Sectorized Codebook Design for a Polyhedron-Based Antenna Array Structure

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***Abstract*—Utilization of massive Multiple-Input Multiple-Output (MIMO) arrays for reliable data transmission at a very high bandwidth efficiency is one of the key techniques required for the Fifth-Generation (5G) wireless systems. In order to steer data beams to various moving targets including vehicular and aerial objects, new types of array structures are under study. One of promising candidates for such structures is the spherical array based on polyhedrons. In this paper, we investigate how the icosahedron shape can be used to perform full-dimensional beamforming to multiple receivers, and propose codebooks applicable to such a transmission scenario. The correlation performance of the proposal is verified for different codebook sizes, which is shown to exceed the greedy search algorithm performance.**

Keywords-5G; spherical arrays; beamforming; codebook; massive MIMO.

I. INTRODUCTION

For next-generation wireless systems, connectivity to various types of moving objects including self-driving cars and drones is becoming an important issue. In order to provide a sufficient coverage to such objects, full-directional beamforming capable of performing vertical tilting of all zenith angles is required. Utilization of Three-Dimensional (3D) antenna arrays on a spherical structure can be especially advantageous in such transmission scenarios [1]. Spherical arrays are generalization of uniform circular arrays which mainly target azimuthal transmission [2], and can be combined with millimeter-wave carriers to formulate beams based on a sufficiently large number of antenna elements located in a compact-size structure [3]-[5]. Arrays on geodesic domes have been investigated for satellite communication applications [6],[7].

In this study, we investigate an efficient beamforming strategy based on spherical arrays and propose codebooks applicable in a limited-feedback environment. We assume a polyhedron-based array, for which antenna elements are located on vertices of the icosahedron. The boresight of each antenna element form a 3D sector, partitioning the whole isotropic space into 12 sectors. At each antenna location, a set of antenna elements or a subarray can be used for sharper beams with more flexible beam tilting adjustment. This type of sectorization can be regarded as an extension of high-order sectorization used in 3GPP cellular system design in the conventional 2D space [8].

In Section II, the proposed codebook design is explained, followed by the performance evaluation result in Section III. Conclusions are given in Section IV.

II. SECTORIZED CODEBOOK DESIGN

Our strategy is to determine the beamforming vectors for each sector, and apply those vectors to other sectors as well by performing coordinate transformations. Figure 1 shows the sectorization of 3D space using the 12 antennas in the spherical array. As can be seen from the figure, each sector has the form of pentagonal pyramid, and we can indicate the beamforming direction of each vector at its base. Note A_m denotes the m-th coverage sector, (θ_q, ϕ_q) represents the codevector location, and (θ_q', ϕ_q') is the location after transformation. Figure 2 is an illustration of such indication. With a single representative codevector at the antenna boresight, we evenly distribute the remaining vectors at a certain angular distance. The distance is determined by the correlation measure between the geometric channel and the codevector, in such a way that the average correlation is maximized. We progressively use more beamforming vectors to include $Q = 2^B$ entries in the codebook as the number B of feedback bits increases.

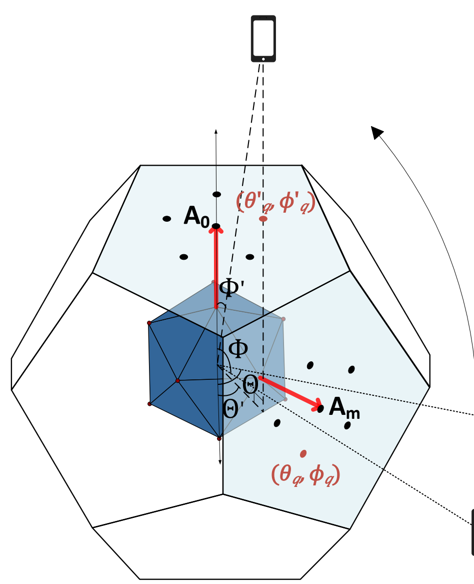

Figure 1. Beamforming vectors for each of 12 sectors in 3D space.

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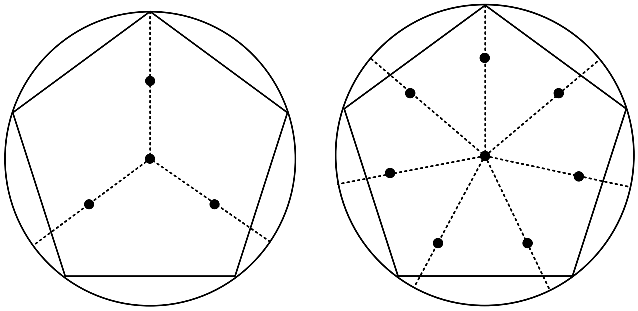

(a) (b)

Figure 2. Beam directions for the chosen codevectors: (a) $B = 2$, (b) $B = 3$.

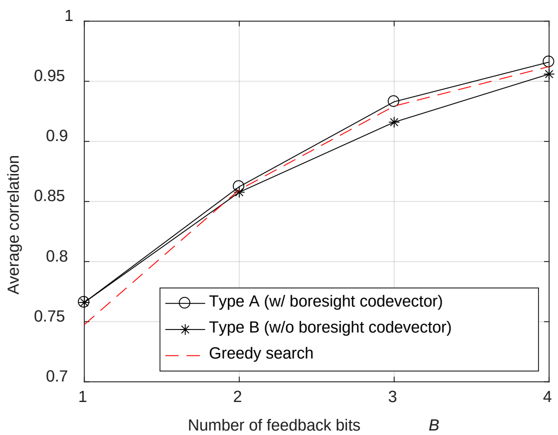

Figure 3. Perfomance of the proposed codebook in comparison to greedy search results.

Constructed codebook $\mathbf{C} = \{\mathbf{w}_1, \mathbf{w}_2, \ldots, \mathbf{w}_Q\}$ includes codevectors $\mathbf{w}_q$ for which the phase vector has the form

$$\text{Phase}(\mathbf{w}_q) = -(2\pi/\lambda)\,[\, d_0, d_1, \ldots, d_{M-1}\,]^T$$

for $q = 1, 2, \ldots, Q$, where λ is the carrier wavelength, M is the number of antenna elements, and d_m is the distance between the m-th antenna and the target receiver. The distance is determined using the geometry characteristics of the array polyhedron. For the antenna elements located at vertices of icosahedron, the distance has the form of

$$d_m = \sin\theta \sin\alpha \cos(\phi - \beta) + \cos\theta \cos\alpha$$

where ϕ and θ are position angles for the codvector points in Figure 2. Symbols $\alpha \in \{0, 31.7^o, \pi - 31.7^o, \pi\}$ and $\beta \in \{0, \pi/10, 2\pi/10, \ldots, 9\pi/10\}$ are obtained from the geometry information of icosahedron. By computing the distances, the codebook of a given size is obtained and the corresponding performance can be evaluated.

III. Performance

We evaluated the average correlation performance of the proposed sectorized codebook for different codebook sizes. The result is summarized in Figure 3. As the codebook size increases, the correlation rapidly approaches to unity, the performance for beamforming vectors with infinite resolution. We found the case with the codevectors pointing the antenna boresight at the sector center (indicated as Type A in the figure) outperforms the case without them (indicated as Type B). We also have constructed search-based codebooks using the greedy algorithm, by successively selecting the beamforming vector, which is most preferred by the random channel location samples. As can be verified from the figure, the proposed Type A codebook exhibits enhanced performance over the search method.

IV. Conclusion

We proposed the codebook which can be applied to the 3D space covered by spherical arrays. The design can be generalized to different array structures including geodesic-based spheres and those including antenna subarrays. Planned future work is the multi-rank extension exploiting the orthogonality of the spherical beams.

Acknowledgment

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