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Convex-hull of Users under Adaptive Beam in WAN to Minimize Interference

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Abstract— In a mobile cellular network, users are located at a random position inside the cell. Sometimes users are highly concentrated in a region for example vicinity of a growth center on a holiday or near a stadium when a big football match is going on. In this case, a group of users under a convex hull can be covered by the beam of the adaptive Array Antenna System (AAS). Therefore the desired signal will be directional hence very low interference caused by the side lobes to other users. In this paper, an algorithm in the formation of a quick convex hull of a user group, determination of the inscribed angle of the convex hull from the center of the cell/Node-B, and formation of an adaptive beam to cover the convex hull. The paper reveals the results integrating the above three phenomena to achieve the communication of WAN (wide area network) with minimum interference. The concept of the paper is applicable in massive MIMO (multiple input and multiple output) of the 5G mobile cellular network.

Keywords - Beamformer, DOA, AAS, SINR, and Quickhull algorithm.

I. INTRODUCTION

This section provides some previous works relevant to adaptive beamforming and application of convex hull separately. In the conventional mobile communication system, the radiation pattern of a evolve Node-B (eNB) is omnidirectional for an individual user or group of users, hence huge interference is experienced by users. The adaptive algorithm of digital signal processing is used in adaptive beamforming, which becomes popular with the proliferation of research work in the reduction of interference in WAN. In 4G and 5G WAN, massive MIMO is used for outdoor users, where adaptive beamforming is used to transmit or receive a signal in the desired direction. This concept is considered as one of the breakthroughs of mobile cellular network till 3G. This section deals with some state-of-art research work relevant to bean forming and convex-hull. The simplest adaptive algorithm called Least Mean Square (LMS) is applied in adaptive beamforming in [1], where the algorithm is verified with a two-dimensional radiation pattern. In [2] four-element antenna array is used under software-defined radio. The two-dimensional radiation pattern of the array is shown graphically (gain in dB vs. physical angle). In [3] authors compared the performance of several adaptive algorithms: LMS, Signed Data Algorithm, and ‘cyclic variable step-size LMS’ in beamforming of WAN. Comparison is made on the plot of MSE in the dB vs. iteration index, where the proposed algorithm, ‘cyclic variable step-size LMS’ is found as the best. The complexity of adaptive beamforming depends on the input signal-to-noise ratio (SNR). For low input SNR, the complexity of the algorithm becomes high in reconstruction-based beamformer. To alleviate the situation, authors in [4] proposed a new algorithm, which is compared with ‘interference-plus-noise covariance matrix (INCM) based reconstruction’ and ‘minimum variance distortionless response (MVDR)’. The proposed algorithm provides better results at both low and high SNR at the same time reducing the complexity of the beamforming algorithm.

The application of the convex hull algorithm is found in [5] in reducing the data delivery latency of mobile elements of wireless sensor networks. Here convex hull structure of sensing nodes is determined to make a visiting order of nodes. The traveling time is plotted against the number of sensor nodes and communication radius, where the proposed algorithm (three-step geometric method) is compared with the other four existing techniques. Another application of convex-Hull in wireless sensor networks is found in [6], where the boundary of unattended sensor nodes are detected. The authors used three algorithms: Distributed Convex-Hull Algorithm, Centralized Convex-Hull Algorithm, and Mobile Initiator Based Convex-Hull Algorithm in boundary detection. The relative performance is determined using average energy consumption vs. the number of nodes graphs. The third algorithm (Mobile Initiator Based Convex-Hull Algorithm) shows the lowest energy consumption and the first one (Distributed Convex-Hull Algorithm) shows the highest energy consumption.

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So far we know, still, no research work is done with a combination of adaptive beam and the convex hull of the user group in a cell of WAN. In this paper, we propose a novel mechanism for adaptive beamforming to a targeted user group using the Convex Hull algorithm. Section I illustrates the introduction of our mechanism for adaptive beamforming. The rest of the paper is organized as section II provides a rudimentary model to form a convex-hull with concentrated users under eNB, the algorithm of adaptive beamforming and algorithm of forming quick convex-hull, and derivation of SINR of a target user; section III provides result combining adaptive beam and convex-hull under wireless WAN and section IV concludes the entire analysis.

II. SYSTEM MODEL

This section provides four sub-sections: formation of the user group, adaptive beamforming algorithm, quickHull algorithm of User Equipment (UEs), and evaluation of signal to noise and interference ratio (SINR) of users. The paper provides results aggregating the four sub-sections together.

A. Formation of the user group

In LTE-A a macrocell deals with outdoor users. A user can locate its position (latitude and longitude) within a macrocell by mobile apps or GPS within the accuracy of a few meters. The location of each user is converted to a local Cartesian coordinate system by axis transformation (parallel shifting and rotation of axis). Here the macro eNB of the cell is located at (0, 0), a reference direction is considered as the *x*-axis and its normal along the positive angular direction is *y*-axis like figure1.

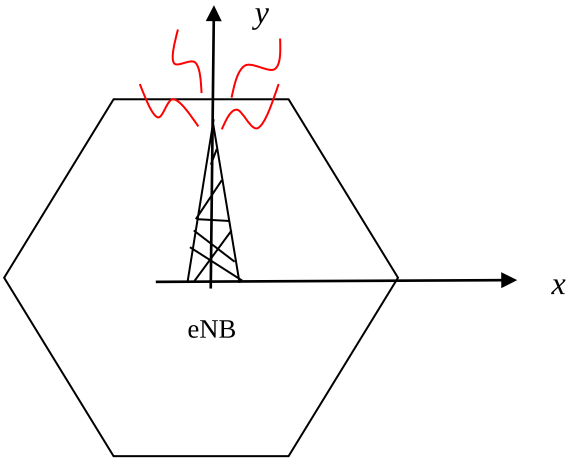


Figure 1. The eNB and reference direction

Since both UE and eNB use multiple antennas hence radiation beam from eNB to UE or UE to eNB can be changed adaptively (both beam width and direction). In a cell, there are one or more growth centers especially in the urban or suburban area, hence the concentration of users in the growth center is high, for example, 40% of users may be concentrated inside or vicinity of the growth center.

The concentrated user group can be determined using the concept of the Closest-Pair Problem. If the location of a huge amount of users is found in a concentrated region, then the adaptive beam can be directed towards the UEs of that small region. At the same time, UEs can also send the signal using a narrow beam along with eNB. After getting the location of UEs concentrated in a small region, a convex hull of the UEs is formed using a local coordinate system like figure 2.

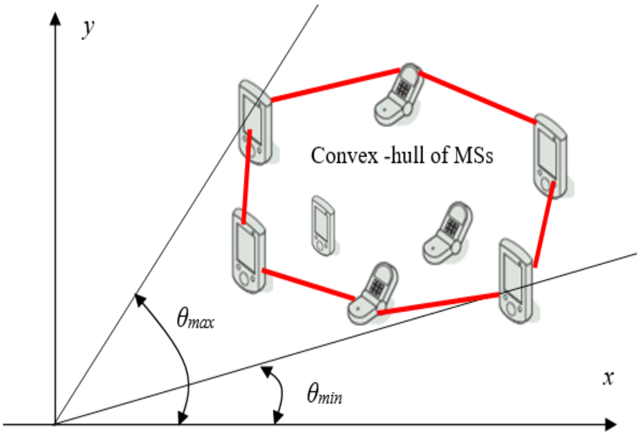


Figure 2. Convex-hull formed by closed users under eNB

Let us determine the angle θ_{max} and θ_{min} w.r.t. reference direction as the tangent of the convex hull is shown in fig.2. The angle θ_{max} and θ_{min} are the extreme left and right of the axis of the antenna beam. The following algorithm gives the steps of determination of closely located UEs, direction, and width of the antenna beam.

Algorithm-1

(a) Determine latitude and longitude of a set of concentrated UEs

(b) Convert the latitude and longitude to local Cartesian co-ordinate (x, y) under the eNB

(c) Determine a group of user closely located at (x_i, y_i), $i \in \{1, 2, 3, \dots, M\}$, M is the number of UE and the distance between any two UEs is less than the threshold D_m as,

$$\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \le D_m$$

(d) Form a convex hull with the user group of step (c) using the algorithm of section 2.3.

(e) Determine the angle of the UE w.r.t. *x*-axis as, $\theta_i = \tan^{-1}(y_i/x_i)$

(f) Determine θ_{max} and θ_{min} of fig.2 using $\theta_{max} = max(\theta_1, \theta_2, \theta_3, \dots, \theta_M)$ and $\theta_{min} = min(\theta_1, \theta_2, \theta_3, \dots, \theta_M)$

(g) Now the axis of the beam of the adaptive array (downlink) will be along: $\theta_D = (\theta_{max} + \theta_{min})/2$ and the width of the beam will be, $\Delta\theta = (\theta_{max} - \theta_{min})$.

(h) For up-link, the direction beam of *i*th UE will be along θ_i.

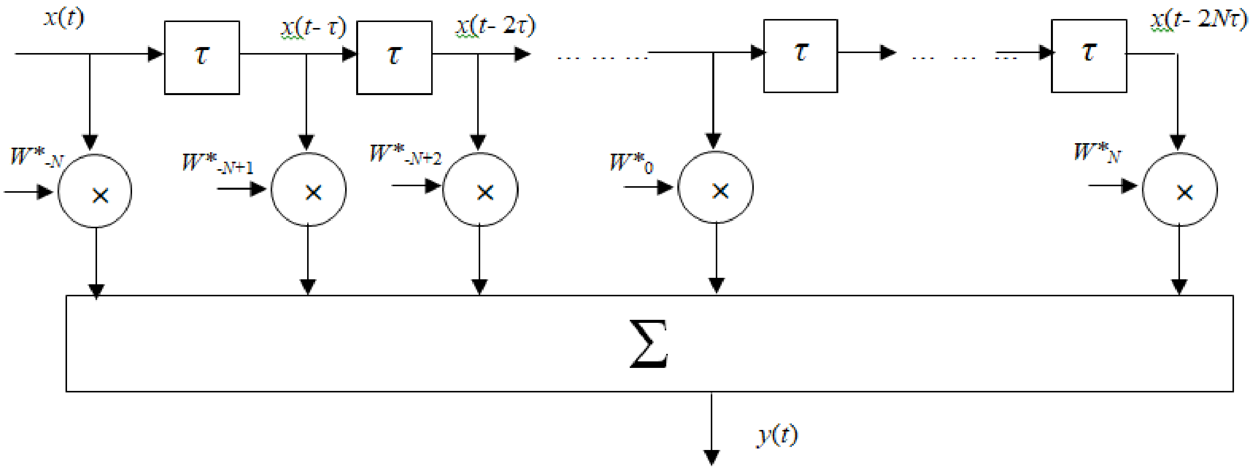


Figure 3. Tapped delay equalizer

Because of the use of a directional adaptive beam for a group of UE (within the convex hull), the interference within the cell will be heavily reduced compared to omnidirectional radiation.

B. *Adaptive Beam Forming*

The adaptive Beamforming algorithm uses the basic concept of the tapped delay FIR filter of figure 3, where the weighting factors of the filter are varied using the adaptive algorithm of [7]. The output of the filter is expressed as,

$$y(t) = \sum_{k=-N}^{N} W_k^* x(t - k\tau) \qquad (1)$$

Using the notation of discrete time sequence equation (1) can be expressed as,

$$y(n) = \sum_{k=0}^{M-1} W_k^* x(n-k) \qquad (2)$$

where $x(n\text{-}k)$ is the input sequence and W_k is the corresponding weighting factor.

The power of the output signal becomes [8],

$$P = |y(n)|^2 = \sum_{k=0}^{M-1}\sum_{i=0}^{M-1} W_k^* W_i E[x(n-k)x(n-i)]$$

$$= \sum_{k=0}^{M-1}\sum_{i=0}^{M-1} W_k^* W_i R(i-k) \qquad (3)$$

where $E\left[x(n-k)x(n-i)\right] = R(i-k)$ is the autocorrelation function of the input sequence. If we include the direction of radiation as a linear constraint, $\sum_{k=0}^{M-1} W_k^* e^{-j\theta_0 k} = h$ with the eq. (3) then the Lagrangian function becomes,

$$\xi = \sum_{k=0}^{M-1}\sum_{i=0}^{M-1} W_k^* W_i R(i-k) + \mathrm{Re}\left[\lambda^*\left(\sum_{k=0}^{M-1} W_k^* e^{-j\theta_0 k} - h\right)\right] \qquad (4)$$

where ξ is called cost function, h is the complex gain of the array antenna system, θ_0 is the desired angle of arrival and λ is a complex Lagrange multiplier. Solving eq. (4) using an adaptive algorithm provides the optimum weighting vector **W** to acquire the radiation bean of AAS along the desired direction. The more realistic result of adaptive AAS is to achieve the highest gain along the direction of the desired signal and lowest gain along with the interference. This can be implemented using 'linearly constraint minimum variance' (LCMV) beamformer as explained in [9-10].

C. *Convex hull of UEs*

In this section, we first provide the conventional algorithm of formation of the convex hull then another algorithm called quick-hull to make the real-time operation in proposed WAN. The convex hull of a set of points *Q* is the smallest convex polygon *P* that encloses all the points of *Q* and is denoted by CH(*Q*). The term convexity refers that each line segment between any two vertices of the polygon is completely inside the polygon as shown in figure 4.
There are many algorithms to find the convex hull from a given set of points. One of the widely used algorithms of the convex hull was proposed by Ronald Graham in 1972 which is known as Graham's Scan algorithm [11]. The running time of this algorithm is $O(n \log n)$, where *Q* is a set of *n* points in a plane. The algorithm of finding the convex hull CH(*Q*) is:

Preprocessing:

1. From the set of points *Q*, find the point with the smallest ordinate. In case of multiple such instances choose the one with the smallest abscissa denoted as p_0.
2. Sort the remaining *n*-1points in non-decreasing order of the angle formed by each point p_i and p_0 with *x*-axis.

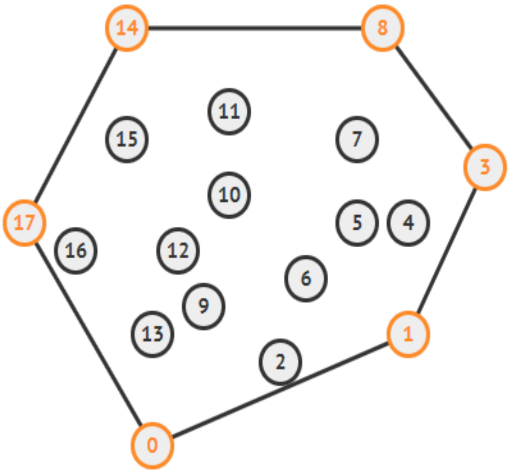


Figure 4. Convex hull CH(Q) ={0, 1, 3, 8, 14, 17} of a set of points Q ={0, 1,2,…,17}

Algorithm:

```
1. Let S be an empty stack
2. PUSH($p_0$,S)
3. PUSH($p_1$,S)
4. for i = 2 to n-1
5.     while angle formed by points NEXT_TO_TOP(S), TOP(S) and $p_i$ makes a non-left turn
6.         POP(S)
7.     PUSH($p_i$, S)
8. Return S
```

Another efficient approach to finding the convex hull is the Quick Hull algorithm. It uses a divide and conquer approach similar to the quick sort, hence the name is quick hull [12]. This algorithm performs well under average cases, but, when the points reside on the circumference of a circle then it shows poor performance. The average case complexity of a quick hull is $O(n \log n)$ and in the worst case, it is $O(n^2)$.

The steps of the Quick Hull Algorithm is given below:

***QuickHull* (Q)**

```
1. Sort the points based on their abscissa.
2. Find the leftmost point L, and rightmost points R, based on the abscissa.
3. The line segment LR divides the $n-2$ points into the following groups:
       $Q_0$= points on the LR line segment, which we can ignore.
       $Q_1$ = points on the left side of the LR line segment.
       $Q_2$ = points on the left side of the RL line segment.
4. FindHull($Q_1$, L, R)
5. FindHull($Q_2$, R, L)
```

***FindHull*(*Q*, *L*, *R*)**

```
1. if Q has no point then
       return
2. From the LR line segment, find the farthest point M, among the points of Q
   a. Points L, R, and M partition the remaining points of Q into the following groups:
          $Q_0$=points inside triangle LMR, which we can ignore.
          $Q_1$ = points on the left side of the LM line segment.
          $Q_2$ = points on the left side of the MR line segment.
3. FindHull($Q_1$, L, M)
4. FindHull($Q_2$, M, R)
```

In this paper, we consider all the points of the above algorithm as the location of user equipment (UE).

D. *SINR of Users*

Now, the received signal of a user in a convex-hull can be expressed like [13] as,

$P_R=\sqrt{Pd^{-\varepsilon}}gS$ +Co-site interference from other users inside the hull + Negligible interference from other hulls + co-site interference from other Omni-users + awgn

$$=\sqrt{Pd^{-\varepsilon}}gS+I_{s\_convex}+I_{o\_convex}+I_{others}+n \qquad (5)$$

Where,

S → Down-link symbol towards the user

P →Transmit power of eNB

g → Channel gain between eNB and the user

ε→ Path loss exponent

d→ Distance between eNB and user

Therefore the SINR of a user will be,

$$SINR_{convex\text{-}hull}=\frac{Pd^{-\varepsilon}g^2}{P_{I\_s}+P_{I\_n}+P_n} \qquad (6)$$

In conventional WAN the received signal of a user is,

$P_R=\sqrt{Pd^{-\varepsilon}}gS$ + Co-site interference from other omni users + awgn

$$=\sqrt{Pd^{-\varepsilon}}gS+I_{C\_omni}+n \qquad (7)$$

Therefore the SINR of a user will be,

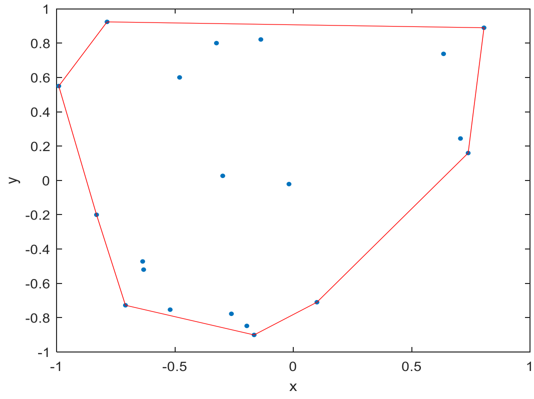
$$SINR_{conventional}=\frac{Pd^{-\varepsilon}g^2}{P_{C\_omni}+P_n} \qquad (8)$$

Here, $P_{C\_omni}\geq P_{I\_s}+P_{I\_n}$

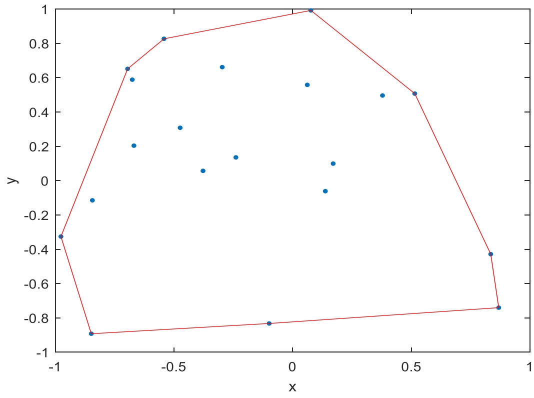
therefore $SINR_{convex\_hull}\geq SINR_{conventional}$

III. RESULTS

In this section first of all we will concentrate on the formation of convex-hull of UEs and its inscribed angle from the eNB of a cell of WAN. Next, we will deal with the formation of an adaptive beam to match with the prepared convex-hull. Figure 5 (a)-(d) shows the example of the formation of convex-hull taking 20 random points like the location of UEs on x-y plane using MATLAB 18. The shape of the convex-hull is different in four cases because of the random position of UEs. Simulation work is done in Matlab 18, taking random points like the location of UEs inside the cell of WAN. Next, we simulate a few concentrated users in a cell to form a convex-hull using algorithm-1 of section 2. The users are randomly located inside a cell but some users are found concentrated near the growth centre hence those users can be brought under a narrow beam of AAS hence points will form the convex-hull under the algorithm of *QuickHull* of section-2. The result of the simulation work is shown in figure6, where three concentrated user group and the corresponding convex hull are visualized. Figure 7 shows the extension of simulation work where three convex hull and corresponding physical angle of inclusion (from Node-B) are shown. The 'inclusion angle' is necessary to match the beam of the array and the convex-hull.



(a)



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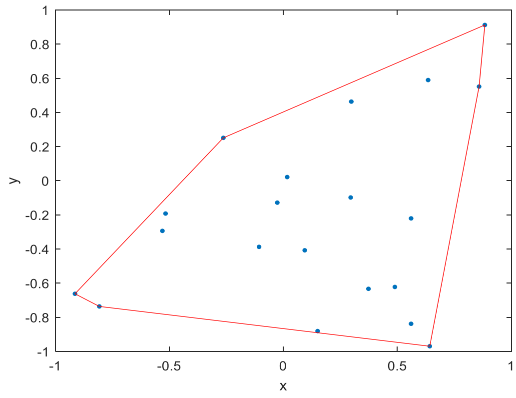
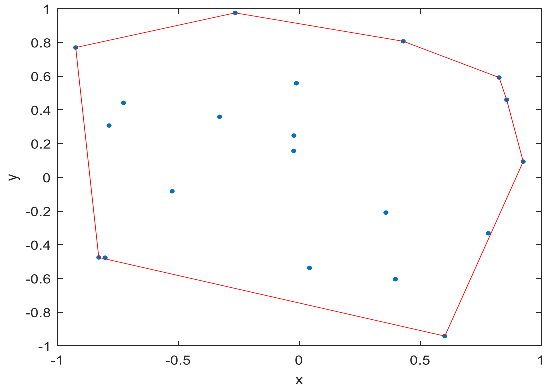


(c)



(d)

Figure 5. Convex-hull of 20 random points on *x-y* plane

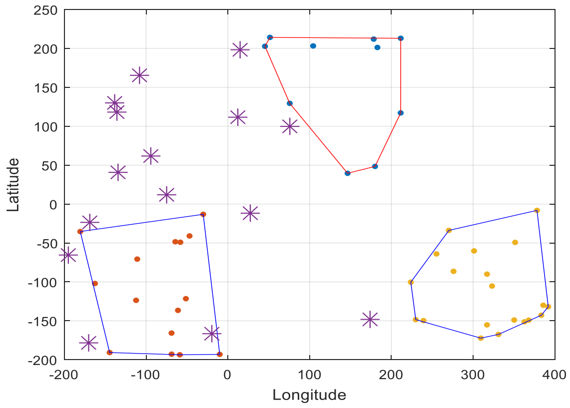


Figure 6. Three concentrated user group and convex hull

The fig.8 (a) shows the 2D (two dimensional) radiation pattern of two different adaptive array antenna systems, where the DOA (direction of arrival) of the first array is 65^0 and that of the second array is -10^0, taking the number of array elements *N* = 4, 8 and 16. In this paper, we use LCMV to achieve the beam in the desired direction with the cancellation of the side lobe. In the first beam, the nulls are at 0^0 and 135^0 but the DOA is at 65^0. In the second beam, nulls are at -45^0 and 25^0 but DOA is at -10^0. Fig.8 (b) shows similar results for *N* = 8. With the increment of the number of antenna elements, the beamwidth becomes narrower i.e. more selective to the desired signal as found in fig. 8(c) taking *N* =16.

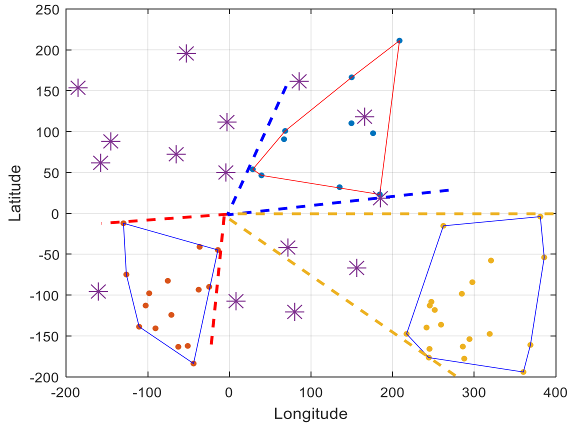
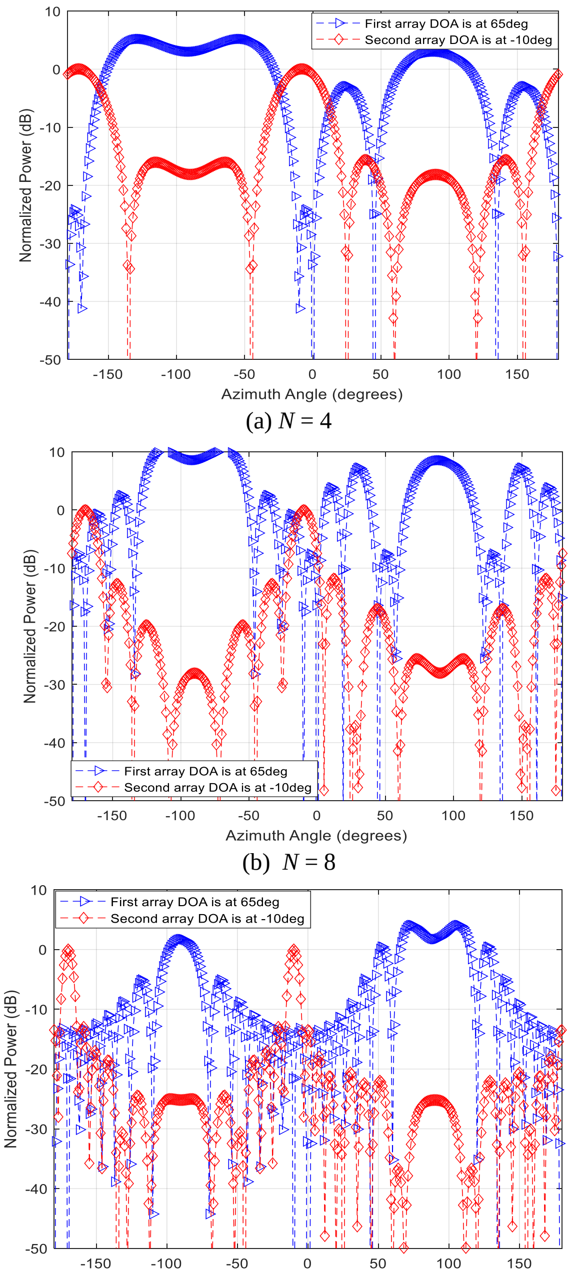


Figure 7. Three convex hull and corresponding inclusion angle



(a) $N = 4$

(b) $N = 8$

(c) N=16

Figure 8. Two dimensional radiation pattern of AAS

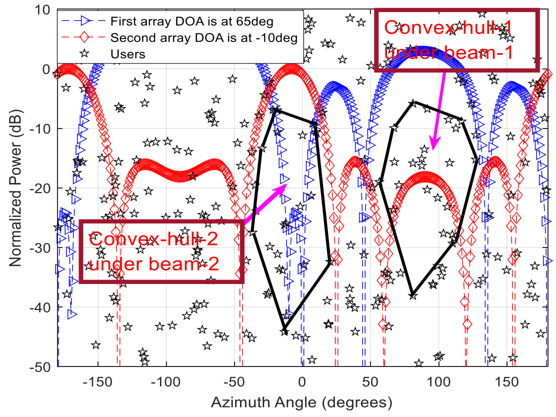
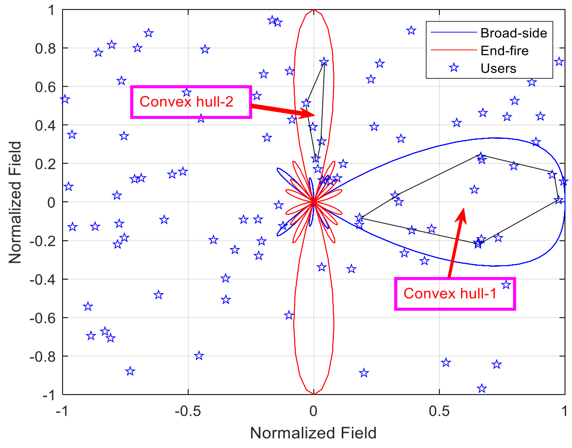
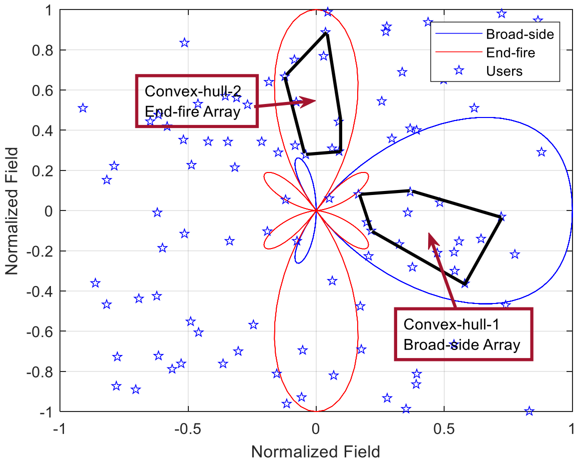


Figure 9. Convex hull confined by beam of adaptive AAS with N= 4



(a) Random user test-1



(b) Random user test-2

Figure 10. Convex hull confined by the beam of board-side and end-fire

Next, simulation work is done with a large number of randomly located UEs and to segregate closely located groups within the cell. In figure 9 the random location of users is indicated by stars. Here the heavily concentrated users are segregated into two groups and two corresponding convex-hull are formed indicated as convex-hull-1 and convex-hull-2. The beam with a DOA of 65^0 uses the convex-hull-1 and the beam with DOA of -10^0 uses the convex-hull-2. We also show the result of simulation in the polar co-ordinate system in figure 10, instead of the Cartesian coordinate of figure 5-9. Here we run the simulation considering two linear AASs. The weighting vector of the adaptive beam is so adjusted that one AAS becomes broad-side (radiation pattern is perpendicular to the axis of the array) and another becomes end-fire (the radiation pattern is along the direction of the axis of the array). The width of the beam is made different visualized from figure 10 (a) and (b), since the shape of the convex-hull is different. Here two convex-hulls are formed: one under the beam of broad-side and the other under the end-fire array.

Table 1. Comparison of SINR

	SINR in dB with ε = 2		SINR in dB with ε = 2.5	
Beamwidth for target user Δθ	Proposed	Convectional Omni antenna	Proposed	Convectional Omni antenna
15^0	-12.65		-12.77	
20^0	-12.97	-14.76	-13.02	-14.90
30^0	-13.46		-13.78	

Finally, another simulation is run to measure the SINR (in dB) of a user under the proposed model then a comparison is made simulating the conventional omnidirectional radiation pattern of the downlink. Here we consider 50 users under an eNB are in service mode; among them, 12 users form a convex hull including the target user, 16 other users participate in the different convex hull and the rest of the users make Omni link with eNB. The simulation is run again considering all the 50 active users make Omni link with eNB like conventional WAN. The link parameters are: free space path loss exponent ε = 2 and 2.5, the radius of the cell r = 500 m, the distance of the target user d = 75m, average transmit power of downlink P =20W, and average path gain g = 0.23. The relative performance is shown in Table I, where the proposed model shows higher SINR for both ε = 2 and 2.5 compared to conventional omnidirectional communication, although SINR decreases with an increase in ε for both cases. The beamwidth $\Delta\theta$ depends on the shape of the convex hull.

IV. CONCLUSION

In this paper we used two algorithms to form convex-hull from concentrated UEs inside a cell then an adaptive beam is applied on the user group from the corresponding eNB. The above phenomenon provides better SINR at the receiving end compared to the conventional downlink of WAN. In the future will compare the performance of different beamforming algorithms in the context of process time to cope with the model of the paper. In this paper, we could not bring the idea of the mobility of users under the convex-hull. The algorithm will work properly for a stationary user group or group of the user in the pedestrian condition. In the future, we will also work on the reshaping of the radiation pattern of ASS to cope with the mobility of users.

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AUTHORS PROFILE

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