Enhancing Network Reception through Directional Antenna Synchronization

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Abstract—This summer, we focused on enhancing the strength and quality of a network's signal reception through the implementation of a novel directional antenna synchronization technique. Our main objective is to achieve a more robust and reliable network connection by concentrating the capturing capabilities of multiple antennas in a specific direction. To accomplish this, we propose a distributed antenna system using Electronically Steerable Antennas (ESAs), with each antenna dedicated to capturing signals from a particular direction simultaneously, resulting in faster transmission rates. This advancement in network reception promises a better communication experience with a stronger and more robust network connection, facilitating smoother communication and quicker data transfers. Such progress in network reception not only ensures better communication but also faster data transmission, offering substantial benefits in various application scenarios. By optimizing the utilization of multiple antennas in a specific direction, we are paving the way for improved network connectivity and an enhanced user experience.

Enhancing Network Signal Reception

- Multi-Antenna Focus: Boosting Signal Reception
- Antenna Calibration for Optimal Reception
- Targeted Capturing: Enhancing Signal Direction
- Result: Strengthened Network Connection

Overall Goal

- Distributed Antenna System (DAS) Implementation
- Focused Antenna Power for Stronger Connection
- Overcoming Antenna Limitations with DAS
- Enhanced Connectivity: Reliable Network & Data Transfer

Mechanically Steered Antenna

Traditional Antenna Limitations:

- Mechanically steered with rotating dish and mechanical arm
- Slow to adjust and reposition
- Poor long-term reliability due to mechanical components
- Physically large in size
- Supports only a single beam and data stream

[1]
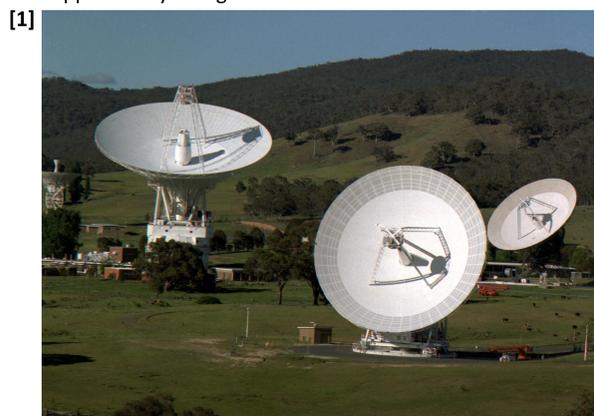
Electrically Steered Antenna (ESA)

Distributed Antenna System (DAS):

- Low profile and reduced volume
- High long-term reliability with no moving parts
- Fast beam steering capabilities
- Supports multiple beams, radiation patterns, and data streams
- Ability to create nulls for interference and jammer elimination
- Low probability of intercept or jamming
- Graceful failures: Tolerates the failure of individual elements

[2]
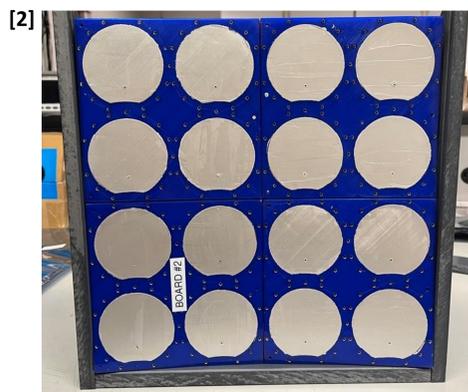
Phased Array Concept

- Array of antenna elements with adjustable relative phase
- Variation in phase steers the radiation pattern or beam
- Constructively reinforces the effective radiation pattern in the desired direction (main lobe)
- Suppresses radiation in undesired directions (side lobes) by destructive interference
- Enables precise beam steering and direction control
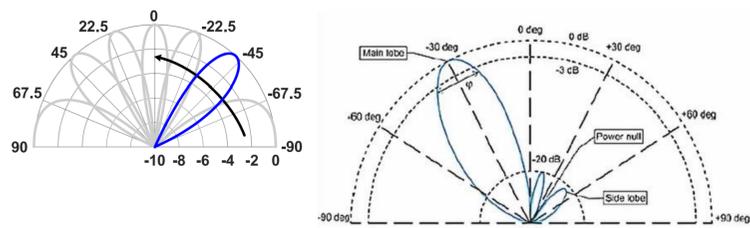

Phased Array Antenna

Analog Beamforming Centralized Receiver

Digital Beamforming Distributed Receivers
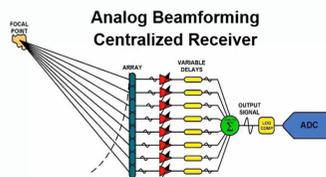
Analog Beamforming

- 1 DAC / ADC
- Phase Shifter/Amplitude Adjustment occurs at RF Frequencies

Benefits:

- Low Power Dissipation
- More Cost Effective
- High Channel Count per IC
- Close to the Antenna Element

Challenges:

- Single Beam per Channel
- Less Flexible than Digital BF
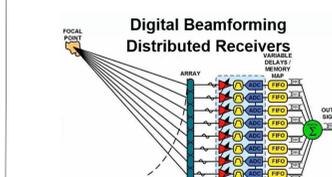
Analog Beamforming

- 1 DAC / ADC per element
- Phase Shifter/Amplitude Adjustment occurs digitally

Benefits:

- Highly flexible, programmable system
- Multiple simultaneous beam patterns
- Adaptive antenna programming

Challenges:

- Managing data volume
- Data converter power dissipation
- Synchronizing/calibrating waveform channels
- LO/Clock/Power distribution

Multi-Element Phased Array Example

- Radiation pattern: red main lobe (high intensity/gain)
- Sidelobes: green (lower intensity)
- Patch antenna elements integrated
- ICs on antenna backside
- Phased array for beam control, better performance.
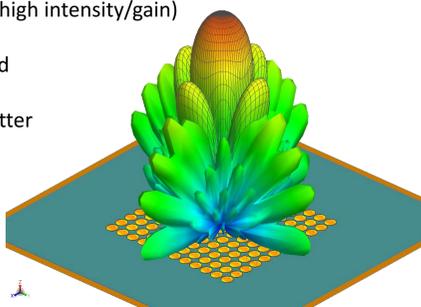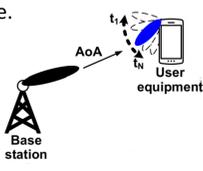
Radiation Patterns – Key Points
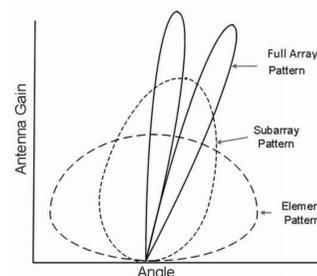
(a) Three Beam Patterns to Consider

- Element Pattern
- Subarray Pattern
- Digitally Beamformed with Analog Sub-Array or Full-Array Pattern

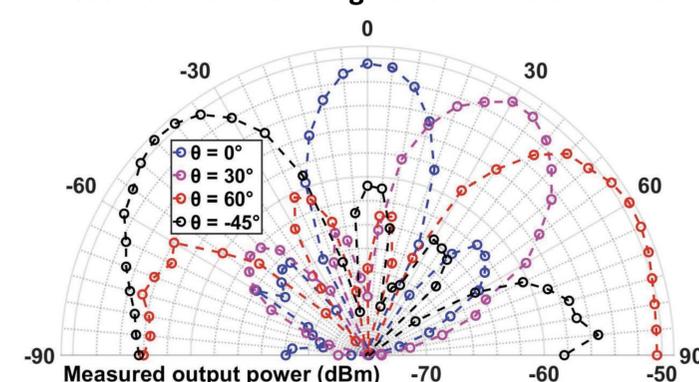**(b) Narrow Beam Provides**

- Angular Resolution
- Localized Power
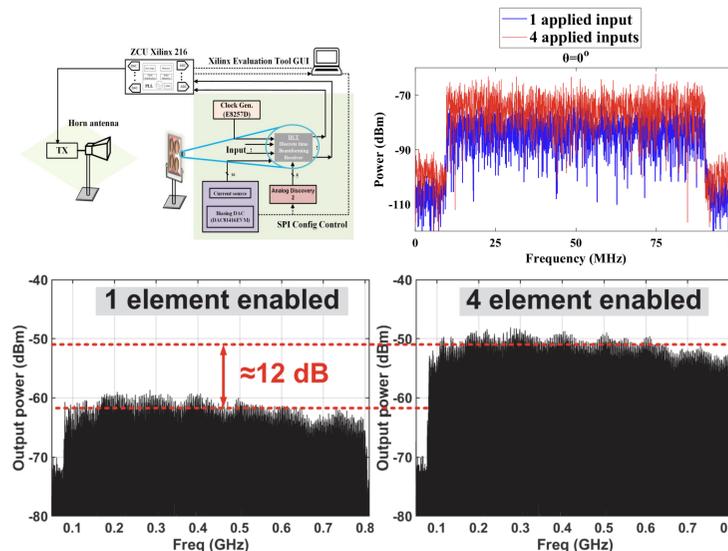
(c) Analog Beamforming

- Single Beam Commonly

(d) Digital Beamforming

- Many Beams, Programmable Nulls

Measured Beamforming Pattern in Polar Format

Measured wideband test with 720MHz span

Phased Array Figures of Merit

(i) Antenna Gain (G_t)

$$G_t = \frac{U}{U_{isotropic}}$$

Where:
G_t = Antenna Gain
U = Radiation intensity in Desired Direction
$U_{isotropic}$ = Radiation Intensity of Isotropic Antenna

- An Isotropic Antenna radiates power equally in all directions.

(ii) Array Antenna Gain Calculation

Array Antenna Gain (G_{array}) $= 10\ logN + G_{element}$

Where:
N = Number of Antenna Elements
$G_{element}$ = Element Gain

Impact of Number of Elements

- Higher Number of Elements (N) results in Increased Gain (G_{array})
- Increased Gain leads to Higher Directivity
- Higher Directivity results in a Narrower Beam

(iii) Effective Isotropic Radiated Power (EIRP) Calculation and Array Impact

$$EIRP = P_t \times G_t$$

Where:
P_t = Transmitter Power
G_t = Antenna Gain

Impact of Array Elements

- Larger N (# of Elements) ⟶ Increased Gain ⟶ Higher Directivity ⟶ Narrower Beam

EIRP Calculation Example

Given: $P_e = 10\ dBm$, $G_e = 5\ dB$, $N = 2000$
$EIRP = 10\ dBm + 5\ dB + 66 = 81\ dBm$

(iv) Antenna Gain-to-Noise Temperature Ratio

$$\frac{G_t}{T_n} = \frac{Antenna\ Gain}{Noise\ Temperature\ (dB/K)}$$

Where:
G_t = Antenna Gain
T_n = Noise Temperature

Example

Given,

- Element Gain = 5 dBi
- Cascade Noise Figure (NF) = 3.3 dB
- Temperature (T) = 286 K
- N = 2400 Elements

$G_t = 10\ logN + Element\ Gain = 38.8\ dB$
$T_n = (Noise\ Factor - 1) \times Temperature = 1.137 \times 286\ K = 328\ K$
$\frac{G_t}{T_n} = 16.63$

References

[1] https://www.nasa.gov/sites/default/files/thumbnails/image/canberra4.jpg

[2] 16-Element Flexible Antenna Array divided into Four 2x2 Sub-Arrays

[3] E. Ghaderi, A. Sivadhasan Ramani, A. A. Rahimi, D. Heo, S. Shekhar and S. Gupta, "An Integrated Discrete-Time Delay-Compensating Technique for Large-Array Beamformers," in IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 66, no. 9, pp. 3296-3306, Sept. 2019, doi: 10.1109/TCSI.2019.2926309.

[4] C. -C. Lin et al., "A 4-Element 800MHz-BW 29mW True-Time-Delay Spatial Signal Processor Enabling Fast Beam-Training with Data Communications," ESSCIRC 2021 - IEEE 47th European Solid State Circuits Conference (ESSCIRC), Grenoble, France, 2021, pp. 287-290, doi: 10.1109/ESSCIRC53450.2021.9567822.

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