LSAB: Enhancing Spatio-Temporal Efficiency of AoA Tracking Systems

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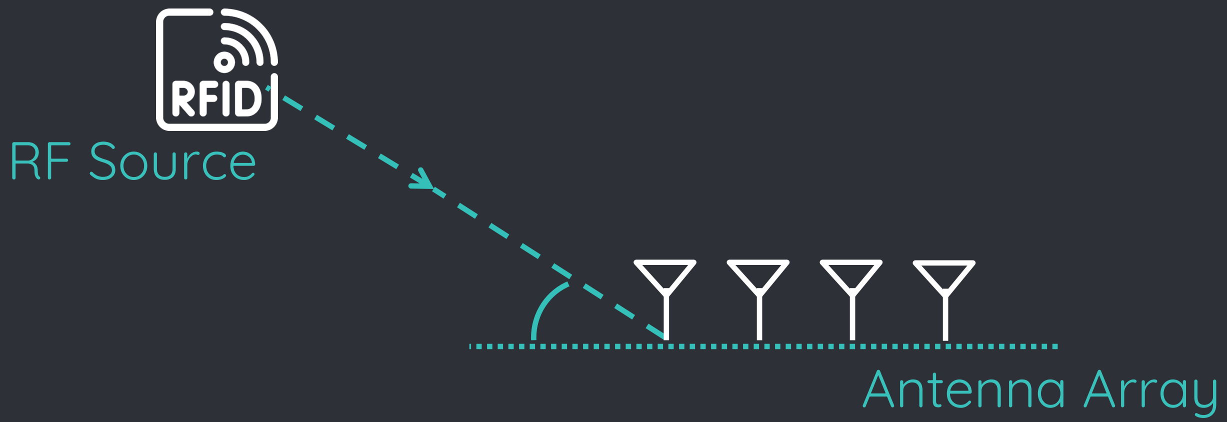
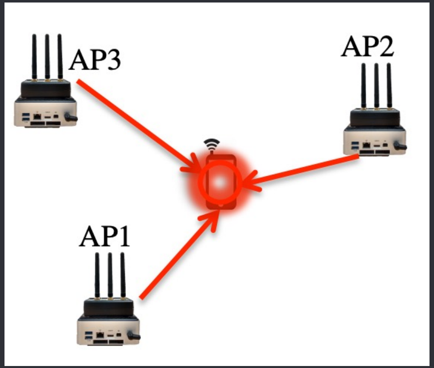
AoA tracking System

Angle of arrival (AoA) of a signal is the **direction** from which an RF signal is propagated.

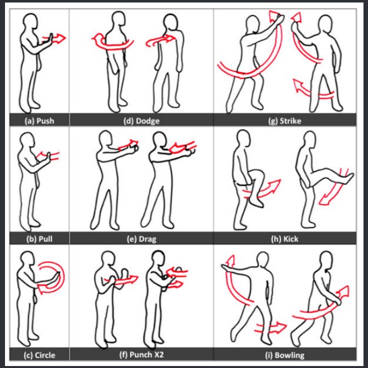


AoA tracking System

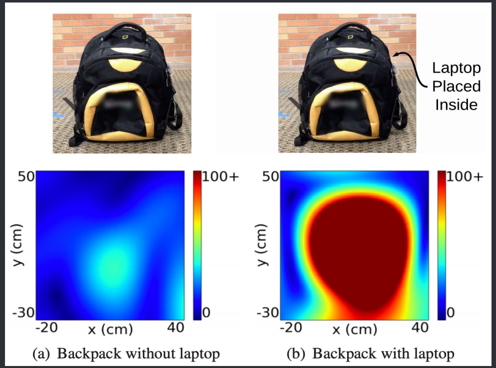
AoA Systems facilitate a wide range of **wireless** applications like **localization** and **sensing**.



Localization and tracking



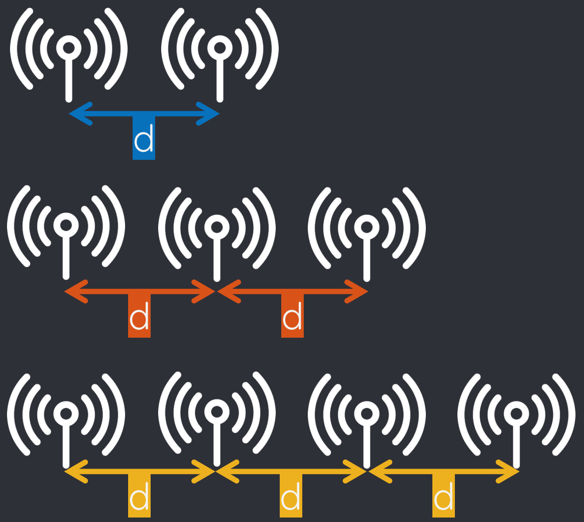
Activity Recognition

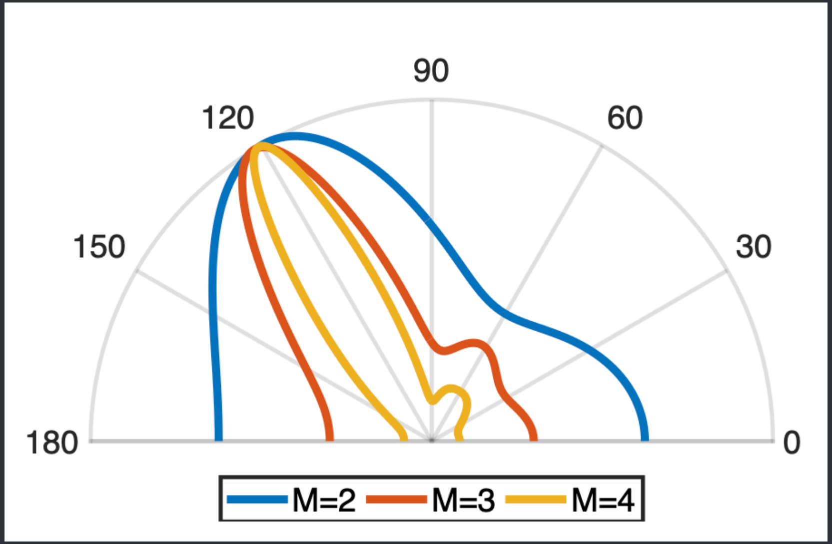


Wi-Fi Imaging

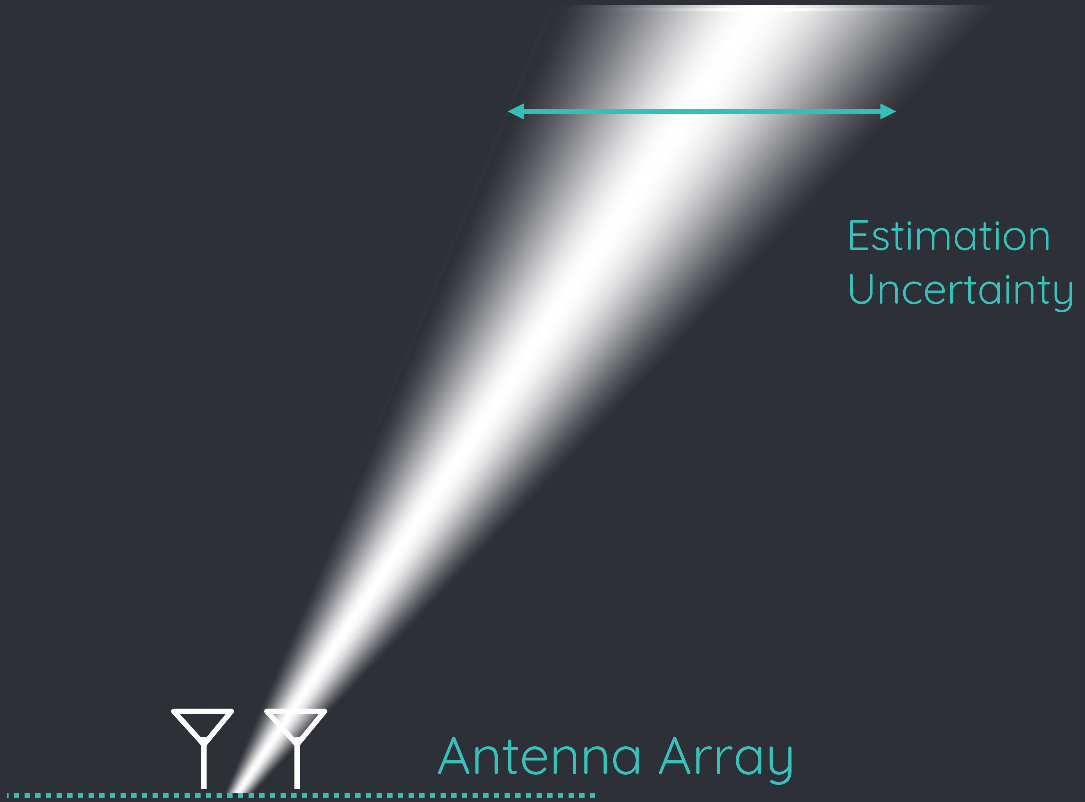
AoA tracking System

Number of antenna elements in a AoA System determine the **resolution** and **accuracy**.

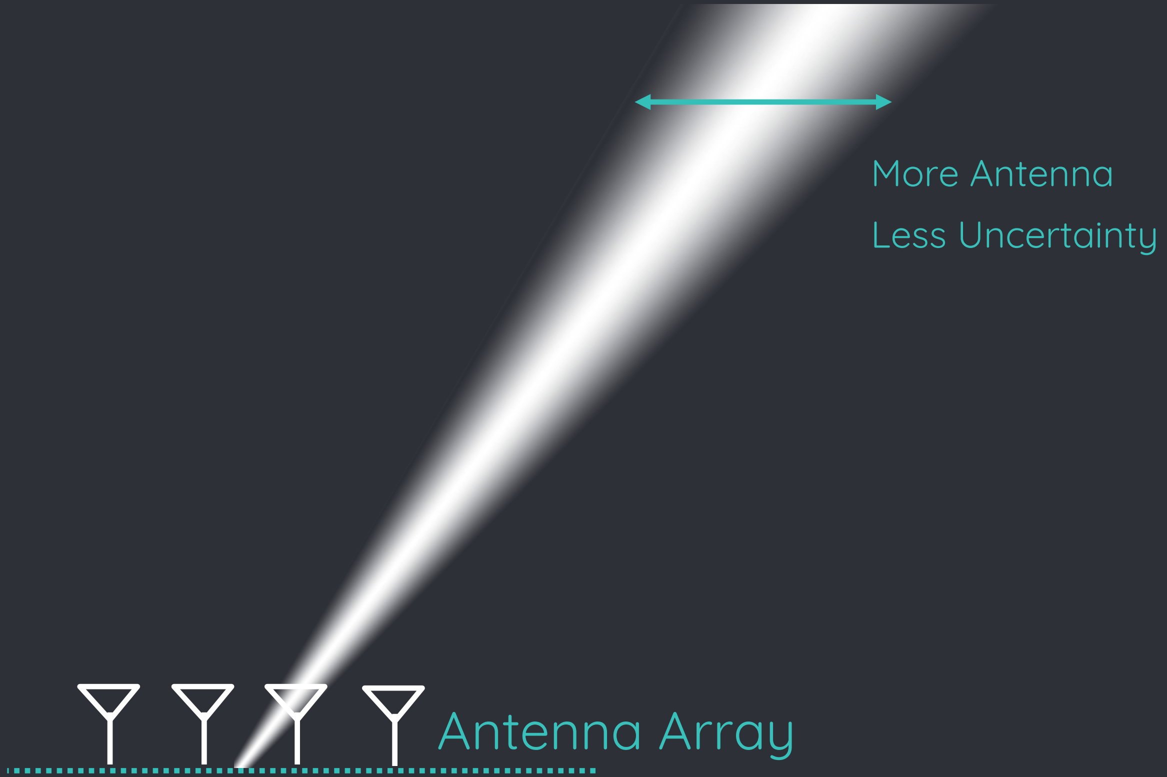




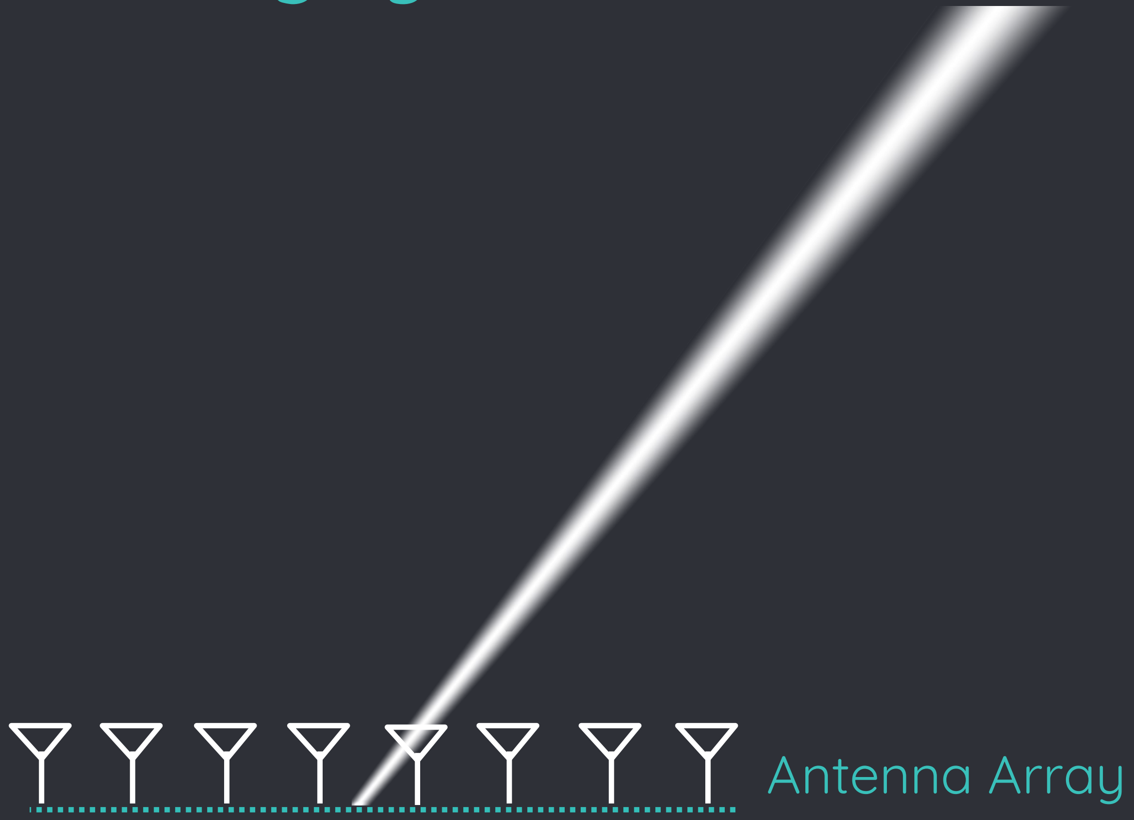
AoA tracking System



AoA tracking System



AoA tracking System



AoA tracking System

Not Practical!

Antenna Array

Challenge:

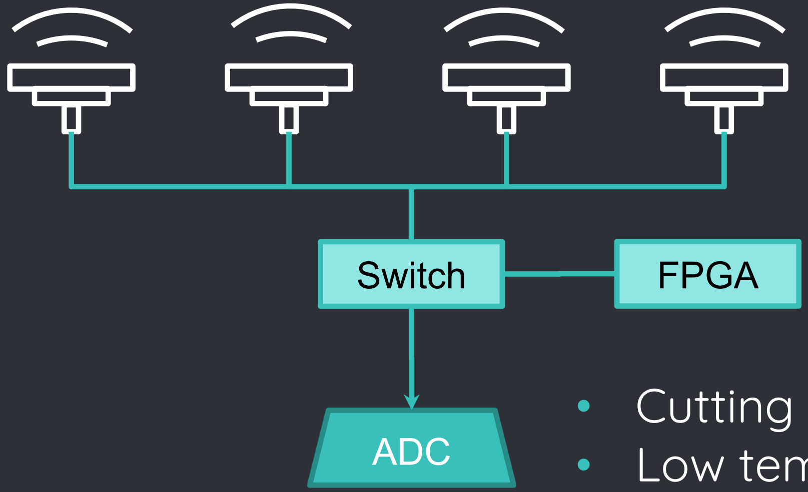
How to cut the number of antenna array but keep the performance?

State-of-the-art Solutions

- RF Switches
- Virtual Linear/Circular Array
- Sparse Array

State-of-the-art Solutions

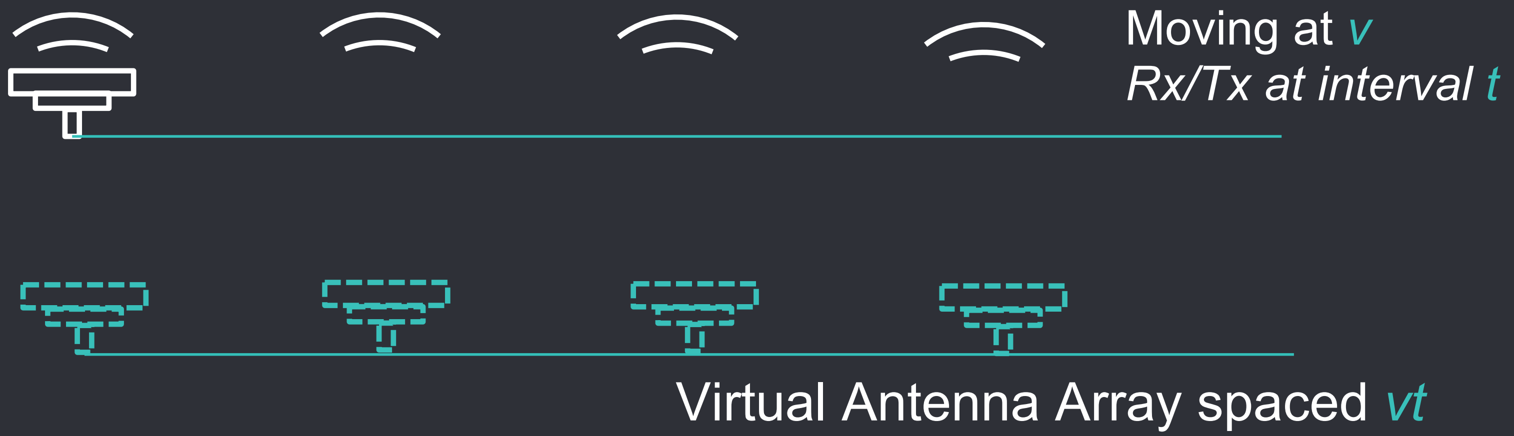
- RF Switches



- Cutting the cost of frontend and ADC
- Low temporal efficiency

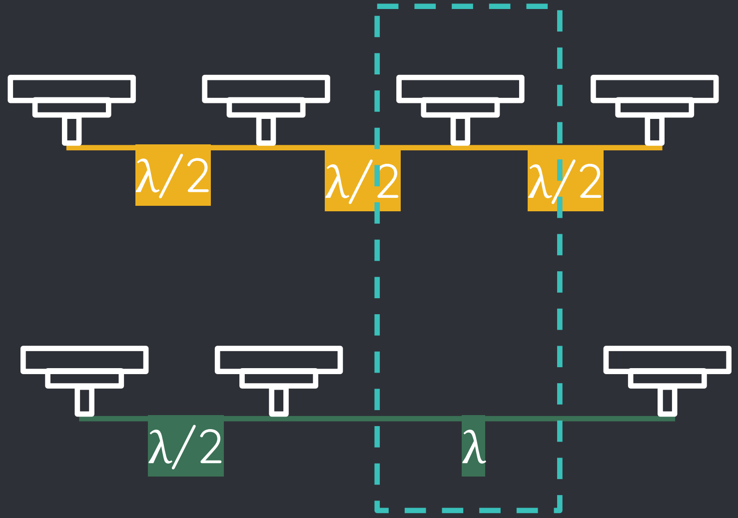
State-of-the-art Solutions

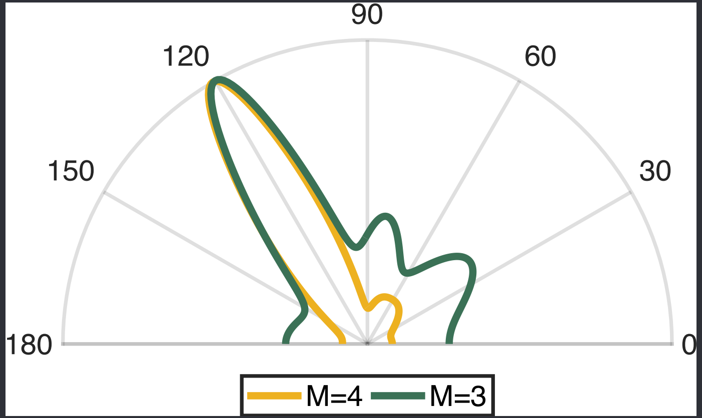
- Virtual Linear/Circular Array
  - Cutting the cost of more components
  - Low temporal efficiency and movement error



State-of-the-art Solutions

- Sparse Array





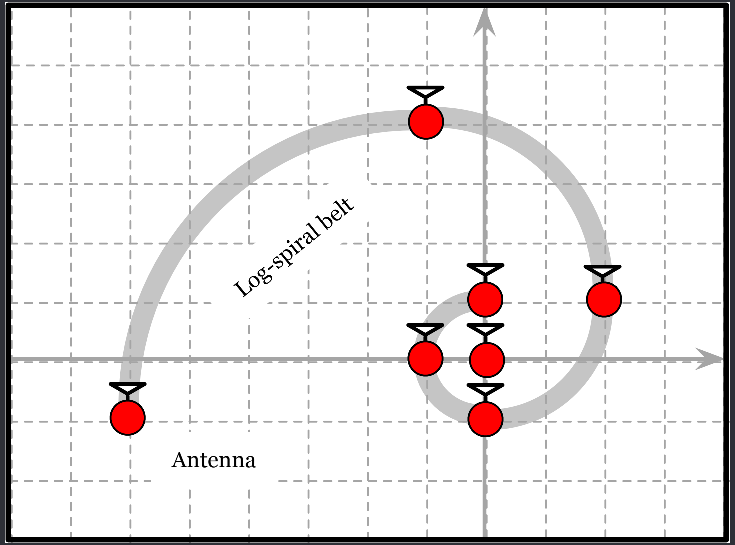
State-of-the-art Solutions

	Advantage	Disadvantage
RF Switches	Cutting the cost of frontend and ADC	Low temporal efficiency and high cost on antenna elements
Virtual Linear/Circular Array	Cutting the cost of all other components	Low temporal efficiency and movement error
Sparse Array	**Cutting cost with high temporal efficiency**	**Lack of research in 2-D aspects**

Our Solution

Log-Spiral Antenna Belt

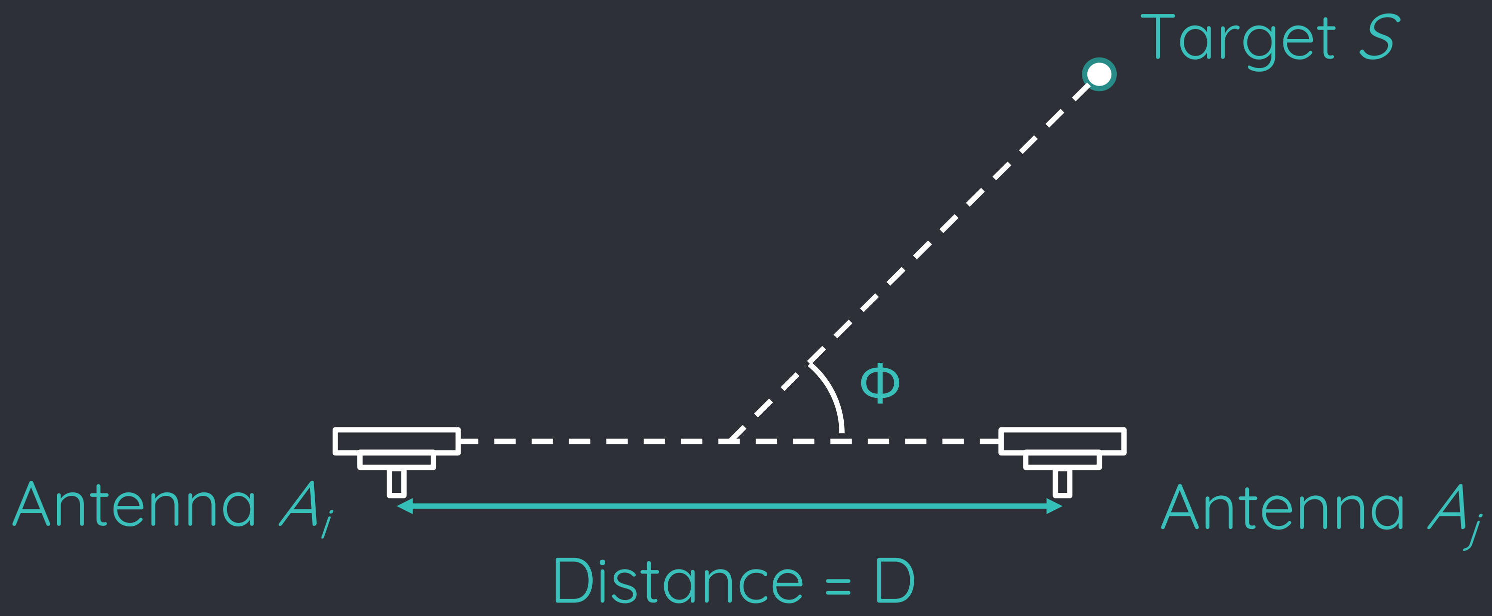
- 2D sparse array
- Decrease antenna number
- Keep high accuracy and temporal efficiency



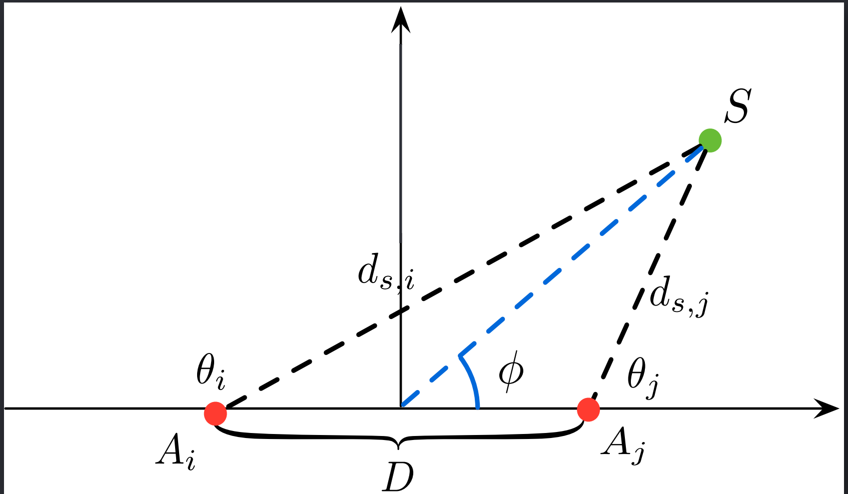
Key Idea:

To evaluate redundancy in an antenna array by the placements of antenna elements

Example: Antenna Array of two elements



AoA Estimation Model

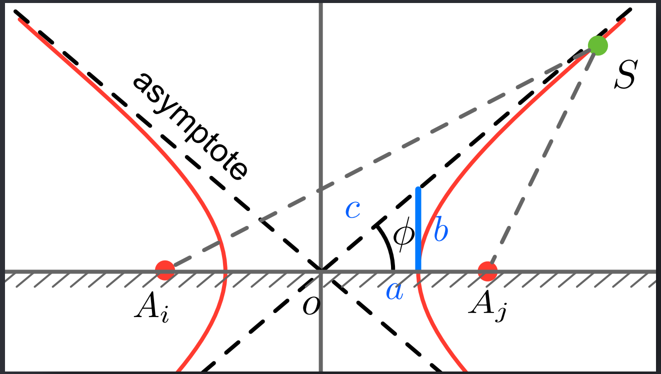


$$\Delta d_{i,j} = d_{s,i} - d_{s,j}$$
$$\Delta \theta_{i,j} = \theta_{s,i} - \theta_{s,j}$$

$$\Delta \theta_{i,j} = 2\pi \Delta d_{i,j} / \lambda \bmod 2\pi$$

$$\Delta d_{i,j} = \lambda \Delta \theta_{i,j} / 2\pi + k\lambda$$

K and Estimation Ambiguity



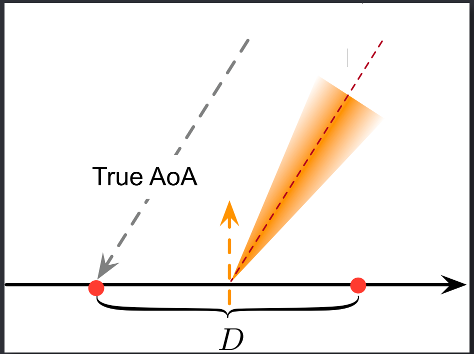
Considering $-D \leq \Delta d_{i,j} \leq D$

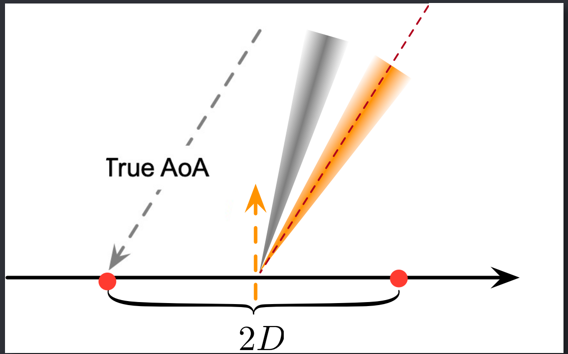
If $D = K \cdot \lambda/2$ then:

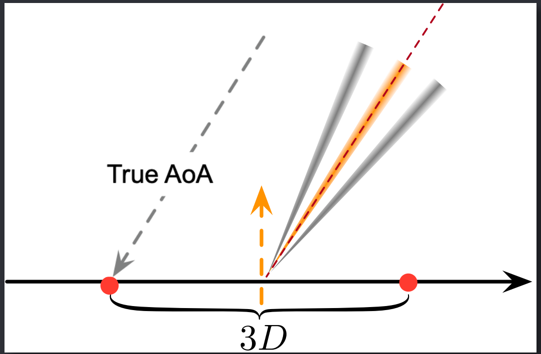
$$\phi \simeq \arccos\left(\frac{a}{\ldots}\right) = \arccos\left(\frac{\Delta d_{i,j}}{\ldots}\right) = \arccos\left(\frac{\lambda}{\ldots}\frac{\Delta\theta_{i,j}}{\ldots} + \frac{k\lambda}{\ldots}\right)$$

Distance $K \cdot \lambda/2$ results in K possible results, denoted as **K Ambiguity**

K and Resolution Degree







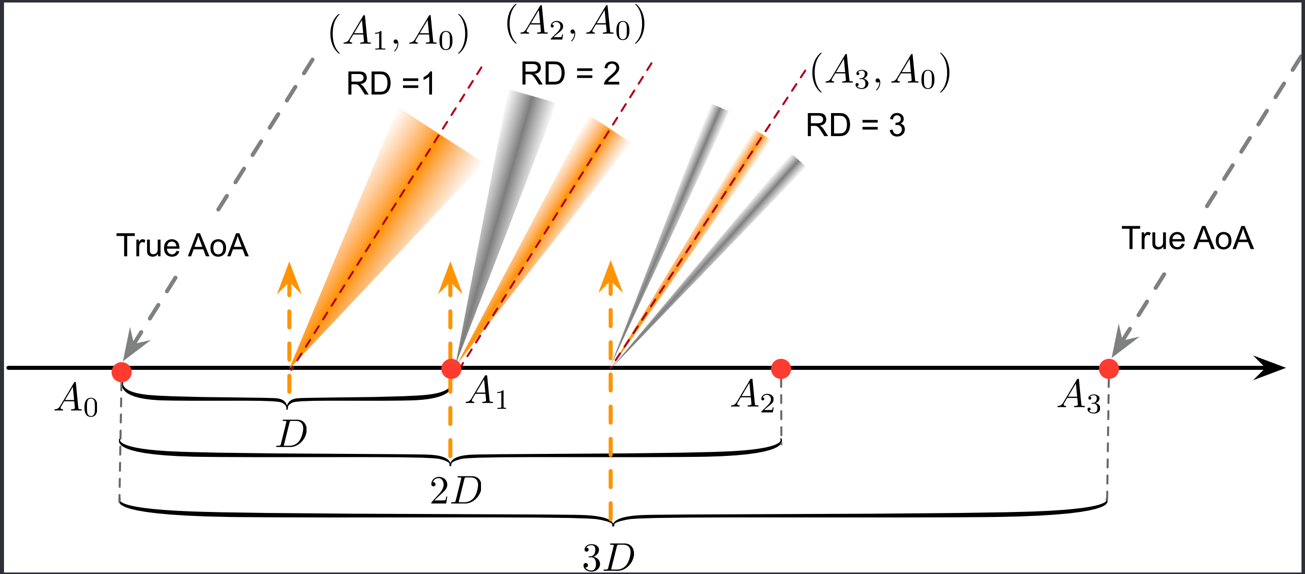
If we consider a phase noise in AoA estimation:

$\phi =$

Distance $K \cdot \lambda/2$ decreases phase noise by K times,
Denoted as **K Resolution Degree**

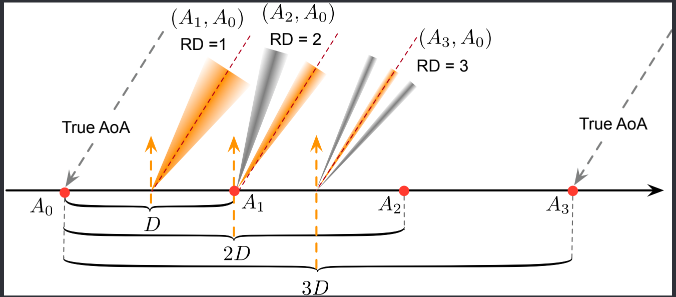
K and Antenna Array

Different element **pairs** in an antenna array cover different **Ambiguities** and **Resolution degrees.**



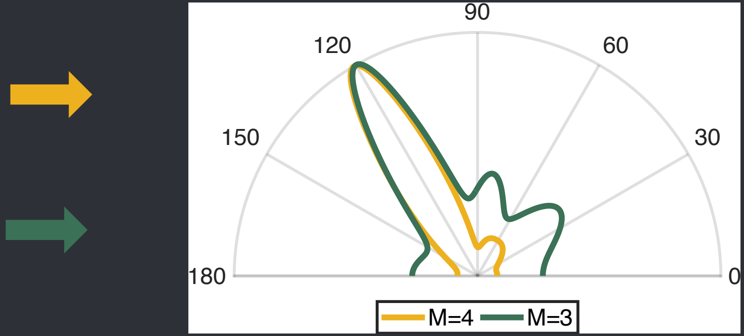
Minimal-resolution-redundancy and Sparse Linear Array

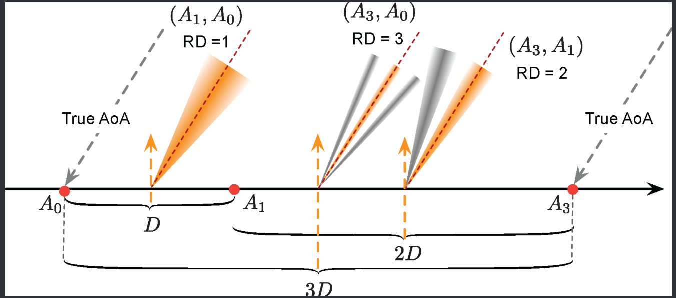
Covering all Ambiguity and Resolution Degree, Antenna Array share similar estimation results.



Uniform Linear Array

(4 elements)





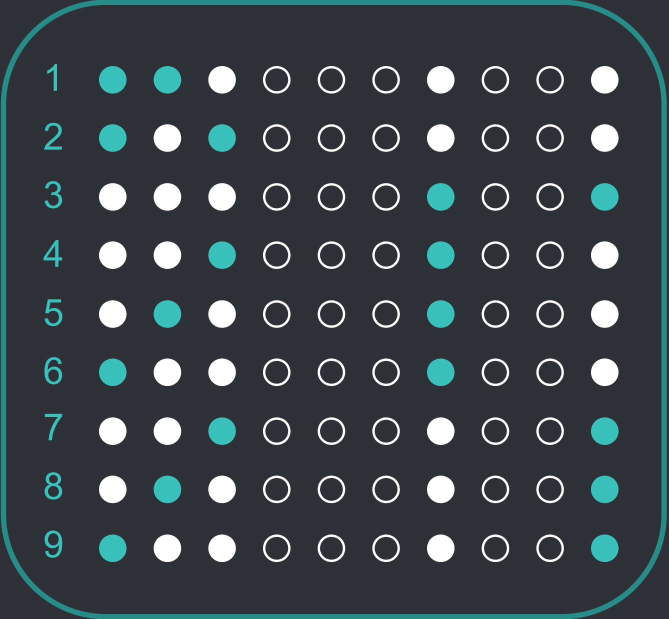
Sparse Linear Array

(3 elements)

Other Sparse Antenna Arrays

Sparse Linear Arrays

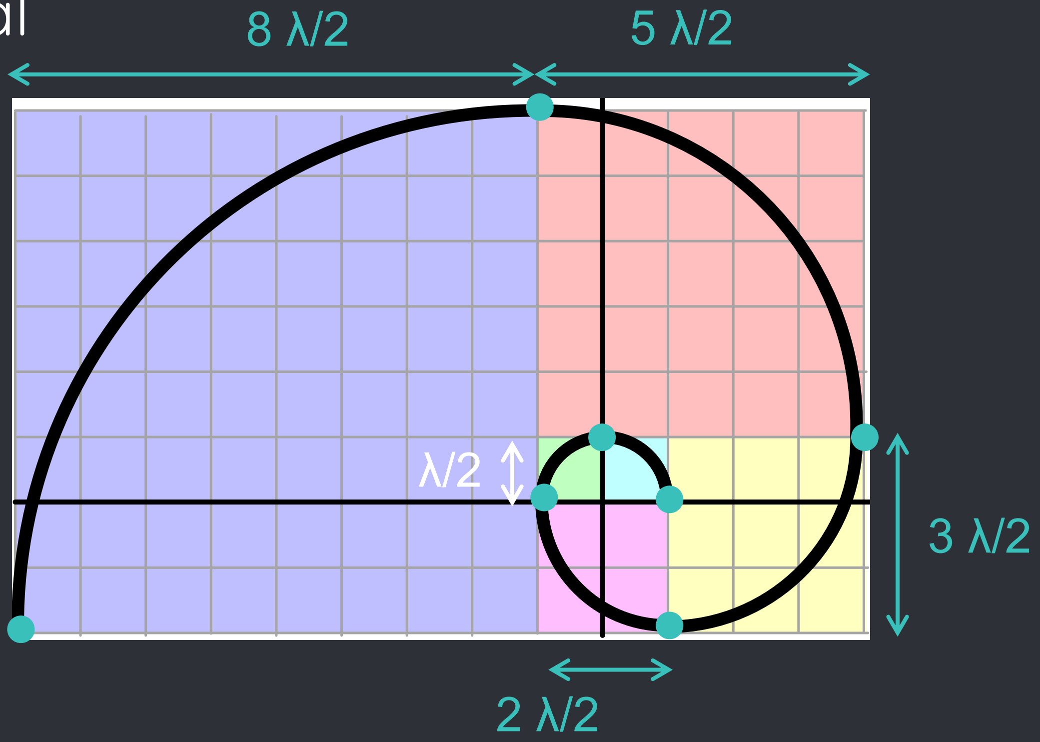
● denote antenna elements
○ denotes empty space



M	Deployment	N	Degrees
2	●●	2	(1,2)
3	●●○●	3	(1,2,3)
4	●●○●●	5	(1,2,3,4)
5	●●●○○○●○○●	10	(1,2,3,...,8,9)
	●●○○●○○●○●		
	●○●○○●○○●●		
6	●●●○○○●○○○●○○●	14	(1,2,3,....,13)
	●●○○○○●○○●○●○●		
	●●○○●●○○○○○●○●		
7	●●●○○○●○○○●○○○●○○●	18	(1,2,3,...,17)
	●●●●○○○○●○○○○●○○○●		
	●●●○○○○○●○○○●○●○○●		
	●●●○○○○○●○○○●○○●○●		

Sparse Linear Array to LSAB

Fibonacci Spiral

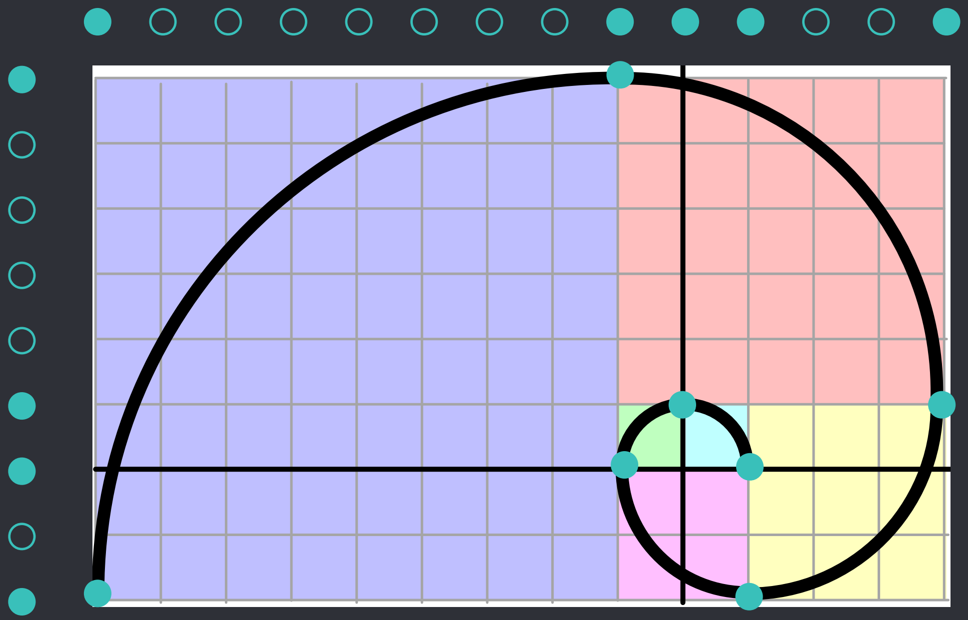


Sparse Linear Array to LSAB

Fibonacci Spiral

K=(1,2,3,4,5, , ,8,9,10, , ,13)

K=(1,2,3, ,5,6, ,8)



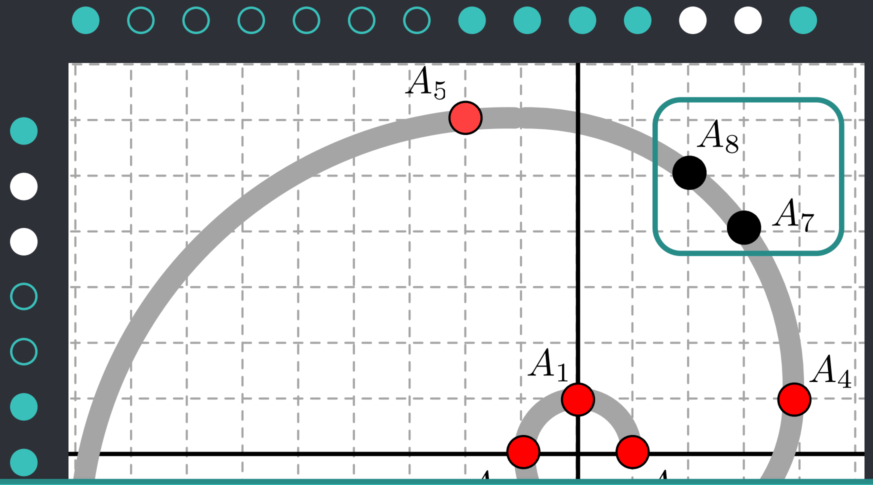
Sparse Linear Array to LSAB

Log-Spiral Antenna Belt

K=(1,2,3,4,5,6,7,8,9,10,11,12,13)

K=

(1,2,3,4,5,6,7,8)



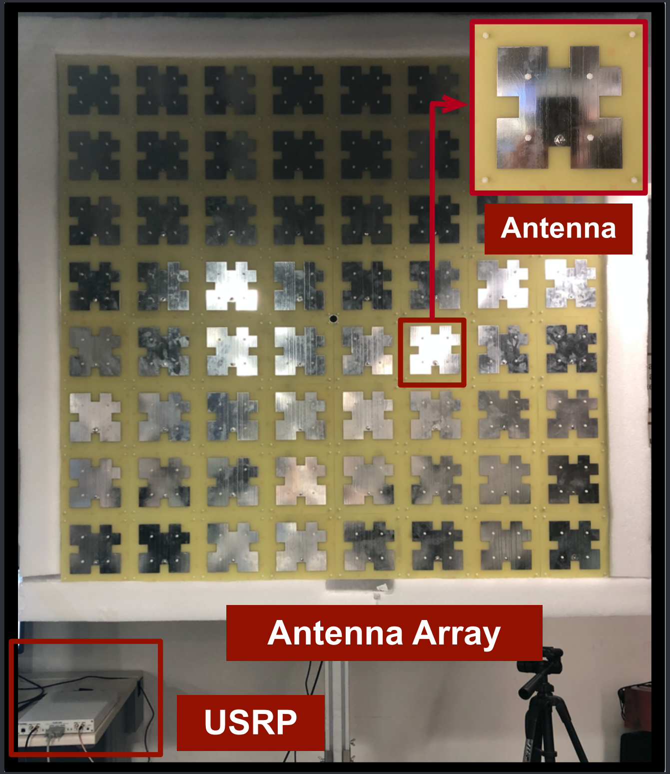
Additional Antenna

Ambiguity and Resolution degree K is fully covered

Implementation and Evaluation

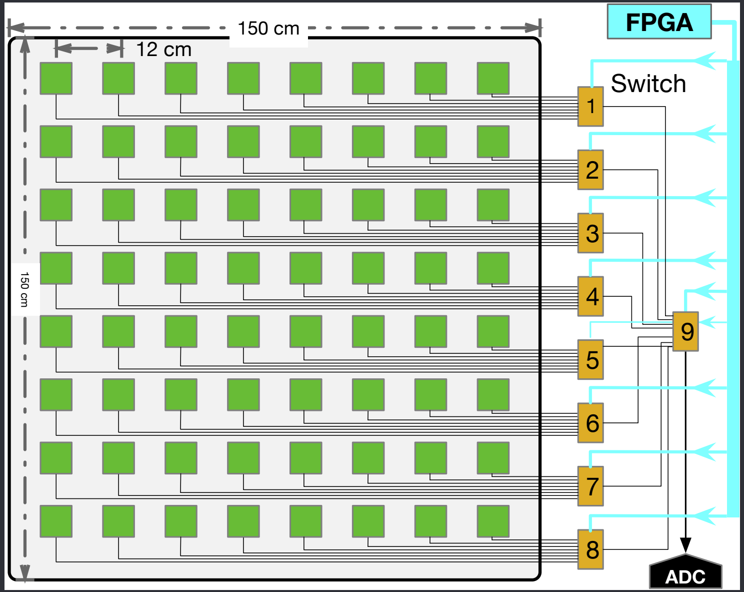
Implementation

- 8 x 8 Antenna Array:
  - Substrate of RT/duroid 5880
  - High-speed RF switches BGS18GA14
- NI USRP 2950 software-defined radio (SDR)
- PC equipped with Intel CPU Xeon E5-2620

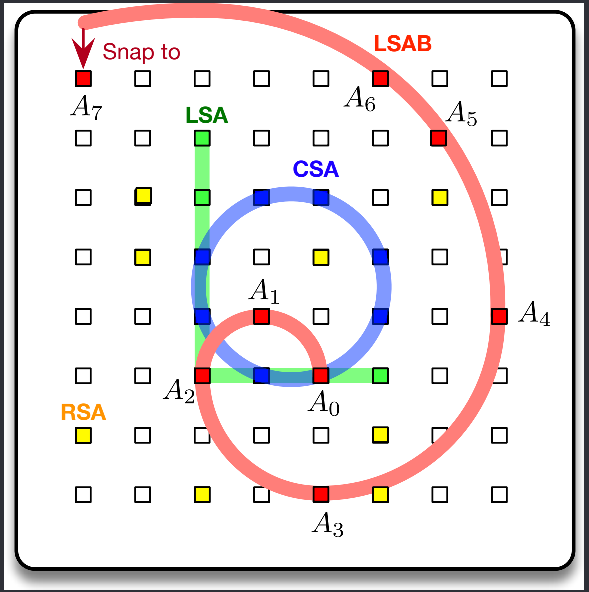


Evaluation

Schematic of the UPA

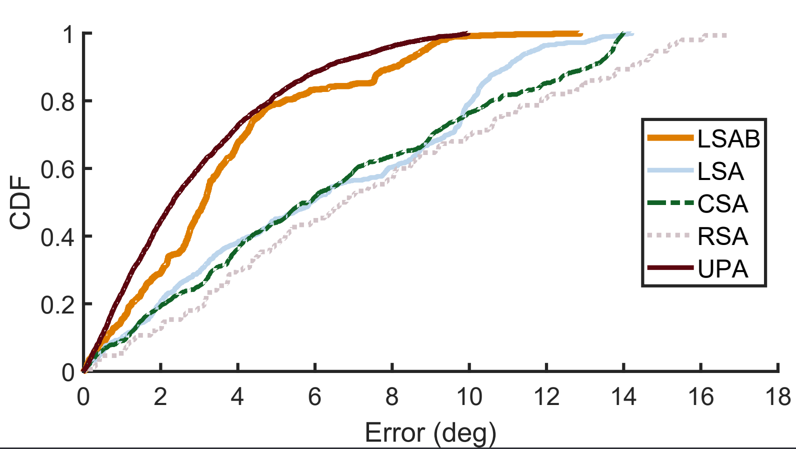


Logical SPAs

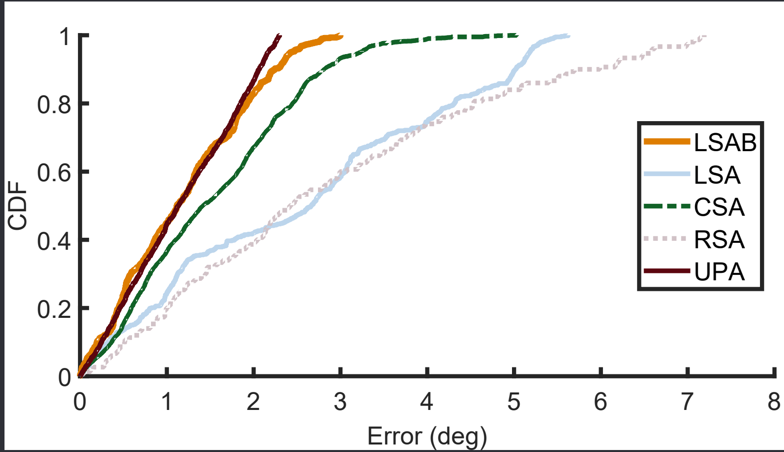


Accuracy of angle estimation

Azimuthal Angle



Elevation Angle



LSAB can achieve median errors of 3.12∘ and 1.11∘, and the 90th percentiles of 8.04∘ and 2.24∘ in the two angles.

Close to UPA and better than other SPAs.

Conclusion

- Estimating the direction of an RF source as accurately as a conventional UPA

- Enhancing the spatio-temporal efficiency of AoA based systems

Thank you!