Influence of Beam Forming and MIMO on the Adaptive Antenna Systems(AASs)

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Abstract

The "all-band-to-5G" transition requires antenna systems to support all bands. Considering 5G network characteristics, antennas must also flexibly adopt to diverse application scenarios. This paper describes the factors influencing the technology in the Adaptive Antenna Systems (AASs), making it a viable option for large scale deployments in the existing 4G and 5G mobile networks. Supporting the integration of baseband, radio and the antenna in the AASs, reduces the digital processing cost per bit and increases the end-user performance. AASs play an important role in enabling the coverage and capacity of the networks through Beamforming and MIMO technologies with better spectral efficiency and increased SINR at the receivers. AASs can overcome the straining RAN, to provide required end-user throughputs and thus helping the Mobile Network Operators scale their revenue at a much faster rate. In the pretext of the AAS, significant advantages are realized in the deployment options dependent on the deployment scenarios cost efficiently with less lead time.

I. Enhancements to the 4G and Legacy Antennas

- Transition of the Passive Antennas to Active Antennas has led to the exploitation of the larger transceiver antenna counts like 16T16R, 32T32R, 64T64R and so on to co-exist with passive antennas up to the order of 8T8R.
- In addition to the exploitation of Beamforming in the Data channels, 5G NR extends the ability to the control and broadcast channels.
- The increased orders of the MIMO and the closely placed clustered linear arrays, enable the antenna diversity in the AASs to overcome the multipath fading as opposed to the widely spaced radomes in the LTE.
- The fully integrated transceivers and antennas will include antenna elements in the order of more than 100 which enables high beamforming gains for challenges in directive coverage and capacity requirements.
- The antenna array is partitioned into sub-arrays known as Array of Sub Arrays (AOSA) and they define the degrees of freedom between the antenna elements to determine the beamforming and MIMO capabilities.
- Shaping of the main and the null beams in the beamformers are advantageous over the fixed beam radiation patterns in the LTE antennas.
- The inter distance between the Antenna Elements (AEs) helps in minimizing the grating lobes and thus narrowing the main lobe pointed at the specific UE.

II. Beam Forming and its Relevancy in 5G

- The future of the antennas are the beam formers where the fixed radiation beam patterns are dynamically shaped according to the location of the connected users.
- The significant advancements in the PHY and MAC layer procedures for directional communication controls in the Synchronization Signal (SS) Blocks.

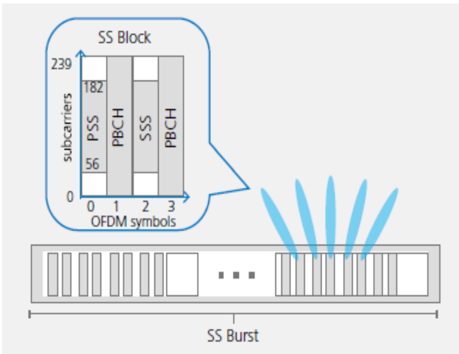


Figure 1. Directional SS Block Transmission

- The directional version of the synchronization signals is defined by 3GPP. Unlike in LTE, the synchronization signals (PSS, SSS) and the PBCH are transmitted together with a typical periodicity of 20 ms in the SS Blocks.

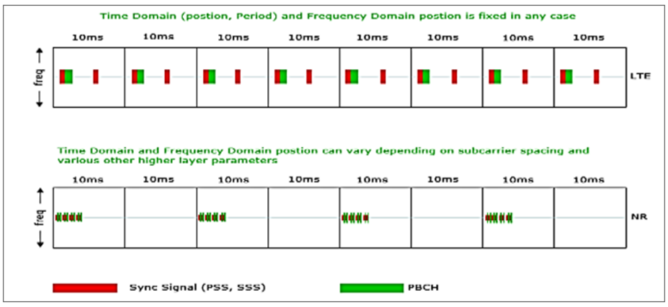


Figure 2. SS Block cross reference in LTE and 5G

III. CELL SEARCH & BEAM MANAGEMENT PROCEDURES

- The Beam management procedures include,

  Beam Sweeping: The radiation pattern covering a spatial area.

  Beam Measurement: Evaluation of the quality of the received signal at the gNodeB or the UE.

  Beam Determination: Selection of the suitable beams either at the gNodeB or the UE.

  Beam Reporting: UE feedback on the beam quality and the decision information to the Radio Access Network.

- In the **Idle Mode Beam Management** gNB initially sweeps several SS blocks in different beam directions and the UE evaluates them to select the beam with maximum SNR using Beam measurement and determination.
- The **Connected Mode Beam Management** uses the downlink CSI-RS and Uplink SRS signals to maintain the alignment of transmitter and receiver beams as the UE is moving.
- The **Downlink Beam Management** procedure involves, as in Fig 3,4 & 5 respectively.
  - **DL Tx and Rx Beam Selection**
  - **DL Tx Beam refinement**
  - **DL Rx Beam refinement**

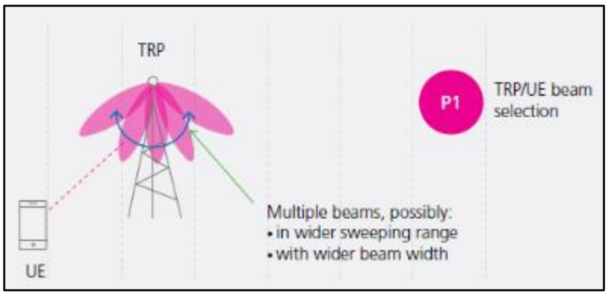


Figure 3. Tx and Rx Beam Selection

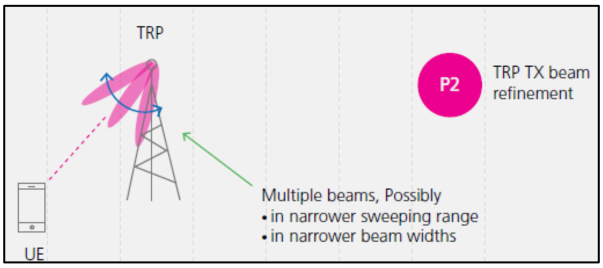


Figure 4. Tx Beam Refinement

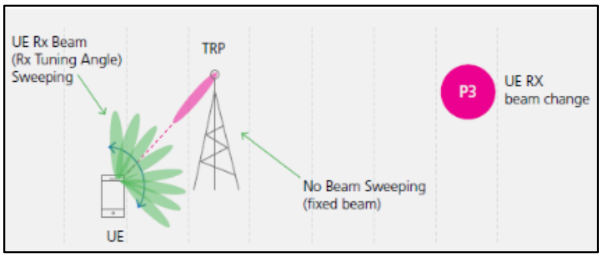


Figure 5. Rx Beam Refinement

IV. FACTORS INFLUENCING THE ADAPTIVE ANTENNA SYSTEMS

- Beam Forming and MIMO have been the underlying technologies in bringing the Adaptive Antenna Systems to reality, exploiting the benefits of the latter in the Era of 5G.
- MIMO is like a multiple number of Base stations serving a fixed number of single antenna terminals. A large number of mMIMO antenna elements allows narrower, focused and highly directive beams.
- As the number of RF chains (from transceivers to antenna elements) increases, external jumper cables become impractical. This has led to the integration of radios inside the antenna panels themselves, establishing another breed of beamformers: the so-called Active beamformers.
- There are certain factors that influence the MIMO dimensioning and in turn affects the Adaptive Antenna Systems. They are as follows:
  - Antenna Element Spacing & Scanning Angle
  - Beam Forming Type
  - No of Antenna Elements/Subarray

Antenna element spacing & scanning angle

- The Antenna element spacing and the steered angle determines the formation of the grating lobes. In the precise directive beam forming technology, it is crucial to eliminate the grating lobes for increased Antenna Gains and least possible interference in the panel.

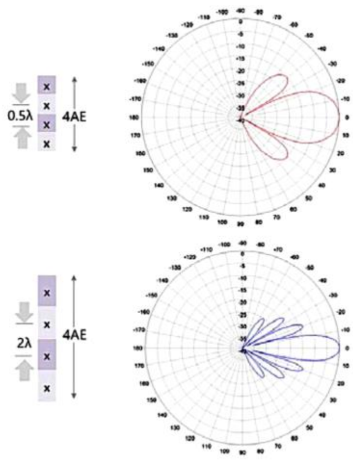


Figure 6. Antenna Element Spacing Effect

- From the above figure, it is evident that the grating lobe maxima is minimized to a greater extent when the AEs are placed at a distance of 0.5 λ than 2 λ from each other.
- Antenna Element Spacing (λ) is the inter element distance of the antenna panel. The scanning angle is the steering angle for each antenna element fed by the phase shifters to direct the beams towards the UE/ point of focus.
- Let the Antenna Element Spacing be dx and the scanning angle be sinθ. Then,
  For, Antenna Element Spacing – **dx**
  Scanning Angle – **sinθ,** ($-90° < \theta < +90°$)

The condition **dx ->** $(0.5\lambda < dx < \lambda)$

$|\sin\theta|$ **->** $1/s - 1$, $S = dx / \lambda$,

should be met in order to

- Obtain one single major lobe
- Eliminate the grating lobe maxima

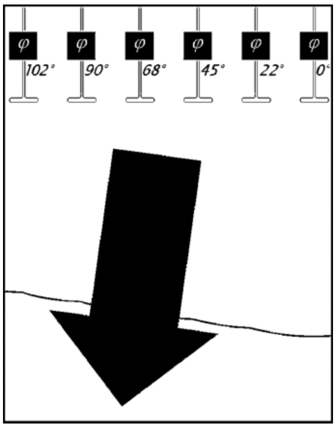


Figure 6. Electronic Beam Steering

- From the above figure, we can observe the electronically steered beam in a particular direction with reference to the phase applied at each of the antenna element of the subarray.
- Relating the phases applied above to our condition below **(To be cont)**

Beam Forming Type

- For Massive MIMO dimensioning, Hybrid Beamforming is used, i.e Digital Beamforming in the Baseband and Analog Beamforming in the RF Domain. Each RF chain is digitally controlled and mapped to a single subarray.

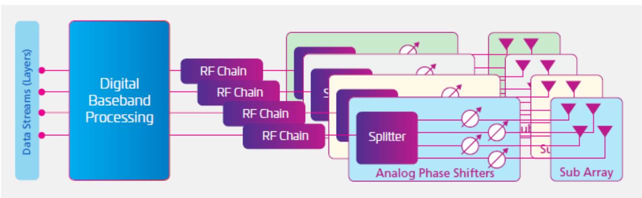


Figure 7. Hybrid Beam Forming in mMIMO Antenna

- In the Hybrid Beamforming type, there will be a large number of phase shifters with one for each Antenna Element and make the beam deflection possible in 2 planes.
- This beam forming type suffers signaling overheads with high power consumptions.

Antenna Panel Gain

- A uniform phased planar array with half-wavelength element spacing gives maximum directivity and hence the increase in the overall gain of the antenna.
- Though the Gain of each Antenna Element (AE) is same, the overall gain of two identical antennas might differ based on the MIMO mapping and sub- array partitioning.
- Doubling the elements in a sub-array doubles the gain of the antenna.

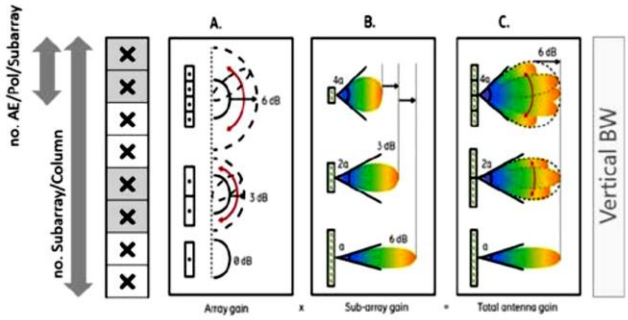


Figure 8. AE spacing influence on Subarray Gain

V. Factors Involved in MIMO Mapping & Configuration and Panel Gain Calculations

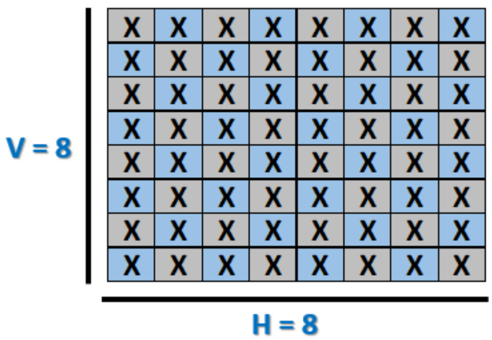


Figure 9. Adaptive Antenna Array Panel

- For Antenna Panel Gain Calculation, consider
  H = 8 **(Horizontal subarrays)**
  V = 8 **(Vertical subarrays)**
  A = 1 **(Antenna elements in each subarray)**
  If the antenna elements are cross polarized, then (**A**) is for a single polarization.

- The value V and H are the number of partitions in the vertical and Horizontal array. Therefore, product of V and H gives the number of the Subarrays.
- Each Subarray will have 2 beams coming out of it: Co and Cross- polarized Beams.

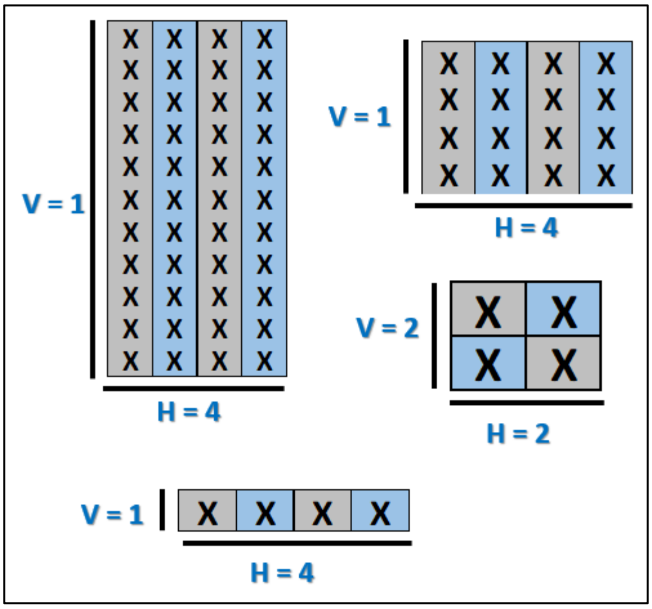
- The transceiver count is always equal to nTR = 2*(No of Subarrays) and represented as nTnR.. The nTnR is itself the MIMO order of the Antenna.

  Note: mMIMO is applicable for n>8, i.e. n=16/32/64/……

No of Subarrays = V*H
Transceiver Count = 2*(V*H)
MIMO order = TR
For **TR >8, MIMO = mMIMO**

GainSubarray = Gainelement + 3log2(A)
GainPanel = GainSubarray+ 3log2(H.V.)
GainPanel = Gainelement + 3log2(A) + 3log2(H.V.)
= Gainelement + 3log2(A.H.V.)

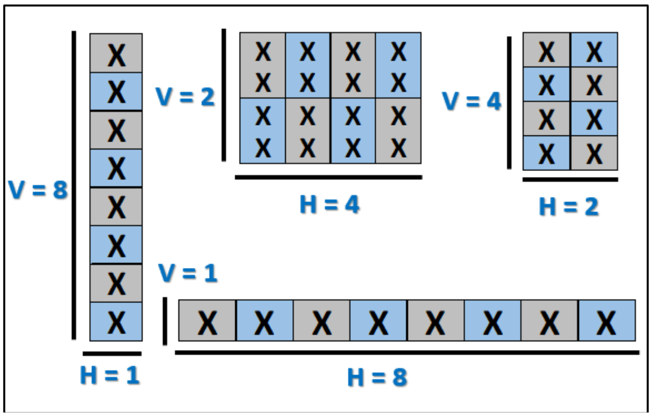
MIM Order - 8T8R



	Case 1	Case 2	Case 3	Case 4
Horizontal Arrays (H)	4	4	2	4
Vertical Arrays (V)	1	1	2	1
No of Sub arrays	4	4	4	4
Transceiver Count	8	8	8	8
AE/Sub array	11	4	1	1
Total AE (Panel)	44	16	4	4
Total AE (Dual Pol)	88	32	8	8
AE gain (dBi)	5.1	5.1	5.1	5.1
Sub array Gain	15.48	11.1	5.1	5.1
Antenna Panel Gain / Per Pol	21.48	17.1	11.1	11.1

Figure 10. MIMO Mapping and Gain Calculation for 8T8R

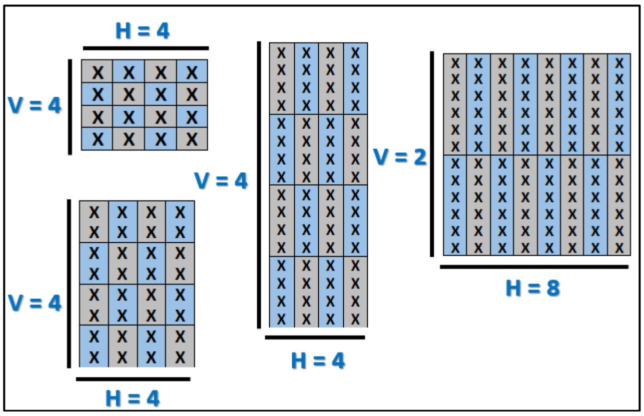
MIM Order – 16T16R



	Case 1	Case 2	Case 3	Case 4
Horizontal Arrays (H)	1	4	2	8
Vertical Arrays (V)	8	2	4	1
No of Sub arrays	8	8	8	8
Transceiver Count	16	16	16	16
AE/Sub array	1	2	1	1
Total AE (Panel)	8	16	8	8
Total AE (Dual Pol)	16	32	16	16
AE gain (dBi)	5.1	5.1	5.1	5.1
Sub array Gain	5.1	8.1	5.1	5.1
Antenna Panel Gain / Per Pol	14.1	17.1	14.1	14.1

Figure 11. MIMO Mapping and Gain Calculation for 16T16R

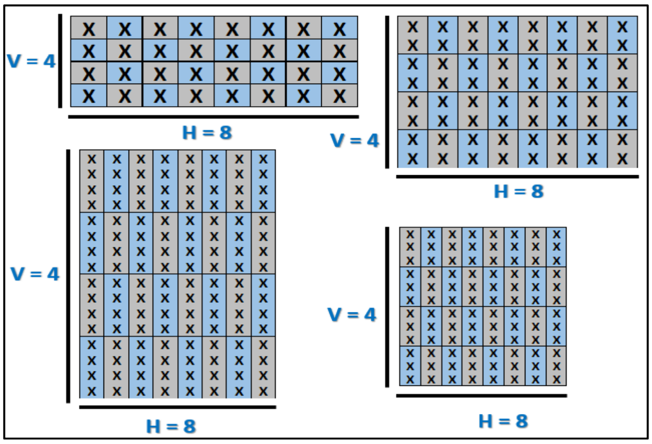
MIM Order – 32T32R



	Case 1	Case 2	Case 3	Case 4
Horizontal Arrays (H)	4	4	4	8
Vertical Arrays (V)	4	4	4	2
No of Sub arrays	16	16	16	16
Transceiver Count	32	32	32	32
AE/Sub array	1	2	4	6
Total AE (Panel)	16	32	64	96
Total AE (Dual Pol)	32	64	128	192
AE gain (dBi)	5.1	5.1	5.1	5.1
Sub array Gain	5.1	8.1	11.1	12.86
Antenna Panel Gain / Per Pol	17.1	20.1	23.1	24.86

Figure 12. MIMO Mapping and Gain Calculation for 32T32R

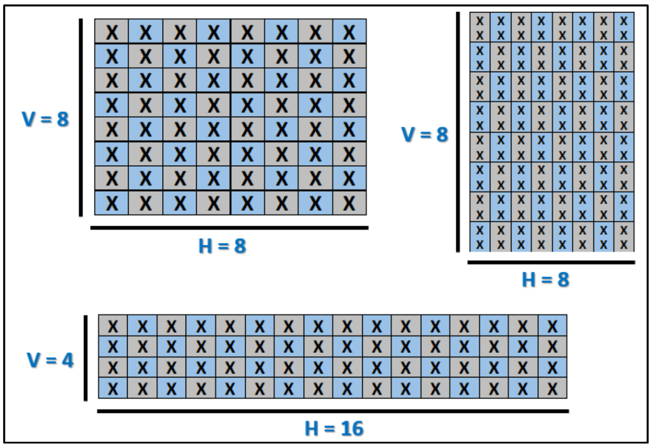
MIM Order – 64T64R



	Case 1	Case 2	Case 3	Case 4
Horizontal Arrays (H)	8	8	8	8
Vertical Arrays (V)	4	4	4	4
No of Sub arrays	32	32	32	32
Transceiver Count	64	64	64	64
AE/Sub array	1	2	3	4
Total AE (Panel)	32	64	96	128
Total AE (Dual Pol)	64	128	192	256
AE gain (dBi)	5.1	5.1	5.1	5.1
Sub array Gain	5.1	8.1	9.86	11.1
Antenna Panel Gain / Per Pol	20.1	23.1	24.86	26.1

Figure 13. MIMO Mapping and Gain Calculation for 64T64R

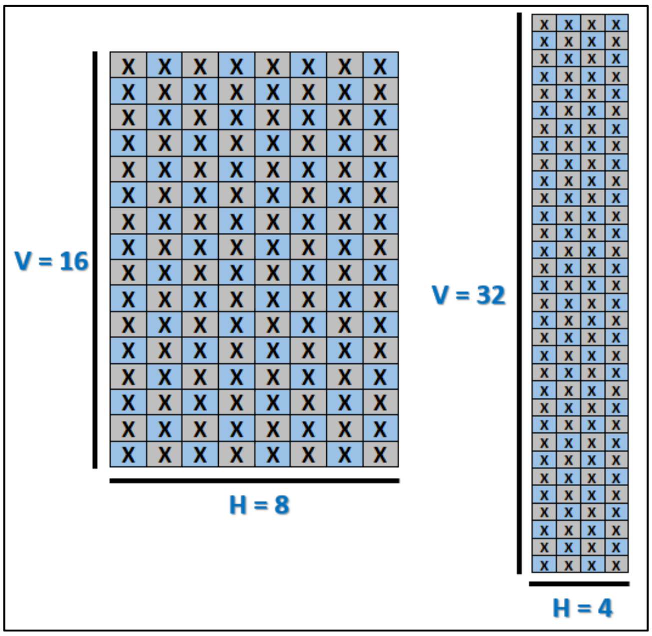
MIM Order – 128T128R



	Case 1	Case 2	Case 3
Horizontal Arrays (H)	8	8	16
Vertical Arrays (V)	8	8	4
No of Sub arrays	64	64	64
Transceiver Count	128	128	128
AE/Sub array	1	2	1
Total AE (Panel)	64	128	64
Total AE (Dual Pol)	128	256	128
AE gain (dBi)	5.1	5.1	5.1
Sub array Gain	5.1	8.1	5.1
Antenna Panel Gain / Per Pol	23.1	26.1	23.1

Figure 14. MIMO Mapping and Gain Calculation for 128T128R

MIM Order – 256T256R



	Case 1	Case 2
Horizontal Arrays (H)	8	4
Vertical Arrays (V)	16	32
No of Sub arrays	128	128
Transceiver Count	256	256
AE/Sub array	1	1
Total AE (Panel)	128	128
Total AE (Dual Pol)	256	256
AE gain (dBi)	5.1	5.1
Sub array Gain	5.1	5.1
Antenna Panel Gain / Per Pol	26.1	26.1

Figure 15. MIMO Mapping and Gain Calculation for 256T256R

VI. SUMMARY

The paper summarizes that from the above gain calculation tables, it is evident that, for the same MIMO order of xTxR, the number of antenna elements in each subarray is different for their respective antenna panels and thereby directly influence the gain of the entire panel. Also, the Adaptive Antenna Systems mainly work based on its active beamforming capabilities and mapping of the Antenna Elements per sub-array/per pol (MIMO order).