Beam Search Algorithm for Large Antenna Arrays Reducing Beam Search Time

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***Abstract*—In mmWave cellular systems, beamforming is required to overcome high pathloss. Beam search is required at initial access stage because position of mobile station (MS) is not known to base station (BS). So BS transmits beams in all directions. For large antenna arrays with large number of beams, this process consumes a lot of time. In this paper, we propose a fast beamforming which significantly reduces the search time, keeping the performance same as conventional system. In proposed technique, uniform planar array (UPA) is divided into set of horizontal/vertical arrays. Zadoff–Chu sequence is used for designing the beam search preamble (BSP), which allows a mobile user to distinguish beams in multi-cell multi-beam environments**

***Index Terms*—Fast 3D beamforming, millimeter wave, uniform planar array, beam search preamble**

I. Introduction

There has been a rapid increase in the demand for high data rate transmission owing to the widespread use of smart devices and sensor nodes in various applications and services. Millimeter wave (mmWave) communication is a potential technology that enables the use of a wide bandwidth for highly advanced broadband cellular communication [1]–[3]. Highly directional beamforming antennas are necessary at both the base station (BS) and the mobile station (MS) to compensate for the high attenuation in the mmWave frequency band and extend the coverage area. With a small wavelength of an mmWave frequency, antenna arrays can be conveniently installed at the MS.

In this paper, we propose a fast 3D beamforming technique for mmWave cellular systems with a uniform planar array (UPA). In this technique, a UPA is decomposed into a set of horizontal/vertical uniform linear arrays (ULAs), from which the optimal beam direction in the azimuth/elevation domain is obtained. The optimal 3D beam direction is determined by combining the results obtained from each domain. The beam search time is further reduced by simultaneously transmitting beams in different directions from horizontal or vertical ULAs. Two types of signals Zadoff–Chu (ZC) sequence and linear frequency modulated (LFM) waveform are used for designing a beam search preamble (BSP), which allows MS to distinguish beams in multi-cell multi-beam environments. Detection probability of both proposed sequences is checked in presence of carrier frequency offset (CFO).

II. Fast 3D Beamforming Technique

For beamforming systems, beams are needed to be scanned from all possible directions because position of MS is not known. This induces some beam search time which is directly proportional to number of beams when exhaustive search is used. For large antenna arrays with large number of beams, reducing this beam search time can improve time required for initial access.

To speed up the beam search procedure, this paper proposes to divide UPA into vertical and horizontal ULAs, as indicated in Fig. 1. First, UPA is divided into horizontal ULAs. Beams are transmitted in different azimuth directions from each horizontal ULA simultaneously. In order to distinguish each beam, BID is transmitted by using BSP. MS performs Rx beamsweeping by switching its beams and performs correaltion. BID with maximum correlation result is transmitted back to BS. Similarly, in next step, UPA is divided into vertical ULAs and beams are transmitted in different elevation angles. MS again performs Rx beamsweeping and selects beam with maximum correlation value. Then using the knowledge of best azimuth angle and best elevation angle for targeted user, BS forms sharp beam in that direction. It should be noted that for proposed technique, only two rounds of beam transmission is required when number of ULAs and number of beams are same and for conventional technique, number of required beam scans is product of number of horizontal beam directions and number of vertical beam directions.

III. ZC-based 3D Beamforming Technique

In order to enable an MS to identify the Tx BID and the CID from the received signals, the BID needs to be designed in conjunction with the CID in the BSP. As multiple beams are transmitted in parallel in the proposed fast 3D beamforming technique, the horizontal BID $b_j^{BS,H}$ and $b_j^{BS,V}$ are distinguished by the amount of cyclic shift spacing in the proposed ZC-based BSP (ZC-BSP). In addition, the CID designed in conjunction with the horizontal/vertical BID in a ZC-BSP is distinguished by the root index of ZC sequence. In the proposed ZC-BSP, the BID and CID are mapped to the prime-length ZC sequence as follows:

$$x_{ZC}^{c,b}(n) = e^{\frac{j\pi r^c (n+Qb_j)(n+Qb_j+1)}{N_z}} \tag{1}$$

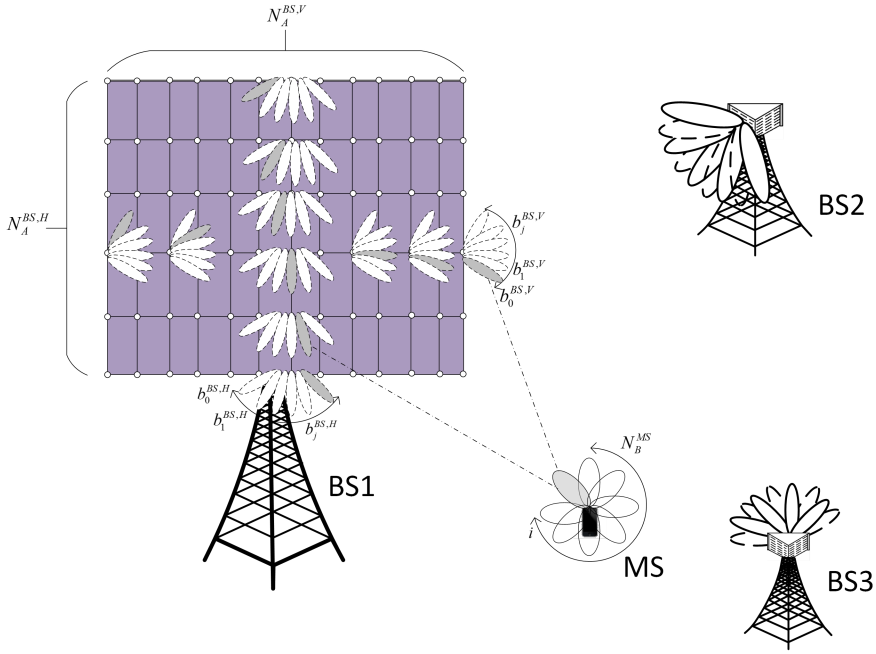

Fig. 1. Proposed 3D Beamforming Technique for a mmWave Cellular System with UPA

where $1 < r^c < N_z$ and $\gcd(r, N_z) = 1$. Here, N_z, r^c, and Q denote the length of the ZC sequence, root index for the CID c and cyclic shift spacing constant, respectively. As the horizontal and vertical beams are transmitted at different time slots, the BID b_j is used for notational convenience rather than the horizontal BID $b_j^{BS,H}$ and vertical BID $b_j^{BS,V}$. The number of available CIDs in the ZC-BSP is given by $N_z - 1$.

Fig. 2 presents comparison of proposed technique and conventional beamforming. It can be observed that proposed technique reduces beam scan time significantly. Here, 16 beams are considered for simulation. For conventional system, number of beam scans increase with number of beam directions, however, for proposed technique, it remains constant.

IV. Conclusion

In this paper, fast beamforming technique is proposed to reduce beam training time. In order to accomplish this goal, UPA is divided into horizontal and vertical ULAs for horizontal and vertical beamsweeping, respectively. Azimuth angle is found via horizontal beamsweeping and elevation angle is found via vertical beamsweeping. As a collective result of two processes, required azimuth and elevation angle for MS are known to BS, so BS forms sharp beam directed towards that MS. Simulation results show that proposed beamforming technique reduces beam scan time significantly.

Acknowledgement

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (2018R1A4A1023826) and (2018R1A2B2002621).

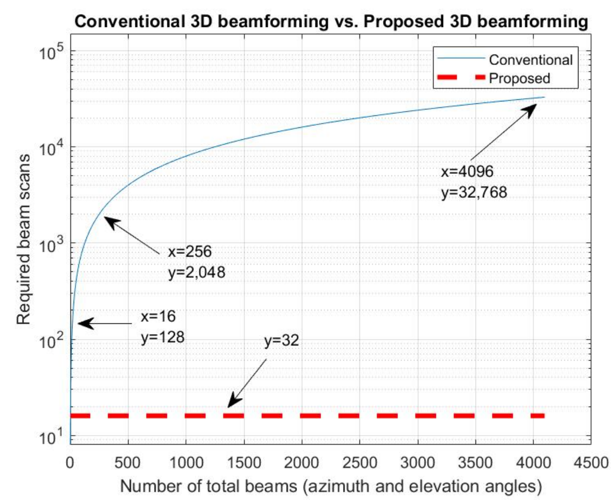

Fig. 2. Number of beam scans required for 3D beamforming

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