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A Low-complexity Spoofing Detection and Suppression Approach For ADS-B

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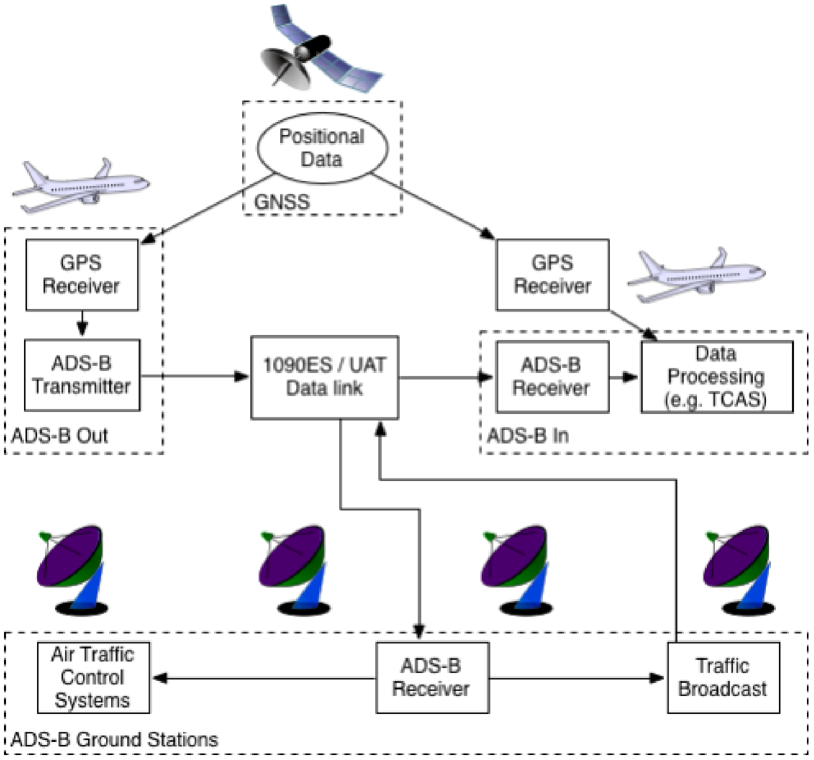
Outline

- Introduction
- Mathematical Model
- The Proposed Algorithm
- Performance Analysis
- Conclusions

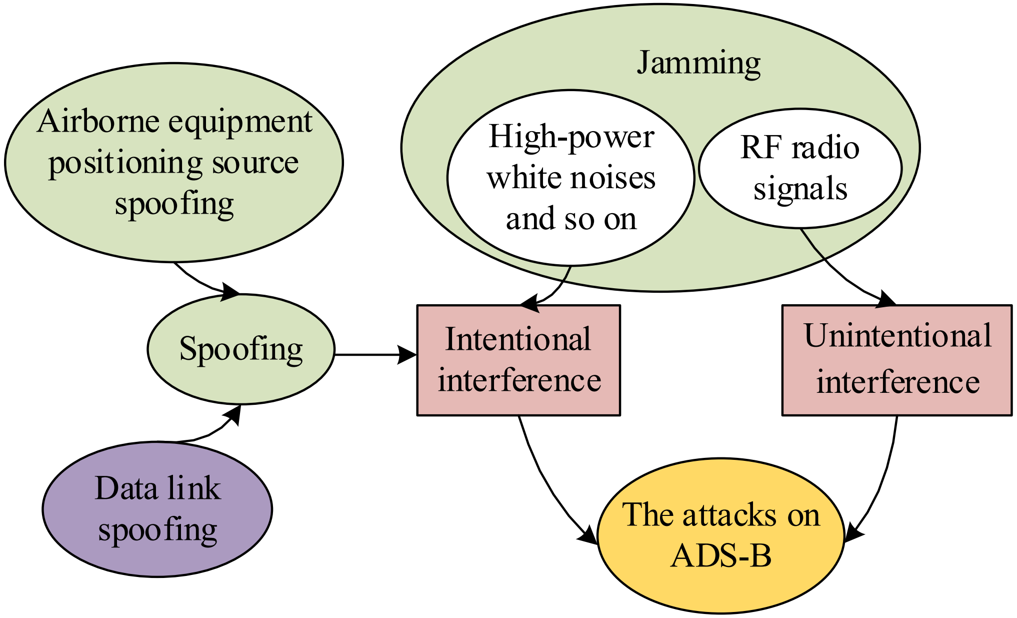
Introduction(1/3)

- **Automatic Dependent Surveillance-Broadcast (ADS-B) is an Air Traffic Management (ATM) Surveillance system that is intended to replace traditional radar based system.**



Introduction(2/3)

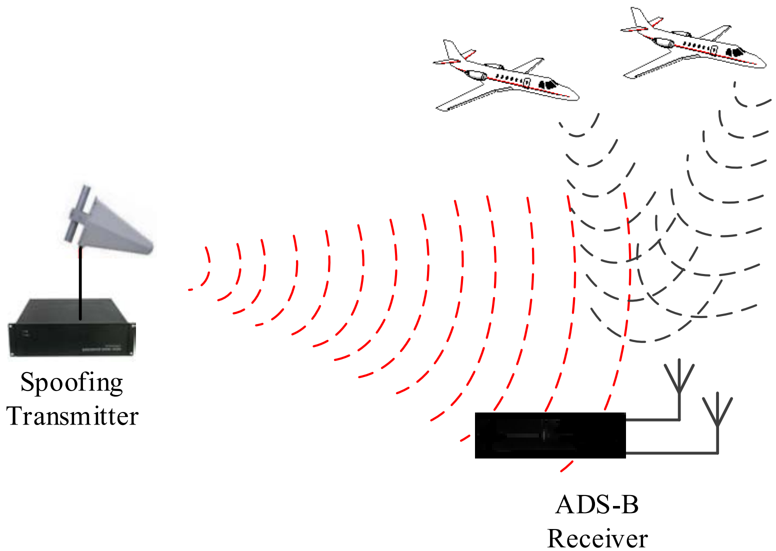
- **Because of the feature of passive monitoring, ADS-B is vulnerable to all kinds of intentional or unintentional attacks.**



The attacks on ADS-B

Introduction (3/3)

The key to identify real ADS-B signals and detect spoofing is the comparison between the DOA of the received ADS-B signal and the declared position in the ADS-B message.

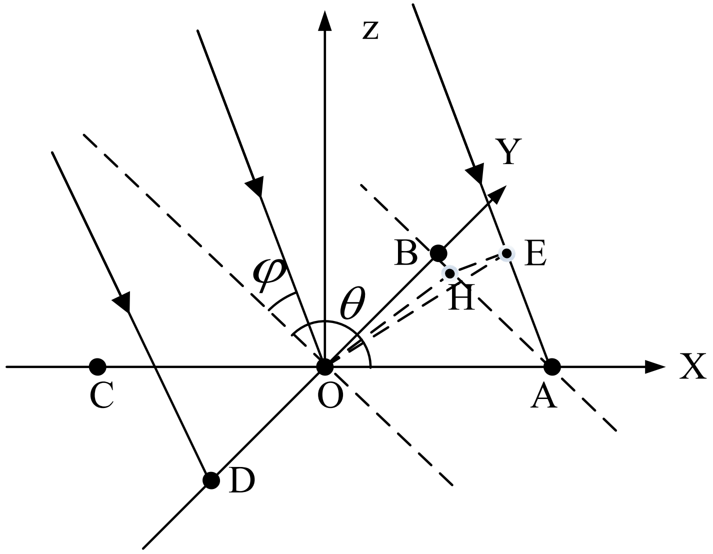


System Model

We proposed an approach to detect and suppress spoofing without DOA estimation.

Mathematical Model (1/2)

The proposed algorithm is based on a cross-antenna array. The cross-antenna array configuration is shown as



Cross array antenna configuration

Mathematical Model (2/2)

The steering vector of the received signal from (θ,φ) is

$$\mathbf{a}(\theta,\varphi)=\left[1,e^{j\beta\cos\theta\cos\varphi},e^{j\beta\sin\theta\cos\varphi},e^{-j\beta\cos\theta\cos\varphi},e^{-j\beta\sin\theta\cos\varphi}\right]^T$$

where $\beta=\dfrac{2\pi d}{\lambda}=\pi$.

The received signal vector at time n can be written as

$$\mathbf{x}(n)=\sum_{l=1}^{L}\mathbf{a}(\theta_l,\varphi_l)s_l(n)+\sum_{q=L+1}^{Q}\mathbf{a}(\theta_q,\varphi_q)j_q(n)+\mathbf{e}(n)$$

where $\mathbf{a}(\theta,\varphi)$ is the steering vector of the received signal from (θ,φ), $\mathbf{e}(n)$ is the complex white Gaussian noise vector , $s_l(n)$ and $j_q(n)$ are the lth ADS-B signal and the qth spoofing respectively.

The Proposed Algorithm(1/10)

The proposed algorithm can be expressed as follow:

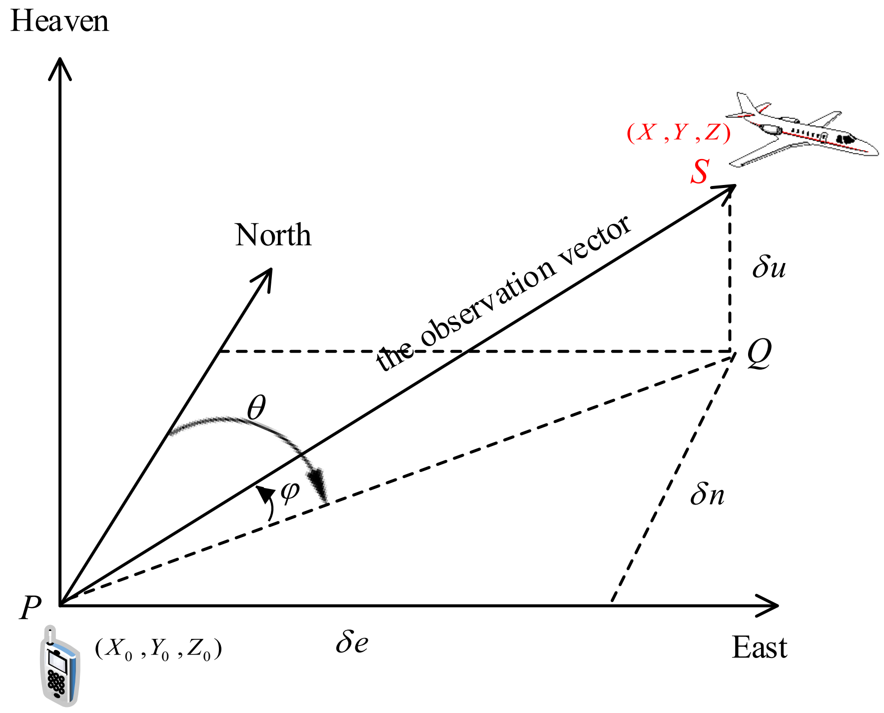
Firstly, the location of target is received by the antenna array. Then the azimuth and the elevation according to the antenna array are obtained based on the locations of target and the central element of array.

The earth-centered earth-fixed (ECEF) system can be used as the bridge between the LLA coordinate system and the ENU coordinate system.

The Proposed Algorithm(2/10)

For the target: $(lon, lat, h) \longrightarrow (X, Y, Z)$

(LLA) **(ECEF)**



The ENU coordinate system

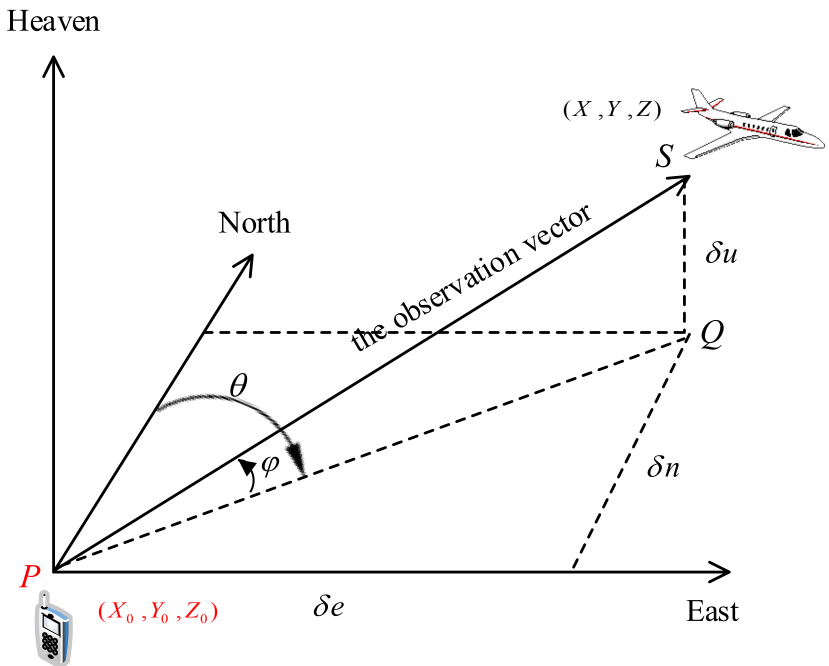
$$
\begin{cases}
X = (N + h)\cos(lon)\cos(lat) \\
Y = (N + h)\cos(lon)\sin(lat) \\
Z = \left(N * \left(1 - e^2\right) + h\right)\sin(lon)
\end{cases}
$$

where e **is the first eccentricity of the earth,** $e^2 = \left(a^2 - b^2\right)/a^2$, $N = a/\sqrt{1 - e^2 \sin^2(lon)}$ **,** a **is the equatorial radius, and** b **is the polar radius.**

The Proposed Algorithm(3/10)

For the central element of the array : $\left(lon_0, lat_0, h_0\right) \longrightarrow \left(X_0, Y_0, Z_0\right)$

(LLA) **(ECEF)**



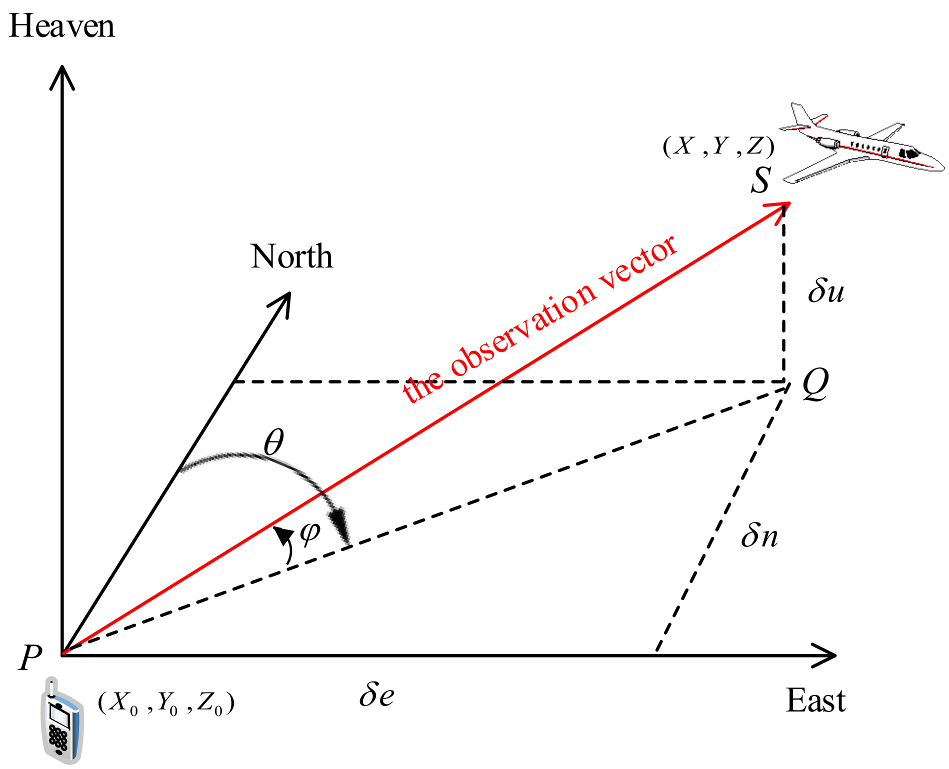
$$\begin{cases} X_0 = \left(N_0 + h_0\right)\cos\left(lon_0\right)\cos\left(lat_0\right) \\ Y_0 = \left(N_0 + h_0\right)\cos\left(lon_0\right)\sin\left(lat_0\right) \\ Z_0 = \left(N_0 * \left(1 - e^2\right) + h_0\right)\sin\left(lon_0\right) \end{cases}$$

where $N_0 = a \Big/ \sqrt{1 - e^2 \sin^2\left(lon_0\right)}$.

The ENU coordinate system

The Proposed Algorithm (4/10)

The observation vector can be expressed as



The ENU coordinate system

$$\begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} - \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix}$$

The Proposed Algorithm (5/10)

The observation vector can be described in the ENU coordinate system as

$$\begin{bmatrix} \delta e \\ \delta n \\ \delta u \end{bmatrix} = \mathbf{S} \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix}$$

where

$$\mathbf{S} = \begin{bmatrix} -\sin(lon_0) & \cos(lon_0) & 0 \\ -\sin(lat_0)\cos(lon_0) & -\sin(lat_0)\sin(lon_0) & \cos(lat_0) \\ \cos(lat_0)\cos(lon_0) & \cos(lat_0)\sin(lon_0) & \sin(lat_0) \end{bmatrix}$$

The Proposed Algorithm (6/10)

The elevation can be expressed as

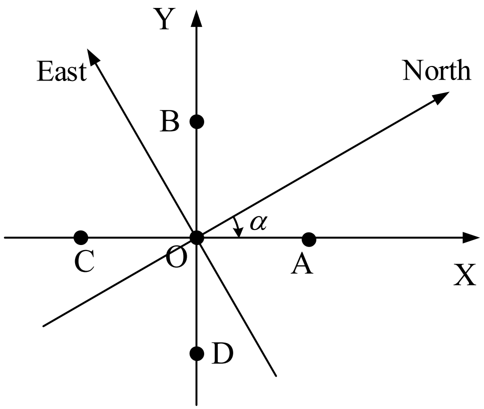
$$\varphi = \arcsin\left(\frac{\delta u}{\sqrt{(\delta e)^2 + (\delta n)^2 + (\delta u)^2}}\right)$$

The azimuth can be expressed as

$$\theta = \arctan\left(\frac{\delta e}{\delta n}\right)$$

The Proposed Algorithm (7/10)

The horizontal surface of the ENU coordinate system is shown as



If the angle between X axis and the north direction is α, the azimuth can be amended as

$$\theta_n = \theta - \alpha$$

θ_n is the azimuth, and $\varphi_n = \varphi$ is the elevation of the target according to the array.

The Proposed Algorithm(8/10)

Secondly, the signal from the estimated direction is suppressed by projecting the received signal onto the orthogonal complement space of estimated steering vector.

The estimated steering vector can be written as

$$\hat{\mathbf{a}}\left(\theta_n,\varphi_n\right)=\left[1,e^{j\beta\cos\theta_n\cos\varphi_n},e^{j\beta\sin\theta_n\cos\varphi_n},e^{-j\beta\cos\theta_n\cos\varphi_n},e^{-j\beta\sin\theta_n\cos\varphi_n}\right]^T$$

where $\beta=\dfrac{2\pi d}{\lambda}=\pi$.

The Proposed Algorithm(9/10)

The orthogonal projection matrix to the orthogonal complement space of estimated steering vector can be expressed as

$$\mathbf{P}_n = \mathbf{I} - \hat{\mathbf{a}}\left(\hat{\theta}_n, \varphi_n\right)\left(\mathbf{a}^H\left(\theta_n, \varphi_n\right)\mathbf{a}\left(\theta_n, \varphi_n\right)\right)^{-1}\mathbf{a}^H\left(\theta_n, \varphi_n\right)$$

The orthogonal projection is applied to the received signals as

$$\mathbf{Rec} = \mathbf{P}_n^H \mathbf{X}$$

where $\mathbf{X}$ is the received signal matrix.

The Proposed Algorithm(10/10)

Finally, the target is recognized as a real target or spoofing according to the spoofing decision algorithm.

The spoofing decision algorithm can be expressed as follow.

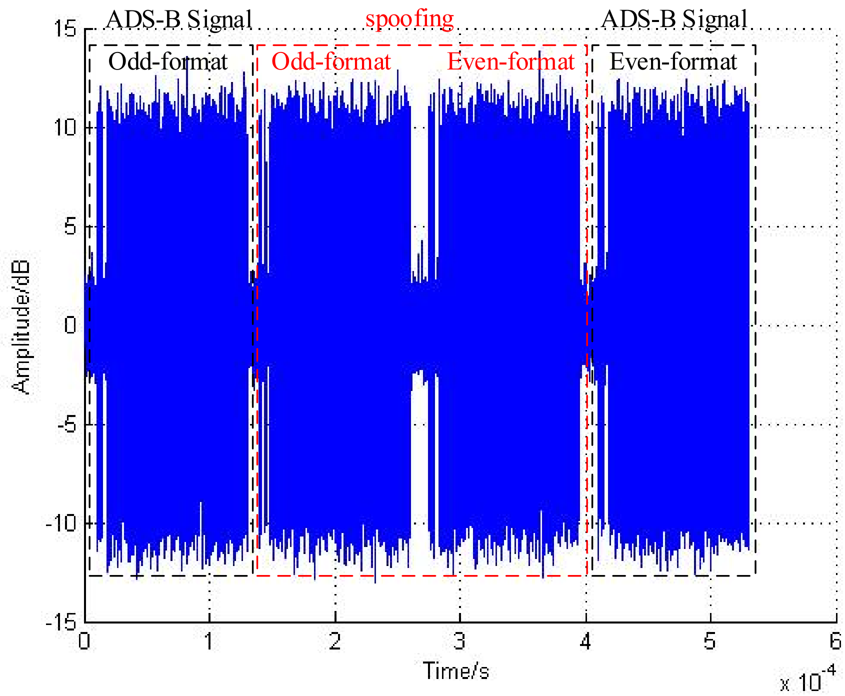
If the identity of the detected target can still be detected in this step, it means that the location information of the target is fake. Then the detected target is recognized as a spoofing.

Otherwise, the detected target is recognized as a real ADS-B target.

Performance Analysis(1/5)

Simulation example:

The signals are shown as



The simulation signals

Performance Analysis(2/5)

There is a real ADS-B target and a spoofing.

The broadcast location of each target

	"AA" Field(hex)	Longitude (degree)	Latitude (degree)	Altitude (foot)
1	780456	117.2300	37.1500	31500
2	780ABC	117.3000	37.8000	34100

The real location of each target

spoofing

	"AA" Field(hex)	Longitude (degree)	Latitude (degree)	Altitude (foot)
1	780456	117.23	37.15	31500
2	780ABC	117.9	37.1	130

Performance Analysis(3/5)

The result of ADS-B software receiver are shown as

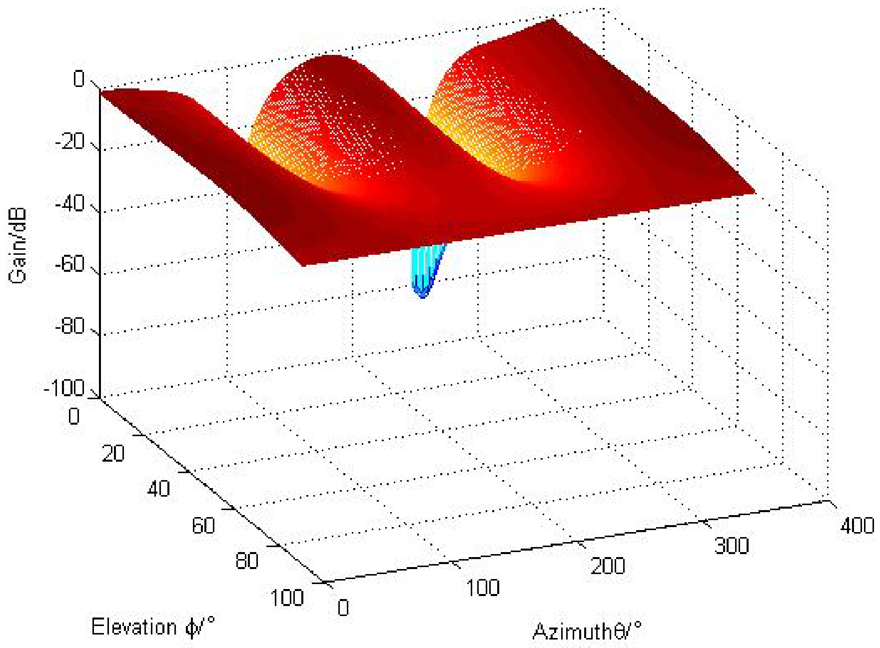
The broadcast location of each target

	"AA" Field (hex)	Longitude (degree)	Latitude (degree)	Altitude (foot)
1	780ABC	117.3000	37.8000	34100
2	780456	117.2300	37.1500	31500

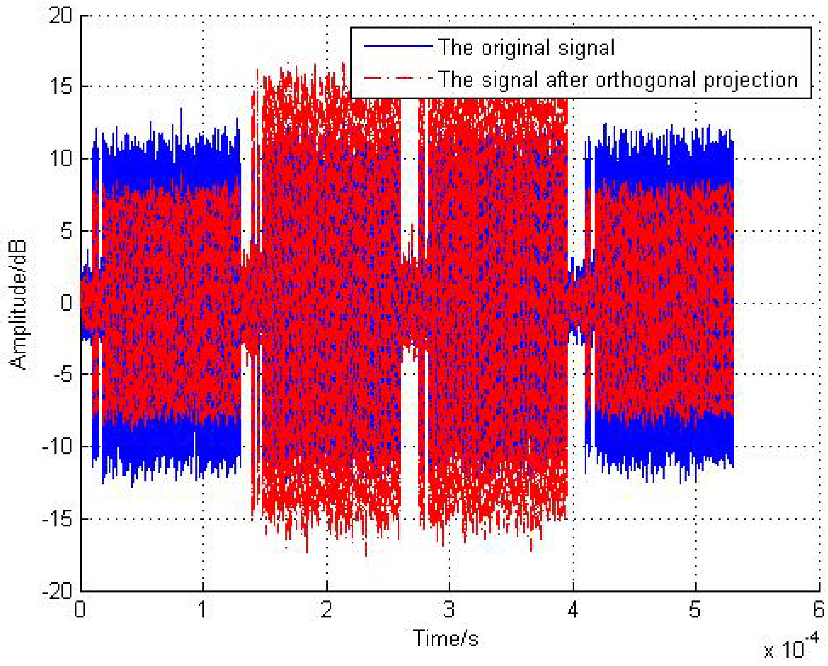
Next, the two detected targets can be recognized whether they are real ADS-B target or not respectively.

Performance Analysis (4/5)

For "780ABC" :



The beam pattern.

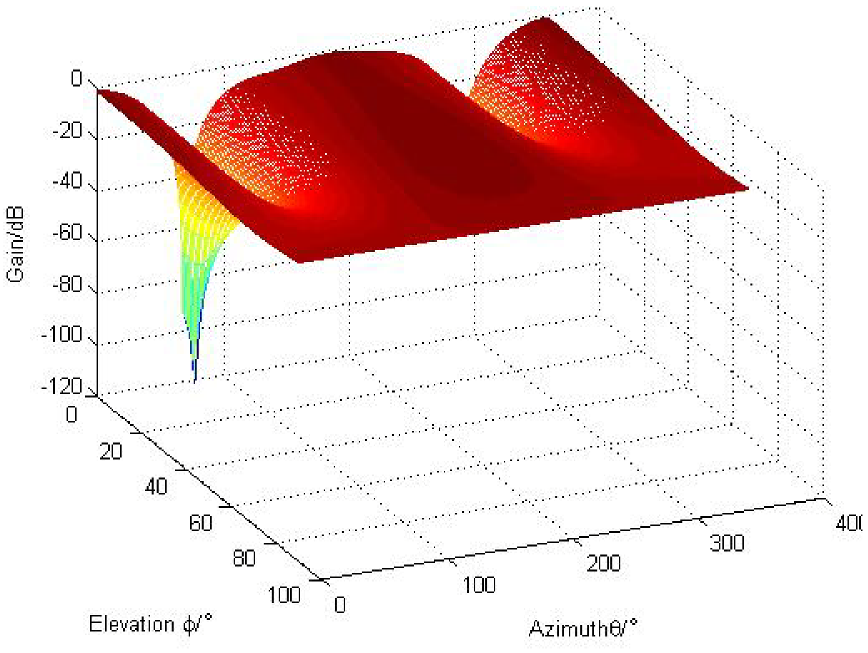


The signals before and after projection.

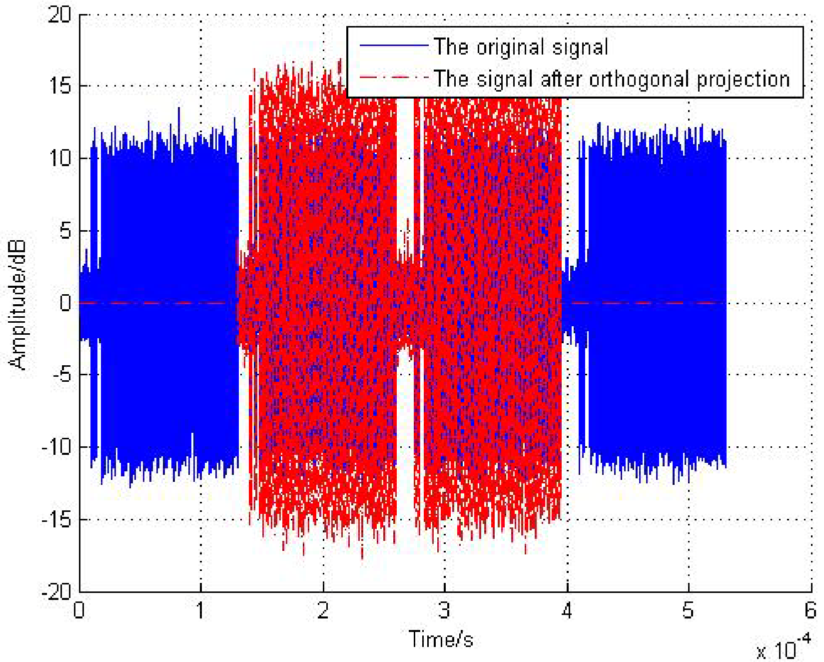
It is a spoofing!

Performance Analysis (5/5)

For “780456” :



The beam pattern.



The signals before and after projection.

It is a real ADS-B target!

Conclusions(1/1)

1. The DOA of target can be obtained based on the locations of target and the central element of array.
2. The detected target can be recognized as a real target or spoofing according to the spoofing decision algorithm.
3. Without DOA estimation, the calculation of the proposed algorithm is reduced.
4. Simulation results show the effectiveness of the proposed algorithm.

Thank you !