number of possible neighbors per MS is simply given by $U - 1$.

The cellular channel modeling includes the long-term fading propagation effects, namely, pathloss and shadowing. Channel variations due to shadowing are modeled with a lognormal distribution of zero mean and standard deviation σ_{sh}. No fast (or short-term) fading model is used, meaning that during the scanning period (phases 1 and 2 of Fig. 1) MSs are assumed to be stationary. Further aspects of the propagation models are

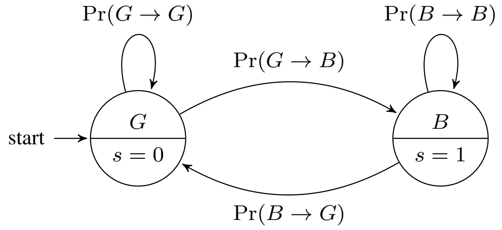

Fig. 3. Stochastic two-state Markov channel

described in [17], [18]. The cellular channel is the one used to build the neighborhood matrix.

B. Device-to-Device Channel

The wireless channel is a time variant channel, therefore an option to characterize that channel is to use Markov chains; which are stochastic processes with a limited number of states and whose transition between them is based on the probability of an event. Those states in Markov chains can be defined in agreement to real channel conditions of a scenario, i.e., long- and short-term fading effects [19].

As such, to model the D2D channel we used a simplified stochastic two-state Markov channel like in [20], $S = \{0, 1\}$, as presented in Fig. 3, where $s \in S$ represents the channel link quality state. When the channel link quality is good, the state is G or $s = 0$. For the case of bad channel link quality, the state is B or $s = 1$. The good is meant for the Line of Sight (LOS) condition, while bad reflects the opposite, i.e., Non-Line of Sight (NLOS) condition.

The switching between states is established in the probability transition matrix $\mathbf{M}$. This is a squared matrix whose order equals the number of states, and its elements represent the probability, $\Pr(\cdot)$, of changing or remaining in the same state.

$$\mathbf{M} = \begin{bmatrix} m_{0,0} & m_{0,1} \\ m_{1,0} & m_{1,1} \end{bmatrix} = \begin{bmatrix} \Pr(G \to G) & \Pr(G \to B) \\ \Pr(B \to G) & \Pr(B \to B) \end{bmatrix}, \quad (4)$$

where $0 \leq m_{i,j} \leq 1$ and $\sum_j m_{i,j} = 1$ and $i, j \in S$.

The total appearing percentage of a state in Markov chain is given by the steady-state vector $\boldsymbol{\pi} = \begin{bmatrix} \Pr(G) & \Pr(B) \end{bmatrix}$. This vector can be computed by raising $\mathbf{M}$ to a large power, i.e.,

$$\lim_{n \to +\infty} \mathbf{M}^n = \mathbf{1}\boldsymbol{\pi},$$

implying that in a steady state $\boldsymbol{\pi} = \boldsymbol{\pi}\mathbf{M}$, where $\mathbf{1} = \begin{bmatrix} 1 & 1 \end{bmatrix}^{\mathrm{T}}$ is a column vector of ones. A property of vector $\boldsymbol{\pi}$ is that the sum of its elements must be equal to the unity, $\sum_j \pi_j = 1$, with π_j being the steady-state probability for state j.

For the case of low probability of LOS conditions and strong multipath because of, e.g., the motion of MSs, buildings and/or trees blockage, we used $\mathbf{M}$ and $\boldsymbol{\pi}$ as in Eq. (5),

$$\mathbf{M} = \begin{bmatrix} 0.2 & 0.8 \\ 0.2 & 0.8 \end{bmatrix} \Rightarrow \boldsymbol{\pi} = \begin{bmatrix} 0.2 & 0.8 \end{bmatrix}. \quad (5)$$

In our simplified model, we consider that a neighbor is only detected if the channel link quality between two D2D-capable MSs is good, i.e., state G or $s = 0$, because only in that state the Signal to Interference-plus-Noise Ratio (SINR) is above an established detection threshold.

TABLE I
SIMULATION PARAMETERS

Parameter	Value	Ref.
Number of BSs (B)	7	
Cellular environment	Urban-microcell	[17]
Inter-site distance	500 m	[17]
BS transmit power	38 dBm	[18]
Number of MSs per cell (U)	8, 16, 32, 64, 128	
CSI knowledge	Perfect	
Correlation threshold (P_{TH})	0.75	
Central carrier frequency	1.90 GHz	[17]
Cellular pathloss model [dB]	$34.5 + 38\log_{10}(d)$, d in meter	[17]
Shadowing std. dev. (σ_{sh})	10 dB	[18]
Antenna configuration	SISO, omnidirectional	
D2D channel links	Two-state Markov channel	[20]
Probability of LOS conditions	Low: $\Pr(B) = 0.8$	

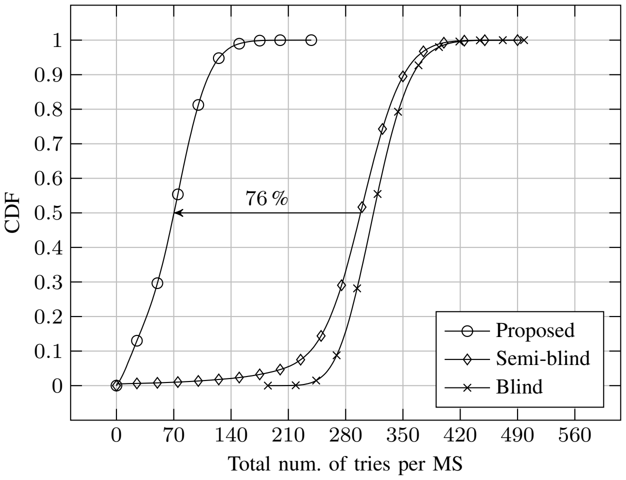

Fig. 4. Total number of tries to detect all neighbors per MS with 64 MSs/cell

IV. RESULTS AND DISCUSSION

In this section, the results regarding the time to detect all neighbors per MS, measured in terms of the total number of tries[2], are presented. Table I summarizes the parameters used in simulations. Moreover, three methods are compared:

- Proposed: previously described, where each MS has the full information of its neighbors (i.e., total number of neighbors and their IDs) provided by the serving BS, and for this method no false detections happen;
- Semi-blind: follows a beaconing approach [7], [8], where each MS knows the number of its neighbors, but their IDs remain unknown;
- Blind: similar to semi-blind method, but each MS only knows the number of its potential neighbors, i.e., the total number of MSs within the cell except itself.

The total number of tries to detect all neighbors considering 64 MSs per cell is presented in Fig. 4. As it can be seen the

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[2] A try is defined as an attempt to detect a neighbor; a successful try means that a neighbor was detected.

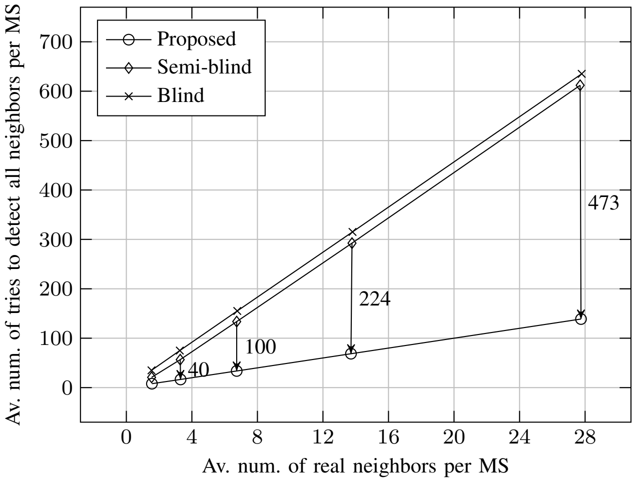

Fig. 5. Comparison between the different methods considering the average number of tries to detect all neighbors

proposed method clearly outperforms the other two methods. Particularly, when compared with the semi-blind method in the 50th percentile, the number of tries are reduced about 76 %.

Furthermore, the complexity of the proposed method, measured by the number of tries required to detect all neighbors when the number of neighbors increases, is also considerable reduced, which is observable in the slopes of straight lines in Fig. 5. Notably, when there are around 28 neighbors per MS, less 473 tries are required to detect all neighbors in comparison with the semi-blind case.

V. CONCLUSION

In this paper we proposed and explained a neighbor discovery process based on power vectors for network-assisted D2D communications. The method may be used in current wireless networks because it uses already available measures and does not add considerable network load on signaling.

Results show that with the network help, the time to detect all neighbors per MS is significantly reduced, letting more time for data transmission. In future publications we will focus on:

- Enable the discovery of MSs that belong to different cells, that may happen close to cell boundaries;
- Implement a timeout for the discover to happen and count the false/missed detections;
- Discover neighbors that do not fulfill the service request, which can be especially useful in social networks.

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