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3D directional cell discovery for mm-wave access

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Abstract

For the last few years the global mobile data has grown significantly. And the forecast of Cisco VNI convinces us that this is just the first stage of the growth. According to Cisco VNI [1], global mobile data usage will reach almost 49 Exabytes per month by 2021. In order to see how significant the changes are we can simply say that at the end of 2016 all over the world people used only 7 Exabytes per month. (1 Exabytes equals to 10^{18} bytes).

There are plenty of reasons for this growth. We can easily notice the increased number of mobile devices per person. Nowadays almost everyone has either tablet or smart watches let alone personal laptop and smart phone. But telecom community is secondly interested in these reasons. First of all, there is a need in new technologies in order to satisfy increasing demand.

Since frequency spectrum below 2.5GHz is almost fully used [2], the exploitation of the millimeter-wave bands is one of the most foreground solutions for 5G mobile radio networks. As a consequence of usage very short wave length, we, as expected, experience a number of challenges that must be solved.

First of all, high frequency antennas are small in size and, correspondingly, have reduced covered area with respect to lower frequencies. Limited coverage area is the limiting factor to provide full service to the end user. Therefore, the need to exploit legacy network working on the lower frequencies.

Secondly, high frequencies are characterized by harsh signal fading. Directional transmissions are used to overcome this problem. It will be possible to implement mm-wave technologies using directional transmissions and conceptual new network architecture. In new architecture the whole system is splitted in two planes: Control-plane works with legacy technologies and guarantees continuous signaling channel between base station(BS) and mobile station(MS), User-plane works with mm-wave directional transmissions and provides high data rate to the end user [3]. Keeping in mind all the problems listed above, we add the presence of non opaque obstacles and the reflections which depend on the incident angle and the reflection material.

During the cell discovery process we tend to experience some delays due to the directional transmissions of mm-waves. So, the demand of smart algorithm which is able to speed up the directional cell discovery is evident.

In this work we will consider discovery algorithms implemented in the new architecture of 5G network, compare its performance in different 3D environment conditions.

KEY WORDS: millimeter-waves, 5G networks, directional transmissions,cell discovery procedure, obstacle blockage, reflections.

Introduction

The need of high-speed mobile connectivity is evident even nowadays in the wireless world. Day by day society requires higher and higher peak rates everywhere [1]. If exponential traffic growth continues, very soon current capacity will not be able to satisfy the growing demand. This demand comes from increasing users' interest in high quality video and audio content, availability of plenty of on-line gaming applications and the willing of the end user to have reliable communication technology.

As more devices come on-line we inevitably experience slow service and more dropped connections. To address this challenge, out-of-use frequency spectrum must be exploited. A large bandwidth above 30 GHz is being investigated. In particular research community is focused on 30 and 60GHz bands. We can assume that at least about 40 percent of millimeter wave band can be taken into usage, this means 100GHz new spectrum of mobile broad band can be fully exploited for wireless mobile communications. To highlight the core difference, it is enough to say that it is more than 200 times the spectrum currently allocated for this purpose below 3GHz [4].

But in order to use these bands for 5G networks a lot of efforts must be done. The price for using high frequencies is in its features. High frequencies suffer from significant propagation losses and limited ability to diffract obstacles. These are new initial challenges which must be solved by research community.

In fact, high path loss attenuation can be overcome by using directional antennas. More over, short wavelength allows to use antennas with high number of elements($\geqslant$ 32 elements) [5] and this fact permits to increase coverage area and cover up to hundreds of meters. These hundreds of meters create a small cell with mm-wave BS. In its turn, these features create further problems because, obviously, hundreds of meters is not enough. It is absolutely clear that the service must be provided continuously to the end user and the usage of mm-waves is limited by short-range small cells. Hence, in order to provide reliable and continuous service we must use current legacy technologies.

For this purpose, in the MiWEBA project (Millimeter - Wave Evolution for Backhaul and Access) the new system architecture is presented and it is based on heterogeneous technologies [6]. In this new network architecture the conceptual functional split between control-plane (C-plane) and user-plane (U-plane) is implemented. Despite the increasing complexity, the advantages are evident. This guarantees the availability of a signaling channel through traditional technologies with additional opportunity to provide context information to the network, while data is transfered by using high frequency small cells. Thereby integration of mm-wave transmissions with traditional wireless networks can be done. The main goal of the splitting is to provide required information necessary for the spatially alignment of the receiver and transmitter. Considering this functional split the signaling issue comes to the fore. In terms of signaling the things are organized as following: a mobile station exchanges signaling messages through legacy technology and get radio resources for high capacity mm-wave connection.

In opposite to previous 3G/4G techniques where synchronization signals were broadcasted without any beam forming scheme, cell discovery process in mm-wave access is extremely critical and important. Since the directional transmissions are used, each MS (mobile station) and BS (base station) must sweep through all possible antenna capabilities at each side until they detect each other. And this procedure must be repeated for each mobile station in the cell. Clearly, scanning algorithm must be efficient enough to avoid delays at the access stage and prevent negative impact to the network behavior during handovers, affecting delay-sensitive applications.

Taking into account the fact that the new architecture is adopted, we can exploit the C/U split to significantly reduce time needed for spatial alignment. C-plane is able to provide the essential context information from the user to the network. This information can be used to design smart directional cell discovery algorithms in order to maintain a reasonable discovery delay.

Indeed, the core point in the directional cell discovery procedure is the user-context information. The knowledge of user position, its mobility, application needs, etc., should speed up the discovery performance.

Our investigation started from the exploring of works which has been done so far. In particular we refereed to the solution developed for the same problems, but in 2D environment [7]. In this work we will consider the challenges of initial cell discovery procedure in mm-wave access in 5G networks with context awareness. The key condition is that 3D environment will be considered. We will come up with different discovery algorithms and compare their efficiency with respect to both the estimated user position and the accuracy of this estimation. At the end, my analysis shows how the usage of user-context information affects the overall discovery time, how significant is the presence of the obstacles and the impact of number of obstacles to the efficiency of the algorithms.

This work is organized in the following way: Chapter 1 introduces the importance of directional cell discovery algorithms. In this chapter the fundamental trade-off the algorithms is discussed in details. Chapter 2 presents the discovery algorithms suitable for 3D environment. In Chapter 3 the numerical results of the algorithms' performance are presented and examined in details taking into account different level of context information and different environmental conditions. Chapter 4 consists of final conclusions where pros and cons of considered algorithms are presented and future works proposals.

Chapter 1

Directional cell discovery procedure

As it was mentioned in introduction part, mm-wave usage requires to mitigate some challenges related to features of high frequencies. Evidently, signal propagation at high frequencies is significantly different from accustomed signals at 2.5 GHz. Firstly, a free space path loss at 60GHz is 20dB worse than at 5GHz since free space loss increases quadratically with frequency. Secondly, high frequency transmissions suffer from atmospheric effects: mainly oxygen absorption (57GHz - 64GHZ) and water vapor absorption (164 GHz - 200GHz) [4]. They change exponentially with distance. Thirdly, millimeter length waves are not suitable for non line of sight (NLOS) transmissions due to limited ability to diffract obstacles. Penetration losses increase even more dramatically than atmospheric effects with growing distance. In addition to above problems, we need to take into account multi-path propagation (frequency dependent) due to the roughness of reflecting surfaces.

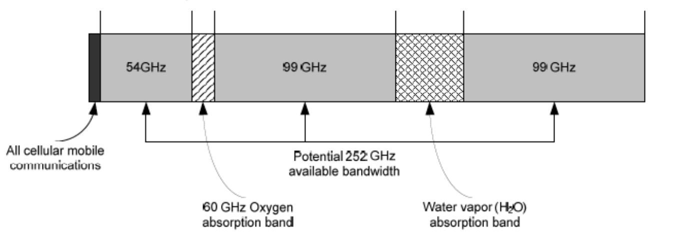


Figure 1.1: Millimeter-wave band

Nevertheless, all the challenge listed above must be solved to provide required service to the end user. For this purpose new architecture of 5G wireless networks is developed. It implies the split of current architecture to User and Control planes. Accustomed legacy base station radiates constant power level in all directions using omnidirectional antennas. As a consequence, it can cover mobile station with minimum delay time. During the synchronization stage between legacy BS and MS, BS gets all needed context information from MS. Only after the initial synchronization through legacy technologies is done, User plane comes into a play. At this phase mm-wave cell discovery procedure must be executed.

Comparing to the current LTE networks, synchronizations signals are periodically transmitted by omnidirectional antenna. However, dealing with millimeter-wave part of the spectrum forces to overcome some challenges related to the coarse propagation conditions. Since, penetration losses are huge (increase with the square of frequencies), therefore, directional transmissions must be used even at the initial stage of the communication process between mm-wave base station and mobile station. During the directional cell discovery process we must find antenna configurations at both sides (BS and MS) capable to provide sufficient received power level to decode the signals.

The most straight forward way for directional cell discovery could be simple scanning over all possible antenna configurations looking for the matching one between BS and MS which provides sufficient received power level. This idea definitely works, however, this algorithm may take some time, thus, synchronization process will be delayed. Nowadays, current antenna technologies allow to have different beam-width and, as consequence, plenty of pointing directions must be scanned before couple BS-MS finds the match. It takes even a greater weight when we are talking about 3D environment where both BS and MS can have number of antenna capabilities in azimuthal and elevation planes. Hence, the beam-width has huge impact on the discovery procedure and we can express fundamental trade-off of the beam-width. Larger the beam width, fewer switches we need, but only relatively close MSs can be covered and vice versa statement holds as well: the narrower the beam width, more switches we need to detect the user, but far away located MS can be covered.

Considering the example from Figure 1.2, where BS has 5 possible beam width configurations in both azimuthal and elevation planes. In azimuthal plane we obtain 249 different pointing directions, while in elevation planes there are 89. In total BS has 22 161 possible main beam pointing directions. Knowledge of the fact that each side of communications must switch at most 22 161 times, forces to look for more smart algorithms to be executed during the directional cell discovery.

Indeed, beside fundamental beam-width trade-off, there are several aspects to be considered and taken into account in order to obtain efficient

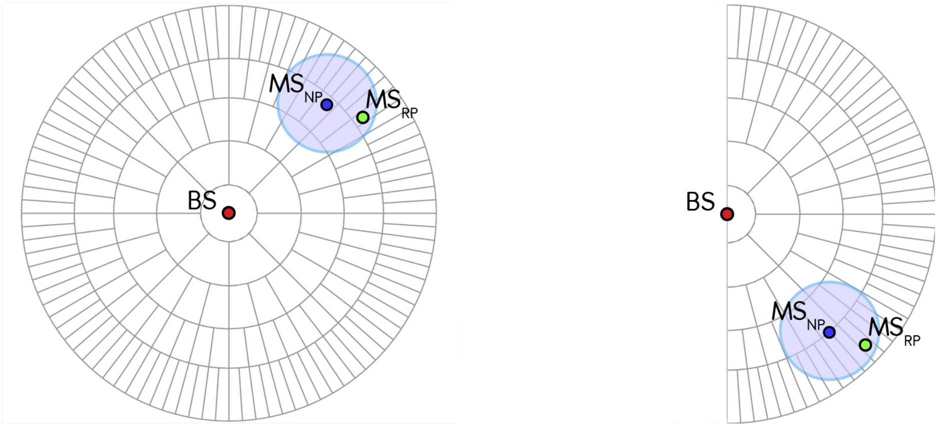


Figure 1.2: BS antenna capabilities. View from the top and from the side

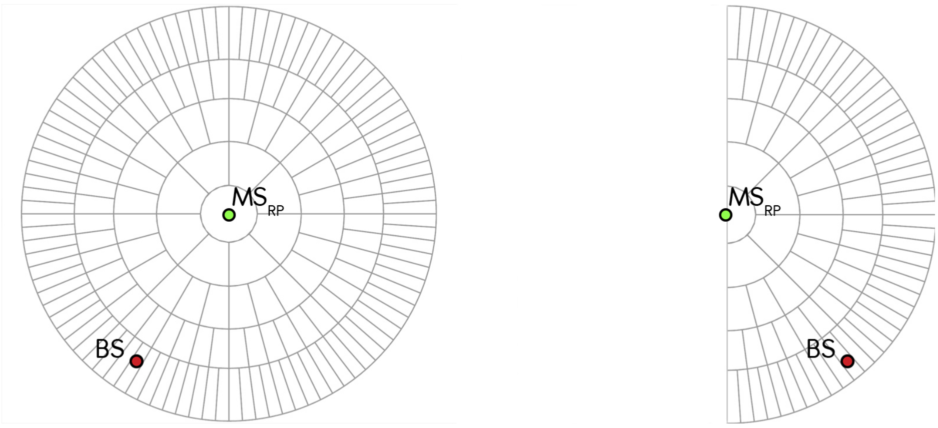


Figure 1.3: View from MS point on view

discovery algorithm. Independently on the number of antenna configurations, mm-wave access network has to deal with surrounding environment and we may come up with the case when MS requesting the high data rate service is located in not ideal position from the propagation point of view. As I said before, negative impact of fading effects may turn any obstacle in a serious challenge in the initial access phase. We can distinguish two main types of obstacles. Fixed part of environment such as buildings, billboards, etc., and dynamic part of environment such as trains, cars and trucks in particular, people etc. These types of obstacles have different influences. Fixed obstacles can drop completely the signal and the user will not get any service. However, the nature of high frequencies can be fully exploited, thus, fixed obstacles surrounding Tx and Rx can be treated as reflecting surfaces in that sense even ground can act as a mirror surface for the signal. While moving obstacles can be addressed by physical layers solution and can be treated as fading effects.

When the user is not in LOS condition and can not be covered by the direct path, then the reflection effect must be exploited. In our simulation we calculate the received power level after the reflection according to [8].

$$P_r = 20log_{10}\left(\frac{\lambda}{4\pi s}\right) - A_o s + R + F \tag{1.1}$$

where

$$R = 20log_{10}\left(\frac{\sin\theta - \sqrt{\epsilon - \cos^2\theta}}{\sin\theta + \sqrt{\epsilon - \cos^2\theta}}\right) \tag{1.2}$$

$$F = \frac{-80}{\ln(10)}\left(\frac{\pi \sin\theta\sigma}{\lambda}\right)^2 \tag{1.3}$$

We name ϵ and σ as the roughness and reflection coefficients of the reflecting material respectively, while θ is the incident angle at the reflecting surface and s is the distance.

The Figure 1.3 is given as an example of NLOS condition. In that particular situation the mobile device can be reached only through the reflection path. On one hand, the coverage ability of a cell increases using the reflection paths. However,on the other hand, this can significantly affect the delay in initial access. Thus, reflected paths must be managed in a very efficient way.

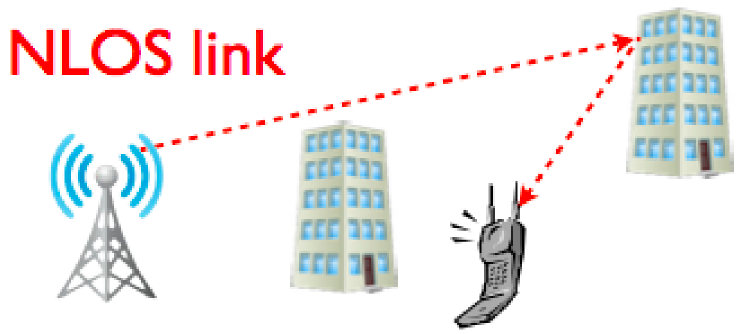


Figure 1.4: NLOS condition

It is to be noted, we need to deal not only with beam-width and reflections, but also fully exploit all the advantages of the context information [9]. Context information is created at MS side. Legacy BS receives all needed context information such as receiver power level, location position, channel information and application needs. In this work I will consider only one type of context information - user position. Nevertheless, other types on context information can be used as well [7]. In ideal conditions, having absolutely precise knowledge of user position, BS and MS must find each other in one switch simply tuning corresponding beam-width. In practice, some inaccuracy is always present and in this case cell discovery algorithm must deal with uncertainty region and exploit this knowledge in order to reduce the search space. In fact it is clearly seen, the quality of the context information is essential in directional cell discovery algorithm efficiency. In the next chapter two directional cell discovery algorithms will be proposed. In Chapter 2 they will be compared using different environmental conditions and, moreover, different quality of context information.

In order to lead the current problem to the core points, a simplified scenario will be considered where the focus is made on downlink synchronization signals, assuming an isotropic type of antenna at the mobile station side. Instead, BS has directional antennas. The key difference with respect to [10] is the type of environment - 3D, both elevation and azimuthal angels are considered in the simulation and in this type of environment the ground is considered as a reflection surface.

In that case the main lobe gain function can be expressed [8]:

$$G_{dB}(\phi,\gamma) = 10lg\left(\frac{16\pi}{6.76\phi_{-3dB}\gamma_{-3dB}}\right) - 12\left(\frac{\phi}{\phi_{-3dB}}\right)^2 - 12\left(\frac{\gamma}{\gamma_{-3dB}}\right)^2 \tag{1.4}$$

where ϕ is the azimuthal angle in the range $[-\pi, \pi]$ and γ is the elevation angle in the range $[-\pi/2, \pi/2]$, while $\phi_{-3dB}, \gamma_{-3dB}$ represent half power beam width for azimuthal and elevation angles respectively.

Chapter 2

Cell Discovery algorithms

In the previous chapter all the issues related to high directional mm-wave communications which must be taken into consideration were analyzed. This chapter presents all the techniques which have to be done by small cells involved into cell discovery procedure. Section 3.1 describes the type of context information provided to mm-wave BS and how it can be beneficially used. Sections 2.2 and 2.3 describe in details the cell discovery algorithms.

2.1 Baseline scenario

As it was mentioned on Chapter 1, thanks to C-plane working on legacy technologies, both sides of direct communication can use context information about each other. In this paper we don't consider the source of context information and just assume the availability of an external positioning system which provides needed location information with given accuracy. In fact, this location information knowledge helps mm-wave cells to take proper decisions leading to significant decrease of cell discovery time. Without loss of generality, we assume that position of the user will not be completely different at the beginning and the end of the discovery process, some deviations are possible but within the beam width. In other words, the user can be covered with the same beam. This assumption can be done based on the duration of the discovery phase.

Figures 1.2 and 1.3 present the complete picture seen by mm-wave BS installed within small cell and MS respectively. Different antenna configurations are represented with the gray lines. MS_{RP} represents user's real position, while MS_{NP} indicates position affected by an error which depends on the localization accuracy, so called the nominal position. Whenever the context information related to the users' position is perfectly precise, the nominal position coincides with the real one. A localization system also provides the location accuracy. This accuracy of users' location in the Figure (1.2) is indicated with the light blue circle. The distance to be covered s, pointing direction ϕ in azimuthal plane and pointing direction γ in elevation plane are estimated given the nominal position MS_{NP}. From the network point of view, the coverage of different antenna configurations of mm-wave BS can be easily estimated exploiting the knowledge about antenna capabilities and channel model. An antenna has a number of different configurations, each configuration has a beam width. Knowledge of a beam width permits to evaluate a number of pointing directions of a given antenna configuration.

The number of pointing directions in azimuthal plane can be found from

$$M = \frac{2\pi}{\phi_{3dB}} \tag{2.1}$$

where ϕ_{3dB} is the half-power beam width in azimuthal plane of the selected configuration. The number of pointing directions in elevation plane can be found from

$$N = \frac{\pi}{\gamma_{3dB}} \tag{2.2}$$

where γ_{3dB} is the half-power beam width in elevation plane of the selected configuration. The pair of parameters $(\phi_{-3dB}, \gamma_{-3dB})$ fully define the radiation pattern of considered antenna pointing direction.

2.2 TBS algorithm

In order to exploit the context information in the most efficient way TBS algorithm is proposed. The name stands for Thinnest Beam Search. At the first setout, the mm-wave BS obtains the context information related to the user nominal position from legacy BS, processes this information and evaluates the pointing direction to the user position where it is expected to be found. Let us call this pointing direction P_{user}. Further we define the set of all possible thinnest beam directions $P_{BS_{thin}}$. The size of this set is defined in the following way: $M \times N$, where M and N are the numbers of thinnest beam pointing directions in azimuthal and elevation planes respectively and can be found from equations (2.1), (2.2).

Core idea of TBS algorithm is that the search is executed over the thinnest beam width in both azimuthal and elevation planes. Hence the name of the algorithm comes. In Figure (2.1) the antenna configurations removed from the search space are colored in light red. When all possible thinnest beam pointing directions are found and set $P_{BS_{thin}}$ is complete, we compare each

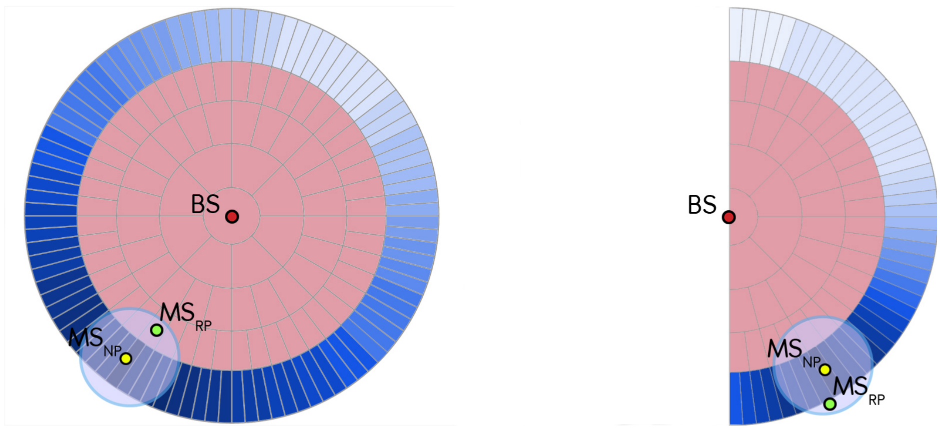


Figure 2.1: TBS algorithm

of these pointing directions from set $P_{BS_{thin}}$ with pointing direction to the nominal position of the user P_{user}. Next step is to sort the results in the increasing order. In such a way we obtain the sequence of all possible thinnest beam pointing directions which must be checked. In Figure (2.1) the closest thinnest beam pointing directions are colored with dark blue. With the increase in the difference between pointing directions, the brightness of clue color decreases. In this sequence the first element is the closest thinnest beam pointing direction to P_{user}. According to this sequence, the mm-wave BS starts scanning process. Once the first thinnest beam pointing direction which is able to provide sufficient received power level required to establish the connection is found, the user is assumed to be covered by this beam pattern. In case all possible pointing directions are explored without any user detection, the user is labeled as uncovered.

The logic behind this algorithm is to try to cover all the users with the beams which most likely will provide sufficient power level to decode the signal. Even the furthest ones, that automatically applies that the close located users will be covered as well.

2.3 3D-D-SLS algorithm

In search of other effective ways to exploit the knowledge of context information in order to reduce directional cell discovery time we came up with the extension of D-SLS algorithm. It was presented previously in [7], [11] and [9] for 2D environment. The extension proposed below will be valid also in 3D environment.

Generally, the idea of the algorithm is quite simple, 3D-D-SLS tries to explore the close-by neighborhood with wide beam patterns.

As previously, the mm-wave BS obtains the context information related to the user nominal position from legacy BS, processes this information and evaluates the pointing direction to the user position where it is expected to be found. Let us call this pointing direction P_{user}.

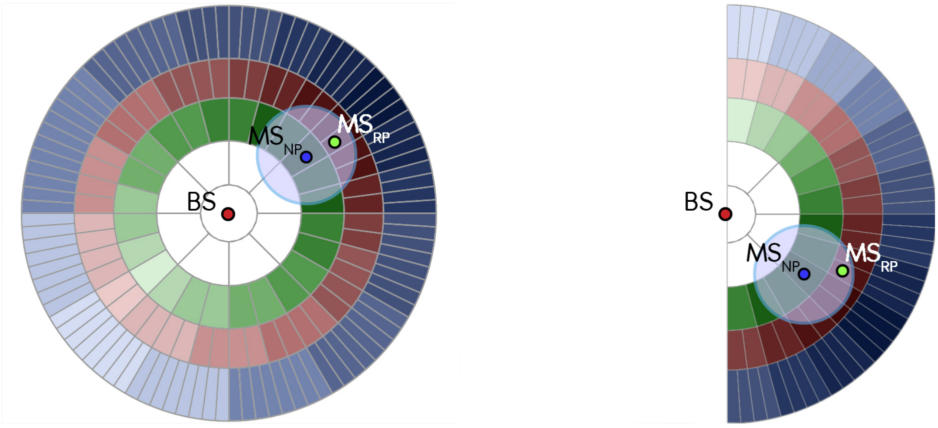


Figure 2.2: 3D-D-SLS algorithm

The search starts from exploring the first antenna configuration combination with the widest beam that can cover the user in its nominal position. Keeping the same beam width mm-wave BS scans all possible pointing direction of this combination of antenna configurations. If the user is not detected, mm-wave BS switches to the next antenna configuration combination which can in principle detect the user and now keeping the beam width corresponding to this antenna configuration combination perform scanning process. The procedure continues until it detects the beam which is able to guarantee sufficient received power to decode the synchronization signal. In other words, the search process starts with wide beams and then if user is not detected, the search is repeated with thinner and thinner beams. Evidently, the usage of narrower beams increases the coverage area of the search but at the same time requires more switches.

In the example given in Figure 2.2, first two antenna configurations can not cover the user in its nominal position. These two configurations are uncolored. The search starts from exploring the third configuration. The first pointing directions to be checked are colored in dark green. If the user is not detected, mm-wave BS switches to the red antenna configuration and performs scanning process starting from the darkest pointing direction. If the user is not detected again, mm-wave BS switches to the blue antenna configuration and performs scanning process starting from the darkest pointing direction.

The rationale behind 3D-D-SLS algorithm is to discover near-by situated users with as wide beams as possible. The performance of both these algorithms is presented in the following chapter.

Chapter 3

Performance evaluation

The system level simulations were done to evaluate the performance of directional cell discovery algorithms presented in Chapter 2. The simulations were executed with numerical computing environment MATLAB based on the MiWEBA channel model proposed in [8]. The following chapter is organized in the following way: section 3.1 describes all relevant environment parameters and system model, section 3.2 is divided in two: 3.2.1 provides the numerical results of cell discovery algorithms in the scenario without obstacles and 3.2.2 instead, presents the numerical results obtained within the environment with different number of obstacles.

3.1 Simulation settings

Since we are considering 3D environment, each object at the playground has 3 dimensions(x, y, z). We consider the environment where the height of objects is by several orders of magnitude larger than the basis of the object. In particular, the playground is created by 5 rectangular surfaces (4 walls and a floor). The width of each wall is 400, while the height is greater by one hundred times. Similar situation is about the obstacles, each one of them is created by 4 rectangular surfaces representing the walls of the obstacles. The width of each wall is 20, while the height is greater by two thousand times. Thus, without loss of generality, we can assume infinite length of all obstacles in the given environment. The playground is created in parallelepiped shape with size $(400 \times 400 \times Inf)$. Each surface of this parallelepiped acts exactly as reflecting surface of any other obstacle. The mm-wave BS is placed inside this parallelepiped and has coordinates $(200 \times 200 \times 10)$. In addition to the mm-wave BS, parallelepiped shaped obstacles are places inside the playground with size $(20 \times 20 \times Inf)$. Depending on the environmental characteristics we consider 0,10 and 20 obstacles. The environment with 0, 10 and 20 users is depicted on Figure 3.1 a,b,c respectively. Obstacles are located randomly inside the playground with the condition that they do not overlap each other, mm-wave BS and the surrounding walls. After the environment is completely furnished, 1000 MSs can be placed inside. The MS position is chosen randomly with the condition that they do not overlap each other, obstacles, mm-wave BS and the surrounding walls. The MS position is in the range from 0 to 400 with respect to x and y axis, while the height of MS randomly changes in the range between 0,5 and 2. A couple of words must be said about the location uncertainty. We assume it to be symmetric $\sigma = \sigma_x = \sigma_y$ and referring to Figure (1.3) we consider location error $NA = 3\sigma$.

According to [8] we follow the assumption that the building walls material is concrete with relative dialectic constant $\epsilon_r = 4+0.2i$ and surface roughness standard deviation $\sigma_w = 0.2mm$.

The values shown in the next section are averaged over 10 simulation instances. The positions of surrounding walls, floor and mm-wave BS are fixed, while obstacles and MSs location are changed every simulation instance. Moreover, in this work only LOS and single-refection path transmissions are considered. Following MiWEBA channel model assumption [8], beams can not penetrate obstacles, while they can be reflected from them. The received power of this reflection is calculated based on equation (3.1) presented in chapter 1. Taking into consideration path loss model user for transmissions we refer to [8]

$$PL = \alpha + 10klog_{10}\frac{d}{d_0} \tag{3.1}$$

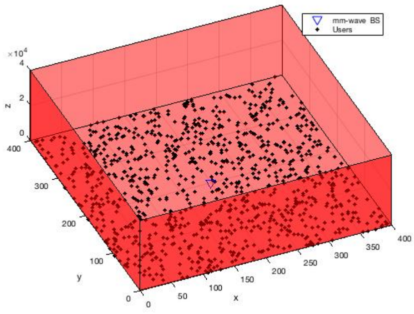
Where d is the path length and $\alpha = 82.02dB$ is the path loss at the reference distance d_0. Referring to the channel model $d_0 = 5$, while the propagation factor k is equal to 2.36 if the distance between Tx and Rx is greater than the reference distance, or equals to 2 otherwise.

In all simulation instances we assume a sufficient signal level for user detection directly derived from the empirical measurements presented in [12], where $SNR \geqslant 10dB$ which corresponds to sensitivity $S = -73dBm$. MS is marked as covered by mm-wave BS only if $P_r \geqslant S$. In the simulations the transmitted power $P_{tr} = 30dBm$ and receiver power level is obtained in the following way

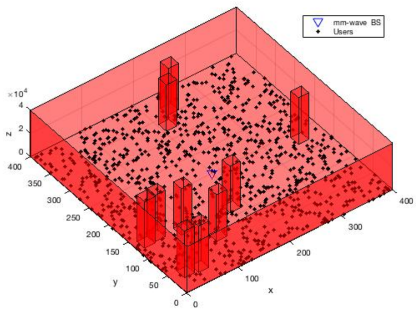
$$P_r = P_t + G_{BS} + G_{MS} - PL - R - F \tag{3.2}$$

where MS antenna gain $G_{MS} = 0dB$ because of the assumption we made in the end of Chapter 1 related to omnidirectionality of MS antenna.

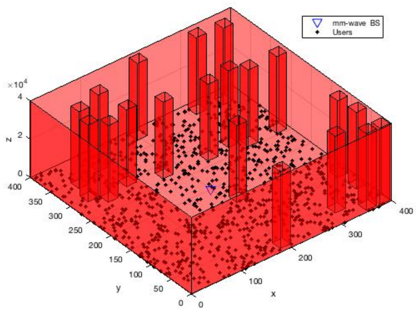
In opposite, the mm-wave BS has different antenna configurations.



(a) 0-obstacle environment



(b) 10-obstacle environment



(c) 20-obstacle environment

Figure 3.1: Cell simulation environment

3.2 Cell discovery algorithms performance evaluation

The performance indicators used were total number of covered users and average number of antenna switches needed to cover the user. Indeed, the second parameter is directly related to the cell discovery time. The delay measured in any time units depends on the available technology and can be easily obtained from the number of antenna switches. In other words, the target is to cover MSs within the minimum number of attempts. Clearly, the best performance is to cover the user in 1 attempt.

3.2.1 Performance evaluation within the empty environment

In the first set of results we want to observe the performance of TLS and 3D-D-SLS algorithms presented in Chapter 2 in empty environment. It is important to highlight the fact that the number of antenna configurations of mm-wave BS in both azimuthal and elevation planes is equal. In both planes we have five different configurations which imply different beam width and they are the following: [1 5 12 36 72]. Keeping in mind that the azimuthal angle ϕ is in the range $[-\pi, \pi]$ and the elevation angle γ is in the range $[-\pi/2, \pi/2]$, we can use equations (2.1), (2.2) in order to find corresponding beam width for each antenna configuration. The widest and the thinnest beams in azimuthal plane are 360° and 5° respectively, while the widest and the thinnest beams in elevation plane are 180° and 2.5°. It turns out that for TBS working only with thinnest beams, mm-wave BS can make at most 5184 switches.

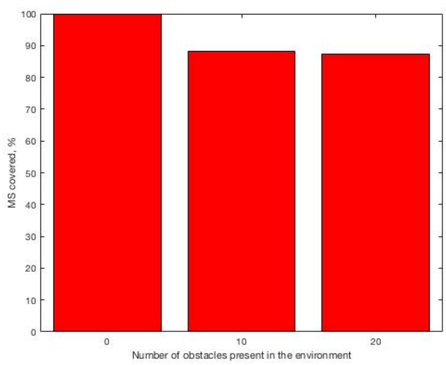


Figure 3.2: Coverage percentage with and without obstacles.

Figure 3.2 shows the number of covered users for both cell discovery algorithms. Both algorithms cover all the users. This result was expected since there is nothing to block synchronization signals and both algorithms are able to reach the user in only one configuration switch. Figure 3.3 shows a key parameter and allows to compare efficiency of TBS and 3D-D-SLS algorithms in the empty environment.

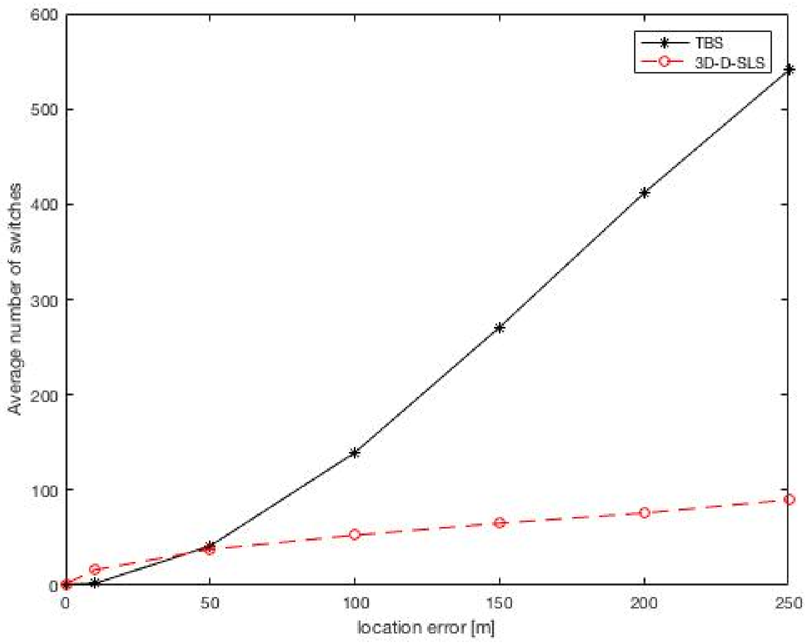


Figure 3.3: Discovery algorithm comparison in terms of average number of beam switches in empty environment.

From Figure 3.3 we can track several trends. First of all, without location error all users are found within one beam switch. Secondly, by decreasing the location accuracy, the required number of switches increases for both algorithms. However, it is clearly seen that 3D-D-SLS algorithms is much more efficient in dealing with big location error, while when the context information is quite precise (location error$\leq$50 meters) TBS shows better performance. This trend can be justified: due to high directivity of TBS algorithm transmissions, mm-wave BS divides the research space in small parts and almost immediately points towards the MS nominal position if this position is known with a given precision. At the same time, 3D-D-SLS algorithm, operating over as wide beams as possible, is able to cope with low location accuracy in more efficient way with respect to TBS because scanning over wide beams definitely requires less switches.

Finally, we can conclude that TBS algorithm demonstrates good performance with high quality of context information. Instead, it is more relevant to use 3D-D-SLS whenever the context information is significantly affected by the error because in this case TBS algorithm confines its search in the wrong area.

3.2.2 Performance evaluation in the environment with obstacles

It is advisable to discover the behavior of proposed algorithms in the empty environment, but, as a matter of fact, this scenario is not realistic and some obstacles are necessarily presented in the surroundings. As it was shown in Figure 3.1, in addition to the empty environment we also investigate the performance of directional cell discovery algorithms in presence of 10 and 20 obstacles. All the parameters of these obstacles are presented in the first section of this chapter. As in the previous simulation, the number of antenna configurations of mm-wave BS in both azimuthal and elevation planes is equal. In both planes we have five different configurations which imply different beam width and they are the following: [1 5 12 36 72].

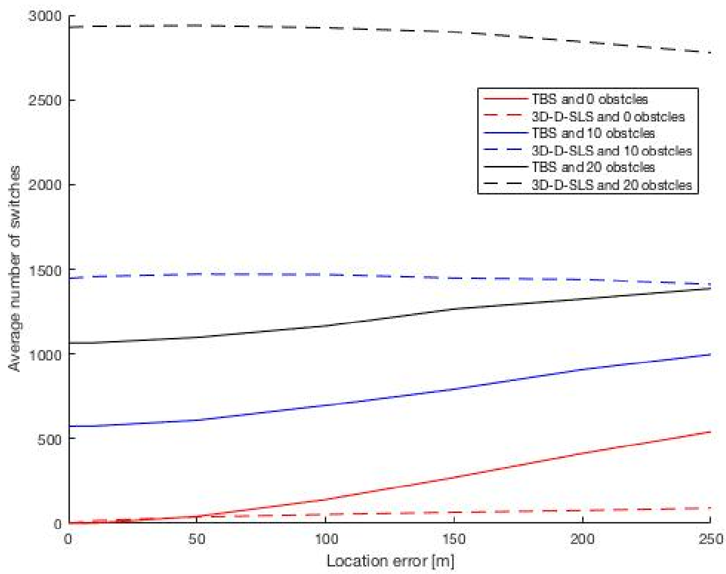
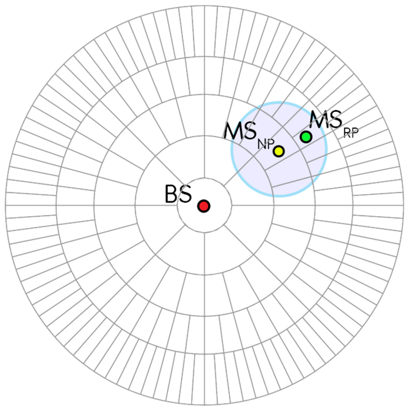


Figure 3.4: Discovery algorithm comparison in terms of average number of beam switches. Symmetric antenna capabilities at BS side

The first point which must be highlighted is the number of covered users. This parameter is presented in Figure 3.2. The presence of obstacles in the environment by the nature of things decreases the number of covered MSs. And the tendency "more obstacles - less covered MSs" has rationale behind. But much more important tendency is illustrated in Figure (3.4). It shows dramatical degradation in the performance of both discovery algorithms in presence of obstacles. The number of required switches to reach MSs is huge and it is thousand times more than in surroundings without obstacles. This can only mean that these algorithms with symmetric antenna configurations can not be adopted in the environment with obstacles due to the fact that in that case directional cell discovery introduces significant delays in the synchronization process.



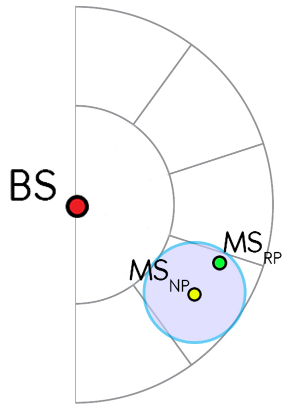


Figure 3.5: BS antenna capabilities in azimuthal and elevation planes. View from the top and from the side.

Taking into account unavoidable presence of obstacles almost everywhere, we need to find a way to adapt cell discovery process to the given environment. Proceeding from the confidence that all algorithms proposed in Chapter 2 have rationale behind, we try to modify antenna capabilities at mm-wave BS side in both azimuthal and elevation planes to be able to overcome these challenges.

Following the description on algorithms from Chapter 2, we know that 3D-D-SLS performs circular scanning over all azimuthal pointing directions that can reach the user.

Assuming the horizontal type of spatial user distribution, we can give up such a wide range of different beam widths in elevation plane in favor of antenna with much simpler range of capabilities in elevation plane. The antenna capabilities of mm-wave BS azimuthal plane are still [1 5 12 36 72], while the elevation plane is now less flexible [1 5].

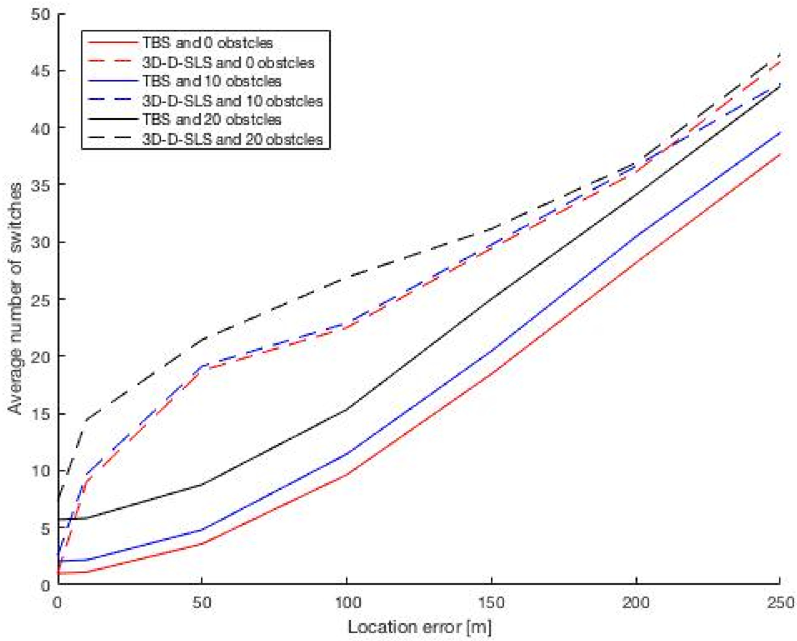


Figure 3.6: Discovery algorithm comparison in terms of average number of beam switches. Asymmetric antenna capabilities at BS side.

In this scenario, the widest and the thinnest beams in azimuthal plane are still 360° and 5° respectively, while the widest and the thinnest beams in elevation plane are 180° and 36°. The simulation results of this scenario are illustrated in Figure (3.6). The advantage of 3D-D-SLS with respect to TBS can easily be tracked. Hence, we can conclude that TBS algorithm demonstrates better performance than 3D-D-SLS. The usage of asymmetric antenna capabilities allows to be more selective in tangential deviation of MS position. The simulation results shown in Figure (3.6) can be treated as reasonable. TBS is expected to be less efficient in the scenario with low location accuracy because it tries to catch MS in the relatively wrong area with very thin beams, while 3D-D-SLS in that time discovers the whole circle around mm-wave BS with wide beams. This fact permits to claim that 3D-D-SLS is more efficient algorithm in the scenario when low quality of context information is provided and independently of number of obstacles presented in the environment.

Chapter 4

Conclusions

In this work we thoroughly investigated the whole range of mm-wave access challenges. They lead to a new way of dealing with legacy network functionalities and presume the functional split of network architecture to the Control and User planes. This functional split (in particular Control plane) is used to deliver context information from mobile station to base station through legacy technology, than this context information is forwarded to mm-wave BS.

After investigation of previous works we proposed two new cell discovery algorithms. TBS and 3D-D-SLS exploiting the full potentiality of MS's location knowledge, reduce the directional cell discovery time in 3D environment with infinite length of obstacles. These cell discovery algorithms build the antenna pattern sequence to be investigated in order to set up the connection between mm-wave BS and MS.

We compared TBS and 3D-D-SLS algorithms efficiency in terms of the average number of antenna switches needed to establish a connection between mm-wave BS and MS. We made a comparison in different propagation scenarios, number of obstacles, user location accuracy and, finally, different number of antenna configurations in both azimuthal and elevation planes.

The outcome of the simulations shows that the knowledge of estimated user position can reduce cell discovery time. We can conclude that proposed algorithms with equal number of antenna configuration in azimuthal and elevation planes might be adopted only in empty environment. They are not suitable for mm-wave propagations in scenario with obstacles due to extremely high cell discovery time. However, this algorithms must be used in the environment with obstacles and in order to adapt them we must change the number of antenna configurations at mm-wave BS side with respect to knowledge of users nominal position. We must carefully analyze the MS spatial distribution. In case of horizontal MS spatial distribution we don't need wide range of antenna configurations in elevation plane and vice versa. The usage of asymmetric antenna configurations allows to be more selective in tangential or radial deviation of MS nominal position. Accepting this change, the comparison between TBS and 3D-D-SLS algorithms illustrates that TBS is much more effective if the location accuracy is given with high precision, while 3D-D-SLS is preferred to use whenever the location accuracy decreases. Additionally, the simulation results show significant decline of cell discovery algorithm efficiency in presence of obstacles.

4.1 Future works

The proposed algorithms demonstrate good efficiency in directional cell discovery procedure. However, this simulation can be extended, even mobile station might be equipped with directional antennas, hence, discovery procedure should be taken into consideration at MS side as well. Assuming this improvements, several scenarios can be modeled. Additionally, the idea of learning memory mechanism presented in [10] can be adopted and adapted for 3D environment. And, finally, other smart directional cell discovery algorithms can be developed.

Bibliography

[1] K. Stordahl and N. K. Elnegaard, "Long-term mobile data traffic forecasts for the western european market," in *Telecommunications Network Strategy and Planning Symposium (NETWORKS), 2012 XVth International*, pp. 1–6, IEEE, 2012.

[2] K. Sakaguchi, G. K. Tran, H. Shimodaira, S. Nanba, T. Sakurai, K. Takinami, I. Siaud, E. C. Strinati, A. Capone, I. Karls, *et al.*, "Millimeter-wave evolution for 5g cellular networks," *IEICE Transactions on Communications*, vol. 98, no. 3, pp. 388–402, 2015.

[3] H. Ishii, Y. Kishiyama, and H. Takahashi, "A novel architecture for lte-b: C-plane/u-plane split and phantom cell concept," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, pp. 624–630, IEEE, 2012.

[4] F. Khan and Z. Pi, "mmwave mobile broadband (mmb): Unleashing the 3–300ghz spectrum," in *Sarnoff Symposium, 2011 34th IEEE*, pp. 1–6, IEEE, 2011.

[5] M. R. Akdeniz, Y. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter wave channel modeling and cellular capacity evaluation," *IEEE journal on selected areas in communications*, vol. 32, no. 6, pp. 1164–1179, 2014.

[6] R. J. Weiler, M. Peter, W. Keusgen, E. Calvanese-Strinati, A. De Domenico, I. Filippini, A. Capone, I. Siaud, A.-M. Ulmer-Moll, A. Maltsev, *et al.*, "Enabling 5g backhaul and access with millimeter-waves," in *Networks and Communications (EuCNC), 2014 European Conference on*, pp. 1–5, IEEE, 2014.

[7] I. Filippini, V. Sciancalepore, F. Devoti, and A. Capone, "Fast cell discovery in mm-wave 5g networks with context information," *arXiv preprint arXiv:1705.07291*, 2017.

[8] A. Maltsev, "Channel modeling and characterization-miweba," deliverable 5.1 eu contract no," tech. rep., FP7-ICT-608637, 2014.

[9] A. Capone, I. Filippini, and V. Sciancalepore, "Context information for fast cell discovery in mm-wave 5g networks," in *European Wireless 2015; 21th European Wireless Conference; Proceedings of*, pp. 1–6, VDE, 2015.

[10] F. DEVOTI, "Directional cell discovery in mm-wave 5g networks with context information," 2016.

[11] F. Devoti, I. Filippini, and A. Capone, "Facing the millimeter-wave cell discovery challenge in 5g networks with context-awareness," *IEEE Access*, vol. 4, pp. 8019–8034, 2016.

[12] C. N. Barati, S. A. Hosseini, S. Rangan, P. Liu, T. Korakis, S. S. Panwar, and T. S. Rappaport, "Directional cell discovery in millimeter wave cellular networks," *IEEE Transactions on Wireless Communications*, vol. 14, no. 12, pp. 6664–6678, 2015.