Directional Array for Millimeter-Wave Cellular Networks

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Abstract**—The development of modern communication devices for the latest technologies such as 5G has brought the millimeter wave technology into the spotlight because it offers higher data rates and bandwidth. Since highly directional transmissions are necessary for communication in these frequencies due to high path loss and atmospheric absorption, the application of adaptive antennas are inevitable. However, the use of highly directional antennas creates new challenges because it will require both the user and base station (BS) to search over a large area to locate a suitable path to initiate communications. In this paper, we develop a statistical model to compare the performance of omnidirectional and directional BS antenna for this purpose. A BS-tracking method from user equipment (UE) is also included to improve the efficiency of the search.**

Index Terms**— Millimeter wave communication, directional cell discovery, analog beamforming.**

I. Introduction

According to [1-3], it is predicted that by the year of 2020, 130 exabits (10^{18}) of data will be required. Therefore, millimeter-wave (mmWave) bands have been growing in cellular systems to meet such a demand of capacity due to their broad bandwidth availability – up to 200 times compared with current cellular system. However, exploiting mmWave bands involve new challenges since they suffer higher propagation loss, lower ability of penetration through objects, and can be significantly affected by atmospheric absorption. To overcome these challenges, high gain antennas with appropriate beamforming are used to compensate for the propagation losses. Fortunately, the wavelengths in the mmWave bands are small allowing a large number of antenna elements to be placed in a compact transceiver system to achieve the practicality of the mmWave cellular network. A more difficult issue emerging with the use of mmWave is that highly directional antennas complicate the initial network search due to their limited view of sight. While current cellular networks have been using beamforming techniques for multiple antenna technologies, they are still based on the assumption of using omnidirectional transmission for initial network discovery [1]. Therefore, since directional transmissions are essential for mmWave cellular system and with potentially large angular space, new algorithms are necessary to reduce the initial discovery time requirements as well as computational resources. Researchers have recently compared the performance between omnidirectional and directional transmissions base station in the search for user equipment over a given time frame [3, 5], which validated the use of omnidirectional transmission. In this paper, we first compare the performance between omnidirectional and directional BS antennas searching for a randomly scanning UE at an arbitrary location. Based on this comparison, we employ a BS-tracking method proposed in [7] to analyze the effects of using a UE which points towards the BS on the performance of cell searching.

The remainder of the paper is organized as follows. Section II discusses the design simulation scheme, analysis of the performance of cell discovery and the method to increase the efficiency of directional transmission, followed by the conclusions in Section III.

II. Simulation Model And GLRT Detector Performance Assessment

Our main simulation model includes a base station (BS) antenna located at origin with a height $h_{BS} = 50\ m$. The user equipment is located at an arbitrary position denoted by (x_{UE}, y_{UE}, z_{UE}) with a height $h_{UE} = 1.7\ m$ as shown in Fig. 1. The base station antenna is an 8 x 8 planar array while the user equipment (UE) is 4 x 4. Both array antennas operate at a center frequency of $f_0 = 28\ GHz$ with element separation $d_x = d_y = \lambda_0/2$ where λ_0 is the operating wavelength. The orientation of the BS array antenna is 45° pointing towards the ground plane. It is also able to physically rotate along z-axis for 360° scanning analysis. In the initial analysis, with similar parameters proposed in [3], at each time slot k^{th}, the signal is transmitted periodically every $T_{per} = 5\ ms$ and the signal duration is $T_{sig} = 100\mu s$. These parameters are chosen to keep a low total primary synchronization signal (PSS) overhead of 2% ($= T_{sig}/T_{per}$). Based on Friis' equation in [5], the receive power P_r at the mobile antenna

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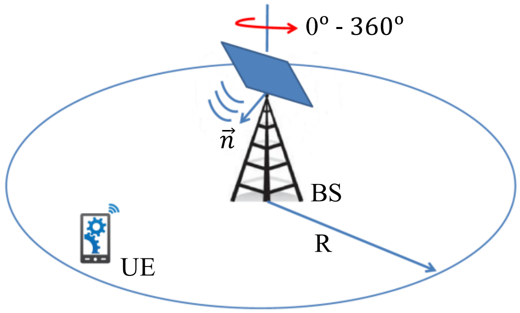

Figure 1. Simulation scheme used in this paper

can be calculated. The voltage received can then be approximated from the power [6] using (1)

$$V_r = \sqrt{240\pi P_r} \quad (1)$$

The complex signal received after N_{slot} has the form:

$$r(t) = \sum_{k=0}^{N_{slot}} V_{rk} p(t-\tau) + \boldsymbol{d}(t) \quad (2)$$

where $p(t)$ is the PSS transmitted signal, τ is the propagation delay of the signal and $\boldsymbol{d}(t)$ is the AWGN.

Since the objective is to detect the presence of the PSS signal from the UE at the instance delay τ, we use Generalized Likelihood Ratio Test (GLRT) to test a binary hypothesis problem under which H_1 is the hypothesis of signal present or H_0 is the hypothesis of signal not present. Analysis of GLRT results gives us the performance of analog beamforming with omnidirectional and directional BS antennas cooperating with a directional UE. With the assumption of random scanning at each time slot k^{th}, for both BS and UE antennas, the GLRT performances shown in [3] claimed that the use of directional antenna is a lot worse than omnidirectional case. Therefore, it is obvious that the performance of directional antennas can be improved if the UE can locate the BS in advance. This can be done by applying a simple technique proposed in [7] which is used to keep track of the transmitter and also electronically steer the main beam of the receiver so that it can always receive the maximum power from transmitter regardless of its location. Due to space constraints, the results for the base station tracking are not presented in this paper. However, the error of the estimated tracking location compared with actual location is only 8%. With the ability of UE to track the BS, the GLRT detector is implemented to assess the performance for three cases: (a) dir-BS with random dir-UE, (b) omni-BS and tracking dir-UE, and (c) dir-BS and tracking dir-UE. Test statistics approximation for analog beam forming is given in [3] with the value of false alarm probability is chosen $P_{FA} = 1.45e^{-8}$. A Monte Carlo simulation with 20,000 trials is also used to evaluate the threshold level *t* by solving (3). Detection probability P_D and misdetection probability P_M are calculated in (4), (5)

$$P_{FA} = \int_t^\infty f_{H_0}(T)dT \quad (3)$$

$$P_D = \int_t^\infty f_{H_1}(T)dT \quad (4)$$

$$P_M = 1 - P_D \quad (5)$$

where $f_{H_0}(T), f_{H_1}(T)$ is the probability density function of test statistics T under hypothesis H_0 and H_1, respectively.

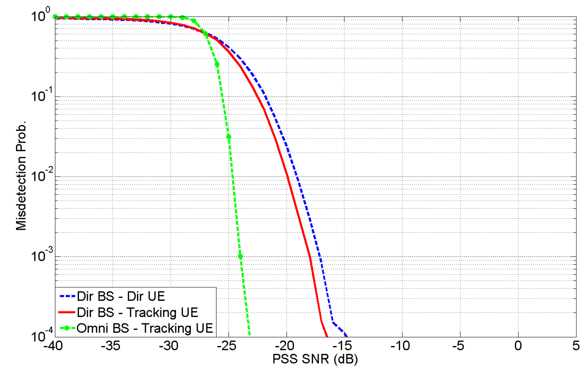

Figure 2. Misdetection Probability vs PSS SNR compared between 3 cases (a), (b) and (c)

Fig. 2 shows the performance of the GLRT detector, the result performance can be ranking as (b) → (c) → (a) from best to worst. With a gap about 2 dB in SNR, it proves that our prediction of using a UE antenna that can keep track of the BS antenna will improve the efficiency of initial cell discovery process. It is also shown in [3] that increasing the time frame (i.e. increase in N_{slot}) will also improve the performance of the detector in case (a) and (c). The tradeoff for this, however, is that long search times will probably induce intolerable delay overhead.

III. Conclusion

In this work, a physical structure of cellular system including BS antenna and UE is simulated to investigate the performance of a GLRT detector to compare the performance in three different cases: (a) directional BS with randomly pointing directional UE, (b) omni-BS and tracking directional UE, and (c) directional BS and tracking directional UE. Simulations results show that by using UE antenna with BS-tracking ability, the efficiency of initial cell discovery process can be significantly improved.

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