Cognitive Radio Testbed for Digital Beamforming of Satellite Communication

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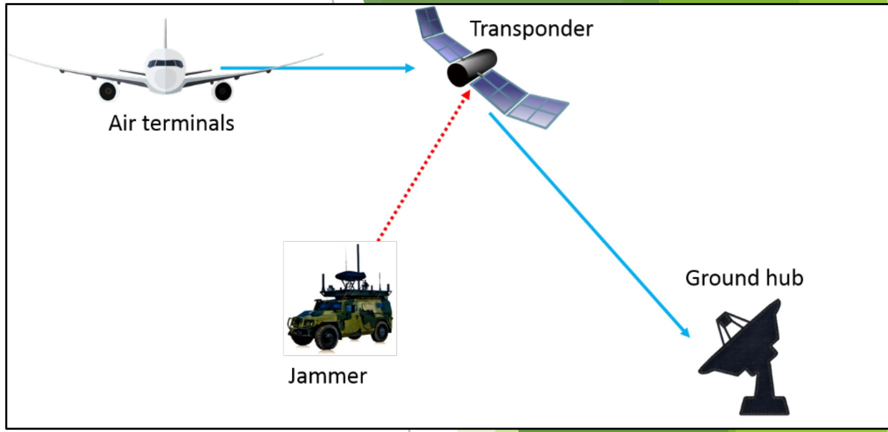
Wenhao Xiong, **Jingyang Lu**, Xin Tian, Genshe Chen
Intelligent Fusion Technology, Inc.

Khanh Pham, Erik Blasch
Air Force Research Laboratory

Outline

- ❖ Introduction
- ❖ System Structure
- ❖ DoA Estimation
- ❖ Numerical Results
- ❖ Conclusion

Introduction



- Jamming signal is a major threat to satellite communication.
- Traditional bend-pipe satellite transponder is not anti-jamming capable.
- Modern Transponder's onboard processor is powerful enough for complex computation.
- DoA estimation provides information of user and jammer signal direction.
- On-board digital beamforming make received signal robust against jammer.

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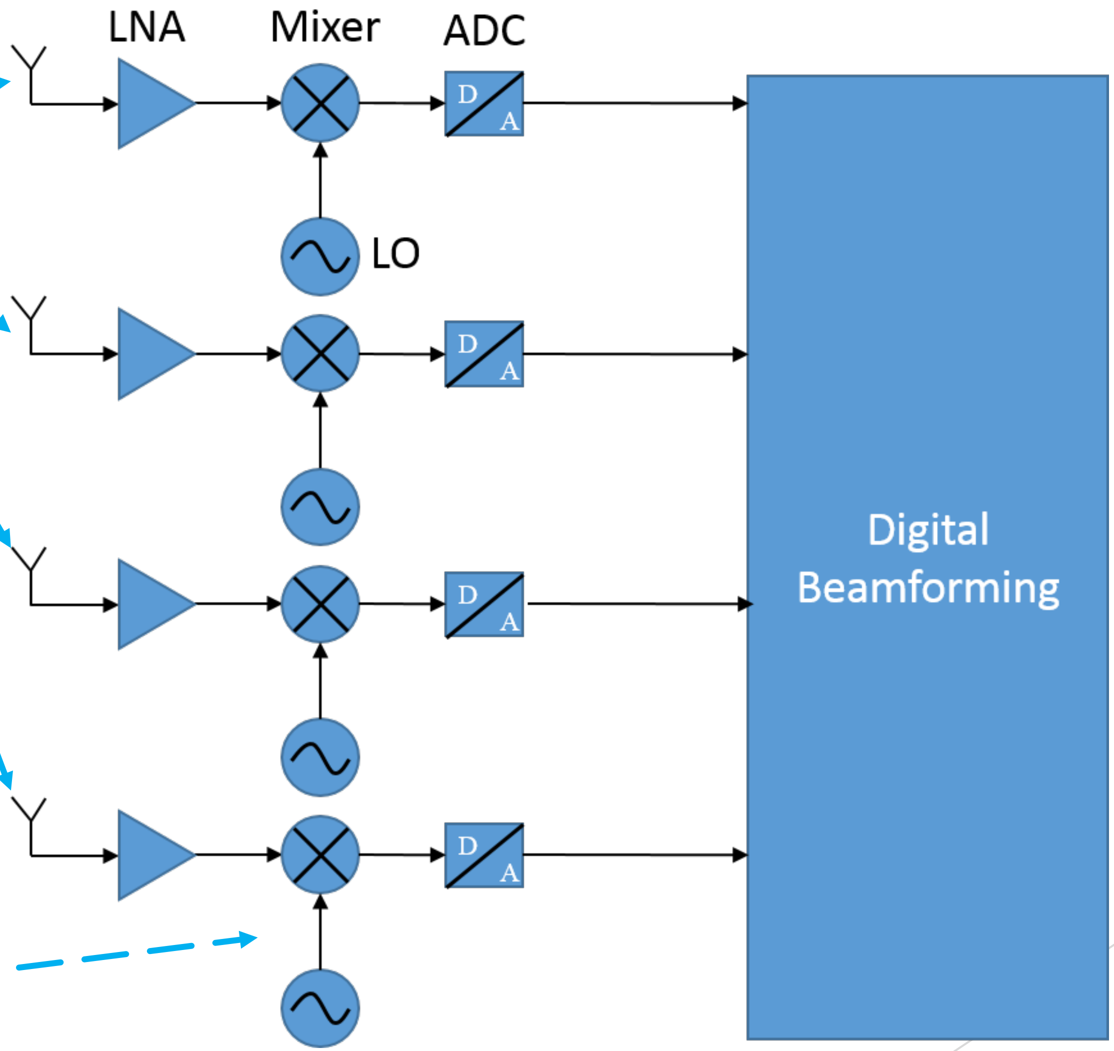
System Structure

Multiple Antenna Receiver

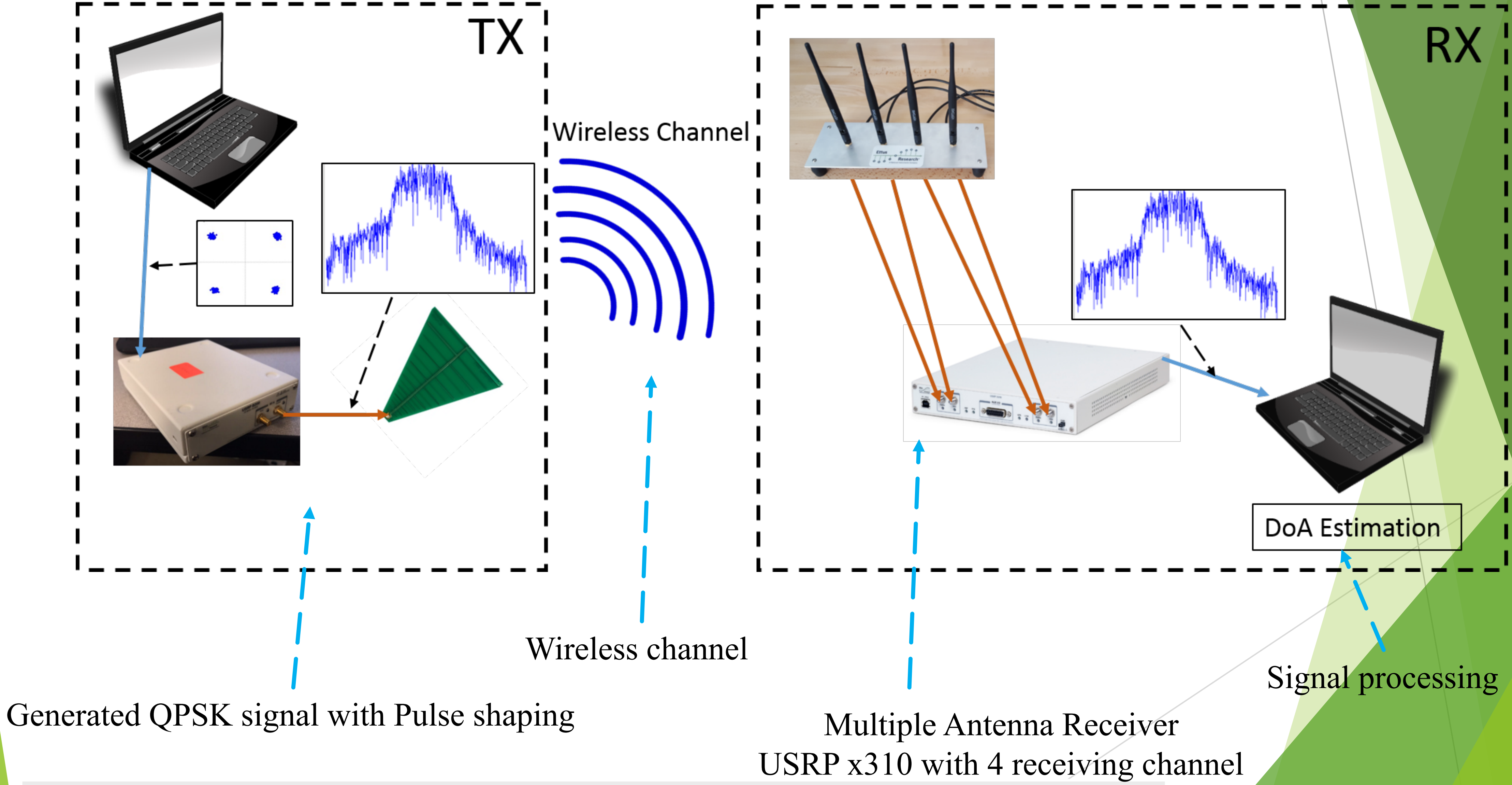


RF chain for each antenna

Uniform Linear Array

Digital Beamforming processing (DoA)

System Structure



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DoA Estimation

Assume there are k transmitting sources, hence for kth source, the steering vector is:

$$\boldsymbol{d}^{T}(\theta_{n}^{k}) = \left[1, e^{-\frac{j2\pi d \sin(\theta_k)}{\lambda}}, \dots, e^{-\frac{j2\pi d(S-1)\sin(\theta_k)}{\lambda}}\right] \qquad (1)$$

Receiver observation is available at time n can be expressed as:

$$\boldsymbol{x}_n = \boldsymbol{D}_n(\boldsymbol{\theta})\boldsymbol{s}_n + \boldsymbol{w}_n \qquad (2)$$

Spatial covariance matrix can be denoted as:

$$\boldsymbol{\Sigma}_x = E[\boldsymbol{x}_n \boldsymbol{x}_n^H], \qquad (3)$$

Set $\sigma_{i,j}$ to be an element of matrix Σ_x, then

$$\sigma_{i,j} = E[x_n(i) x_n^*(j)], \qquad (4)$$

DoA Estimation

Assume the set $F = \{f_0, f_1, \ldots, f_{F-1}\}$ denotes index of the selected antennas.
The reduced signal vector can be characterized as:

$$\boldsymbol{y}_n = [x_n(f_0), x_n(f_1), \ldots, x_n(f_{F-1})]^T \qquad (5)$$

The corresponding spatial covariance matrix is:

$$\boldsymbol{\Sigma}_y = E[\boldsymbol{y}_n \boldsymbol{y}_n^H] \qquad (6)$$

The relationship between Σ_x and Σ_y is:

$$E[\boldsymbol{y}_n(i)\boldsymbol{y}_n^*(j)] = E\left[\boldsymbol{x}_n(f_i)\boldsymbol{x}_n^*(f_j)\right] = \sigma_{f_i, f_j} \qquad (7)$$

DoA Estimation

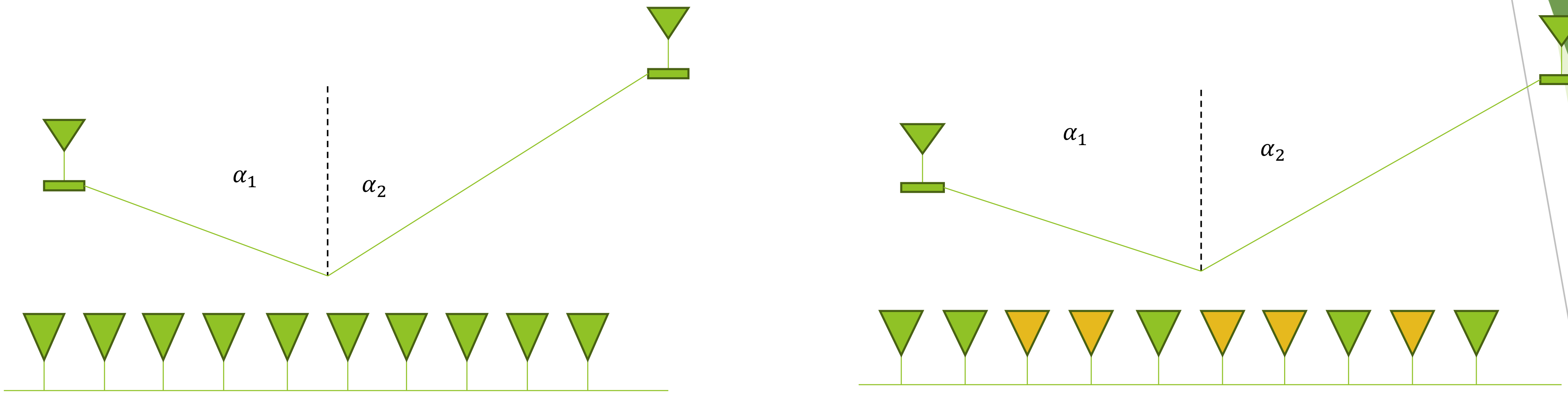

Figure: An uncompressed ULA with ten antennas receiving the signals from five sources in the far field (left). A compressed array with five antennas marked in yellow removed (right).

$$\hat{\Sigma}_{\boldsymbol{x}} = \frac{1}{N}\sum_{n=1}^{N} \boldsymbol{x}_n \boldsymbol{x}_n^H$$

$$\boldsymbol{\rho}[m-l] = \boldsymbol{E}(\boldsymbol{x}_n[m]\boldsymbol{x}_n^*[l])$$

$$\varphi := \{k_0, k_1, \dots, k_{K-1}\}$$

$$\boldsymbol{E}(\boldsymbol{y}_n[i]\boldsymbol{y}_n^*[j]) = \boldsymbol{E}\left(\boldsymbol{x}_n[k_i]\boldsymbol{x}_n^*[k_j]\right) = \boldsymbol{\rho}[k_i - k_j]$$

Compressive Covariance Sensing

Properties of CCS

1. Reduce the ***number of antennas***.
2. Allow the ***cost saving*** associated with the antennas: such as filter, mixers, ADCs.
3. "***Minimal Sparse Rulers*** **(MSR)**" is proposed to reduce the number of antennas required for $\boldsymbol{\Sigma}_{x}$ estimation.

Figure. A sparse ruler can be thought of as a ruler with a part of its marks erased, but the remaining marks allow all integer distances between zero and its length to be measured

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Numerical Results

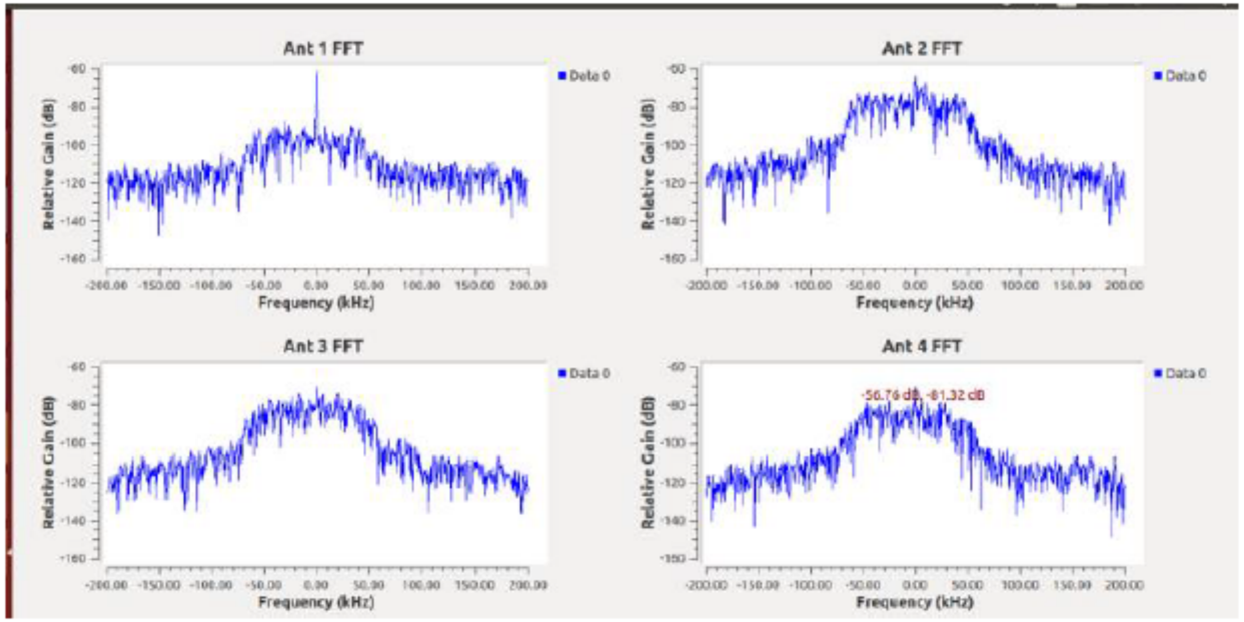

Figure 4: Received spectrum of four channels

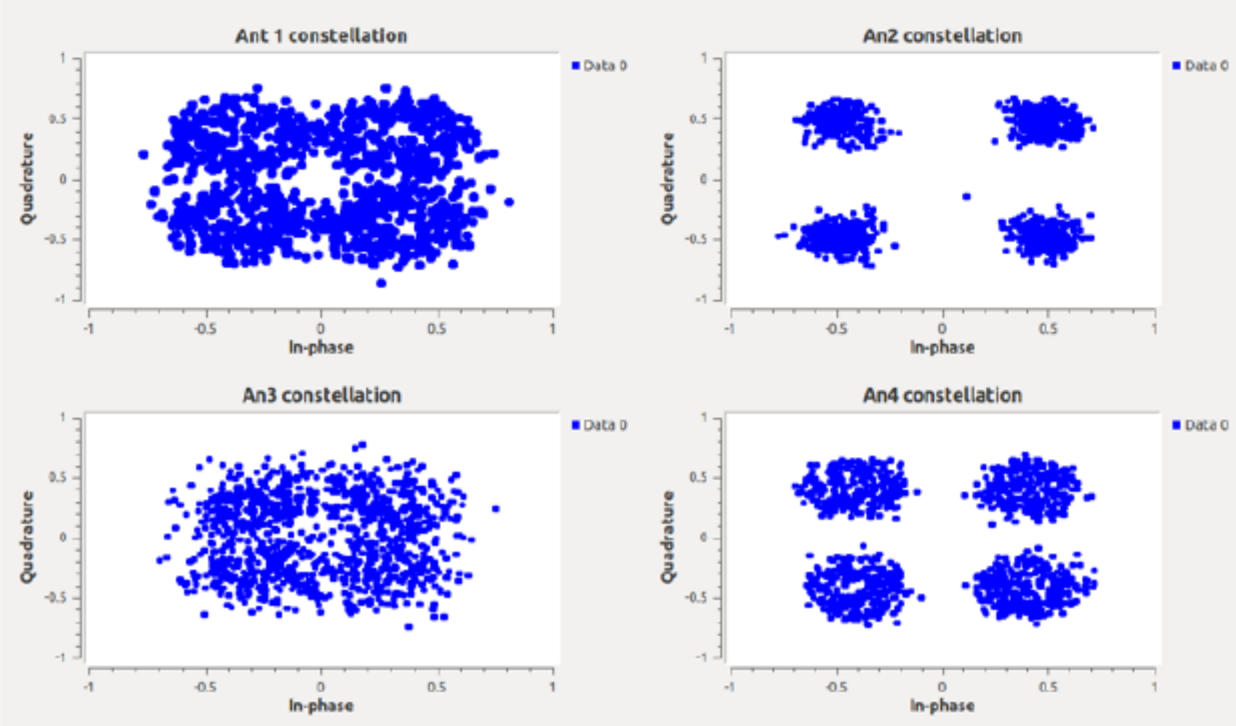

Figure 5: Received constellation of four channels

Spectrum observation directly from RF front end

Constellation after recovering

Numerical Results

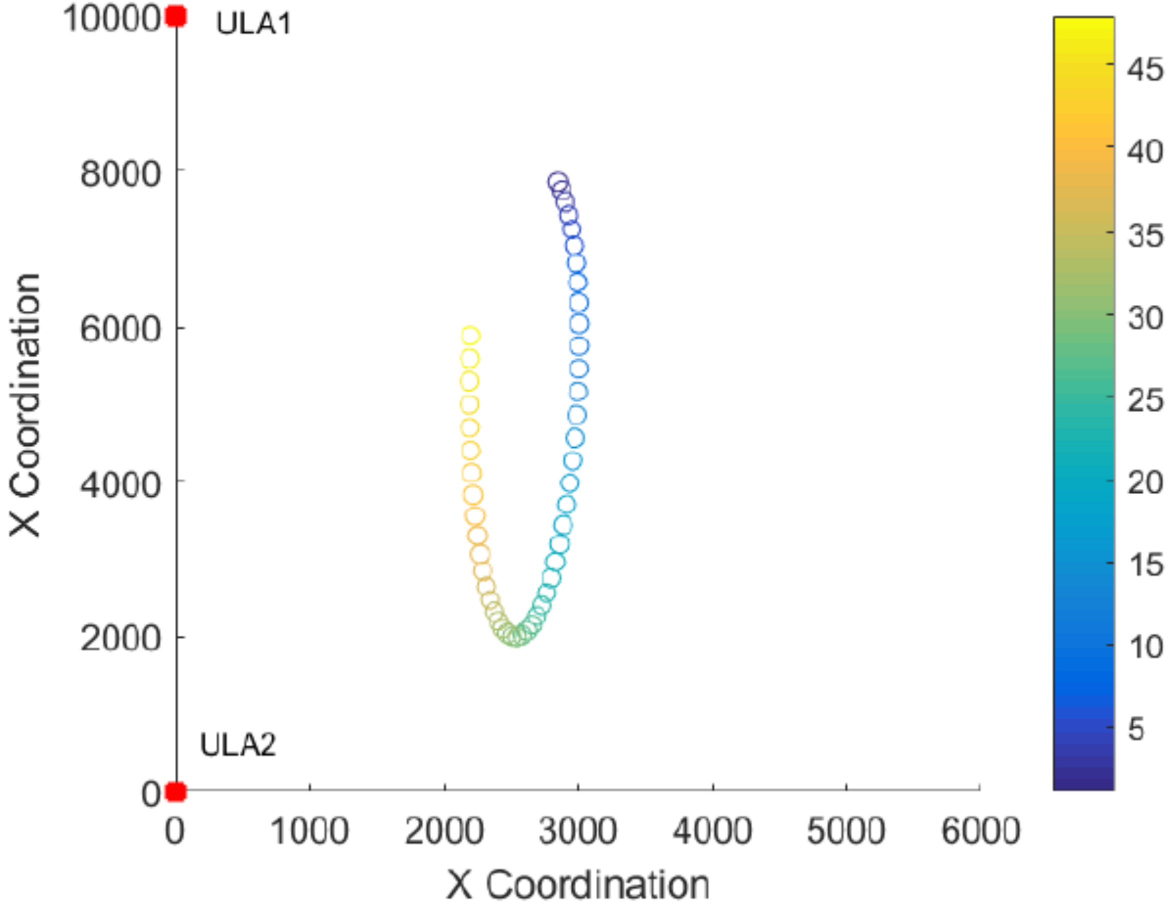

Figure 6 : Trajectory of moving target and locations for two UVAs

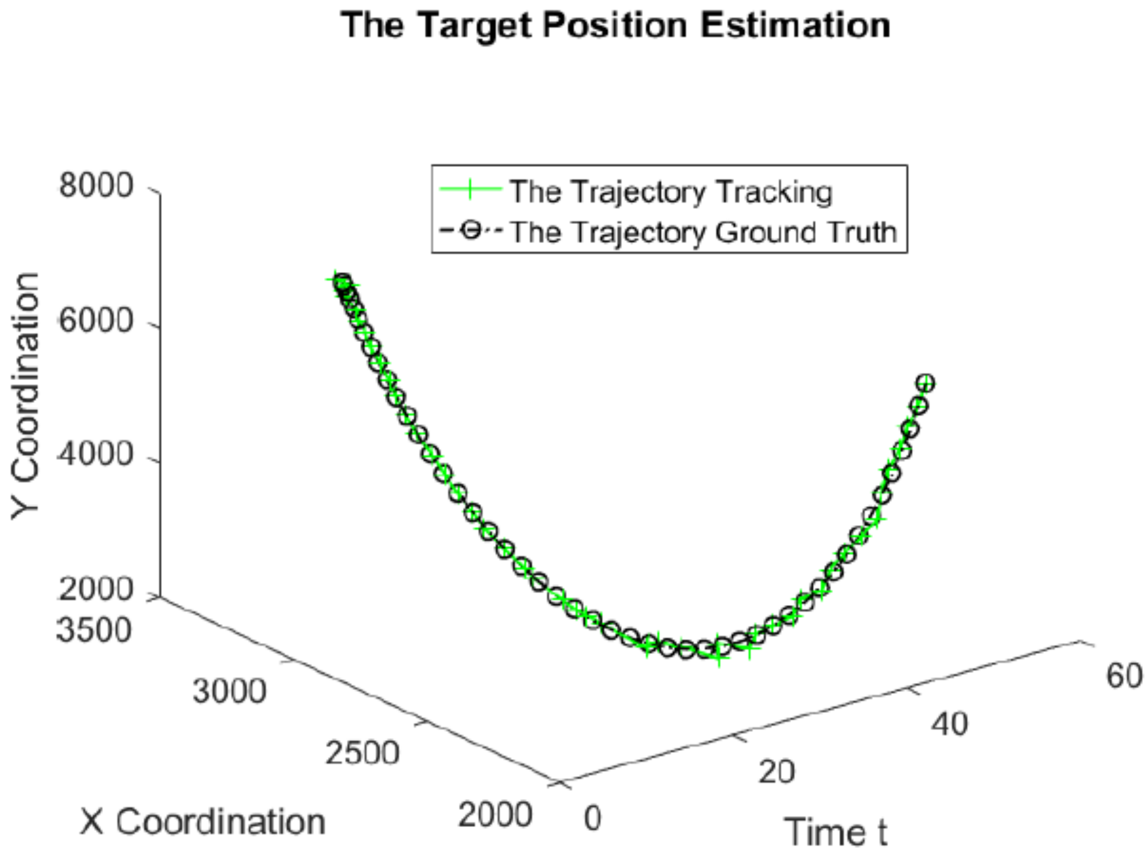

Figure 7: Trajectory tracking based on DOA estimation

Numerical Results

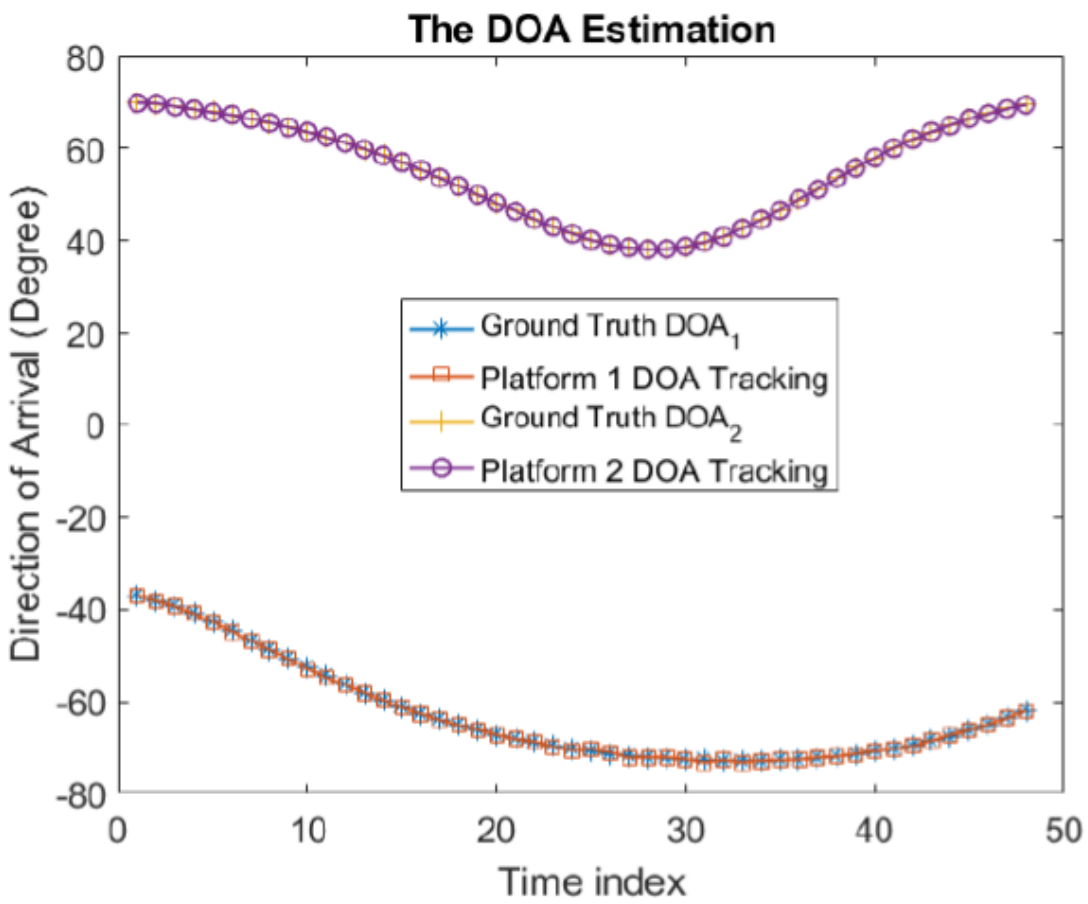

Figure 8: DOA estimation performance

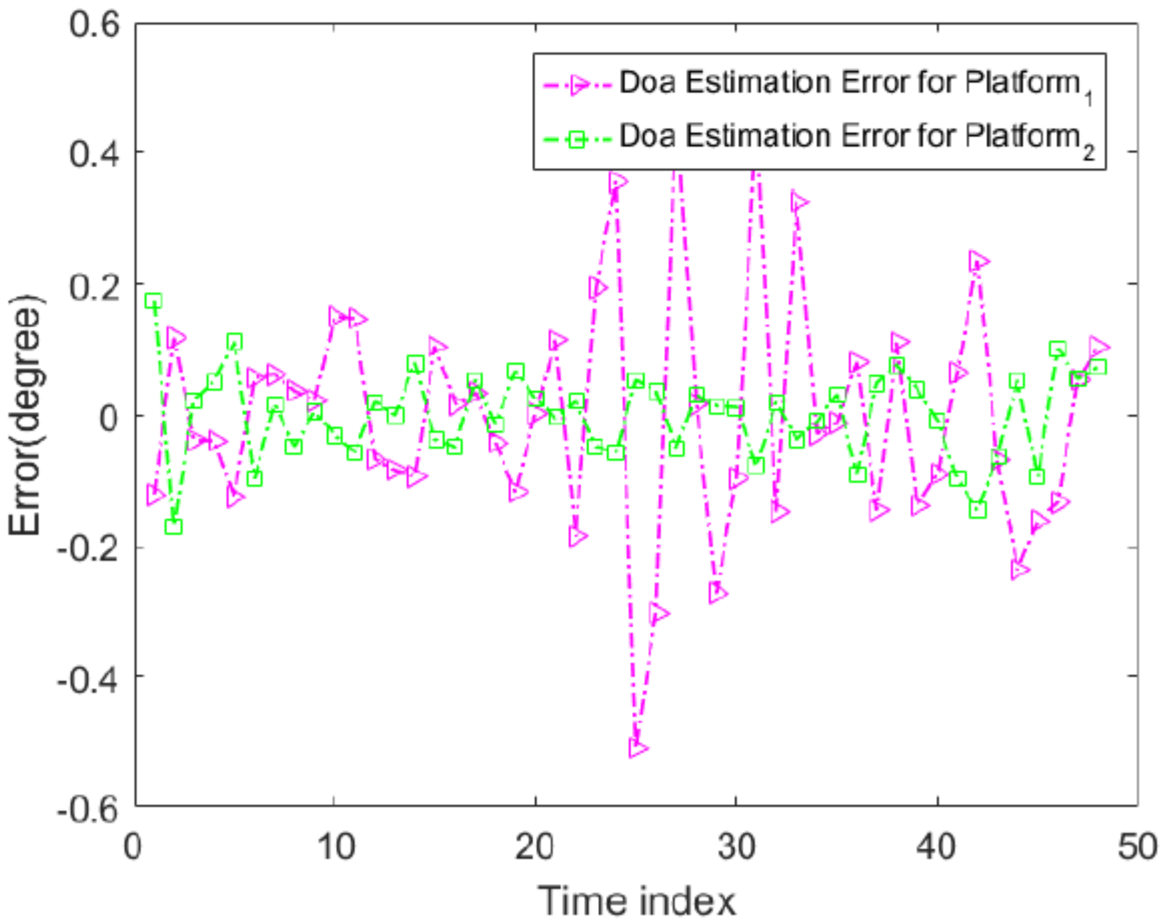

Figure 9: DOA estimation error

Numerical Results

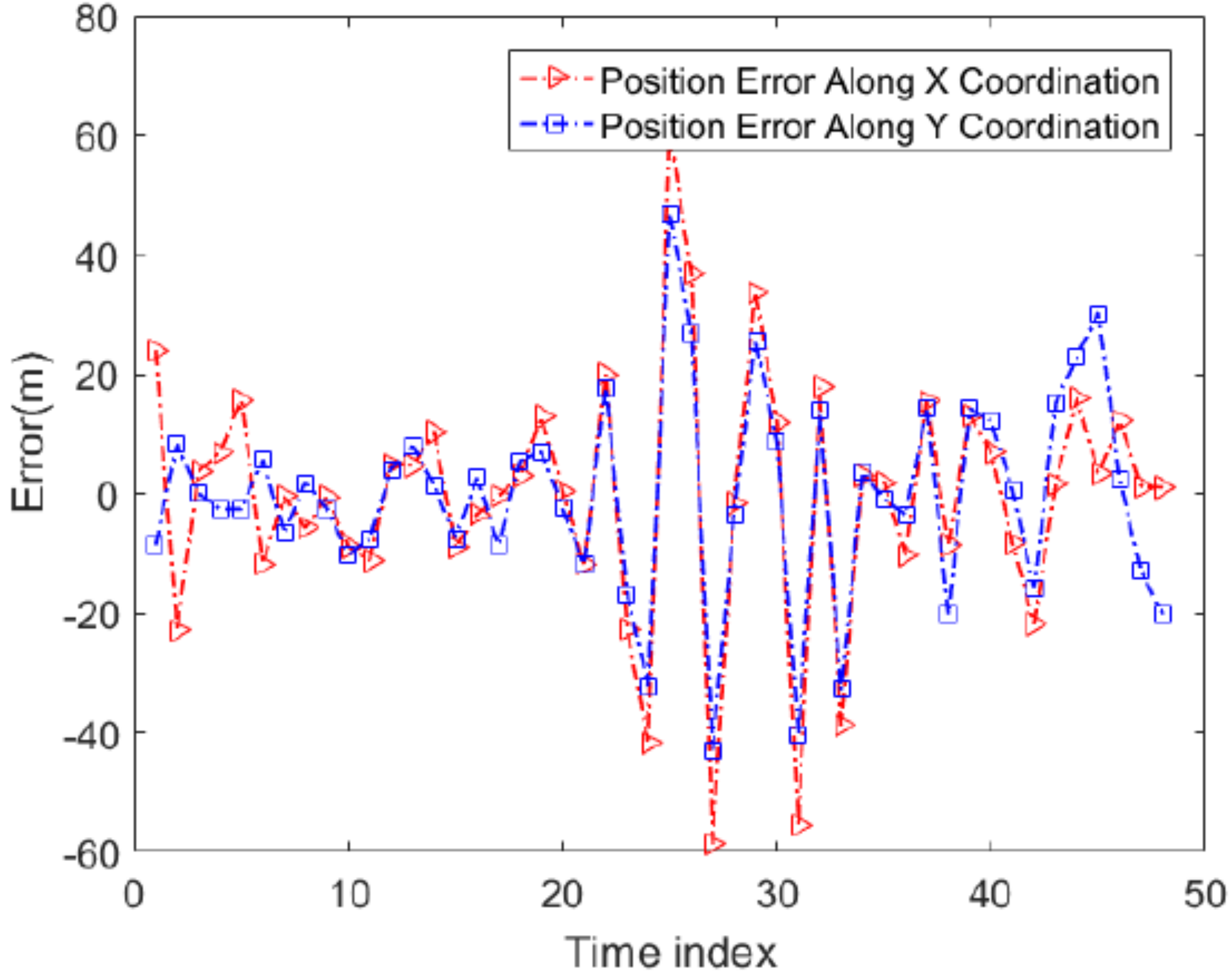

Figure 10: Position estimation error

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Conclusion

- A design of digital beamforming for satellite transponder is proposed
- Software defined radio (SDR) based testbed is proposed
- A DoA estimation method is presented.
- Numerical result is demonstrated.

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