Mobility-Aware Analysis of Directional Deafness in mmWave Communications

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Abstract

Currently, the usage of Extended Reality (XR) device is limited due to high throughput and low latency requirements, which could be supported by the emerging millimeter-Wave (mmWave) communication. However, mmWaves suffer from high pathloss and to overcome that, beamforming techniques are used, which in turn introduces the problem of directional deafness. The problem of directional deafness is further aggravated when the mobility of directional antenna is taken into consideration. We assess the impact of mobility on directional deafness in mmWave communication.

1 Introduction

In the past years, wearables, such as Augmented Reality (AR), Virtual reality (VR), and Mixed Reality (MR), have attracted much attention as it is expected that next decade these devices will be as ubiquitous as mobile phones are today [1]. So far, these devices have been mostly used to enhance the entertainment experience, but their promise goes far beyond that. These devices could potentially revolutionize sectors, such as education and healthcare among others. In the education sector, these devices could allow richer learning experience, and in the healthcare sector, these devices could make it possible for a medical expert to remotely participate to treat patients. AR, VR, and MR may all sound similar but each of these offers different experiences to its users:

- AR lays the digital content over the real world.
- VR offers a digitally simulated environment where the viewer is immersed and can interact with virtual objects.
- MR offers a digital world that is anchored in the real physical world, where the user can interact with the digital content.

Further, XR is an umbrella term encapsulating all three: VR, AR, and MR. At present, the XR devices have not moved beyond a niche market due to a number of technological challenges. From the wireless communications perspective, the challenge is to provide XR devices with low latency and high throughput. In particular, due to the specifics of human perception, latency in XR connectivity can have a very unwelcoming impact on the user. For instance, motion to photon latency of greater than 15 ms [2] in XR can cause motion sickness; hence, to avoid motion sickness and maintain a high quality of experience, ultra-low over the air latency is crucial for the usage of XR devices. XR devices also have to be able to provide extremely high data rates [2], because for high quality of experience the displays of XR devices need to support high-resolution 3D videos with high frame-rate. The microwave networks are incapable of meeting the stringent latency and high data rate requirements of XR devices. A feasible solution may be to rely on the mmWave connectivity, as it is anticipated to have extremely high data rate and latency of around 1 ms [3]. Hence, it is expected that the rollout of mmWave networks will have a major impact on XR adoption and bring XR to the masses.

2 Problem description

MmWave is one of the key technologies that is used in the 5G network. The term mmWave communication is used to refer to communication that occurs in the 23-100 GHz frequency range. The mmWave frequencies are not as crowded as the sub-6 GHz frequencies; there is an abundance of unused spectrum available for wireless communication. With mmWaves, much higher data rate and low latency can be provided but the shortfall of using mmWaves is that they suffer much more from pathloss and blockages as compared to lower frequencies. Pathloss limits the distance at which mmWaves can be effectively used for communication, and hence they require high directionality gains to compensate for the faster signal attenuation. For this reason, beamforming techniques are used while employing mmWaves. In general, wireless systems are prone to the so-called directional deafness problem [4], which occurs when the receiver is unaware that a transmitter is attempting to establish a connection with it, and the use of highly directional antennas only worsens the situation. In the case where directional antennas are used, directional deafness can occur when a transmitter attempts to establish a connection with a receiver that is beamformed toward another transmitter, and therefore the receiver is unaware of the first transmitter's attempt to establish the connection or even of its presence. An illustration of such a problem is shown in Figure 1, where node B is unaware of node A because its beam is pointing toward node C, meanwhile node A repeatedly attempts to establish a connection with node B because it has not been able to sense the directional connection between nodes B and C. Directional deafness is known to result in severe degradation of communication performance [4]. The problem of directional deafness is further aggravated in the presence of mobility. Hence, if any of the devices move, the beams have to be realigned, which complicates establishing a connection.

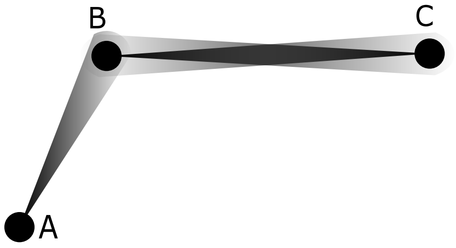

Fig. 1: Directional deafness problem illustration.

3 Previous work

Previous research has been mostly focused on the challenges and solutions at the MAC layer with regards to directional deafness [4–7], whereas insufficient work has been done on quantifying directional deafness. In [8], a minimal feasible system model for mmWave communications was formulated to develop a stochastic geometry based numerical solution to compute the probability of directional deafness; that work was developed further in [9], where 3D deployment was taken into consideration. So far, mobility has not been taken into account while quantifying directional deafness.

4 Future work

In [10], the authors propose a mobility model for on-body antennas, which captures the changes in positions and orientation of the antenna on a moving human body. These antennas may belong to advanced wearable devices (i.e., XR HMDs or smartwatches). In our work, we will aim to assess the effects of micro-scale mobility (such as turning of the head or motion of the wrist) [10] on directional deafness for highly directional on-body antennas typical for XR. The mobility model will be broadened to incorporate highly directional patterns of antennas operating at mmWave frequencies. The numerical solution presented in [9] will be extended to quantify directional deafness when the directional antennas are potentially moving. This work will thus evaluate the impact of mobility on directional deafness and the extent of disruption it may produce in the network.

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