

Purpose

Create a passive radar system to improve aerial security

Background

Terrorism

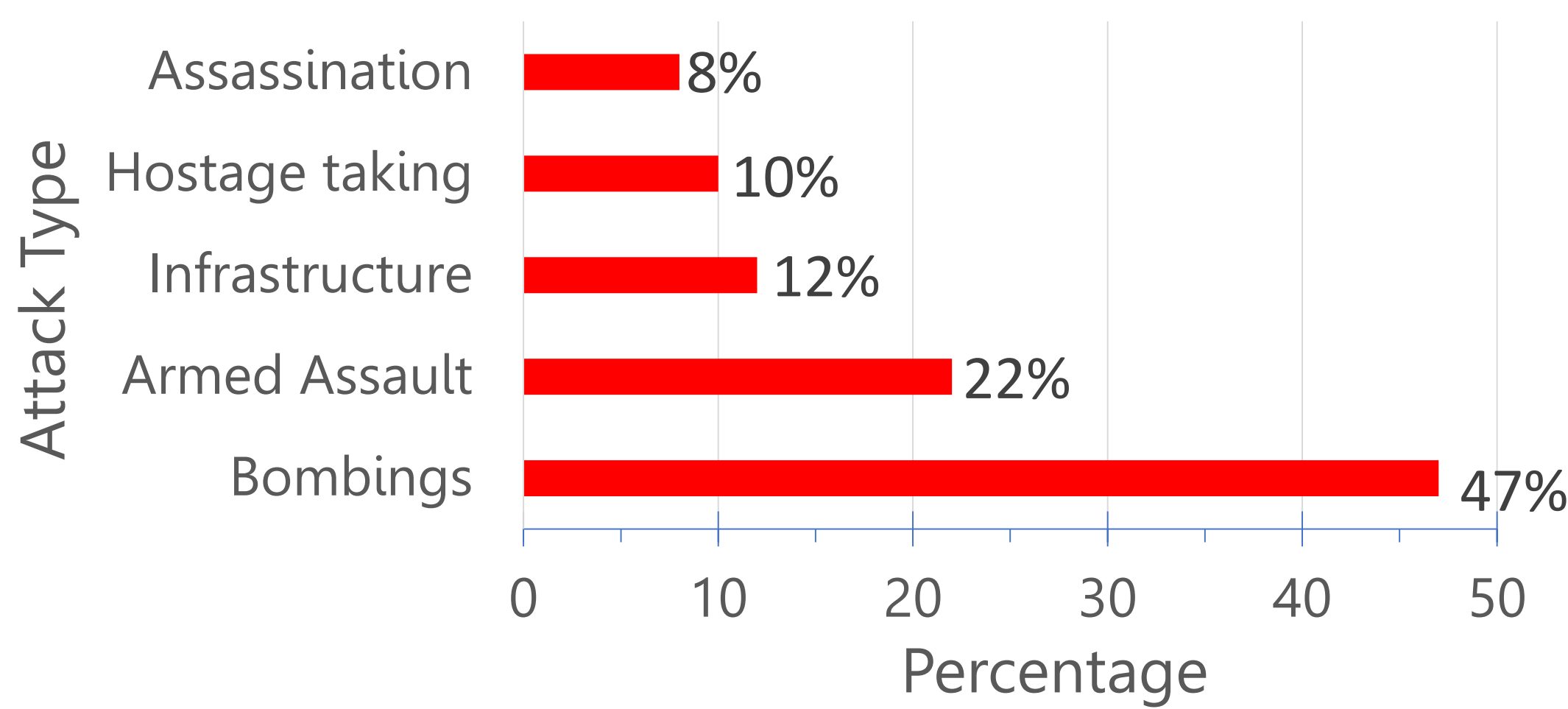


Figure 1. Distribution of attack types used in acts of terrorism worldwide in 2017 (figure adapted from [2])

- Increasing surveillance of governments and intelligence agencies [1]
- 59 aircraft attacks in the U.S. (1970-2016) [3]
- 204 U.S. airstrikes in Yemen in last 3 years [4]
- 390 U.S. airstrikes in Pakistan in last decade [5]

Active and Passive Radar Systems

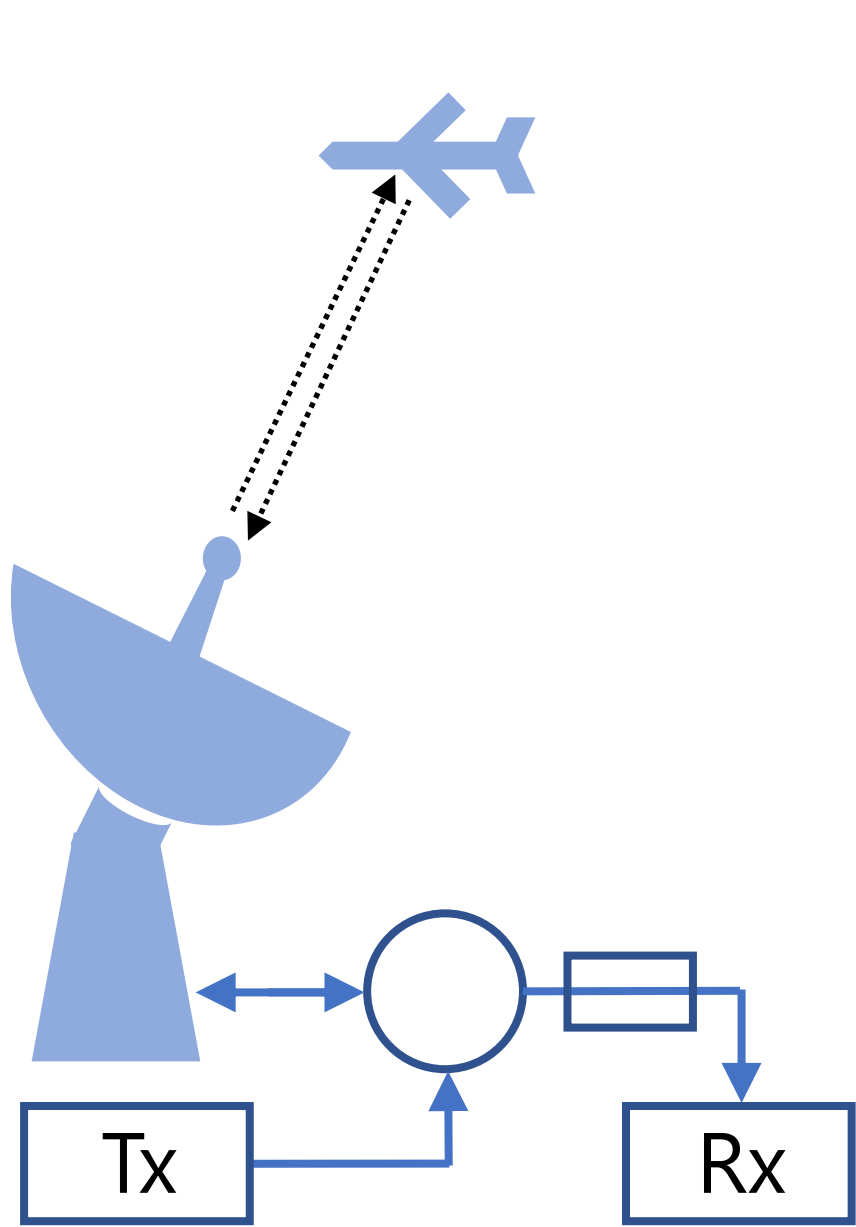


Figure 2. Active Radar System where the transmitter (Tx) and receiver (Rx) are collocated (figure created by student researcher)

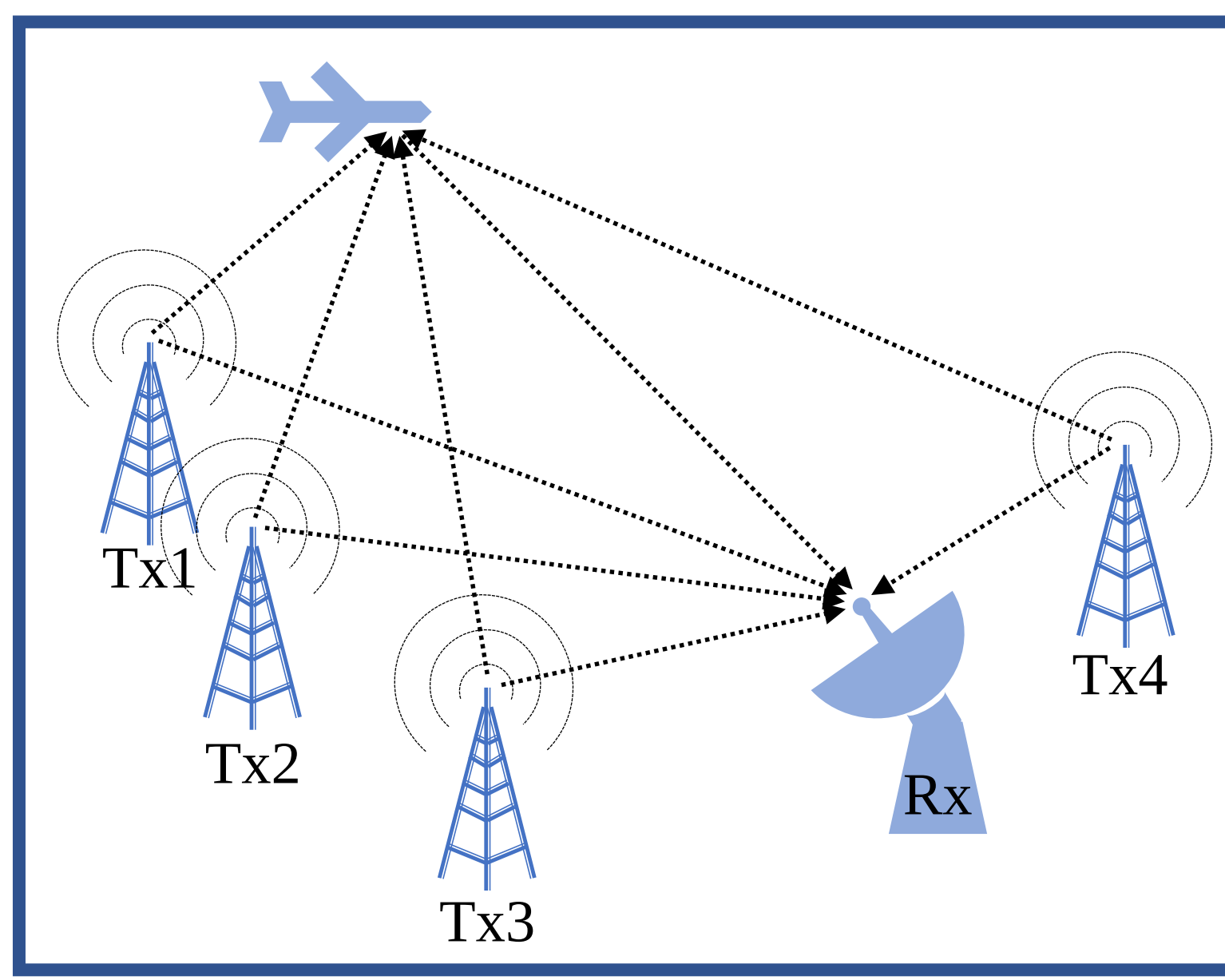


Figure 3. Multi-static configuration which consists of multiple transmitters and a single receiver, or vice versa (figure created by student researcher)

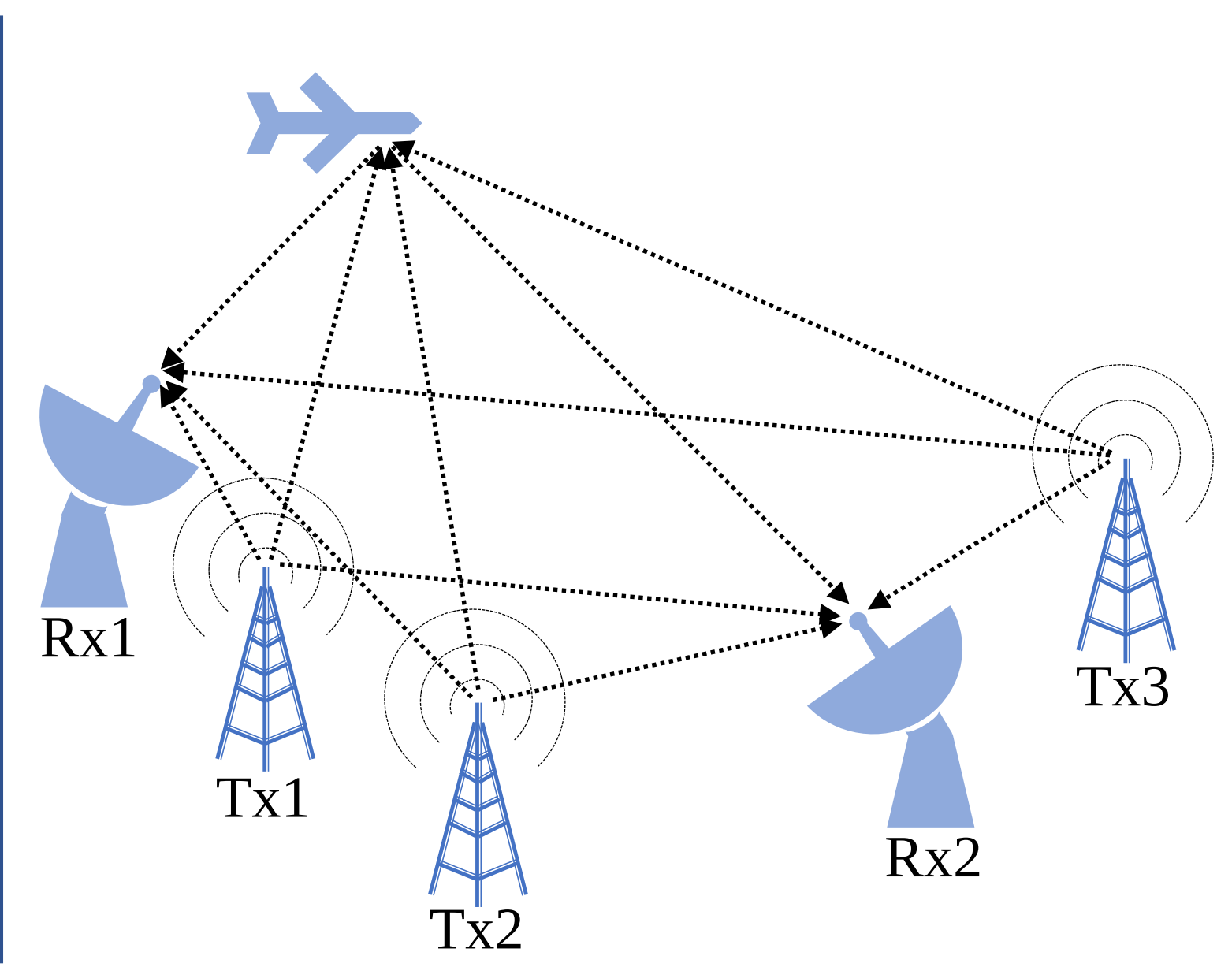


Figure 4. Multiple-Input-Multiple-Output (MIMO) configuration which consists of multiple transmitters and multiple receivers (figure created by student researcher)

- **Multi-static configuration** was chosen for study
- Spatially distributed system **reduces vulnerability** and **increases covertness**
- Use of existing infrastructure **reduces time and cost** required to implement
- Relies on sources of opportunity (e.g. AM/FM radio, Cellular, DVB)
- Difficult to accurately estimate target position [6]

Time-of-Arrival (TOA) and Time-Difference-of-Arrival (TDOA)

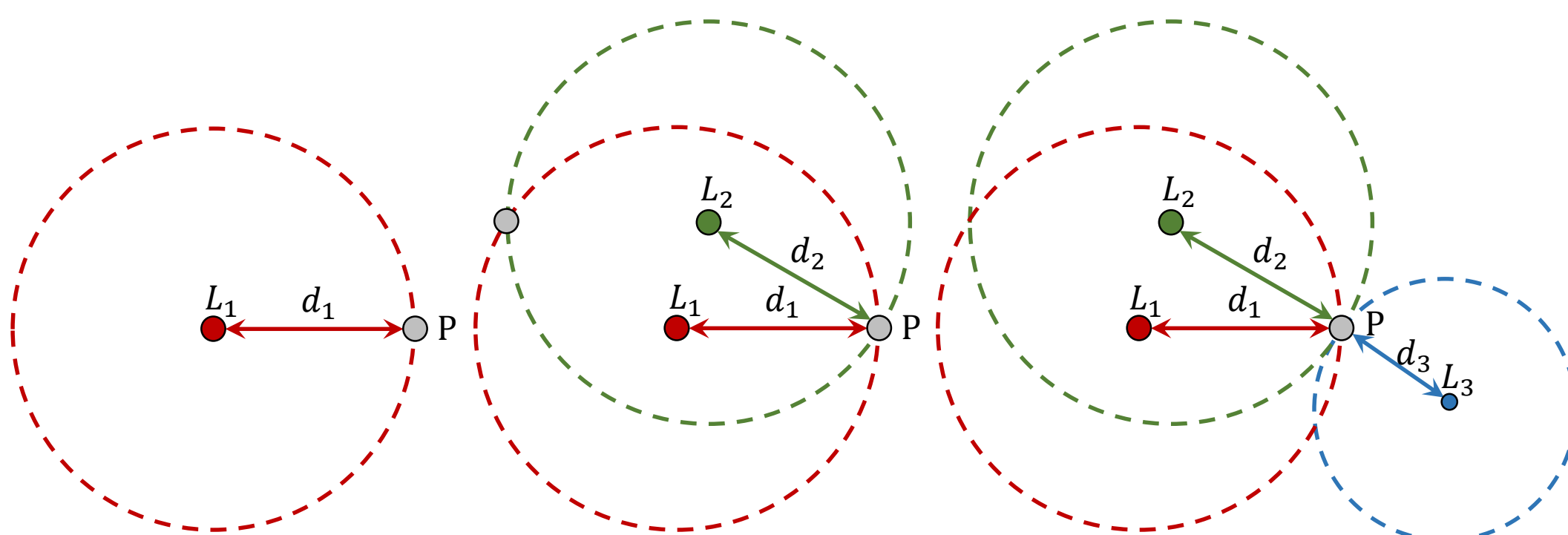


Figure 5. Trilateration illustrated with the use of ellipses, wherein the addition of transmitters reduces the ambiguity of target location (figure adapted from [7])

- Better estimation with more transmitters
- Reference channel (signal direct path) and surveillance channel (reflected path/multi-path)

Artificial Neural Network (ANN) Overview

- Machine learning method used for pattern recognition
- Model trainable using input data
- Supervised learning enables user control over ANN training
- Machine Learning has been minimally implemented in localization and tracking
- Input Data Nodes:
 - TDOA of signals (1 for each transmitter)
- Output Nodes:
 - Target location (x, y, z, coordinates)

Research Goals

Detect and locate a moving target

Artificial Neural Network Based Target Localization Method for Multi-Static Passive Radar Systems

Methods and Results

Virtual Environments:

Create environments and simulate signals

Neural Network Model:

Build, train, and test the models

Receiver Optimization:

Reduce noise impact and improve ANN

Virtual Environments

- Create three unique virtual environments [8][9]
- Assign coordinates to transmitters and receiver [10]
- Generate waveforms for each transmitter along with noise (additive white gaussian noise- using the *awgn* function)

$$Tx/Rx = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad Tx_1 = \begin{bmatrix} 0.4 \\ 1.1 \\ 8.2 \end{bmatrix} \quad Tx_2 = \begin{bmatrix} 0.6 \\ 1.9 \\ 0.8 \end{bmatrix}$$
$$Tx_3 = \begin{bmatrix} 2.4 \\ 2.9 \\ 4.7 \end{bmatrix} \quad Tx_4 = \begin{bmatrix} 7.6 \\ 0.5 \\ 1.3 \end{bmatrix} \quad Rx = \begin{bmatrix} 9.6 \\ 1.1 \\ 9.8 \end{bmatrix}$$

Table 1. Parameters of the generated Linear Frequency Modulated (LFM) waveforms or “chirp signals” wherein the frequency increases with time (table created by student researcher)

	All transmitters emit an identical waveform	Each transmitter emits a different waveform			
	Tx All	Tx1	Tx2	Tx3	Tx4
Sampling Frequency (MHz)	50	8	20	18	20
Bandwidth (MHz)	20	5	10	10	20
Pulse width (sec.)	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
Pulse Repetition Frequency (KHz)	10	4	10	9	10

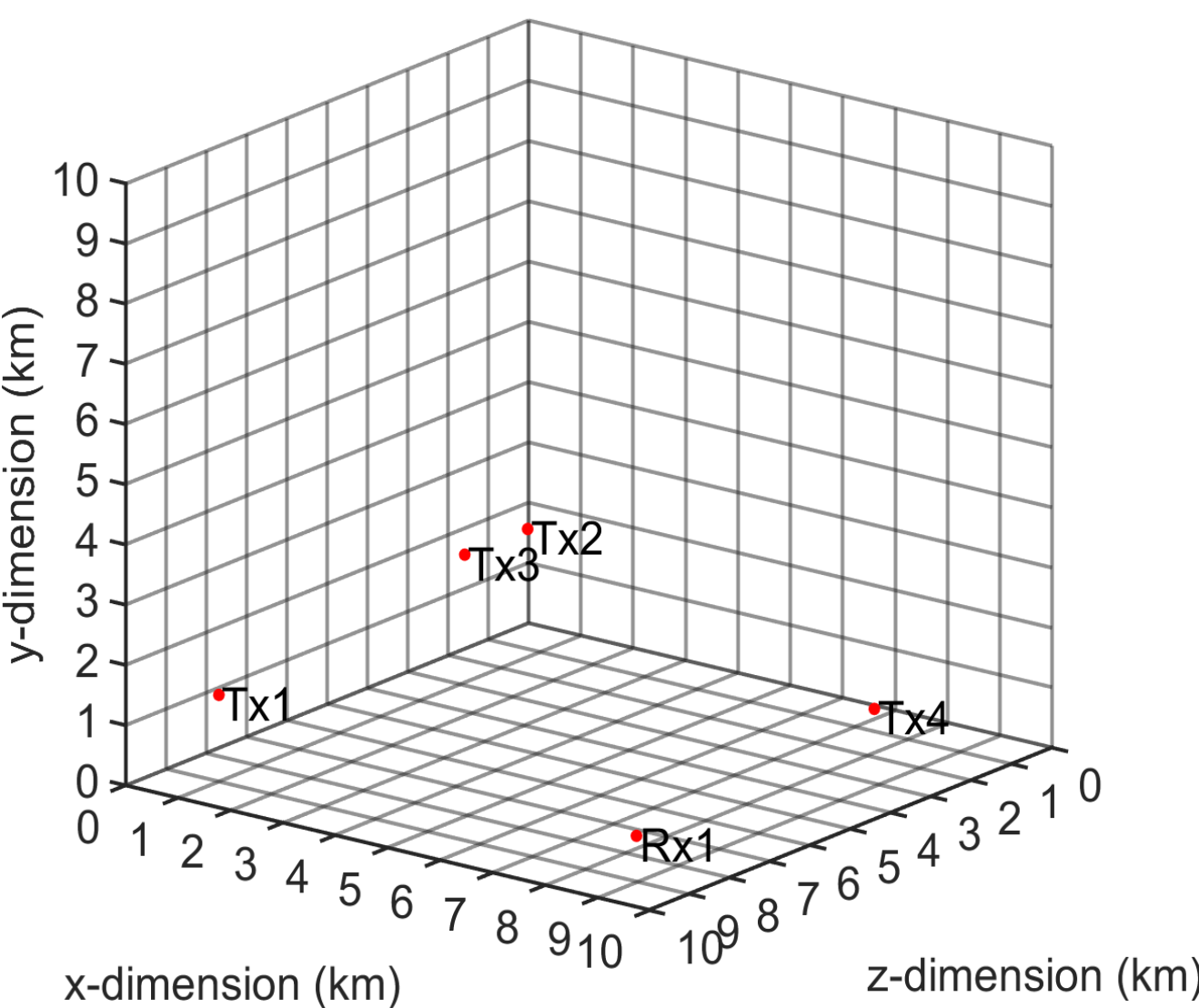
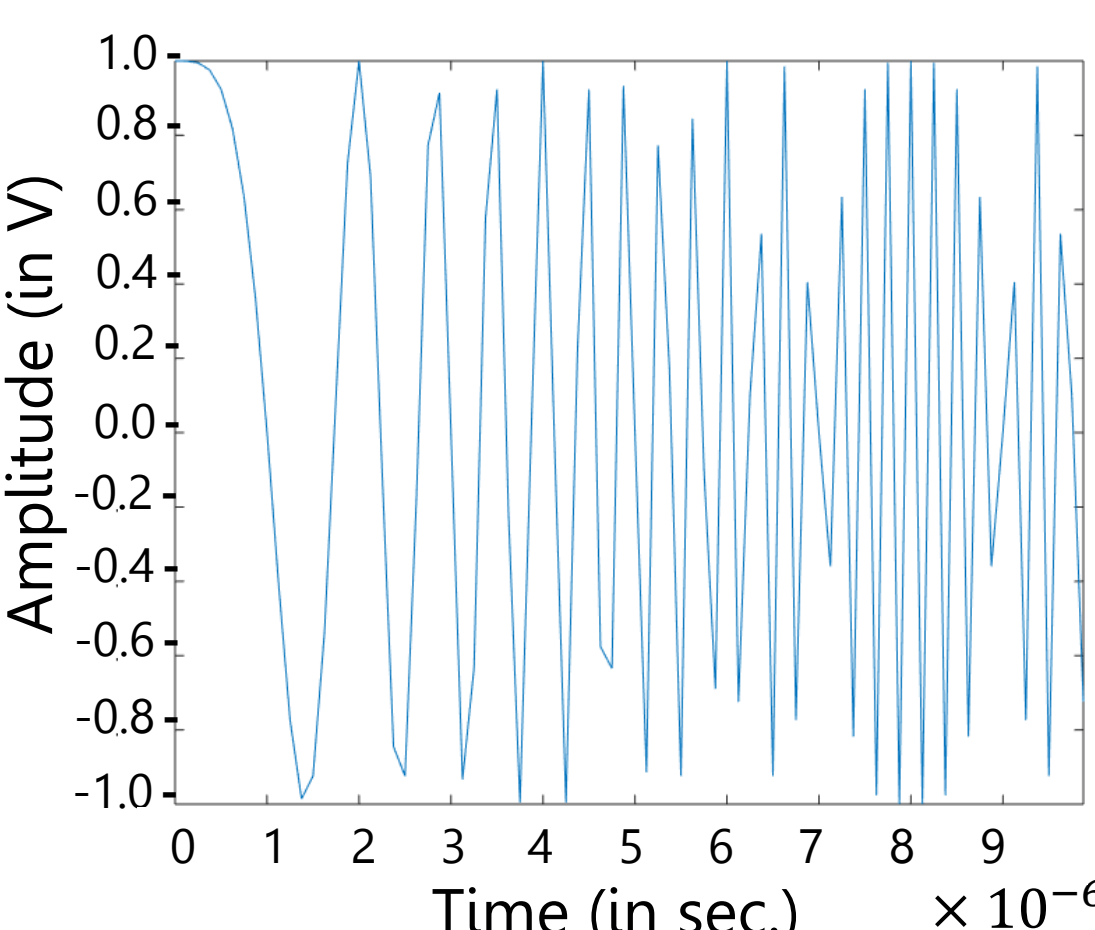
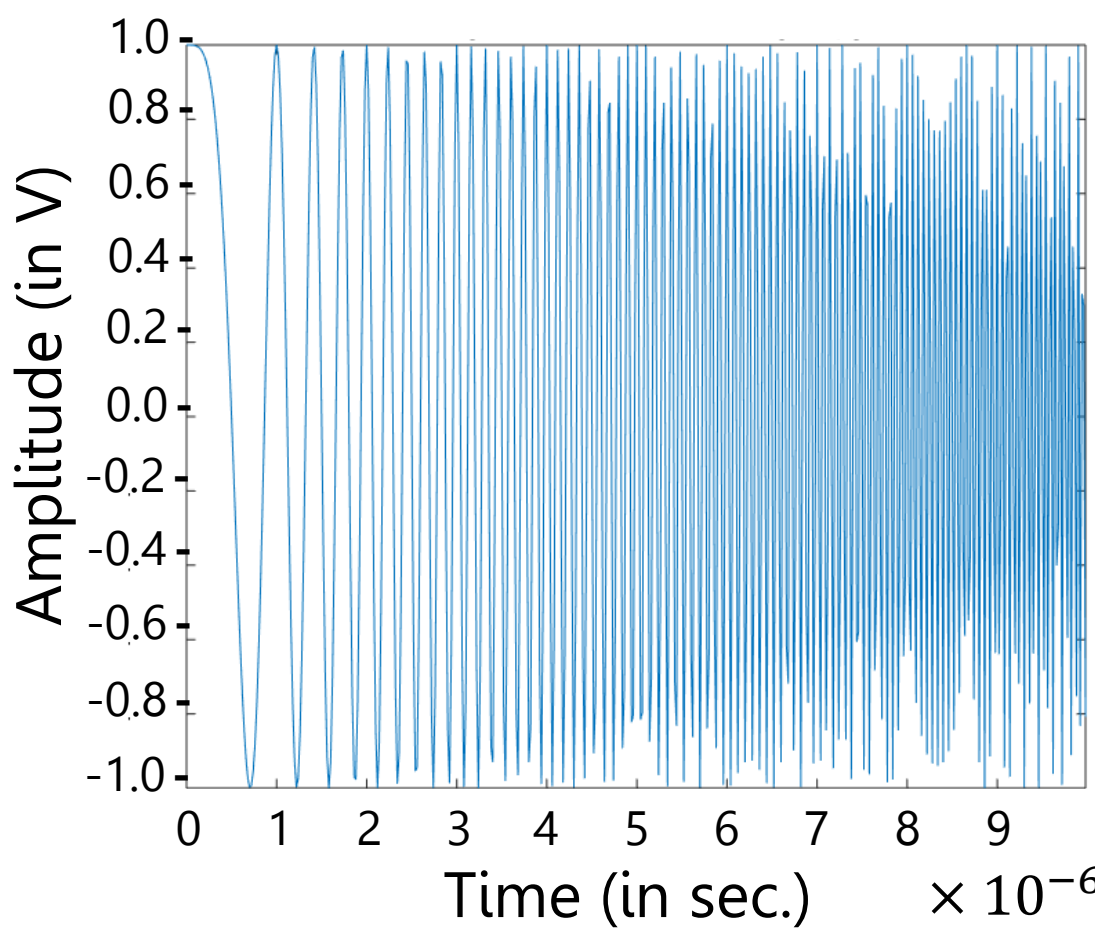


Figure 6. 3D view of fixed transmitters and receivers (figure created by student researcher)

Figure 7. Two of five generated waveforms (figure created by student researcher)

Model Development

- Define the model
 - Input Layer Size: 4 nodes
 - Single Hidden Size: 14 nodes
 - Output Size: 3 Nodes
 - Activation function 1: tansig
 - Activation function 2: purelin
- Train the model:
 - Training Algorithm: Levenberg Marquardt
 - Use of backpropagation
 - Epochs: 24,375 (for all)
 - Learning rate: 1×10^{-6}

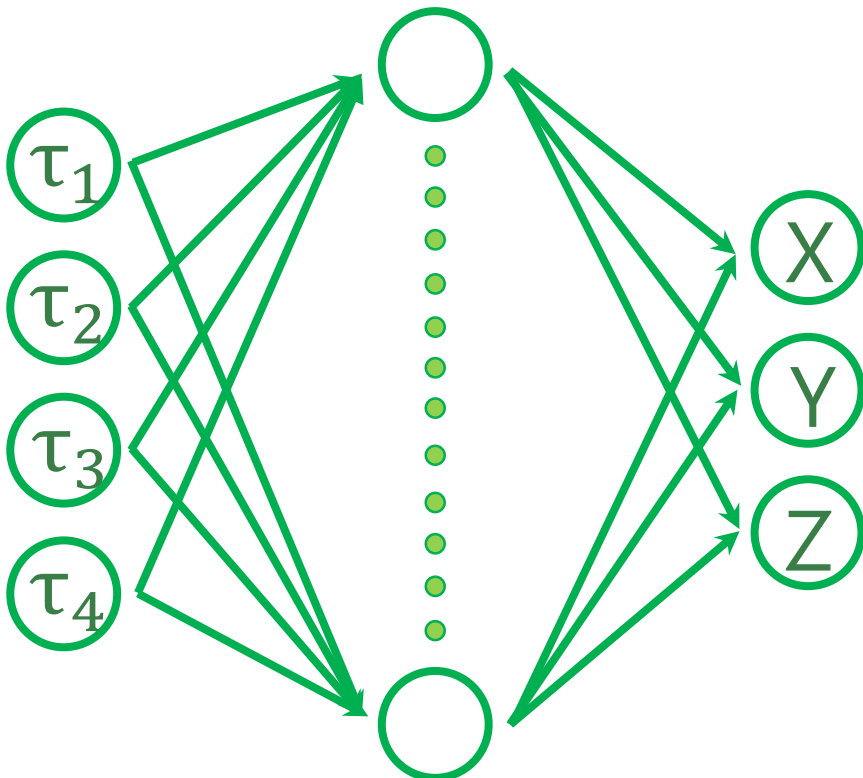


Figure 9. ANN Architecture that was used in the investigation (figure created by student researcher)

Table 2. The datasets that were used during training and their basic properties (table created by student researcher)

Interval	Dataset Size	Training Size (90%)	Testing Size (10%)
0.1 km	1×10^6	9×10^5	1×10^5
0.5 km	8000	7200	800
1.0 km	1000	900	100

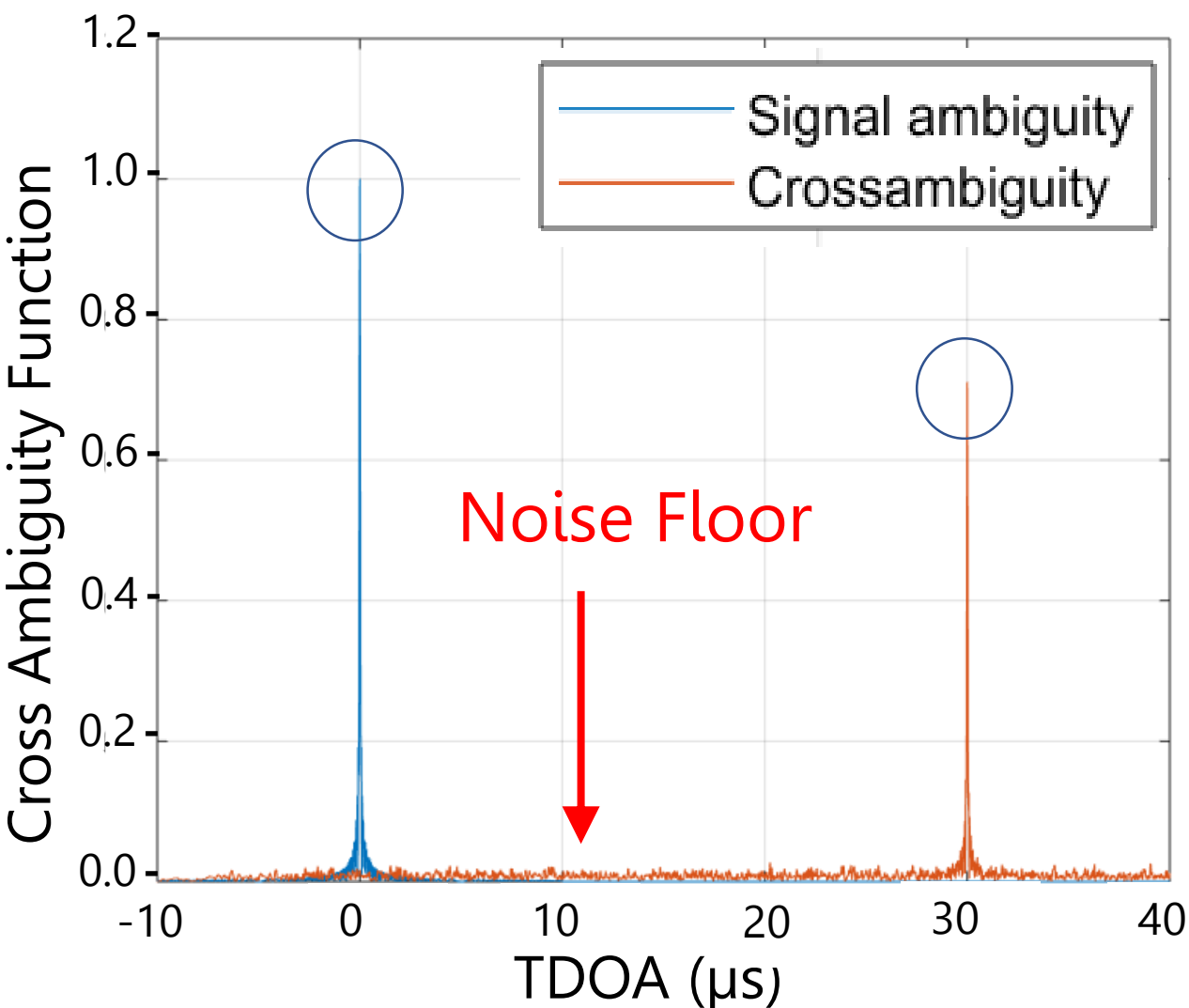


Figure 8. Cross ambiguity function optimizes peak selection, better estimating signal delay, e.g. 30 microseconds as depicted above (figure created by student researcher)

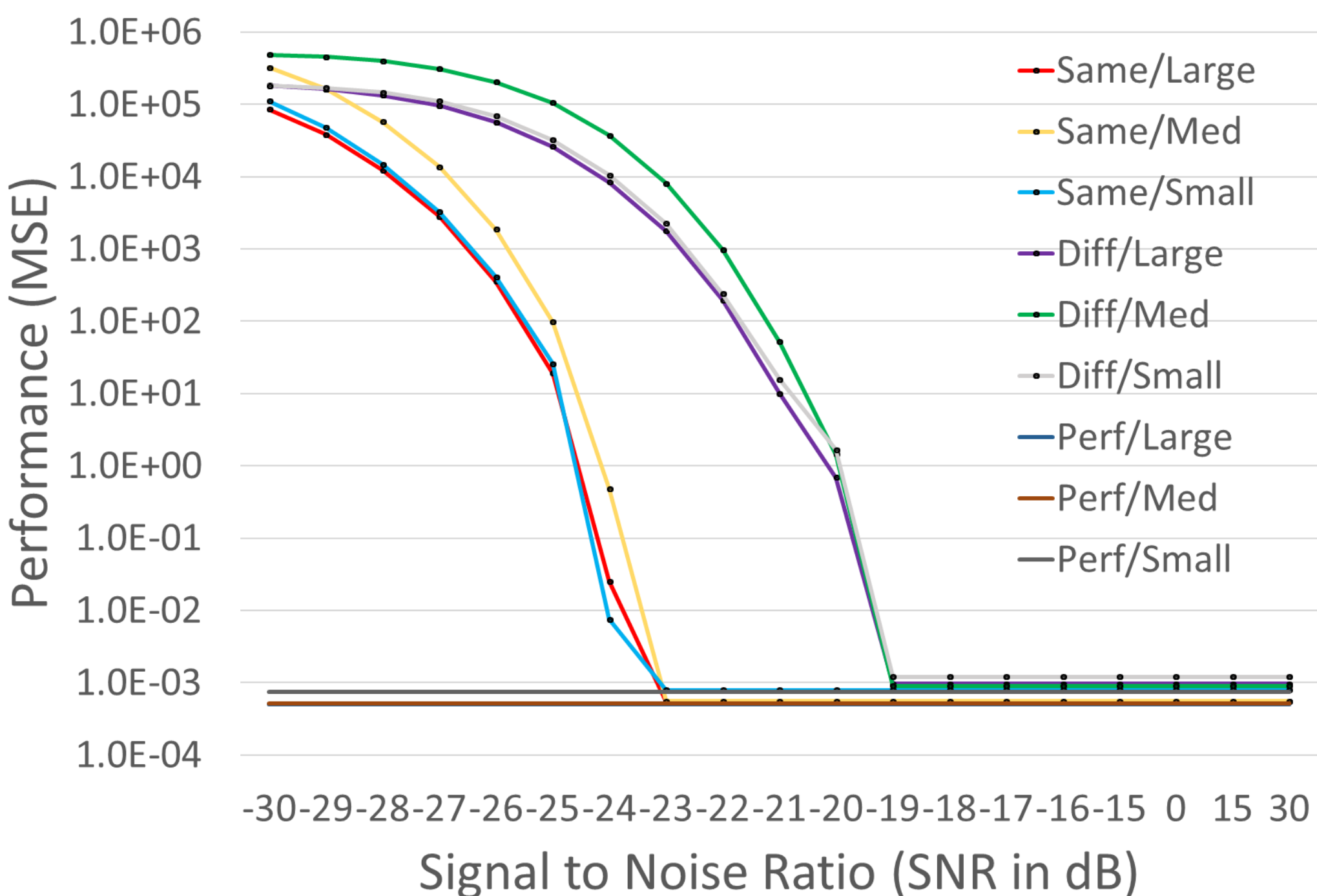


Figure 10. Effect of the observed SNR on three ANNs' performance (figure created by student researcher)

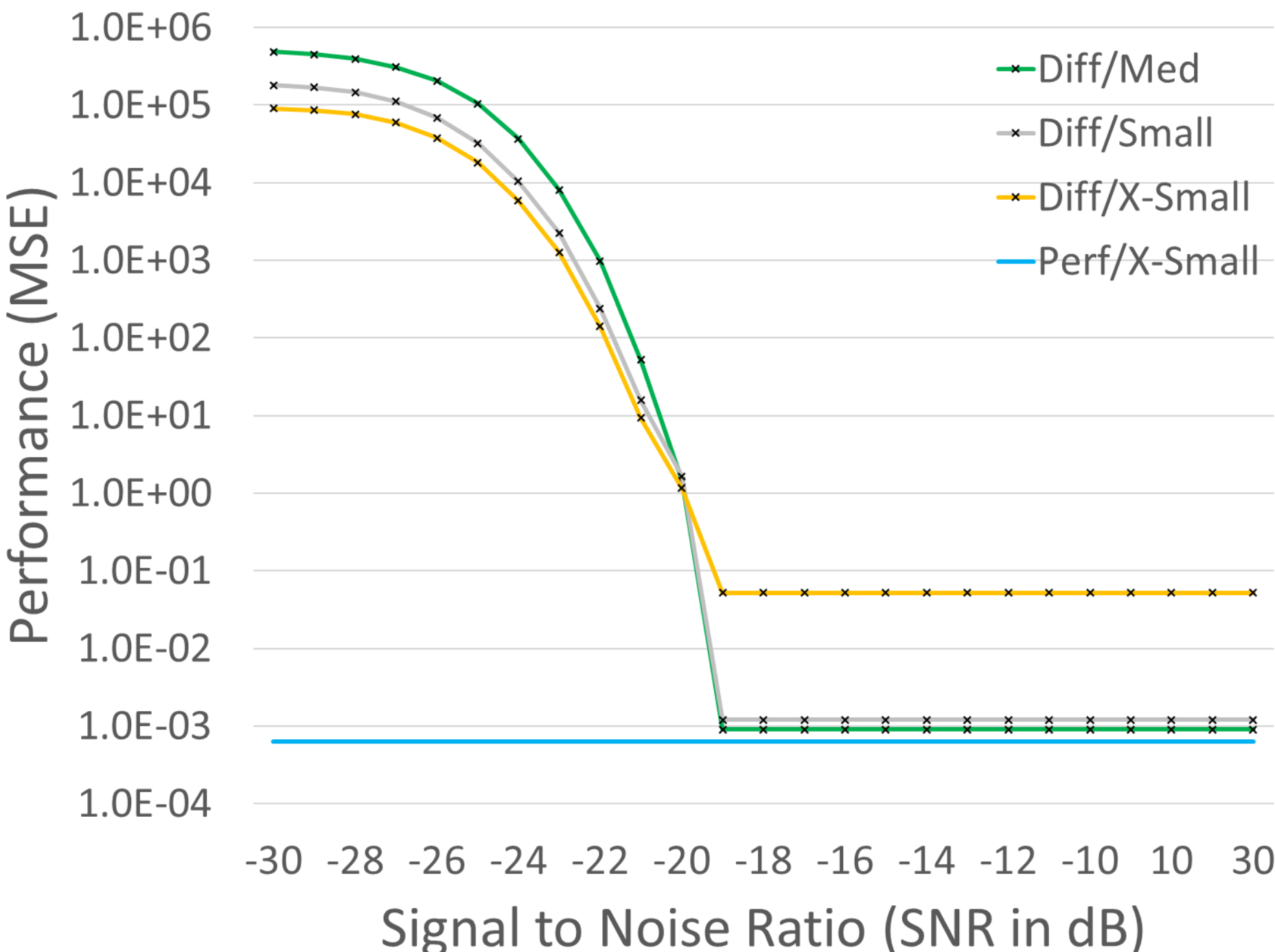


Figure 11. Comparison of MSE values among the lesser trained ANNs (figure created by student researcher)

Methods and Results (Cont'd)

Receiver Optimization

- Improve software capabilities
- Reduce Noise Floor
- Reduce Noise Figure



Figure 12. Software Defined Radio (SDR) Dongle (photo taken by student researcher)

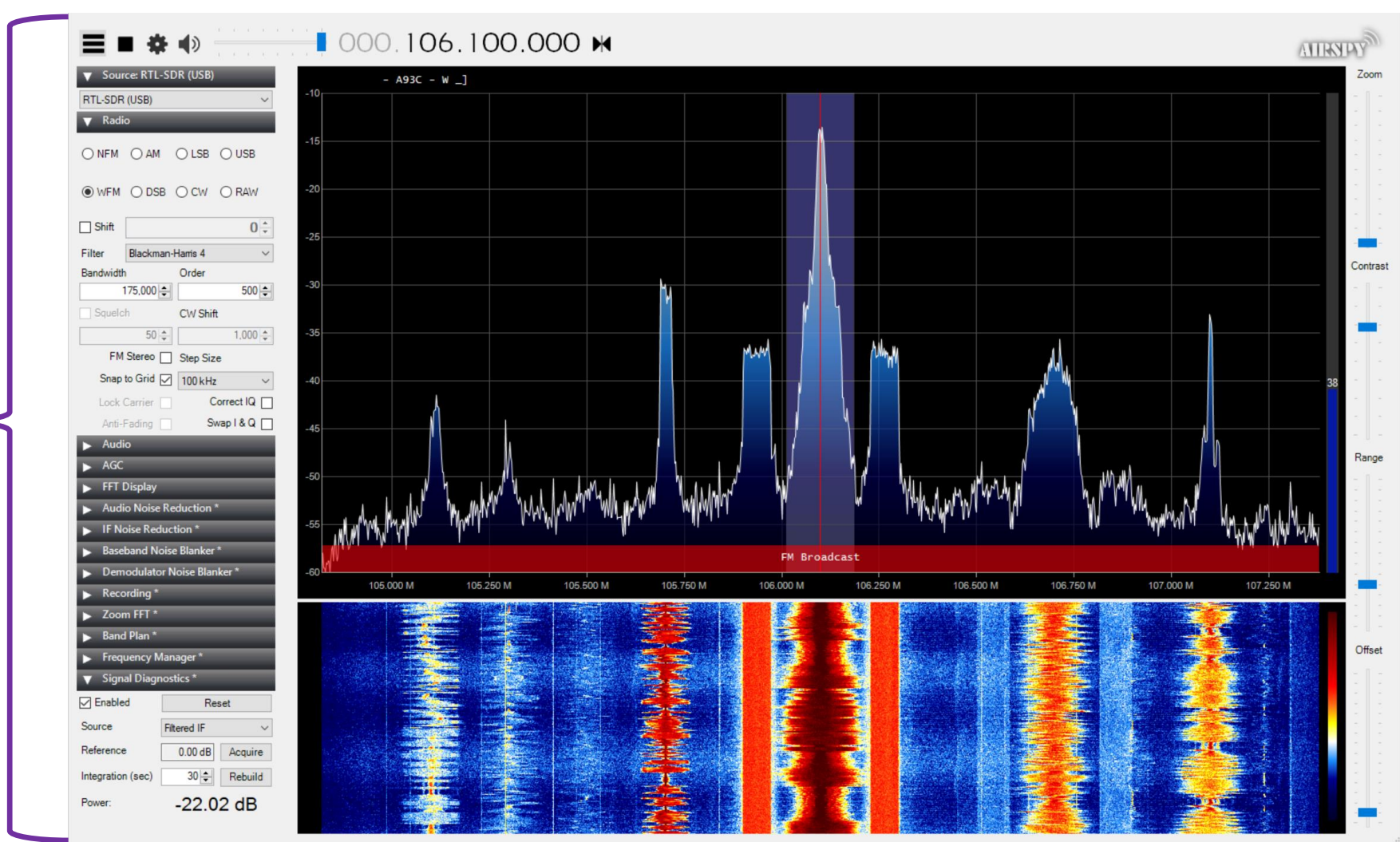
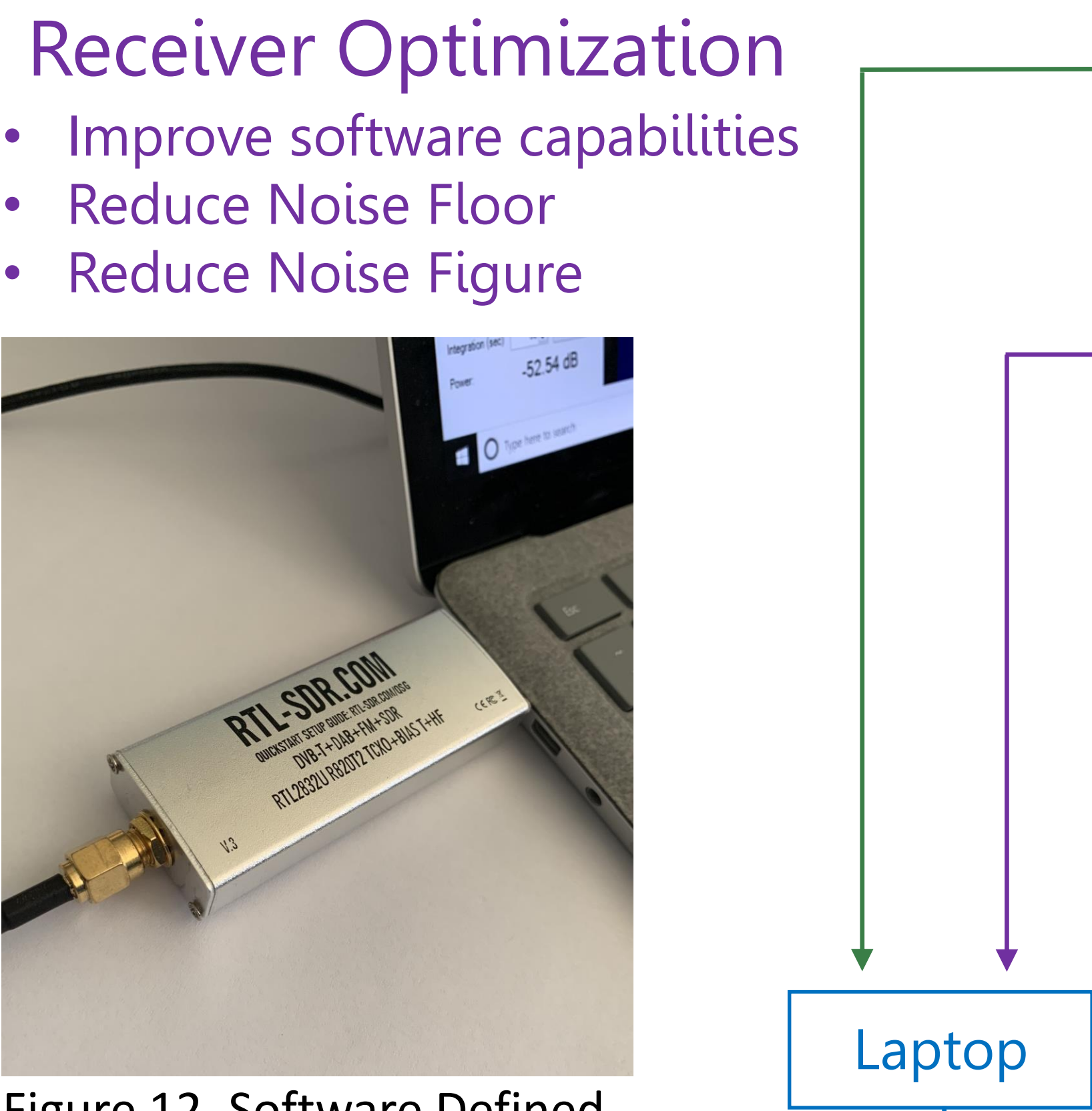


Figure 13. Radio Signals observed via the SDR (figure generated using SDR#)

Table 3. Relevant acquisition distances and times for 2 aircraft and 1 anti-aircraft system (table created by student researcher)

	Average Speed	Critical Zone Radius	Response Time
a) Boeing 747	1056 km/h [11]	2.347 km	60.181 sec
b) N.A. X-15	8273 km/h [12]	18.384 km	0.703 sec
MIM-72 Chaparral	1852 km/h [13]		

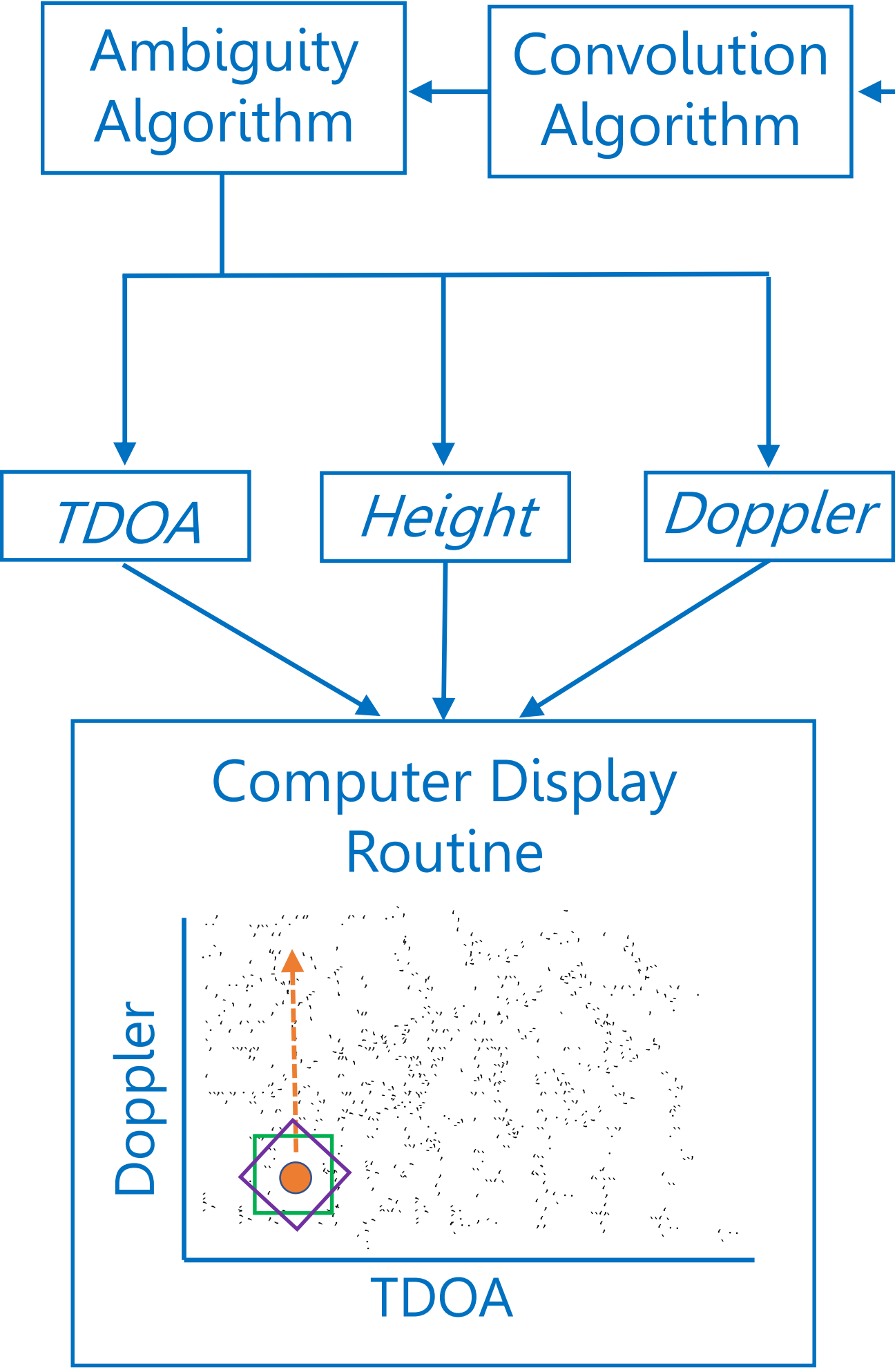


Figure 14. Block Diagram with laptop's capability to use both the ANN and SDR (figure created by student researcher)

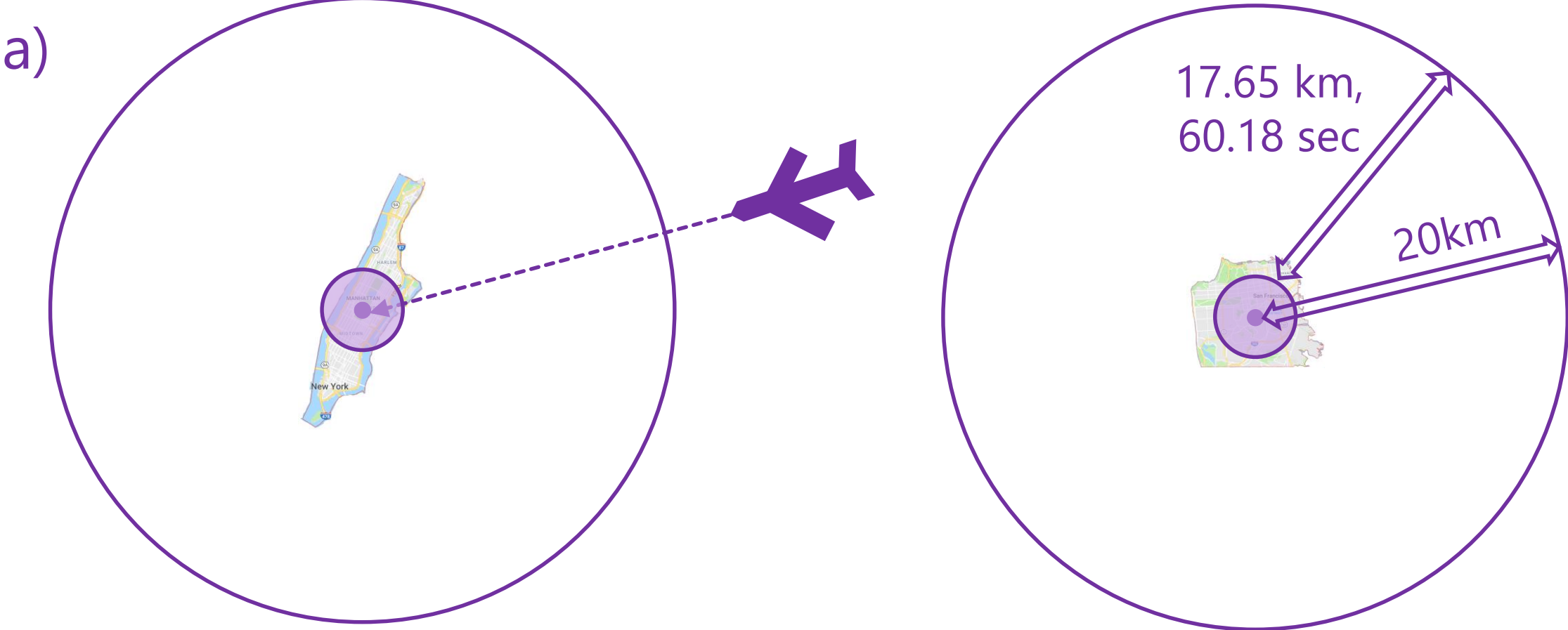


Figure 15. Boeing 747 approaching Manhattan (left) and San Francisco (right) wherein the shaded portion represents a 'critical region' where an anti-aircraft system cannot be deployed in time (figure created by student researcher)

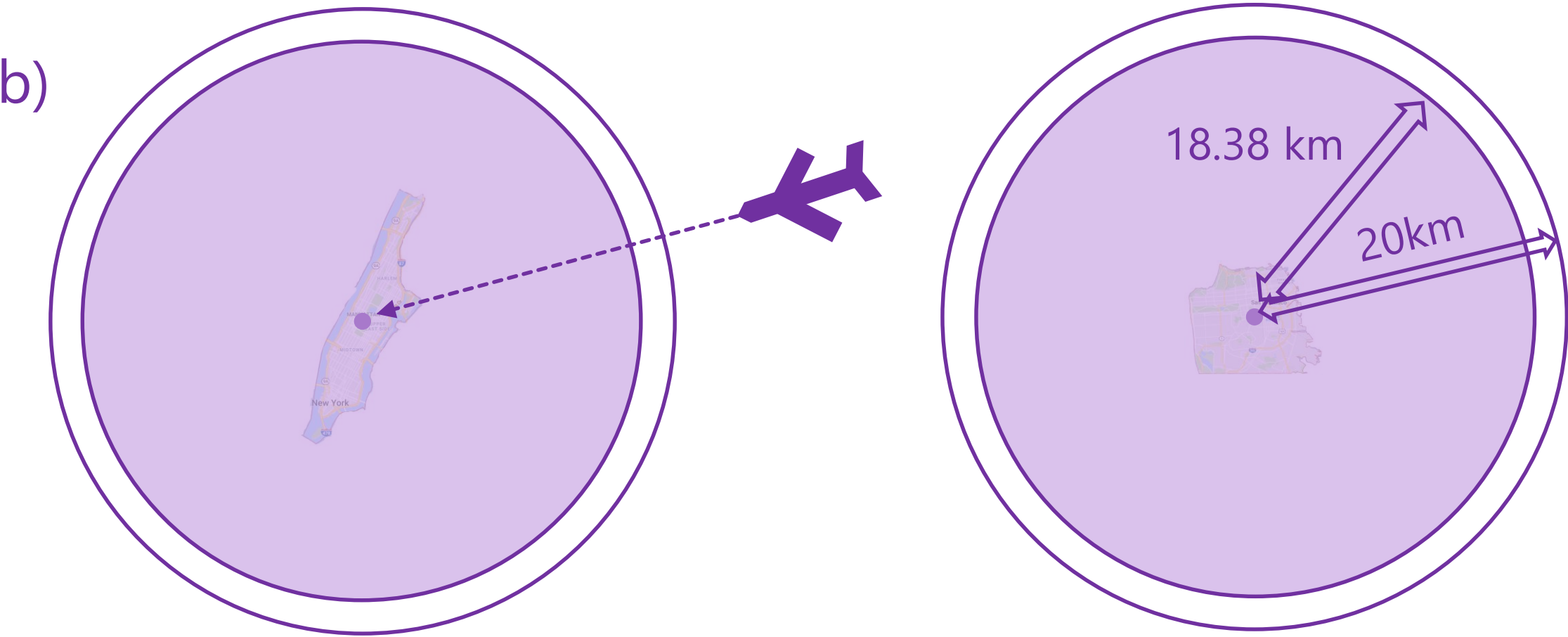


Figure 16. North American (N.A.) X-15 approaching Manhattan (left) and San Francisco (right) with the 'critical region' (figure created by student researcher)

Conclusions

- ANNs can **quickly and accurately** determine target location
 - Average ANN output time: 0.02 seconds
- **Enhanced response time** for point defenses against aerial threats
- System can be applied to **major strategic and metropolitan**
- Lesser trained ANN (<1 minute) performed similarly to the extensively trained ANN (>20 hours)
- ANNs have great potential for **rapid implementation** over a **large geographical area** due to extensive cell coverage (98% of US population) [14] (figure created by student researcher)



Figure 17. Potential passive radar coverage, where the system can be deployed in cities (figure created by student researcher)

Future Research

- Include a tracking feature that uses a signal's doppler shift (refer to figure 14)
- Further optimize noise floor and noise figure
- Study other network architectures
- Compare a robust radar receiver to SDR results
- Create a user-input for transmitters and receiver assignments

Selected References

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