

# Obstacle Avoidance Cell Discovery using mm-waves Directive Antennas in 5G Networks

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**Abstract**—With the advent of next-generation mobile devices, wireless networks must be upgraded to fill the gap between huge user data demands and scarce channel capacity. Mm-waves technologies appear as the key-enabler for the future 5G networks design, exhibiting large bandwidth availability and high data rate. As counterpart, the small wave-length incurs in a harsh signal propagation that limits the transmission range. To overcome this limitation, array of antennas with a relatively high number of small elements are used to exploit beamforming techniques that greatly increase antenna directionality both at base station and user terminal. These very narrow beams are used during data transfer and tracking techniques dynamically adapt the direction according to terminal mobility. During cell discovery when initial synchronization must be acquired, however, directionality can delay the process since the best direction to point the beam is unknown. All space must be scanned using the tradeoff between beam width and transmission range.

Some support to speed up the cell search process can come from the new architectures for 5G currently being investigated, where conventional wireless network and mm-waves technologies coexist. In these architecture a functional split between C-plane and U-plane allows to guarantee the continuous availability of a signaling channel through conventional wireless technologies with the opportunity to convey context information from users to network.

In this paper, we investigate the use of position information provided by user terminals in order to improve the performance of the cell search process. We analyze mm-wave propagation environment and show how it is possible to take into account of position inaccuracy and reflected rays in presence of obstacles.

## I. INTRODUCTION

The 5th generation (5G) of wireless networks is currently gaining the momentum in the research community. Several research activities are focused on new challenges while the smartphone and tablet revolution is strongly affecting the wireless network capacity. Providing 1000 times higher traffic volumes and guaranteeing high peak rates is no longer an option: advanced solutions must be considered to deal with network resource scarcity. The compelling limitation of available frequency band is drawing the attention of academic and industry partners which exert to use frequencies above the conventional 5GHz. In this context, the advantage of exploiting millimeter waves (mm-waves) communication at 60 GHz is two-fold: *i*) unlicensed spectrum band can be smartly managed and *ii*) wide bandwidths (up to 1GHz) may lead to high data rates performance during communications [1].

Although mm-waves channels are attractive and represent the most promising solution for future network design, they suffers from the major drawback due to the coarse propagation at very-high frequencies. Refraction and reflection effects are adversely hampered by the presence of obstacles along the

communication path. Therefore, modeling the propagation channel under those conditions becomes very challenging due to huge number of parameters to be tuned [2]. Fortunately, while the very small wave-length negatively affects the channel attenuation, this readily allows to use much more antenna elements in very limited areas (suitable for mobile devices). This straightforwardly enables the beamforming technique to build a quasi-errorless channel between two physical transmitters in line of sight. On the one hand, the directive transmissions consolidate the effective power over small angle and dramatically extends the coverage range up to few hundred meters. On the other hand, transmitters and receivers must beam out each others beforehand to establish a proper connection by scanning over all possible directions due to the confined viewing angle [3]. The overdue time during the synchronization process between mm-waves small cells and User Equipments (UEs<sup>1</sup>) may delay or brutally causes a service disruption in the mm-waves access network [4].

Interestingly, designed system architectures rely on heterogeneous networks where legacy communication technologies have not been yet surmounted. Continuous connectivity service is always guaranteed while switching on future mm-waves access network to boost the network capacity only when available. For this propose, advanced system architectures are currently under the evaluation of different research projects, such as FP7-ICT EU MiwaveS project [5] or FP7-ICT EU MiWebra project [6]. Additionally, the latter assumes a function split between the user (U-) plane and control (C-) plane when signaling transmissions could be compromised by the unexpected lack of connectivity [7]. Thus, signaling messages are exchanged through conventional communication channels leaving the full management of data connections under the control of mm-wave network functions, as envisaged in Fig 1. The availability of a unfailing signaling layer benefits the network functions related to mobility management and service access. For instance, context information may be available at the mm-waves small cells, which may successfully retrieve information about user positions to minimize the delay for the cell discovery process (also defined as cell search process).

In this paper, we rely on the context-based solution to asses the cell discovery performance when newcomers users join the network. Specifically, an external localization system is involved (e.g., GPS) and user position information are facilitated through the conventional network. However, the compound effect of signal obstruction, due to the presence

<sup>1</sup>Both terms UE and users are used interchangeably throughout the paper.



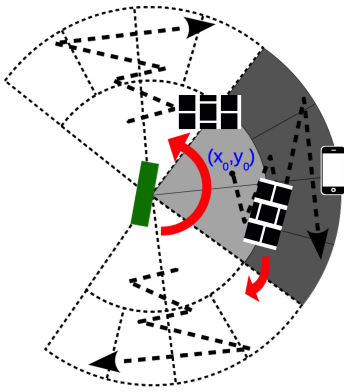


Fig. 2: Example of Enhanced Discovery Procedure (EDP). Estimated user location is  $(x_0, y_0)$  and two obstacles are placed in the area.

### A. Baseline Scenario

The adoption of a small wave-length critically exacerbates the cellular channel conditions exhibiting a strong pathloss effect due to the very-high frequencies involved. Directive antenna transmissions ease the bad channel problem focusing the antenna gain on a limited view angle. Assuming a 2D exploration, the cell discovery procedure could properly set the antenna view angle, namely beam-width  $\phi$ , to speed up the cell search process. When the beam-width is pretty wide, coverage range is poor and mm-waves small cell is able to cover only center-users. Conversely, a narrow beam-width allows to reach faraway users but requiring high pointing accuracy. Once the beam-width is fixed, a spatial exploration (e.g., choose direction  $d$ ) is required to hook the user synchronisation signal.

Considering a obstacle-free environment, where mm-waves small cell has a perfect knowledge about user position, the spatial exploration is trivially reduced to one single attempt, i.e., the mm-waves small cell computes the optimal beamforming configuration pair  $(\phi, d)$  and beam directly the user. Differently, inaccuracy of context information may lead to a wrong beamforming parameters calculation and unsuccessful user recognition. This compels the mm-waves small cell to start a pure search over different direction or even change the beam-width  $\phi$  if no user has been found. Based on that, a simple greedy algorithm is proposed in [4]. Starting from the largest beam-width  $\phi$  the so-called *Discovery Greedy Search* (DGS) performs an exhaustive sequential search over all possible directions. If no user is detected, the beam-width  $\phi$  is reduced and the spatial exploration starts again. While this guarantees that all possible beamforming configuration pairs are correctly evaluated, the entire process may suffer from significant delays. Therefore, choosing a beam-width value becomes a crucial decision: the thinner the beam-width, the more directions must be explored to find out the user. Additionally, a larger beam-width is more robust to uncertain position information exchanged through the context channel.

### B. Obstacles and reflections effects

Real environments impose that some object can lie between mm-waves transmitters placed in different locations, causing a severe signal attenuation. Those obstructions could be caused

by fixed obstacles (tree, buildings, and so on) or by dynamic objects (human body, vehicles, train and so on). While obstacle motions can be modelled as fading effects and can be addressed by physical communication layer solutions, fixed obstacles might drop the signal and must be avoided. Since we consider all objects in the field as opaque obstacles, ray reflections due to the ground or to other obstacle surfaces cannot be negligible. Therefore, when user is not reachable due to a lack of a direct transmission path, the cell search algorithm exploits the ray reflection effect to provide the user with a minimum level of power. In our study, we model the power due to reflection as follows:

$$P_r = 20 \log_{10} \left( \frac{\lambda}{4\pi s} \right) - A_0 s + R + F \quad (1)$$

where

$$R = 20 \log_{10} \left( \frac{\sin\theta - \sqrt{B}}{\sin\theta + \sqrt{B}} \right), B = \epsilon - \cos^2\theta;$$

$$F = \frac{-80}{\ln(10)} \left( \frac{\pi \sin\theta \sigma}{\lambda} \right)^2.$$

We consider  $\epsilon$  and  $\sigma$  as the roughness and reflection coefficients of the material, while  $\theta$  and  $s$  as the angle of reflection and the distance, respectively. We refer the reader to [15] for further details. Ideally, whenever the network is perfectly aware about user locations and fixed obstacles positions in the surrounded area, the cell discovery procedure is able to promptly calculate beamforming parameters (beam-width and pointing direction), avoiding successfully the obstacles. In practice, semi-static obstacles in conjunction with partial UE position information might notably delay the cell discovery process, even when advanced algorithms are implemented.

### C. Enhanced Discovery Procedure

We proposed an enhanced version of the algorithm presented in [4], namely *Enhanced Discovery Procedure*, using a learning approach while running. The algorithm takes into account the possibility of obstacle avoidance using reflected rays while exploiting the context information to reduce the user discovery time.

In the previous scheme, when a user position is retrieved through the context channel, the cell search algorithm computes the optimal beamforming parameters to spot the user. If low accuracy is provided and user is not found, the algorithm looks around the pre-selected direction. Most likely the real user position is very close to the wrong announced place. Thus, EDP sequentially explores *i*) adjacent directions (following clockwise and counter-clockwise directions) keeping fixed the beam-width, and *ii*) farther positions by reducing the beam-width, as envisaged in Fig 2. However, user can be unreachable in that particular area portion (namely, *discovery sector*) because of an obstacle obstruction along the exploration path, and thus, EDP needs to move to the next sector to explore ray reflected paths.

To overcome that, we modified the EDP scheme introducing a memory-store feature which learns about successful choices. Whenever the user is discovered, we store the correct beamforming configuration in a fingerprint map, which keeps

track about user positions and beamforming parameters. This approach takes advantage of previous explorations, speeding up the process when a new user comes close to a known location. However, the user discovery failure could be even caused by an inaccurate user position information and thus, we need to tune properly the learning scheme to use carefully the stored information. We introduce a memory-range  $m$  which represents the maximum error deviation with respect to the stored position. When a user announces its position within  $m$  meters from a stored positions, the corresponding beamforming configuration is used to hook the user synchronization signal. If multiple stored positions are considered, EDP uses the configuration corresponding to the closest location. A large memory-range  $m$  will guide EDP to beam several incoming users relying on stored information, but it may lead to wrong beamforming parameters and thus, to a long discovery time. Conversely, a short memory-range will be more accurate but needs much more successful discoveries to work optimally.

#### IV. PERFORMANCE EVALUATION

We carried out an exhaustive simulation campaign to evaluate our enhanced approach (EDP) when learning feature is applied. For the sake of completeness, we benchmark EDP against the greedy search algorithm (DGS), presented in [4]. Numerical results are obtained through a MATLAB simulator, developed ad-hoc. Each presented value is averaged over 100 simulation instances. In the following, we show the implementation details. All antenna gains are modelled as a Gaussian main lobe profile and log-distance path loss model is implemented, where the pathloss reference value is equal to 82.02dB with a reference distance equal to 5 meters. Reflected rays follow the propagation model shown in Eq. (1), where  $\sigma = 0.2$  mm and  $\epsilon = 4 + 0.2j$ . Full details are provided in [15]. We assume a sufficient signal level for user acquisition directly derived from the empirical measurements presented in [13], where a Signal-to-Noise-Ratio (SNR) must be greater than 10dB. Cell discovery procedure explores beamforming configurations only over a 2D plane. The smallest selectable beam-width  $\phi$  is 0.0157 rad which leads to a spatial exploration of 360 non-overlapping directions  $d$ . Larger beam width are obtained by reducing proportionally the number of directions to 180, 120, 90, 72, 60, 48, 24, 12, 8, 6, 4, 3, 2. Baseline scenario presents a deployment area of  $450 \times 350$  meters where 1 mm-wave small cell is placed in the middle and 250 users randomly dropped in the area.

##### A. Obstacle-free setup

In the first set of results we want to study how learning approach impacts on the cell discovery time. Please note that we evaluate system performance in terms of number of beamforming parameter switches (or number of attempts to successfully hook the user synchronization signal), which is straightforwardly related to the cell discovery time based on the hardware specifications. In other words, we aim at spotting the user within the minimum number of attempts. To fairly evaluate DGS and EDP schemes, we introduce

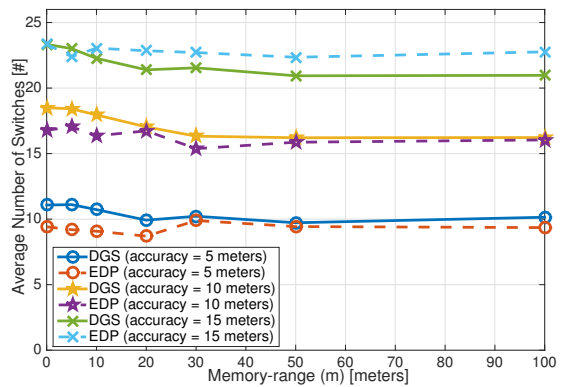


Fig. 3: Average number of discovery attempts (switches) in an obstacle-free network scenario where DGS and EDP are implemented.

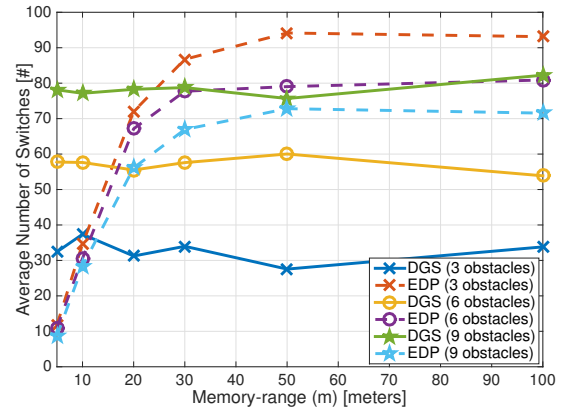


Fig. 4: Average number of discovery attempts (switches) where DGS and EDP are provided with perfect context information.

the learning approach in the greedy search, using the stored successful beamforming configurations as starting point when a newcomer announces a position within  $m$  meters of distance from the stored location. For  $m = 0$ , no additional stored information are used during the cell discovery phase.

Fig 3 shows a comparison between DGS and EDP when the memory-store feature is applied and no obstacle is placed in the area. When no learning approach is applied (e.g., memory-range  $m = 0$ ), EDP outperforms the DGS approach whenever it gets a sufficient level of accuracy of user locations. When the position information error becomes consistent, EDP performs worse than DGS, as much more attempts are wasted in wrong discovery sectors. Although the memory-store approach does not bring significant gains for obstacle-less scenarios, it does not degrade the cell discovery performance. In particular, when the uncertainty in the position information is dangerously high, both approaches rely on wrong stored information leading the system to work on inefficient working points. Learning approach should be activated when the location accuracy is below 10 meters (reasonable values for outdoor GPS) while promptly switched off when position information are mostly affected by errors.

##### B. Learning approach for handling obstruction issues

In the next evaluation set, we randomly drop in our baseline scenario opaque objects which act as obstacles within mm-

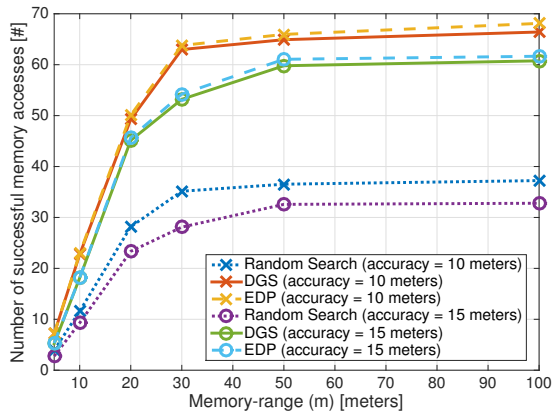


Fig. 5: Number of successful memory accesses when 9 obstacles are placed.

waves transmission paths. The obstacles are built as square of  $20 \times 20$  meters size. Memory-store approach is evaluated when perfect context information are provided through the conventional cellular networks. Whenever an incoming user wants to associate with a mm-waves small cell, the cell discovery algorithm computes the correct beamforming configuration and beams the user. If a signal obstruction occurs, the search discovery algorithm needs to exploit ray reflections to find alternative directions for user covering. In Fig. 4 the average rendezvous time is shown as function of memory-range ( $m$ ) parameter, when the number of obstacles placed in the area varies<sup>2</sup>. Clearly, when the number of obstacles is low (e.g., 3 obstacles), the announced user location can be likely reached through a direct beam (left points on the graph). When obstacles obstruct the transmission paths (for instance with 9 obstacles), EDP exhibits outstanding results with respect to DGS (average number of switches is 8 times less). Conversely, increasing the memory-range ( $m$ ) may result in a disruptive effect, when a few number of obstacles are placed. Finally, EDP still shows better results than DGS when several obstacles are placed in the network area, even though large memory-range is applied.

This is largely confirmed in Fig. 5, where a number of successful memory accesses is represented as function of memory-range ( $m$ ). The more memory-range distance considered, the more successful accesses performed. In addition, we also compare a random search discovery algorithm, where beamforming configurations are randomly chosen and no configuration repetition is allowed. EDP shows the maximum percentage of valid stored information which benefits the algorithm in the discovery time minimization.

## V. CONCLUSIONS

The most promising solution for 5G future network design seems to be the adoption of mm-waves technologies, which may co-exist with conventional cellular network. In particular, we have analyzed the cell discovery procedure when mm-waves technologies are available and incoming users want to boost their cellular network performance. We have proposed an

<sup>2</sup>Obstacles are dropped in different places every simulation instance.

enhanced mechanism (EDP) which jointly exploits the context-based information and the spatial diversity of mm-waves antennas. In addition, we have introduced a learning approach which provides mm-waves small cell with a fingerprint map, where successful beamforming configurations are stored to speed up the discovery process upon a new user comes close to a known position. The EDP shows outstanding results in terms of discovery time providing an appealing alternative to random or greedy search algorithms.

## ACKNOWLEDGMENTS

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